Cowl T

IOWA GEOLOGICAL SURVEY
IOWA CITY, IOWA
DR. STANLEY C. GRANT, Director and State Geologist

WATER-SUPPLY BULLETIN NO. 11

GEOHYDROLOGY OF MUSCATINE ISLAND, MUSCATINE COUNTY, IOWA

by

R. E. HANSEN and W. L. STEINHILBER
U. S. Geological Survey

Prepared Cooperatively
by the Iowa Geological Survey,
the United States Geological Survey,
and the Board of Water and Light
Trustees of the City of Muscatine, Iowa.

Published by the
STATE OF IOWA
Des Moines
1977

State of Iowa
1977

GEOHYDROLOGY OF MUSCATINE ISLAND, MUSCATINE COUNTY, IOWA

by

R. E. Hansen and W. L. Steinhilber
Hydrologists, U. S. Geological Survey

Prepared Cooperatively
by the Iowa Geological Survey,
the United States Geological Survey,
and the Board of Water and Light
Trustees of the City of Muscatine, Iowa.

Published by the
State of Iowa
1977

FOREWORD

Previous publications on water resources have been regional or county-wide in scope. This is the first report for which quantitative data are presented on a single aquifer, of comparatively limited areal extent, that is extensively developed for water supplies.

The availability of large quantities of high-quality ground water from the Muscatine Island aquifer has had a tremendous impact upon urban, industrial and agricultural development of this part of Iowa. Although the nonpumping level of water has been lowered significantly near major pumping centers through time, proper management of this water resource can assure a continued supply of water for all competing users. This report provides basic information for long-range management.

Iowa City, Iowa
May 1977

Stanley C. Grant
Director and State Geologist
Iowa Geological Survey

TABLE OF CONTENTS

ILLUSTRATIONS

TABLES

GLOSSARY

HYDRAULIC CONDUCTIVITY (ft/day) is the volume of water that will move through a porous medium at the existing kinematic viscosity in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

SPECIFIC RETENTION of a rock or soil is the ratio of (1) the volume of water which, after being saturated, it will retain against the pull of gravity to (2) its own volume.

SPECIFIC YIELD of a rock or soil is the ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume.

STORAGE COEFFICIENT is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

TRANSMISSIVITY (ft^2/day) is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

GEOHYDROLOGY OF MUSCATINE ISLAND, MUSCATINE COUNTY, IOWA

by

R. E. Hansen and W. L. Steinhilber

ABSTRACT

Muscatine Island is a wide segment of the west bank of the Mississippi River flood plain that covers about 50 square miles in Muscatine and Louisa Counties; the project area encompasses the 30 square miles in Muscatine County. The flood plain is underlain by thick, permeable alluvial deposits that comprise a water-table aquifer that is developed extensively for water supplies in the area. The aquifer consists principally of sand and gravel, interbedded with lenses of silt and clay. Its saturated thickness ranges from about 40 to 140 feet. The transmissivity and storage coefficients of the aquifer range from about 20,000 $ft.^2$/day and 0.15, respectively, in the western part of the Island to about 39,500 $ft.^2$/day and 0.24 in the eastern part. The amount of water stored in the aquifer, under normal conditions, is about 100 billion gallons.

Discharge from the aquifer is principally by pumpage, which has increased from about 1 mgd (million gallons per day) in 1906 to about 37 mgd in 1970. About 2.5 mgd is normally lost to seepage and evapotranspiration along a 9-mile reach of Muscatine Slough in Muscatine County. About 0.9 mgd is discharged by evaporation from gravel pits.

Recharge to the aquifer is by induced infiltration from the Mississippi River, seepage from the river during major flood events, precipitation, and seepage from the underlying limestone bedrock. Induced infiltration provides about 80 to 85 percent of the water withdrawn from the principal pumping centers along the river and also replaces about 70 to 80 percent of the water that is evaporated from the gravel pits; this amounted to about 30 mgd in 1971. Additional significant recharge from the river occurs during major floods, when prolonged high stages provide the head for considerable underflow to the aquifer. Recharge from precipitation on the Island was calculated to average about 6 inches per year or about 0.3 mgd per square mile. Seepage from bedrock is significant and is attributed to the increased head differential between the alluvial and bedrock aquifers in the areas of major pumping.

The chemical constituents of water from the aquifer are generally within the recommended limits established by the U. S. Public Health Service for drinking water.

Stresses on the hydrologic system have affected the position and

configuration of the water table and the chemical quality of the ground water. The large-scale withdrawals, which began at the principal pumping centers in 1946, have caused the water table to decline from about 1 foot in the interior of the Island to about 5 feet near the edges of the main pumping centers; the decline was more than 8 feet under the pumping centers. A slight increase in hardness of water from riverward wells in the pumping centers is attributed to the induced infiltration of slightly harder river water; a noticeable increase in hardness and iron content in water from landward wells is attributed to seepage of water from the bedrock. In the central irrigated area, which is underlain by very permeable, highly drained soils that are mulched with organic fertilizers, the nitrate content of the ground water is as high as 46 mg/1 (milligrams per liter). Land-use practices have had, and probably will continue to have, an impact on the quality and quantity of water available in the system.

The hydrologic system in 1971 was in dynamic equilibrium or in near-equilibrium with the stresses imposed on it to that date. This equilibrium would be disturbed by any additional stresses on the system and water levels would change until a new equilibrium was established. The effects of future stresses can be reasonably predicted by developing a digital model of the system. The data to develop such a model are available in this report. Continued and expanded monitoring of water levels would provide data for better model verification. Periodic monitoring of nitrate and other chemical constituents would permit early detection of changes in concentration before the concentrations reached excessive levels.

INTRODUCTION

The area known as Muscatine Island contains one of the more prolific aquifers in Iowa. For 25 years, increasingly large supplies of water have been withdrawn from permeable sand and gravel beneath the Mississippi River flood plain. The city of Muscatine, several self-supplied industries, and numerous irrigators withdrew an average 34.5 mgd. (million gallons per day) in 1965 and 37 mgd in 1970. Municipal withdrawals are expected to increase by about 18 percent by 1980. Industrial withdrawals probably will increase significantly, because the area offers attractive features, (i.e., transportation, water supply, labor force, and flood protection) for industrial growth. Withdrawals for irrigation are expected to increase only slightly.

For many years, the water users believed the supply of good-quality ground water was inexhaustible. The history of water development had indicated that properly constructed gravel-packed wells readily produced 1,000 to 1,500 gpm (gallons per minute) of excellent-quality water. Therefore, whenever municipal or industrial water requirements increased, additional wells were drilled in existing well fields--generally without regard for mutual-interference effects. Because the water table was relatively high, irrigation supplies were conveniently and economically obtained by driving large-diameter sand points or scooping large-diameter "pits" to just below the water table and withdrawing water with centrifugal pumps. However, in the early 1960's, several events occurred that changed this optimistic outlook to one of concern. Increasing municipal and industrial pumpage in the northeastern part of the Island caused significant well-interference problems. Attempts by the city to develop additional well fields that would produce supplies of water equivalent in quality to existing supplies were unsuccessful. Large-scale pumpage by a newly established industry, located about 3 miles south of the municipal well field, caused anxiety in some quarters that the water resource was being overdeveloped and that water levels would decline drastically. The irrigators on the Island, most of whom use centrifugal pumps, became particularly apprehensive that increasing industrial and municipal withdrawals would lower water levels below "suction lift" of their pumps.

The concerns of the water users on Muscatine Island can be identified and categorized as follows:

(1) Are the ground-water resources of the Island being overdeveloped?

(2) Are large-scale withdrawals of ground water causing a general decline of water levels on the Island?

(3) What is the areal and vertical distribution of chemical constituents (particularly iron and manganese) and hardness of the water in the aquifer?

What are the possible causes for the distribution?
Are the activities of man affecting the concentrations and distribution of the chemical constituents?

(4) What effect will future withdrawals from the aquifer have on the Island's water resources and the altitude of the water table?

Purpose and Scope

The principal objectives of this report are 1) to provide, within the framework of the available data, answers to the above questions, 2) to provide the basic information necessary to develop a digital model of the aquifer system that would serve as a predictive tool for management, and 3) to lay out a program to monitor the water levels and quality of water on the Island.

In order to meet the above objectives, this report 1) defines and describes the hydrologic system from which water is developed on the Island, and 2) defines and describes the system's response to ground-water withdrawals and other activities of man.

Methods of Investigation

When fieldwork for this study was begun, very little information was available about the physical and hydrologic properties of the aquifer. Therefore a program of test drilling was set up to determine the extent, thickness, composition, and boundaries of the aquifer. Data from these test holes (pl. 1) provided the basic information for the hydrogeologic maps and geologic sections in this report.

Water-level data were collected from an observation-well network that was installed during the early phase of the investigation (pl.2). These data, supplemented by data from existing irrigation and municipal wells, formed the basis for the water-table maps in the report (pl. 3). In addition, several wells were equipped with recorders to obtain a continuous record of water-level changes; one well is being maintained as a continuous-observation station. Water-level graphs for these wells are presented in plate 4.

Two wells, 76-2-10bcb2 and 76-2-14-bbc, were drilled into the underlying bedrock to observe water levels and to obtain water samples (pl. 2). In 1968, additional water-level data were collected at irrigation wells in Louisa County in order to provide better control for the water-table maps.

Well-Numbering System

The well numbers in this report show the location of each well according to the public land survey system of land subdivision. In the location system (fig. 1) the first number of a well number indicates the township, the second the range, and the third the section in which the well is located.

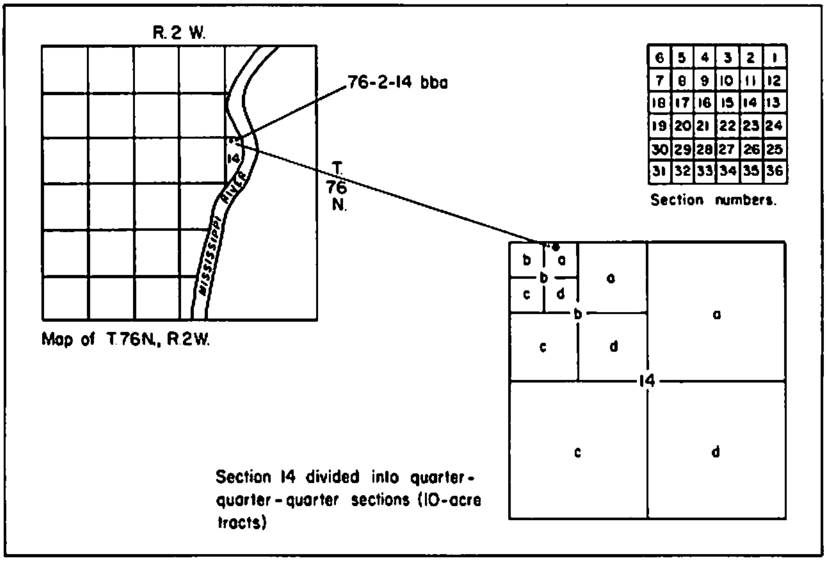


Figure 1.—Map showing the well-numbering system used in this report.

The first letter indicates the quarter section, the second the quarter-quarter section, and the third the quarter-quarter-quarter section (10-acre tract). The letters are assigned to the quarter divisions in a counter-clockwise direction beginning in the northeast quarter of each section. For example, well 76-2-14bba (fig. 1) is in the NE¼ NW¼ NW¼ sec. 14, T. 76N., R. 2W. If more than one well is in the same 10-acre tract, they are numbered serially.

The test borings made by the U. S. Geological Survey during the summer of 1964 are numbered serially TI-1 through TI-48, and are shown in plate 1.

Conversion Factors

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

Multiply English unit	by	To obtain metric unit
inches	$2.54 \times 10^{+1}$	millimeters
feet	3.048×10^{-1}	meters
mile	1.609	kilometers
square feet	9.29×10^{-2}	square meters
acre	4.047×10^{-3}	square kilometers
square mile	2.590	square kilometers
cubic feet	2.832×10^{-2}	cubic meters
gallon	3.785	liters
gallon	3.785×10^{-3}	cubic meters
gallons per minute	6.309×10^{-2}	liters per second
gallons per day	3.785×10^{-3}	cubic meters per day
million gallons per day	$3.785 \times 10^{+3}$	cubic meters per day
million gallons per year	$3.785 \times 10^{+3}$	cubic meters per year
billion gallons per year	$3.785 \times 10^{+6}$	cubic meters per year
Transmissivity ($ft.^2$/day)	9.29×10^{-2}	square meters per day
Hydraulic Conductivity (ft./day)	3.048×10^{-1}	meters per day

ACKNOWLEDGMENTS

Many interested people contributed time, information and facilities during the course of the investigation. The Municipal Water Department provided many records, access to the well fields for water-level measurements, and personnel to aid in the collection of additional data. Industrial pumping records and measurements were obtained from Grain Processing Corporation, Thatcher Glass Company, and Monsanto Chemical Company. The many farmers in the project area provided access to their land for the measurement of water levels in their irrigation wells. Mr. Lewis Peterson at the Muscatine Island Experimental Farm furnished valuable information about the water needs of the various crops that are irrigated in the area.

Additional information and assistance were furnished by the State Hygienic Laboratory, Stanley Consultants, Inc., and the Muscatine-Louisa Drainage District No. 13.

GEOGRAPHY

The brief discussion presented is pertinent to an understanding of the hydrologic system and of the water problems in the area.

Location

Muscatine Island is an isolated wide segment of the west bank of the Mississippi River flood plain below the city of Muscatine (fig. 2). The Island lies in Muscatine and Louisa Counties and encompasses about 50 square miles (32,000 acres).

This report, however, is concerned principally with that part of Muscatine Island located in Muscatine County, which is about 30 square miles (19,200 acres) in area. The city of Muscatine (population 22,400, 1970 census) extends into part of the northern edge of the Island.

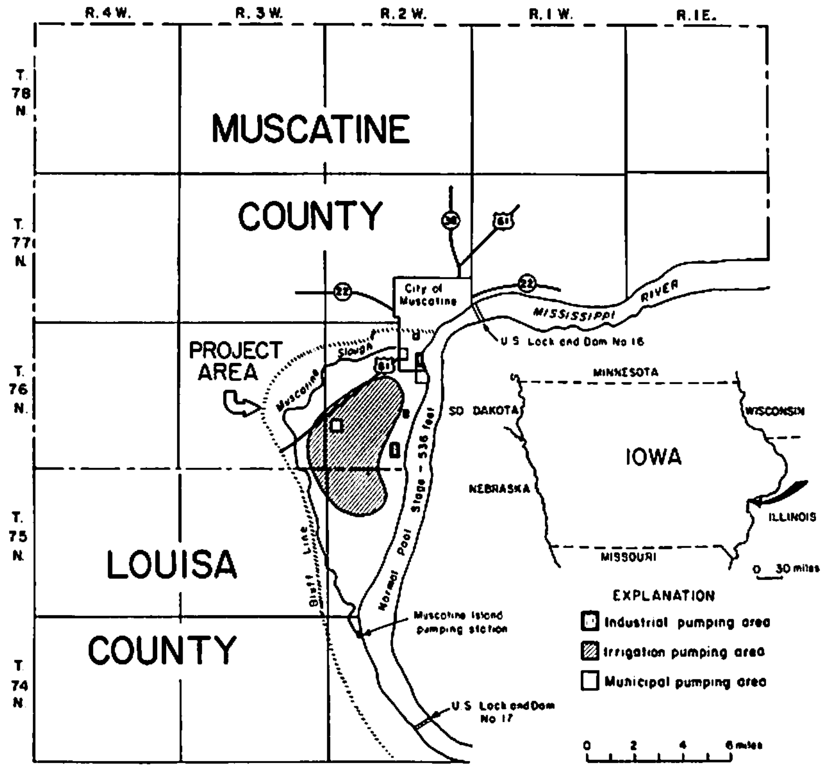


Figure 2.—Location of the project area.

Topography and Drainage

Muscatine Island is a gently undulating flood plain, bounded on the east by the Mississippi River and on the north and west by a line of high bluffs, near the foot of which is Muscatine Slough that enters the river on the south (fig. 2). The altitude of the flood-plain surface between the river and Muscatine Slough varies from about 535 to 550 feet above sea level. Near the bluffs, the surface rises gradually to about 590 feet. The bluffs rise abruptly above the flood plain to an upland surface whose altitude is about 750 feet above sea level (fig. 5).

The channel width of the Mississippi River in this locality varies from about 2,500 to 4,000 feet. The mean low altitude of the channel bottom at Muscatine, according to data from the U. S. Army Corps of Engineers, is approximately 520 feet above sea level. The stage of the river, which is of particular significance in understanding the movement of water beneath Muscatine Island, is controlled in this locality by Lock and Dam No. 17. Normal stage (flat-water pool) is 536 feet; only during severe ice conditions in the winter does the stage drop below that figure. Fifty percent of the time during the navigation season (March 16-December 9), the pool stage is at or higher than 539 feet at the Muscatine gage. (A. F. Burleigh, Corps of Engineers, Rock Island, Illinois, oral commun., August 1968).

The Island is protected from floods by a levee that rises to approximately 560 feet above sea level and extends along the bank of the Mississippi River from the City of Muscatine to the mouth of Muscatine Slough, which forms the southern boundary of the area. This levee was not topped or breached by the flood of record in April 1965, when the Mississippi River crested at 556.27 feet at this location.

The Island is drained by Muscatine Slough. Since completion of the unitized levee system in 1924, however, the slough has no direct outlet to the river. A pumping station built in 1916 and maintained by Muscatine-Louisa Drainage District No. 13, pumps the water over the levee into the river. The bottom of the slough in the central part of the area is at 528.5 feet above sea level. The slough drops only 3 feet from head to mouth (oral communication; Ken Duncan, Treasurer, Muscatine-Louisa Drainage District No. 13, Muscatine, Iowa).

Several small ephemeral creeks drain the bluffs around the northern and western periphery of the Island. This drainage is intercepted by Muscatine Slough.

Climatological Data

Because rainfall is a source of recharge to the Island's ground-water system, pertinent precipitation data is presented. For more information see Climatological Data for Iowa, published monthly and annually by the U. S. Dept. of Commerce. Additional records during the growing season

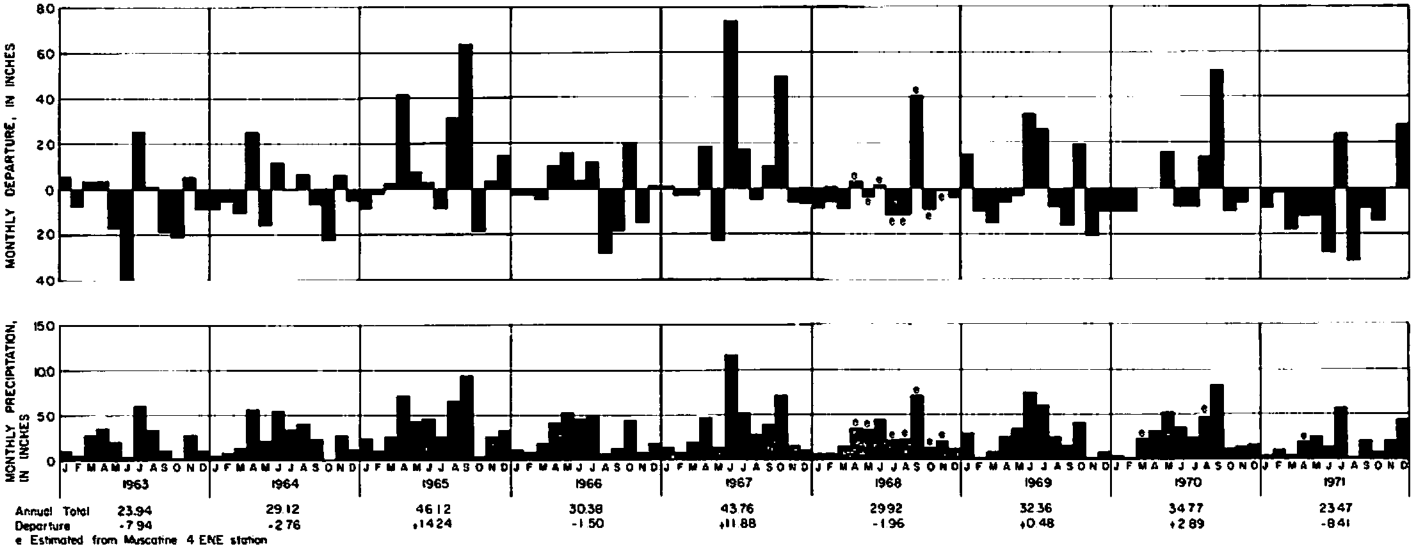


Figure 3.—Total monthly precipitation and the departure from monthly normals for the period 1963-71 at Muscatine, Iowa. (Data from National Weather Service).

are collected by the Iowa State University Agricultural Experiment Station at Fruitland.

According to Climatological Data for Iowa, the mean annual precipitation at Muscatine is about 32 inches. The total monthly precipitation and the departure from monthly normals for the period 1963-71 are shown in figure 3. A graph of cumulative departure from average monthly precipitation (fig. 4) indicates that this investigation was initiated near the end of a dry cycle (1963-64) and extended through a wet cycle.

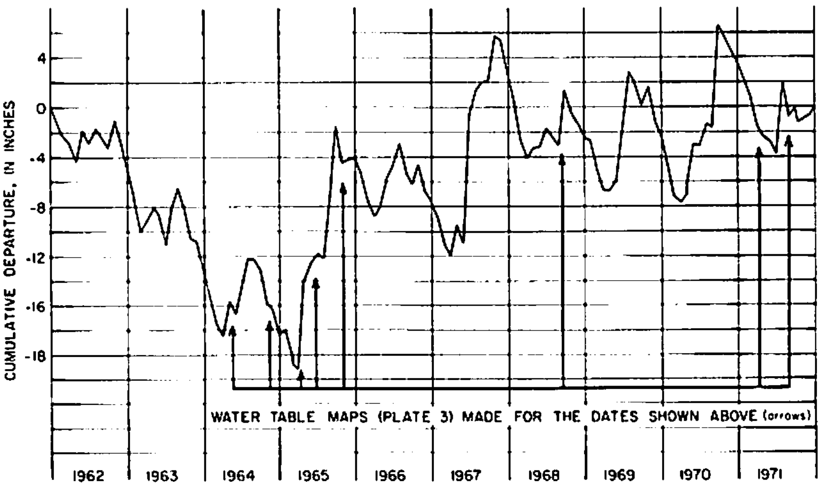


Figure 4.—Cumulative departure from average monthly precipitation at Muscatine, Iowa.

Agriculture and Industry

Agriculture on the Island is principally truck farming; the main crops are cabbage, sweet corn, tomatoes, and melons. Because these crops require large amounts of water, and because the land is sandy, extensive amounts of ground water are withdrawn for irrigation. The economics of irrigation is critically linked to the position of the water table in the area because the method of withdrawal of water is by centrifugal pumps. If the water table drops below the suction lift capabilities of the pumps, more expensive pumping equipment will be required.

Industry on the Island is quite varied. However, only two industries, Grain Processing Corporation (GPC) and Monsanto Chemical Company, pump large quantities of ground water. Thatcher Glass Company pumps a moderate quantity, and the remainder pump small quantities or are supplied by the municipal water system. GPC's well field is about 1,300 feet north of the principal municipal (power plant) field; Thatcher Glass and Monsanto are about 2 and 3 miles to the south respectively (pl. 2).

One other major industry, the sand and gravel industry, exerts an important influence on the hydrologic system of Muscatine Island. Numerous abandoned and operating gravel pits are concentrated in the east-central part of the Island (pl. 2). The total surface area of these water-table ponds was about 300 acres in 1971.

GEOLOGIC SETTING

The regional bedrock in this part of the state consists of limestones and dolomites of Middle Devonian age. These strata form the bedrock floor beneath Muscatine Island, except for a small area in the northeastern part where a shale outlier of Pennsylvanian age extends northward and eastward under the City of Muscatine and caps a limestone bench (pl. 1 and fig. 5).

The bedrock floor of Muscatine Island is at the juncture of two buried valleys that were carved into the bedrock by southerly and southeasterly flowing preglacial and interglacial streams (Hansen, 1972). The bedrock rises abruptly under the City of Muscatine (pl. 1) forming the north valley wall of the buried drainage system. The south valley wall is more than 15 miles to the south in Louisa County. Most of Muscatine Island lies in the buried valley.

Deposits of glacial drift consisting principally of sandy, pebbly clay form the northern and western boundaries of Muscatine Island (fig. 5). The drift is about 70 feet thick over the high bedrock to the north, and is much thicker over the bedrock valley to the west. Loess of variable

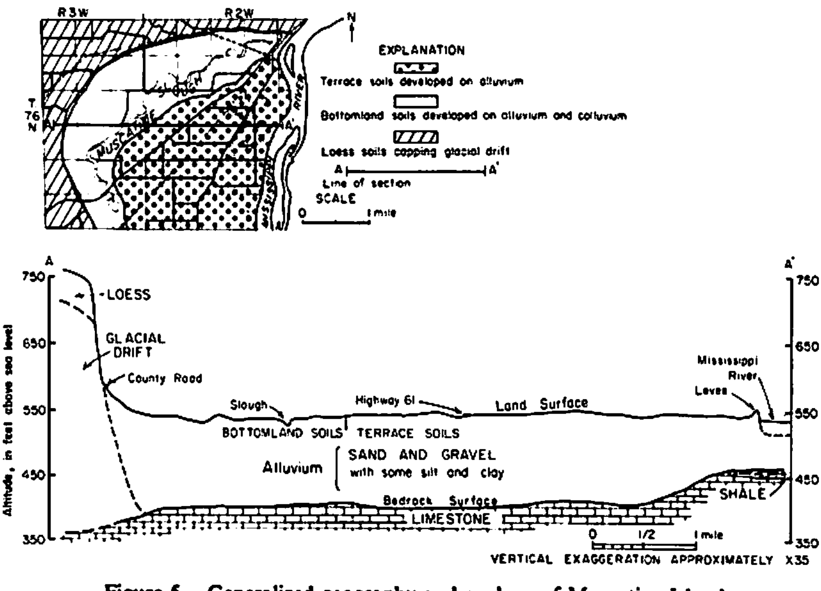


Figure 5.—Generalized geography and geology of Muscatine Island.

thickness mantles the glacial drift along both the northern and western boundaries of the project area.

Muscatine Island is underlain by alluvial sand and gravel with minor amounts of silt and clay. These deposits are about 140 feet thick, except over the bedrock bench in the northeast part where the deposits range from 50 to 80 feet thick. The alluvium extends into Louisa County on the south and beneath the Mississippi River along the eastern edge of the Island.

The soils on Muscatine Island (Stevenson, et al., 1918) are classified as terrace and bottomland soils (fig. 5). The terrace soils are developed on alluvial materials and are composed principally of coarse-to-fine sand and sandy loam. These soils and their subsoils are very porous, permeable, and drain rapidly. The bottomland soils are developed on parent material that is a mixture of fine-grained alluvium from the river and colluvium from the bluffs. The colluvium is principally loess and weathered glacial till composed of clay and silt. Thus, the bottomland soils and their subsoils are principally silty clay loams that occupy the area between the bluffs and the Slough and a narrow strip south and east of the Slough. These soils are not very permeable; therefore, they are very poorly drained.

HISTORY OF GROUND-WATER DEVELOPMENT

Early development of the ground-water resource in the Island area for large, sustained yields was by the City of Muscatine for a municipal supply in 1906. Prior to this time, the municipal supply was obtained from the Mississippi River. The earliest wells were 6-inch diameter driven wells connected by a common header; these were located just north of the present power plant. In the period 1923-26, five additional wells were added just south of the plant and, in 1931, four more wells were added on a line extending south of the plant. The population of 16,000 people was stable during this time, and the estimated water usage was about 1 mgd during the winter months and possibly as much as 3 mgd during the summer.

The period after World War II was a time of change and expansion at the power-plant well field. A population increase of several thousand coupled with the development of an industrial well field north of the power plant during the war had two significant effects: more water was needed for the municipal supply, and interference from the new industrial well field lowered the yield of the sand points in the municipal well field. Between 1946 and 1961, seven large-diameter drilled wells were added at the power plant field. These were located west of the original wells; all the original wells were eventually abandoned. By 1961, production from the power-plant well field was 2 bgy (billion gallons per year) or about 5.5 mgd (fig. 6).

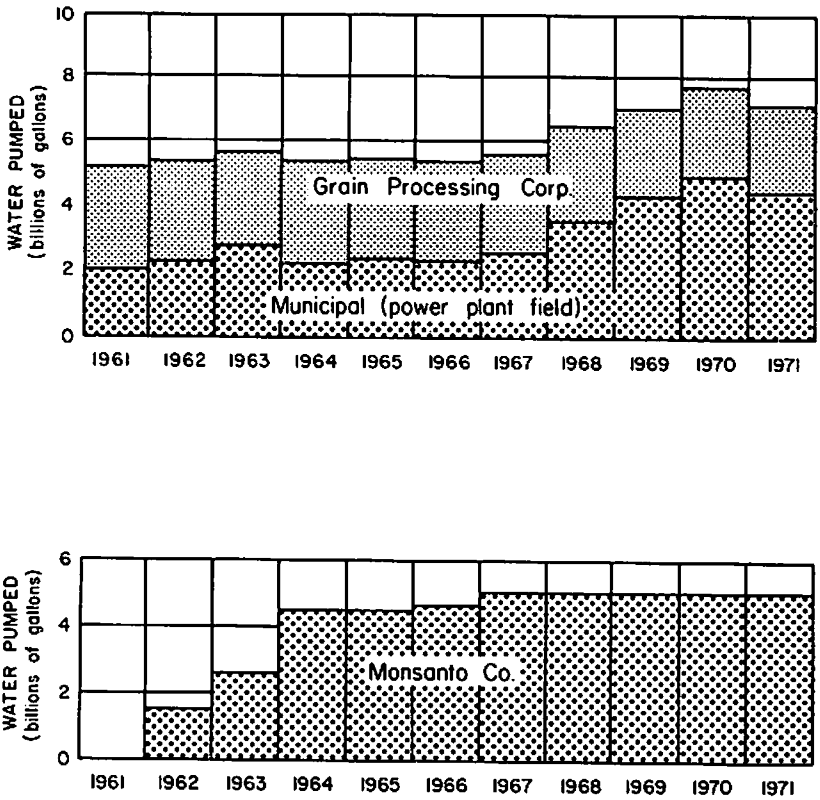


Figure 6.—Annual withdrawals by principal water users on Muscatine Island.

Following this period of growth, new locations for municipal wells were sought to avoid overcrowding the power-plant area. Two wells were installed at the Hershey Ave. well field (extreme northern part of the Island) in 1962-63, and a well was located at the Sampson St. well field (about 1¼ miles northwest of the power plant) in 1964 (pl. 2). However, because the water from these wells was significantly higher in iron content than the water from the power-plant field, production from these wells has been limited. Pumpage from the Sampson St. field has been greater than 0.1 bgy only two years and generally is less than 0.02 bgy; production from the Hershey Ave. field has never been greater than 0.02 bgy and this field is seldom used.

Because of anticipated water demands, additional wells were added to the power-plant field between 1966 and 1970 on property located one-half to three-quarters of a mile south of the power plant (pl. 2). Also, during this time an additional well was added to the upper plant field and two others were abandoned in order to maintain maximum production capacity from the field. By 1970, production from the entire power-plant field was slightly over 4.8 bgy (fig. 6).

In 1971, two additional wells were constructed at Progress Park located in the central part of the Island (pl. 2). Withdrawals from this well field were initiated in 1971 and are planned to average about 0.365 bgy.

Industrial development of ground water began in the Island area in 1943 when Grain Processing Corporation became operative. Following this, Thatcher Glass Manufacturing Company developed a supply in 1949-50 and Monsanto Chemical Company in 1962. Other small industries are present on the Island, but these do not use appreciable amounts of water in their manufacturing processes.

Grain Processing Corporation is located approximately one-quarter mile north of the municipal power plant (pl. 2). Initial production in 1943 was about 1.6 bgy. In 1957 over 2.6 billion gallons of water were pumped from five wells; between 1961 and 1969 pumpage from the well field averaged 3.0 bgy. Beginning in 1969, pumpage from eight wells was reduced to 2.4 bgy because part of the supply was being obtained from the City (fig. 6). Because of the proximity of this field to the municipal power-plant field the two create a single hydrologic influence in this northeast area of the Island (pl. 3). A summary of the total annual pumpage from this area for the years 1961-1971 is given in figure 6.

Thatcher Glass Manufacturing Company (NW¼ sec. 27 T. 76N., R. 2W.) which began operations in 1949-50 is situated about three-fourths of a mile north of Monsanto. The company operates three wells which pump, on the average, 1 to 1¼ mgd or between 0.365 and 0.456 bgy.

Monsanto Chemical Company (SE¼ sec. 28 T. 76N., R.2W.) operates eight wells in the area in and around the plant site (pl. 2). Production began in 1962 with three wells pumping about 1.5 bgy. As wells were added, pumpage increased to 5.3 bgy or about 14.6 mgd in 1967 and has remained constant since then (fig. 6).

Agricultural development of ground water began on a modest scale in the early 1900's when a few scattered acres on the Island were irrigated. Pumpage increased significantly in the early 1940's when the practice of irrigation was given a big impetus with the introduction of lightweight, portable irrigation pipe. Ground-water withdrawals for irrigation on the Island (including the part in Louisa County) were fairly stable from the 1950's to the late 1960's and averaged about 0.275 to 0.3 bgy. Pumpage since 1970 probably is somewhat higher, because irrigation water is being applied to an increased acreage of corn.

In summary, municipal pumpage in 1970 was about 5 billion gallons, industrial 8.2 billion gallons, and irrigation about 0.3 billion gallons. The total pumpage for the year was about 13.5 billion gallons or 37 mgd.

HYDROLOGY OF THE ALLUVIAL AQUIFER

Physical Properties

The alluvial aquifer consists of highly permeable alluvial deposits that overlie permeable limestone bedrock in most of the area and impermeable shale bedrock in the northeast corner of the area (pl. 1). It is bounded on the north and west by relatively impermeable glacial drift. To the east, the aquifer extends under the Mississippi River; to the south it extends under Muscatine Slough and decreases in width as the flood plain narrows. All of these physical boundaries also are hydrologic boundaries.

The alluvial deposits consist principally of sand and gravel, ranging in size from fine-grained sand to large boulders. Most of the coarse materials are found under the eastern third of the Island, particularly in the area of the gravel pits and the principal municipal well field (fig. 7 and pl. 2). They

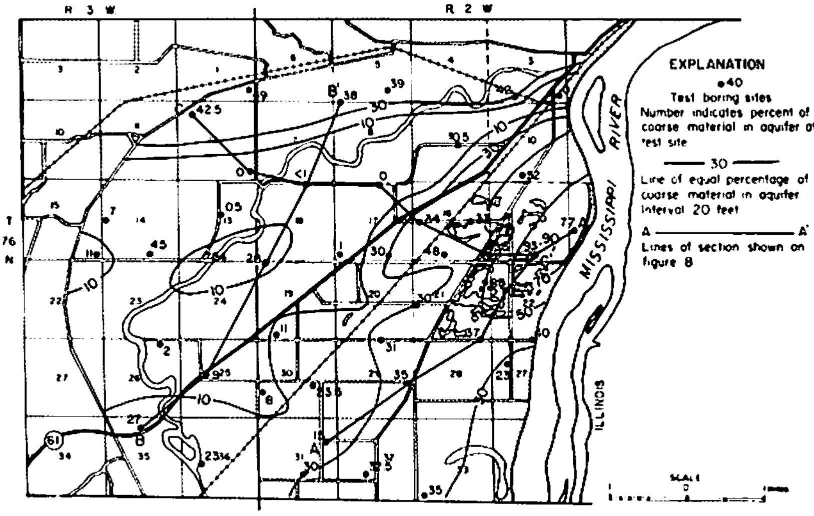


Figure 7.—Percent of coarse material in the aquifer.

also are more persistent in occurrence in that area and can be traced with some confidence (fig. 8). In contrast, the area between Highway 61 and Muscatine Slough is characterized by finer grained deposits.

The thickness of the alluvial deposits in the area ranges from about 50 to 150 feet (fig. 9). In about 87 percent of the area, or 26 square miles, the deposits average 137 feet thick; the deposits average 70 feet thick in the remainder of the area, which overlies the bedrock bench in the northeast corner of the Island.

Silt and clay occur both as surficial deposits and as lenses within the sand and gravel. The surficial layer of silt and clay occurs as a continuous

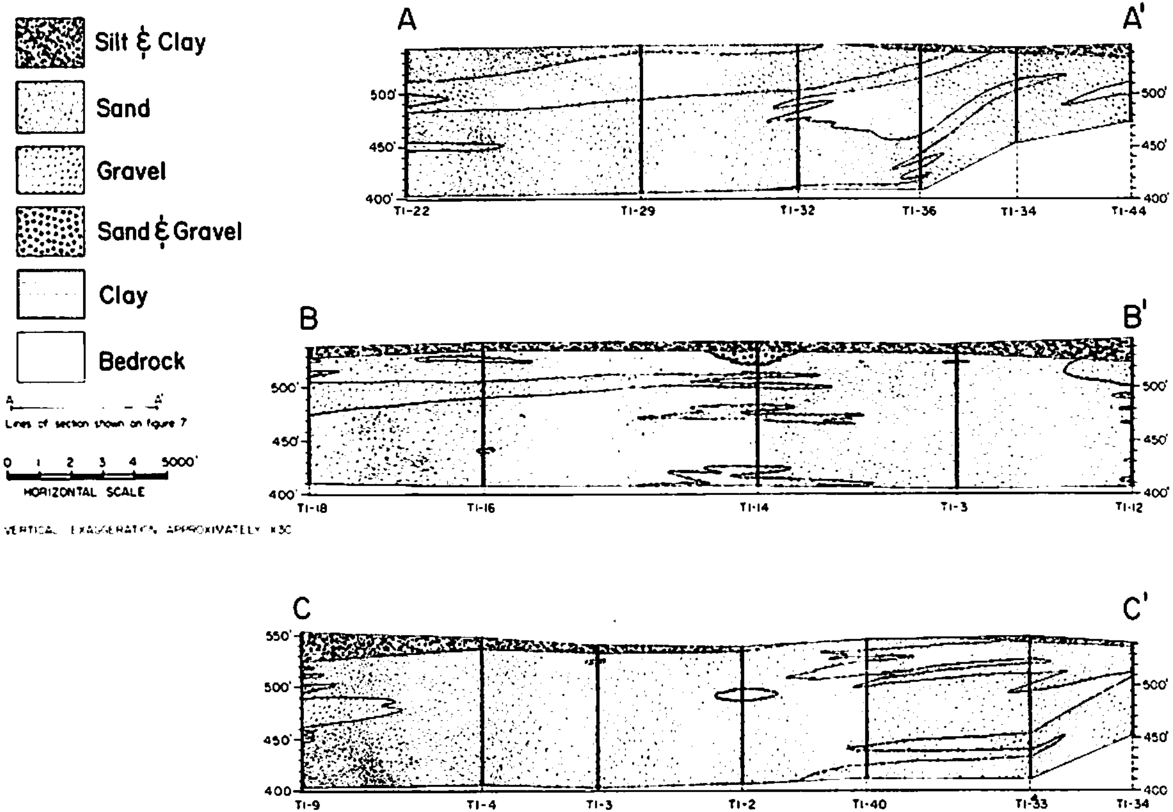


Figure 8.—Geologic sections of the aquifer.

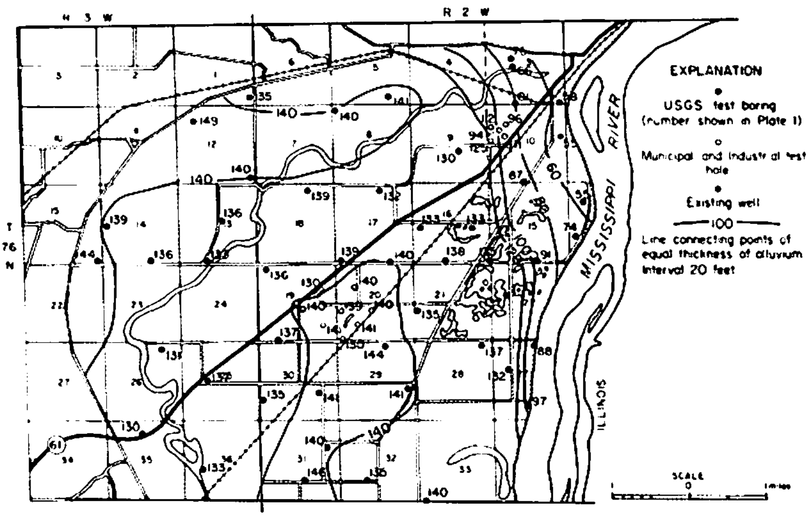


Figure 9.—Thickness of alluvium.

bed over much of the Island, but is absent in the central part (fig. 10). This bed generally is less than 10 feet thick, but is nearly 40 feet thick near the bluffs. Silt and clay are present also as randomly distributed lenses within the aquifer materials. Generally however, the clay lenses do not occur in the bottom 30 to 40 feet of the aquifer

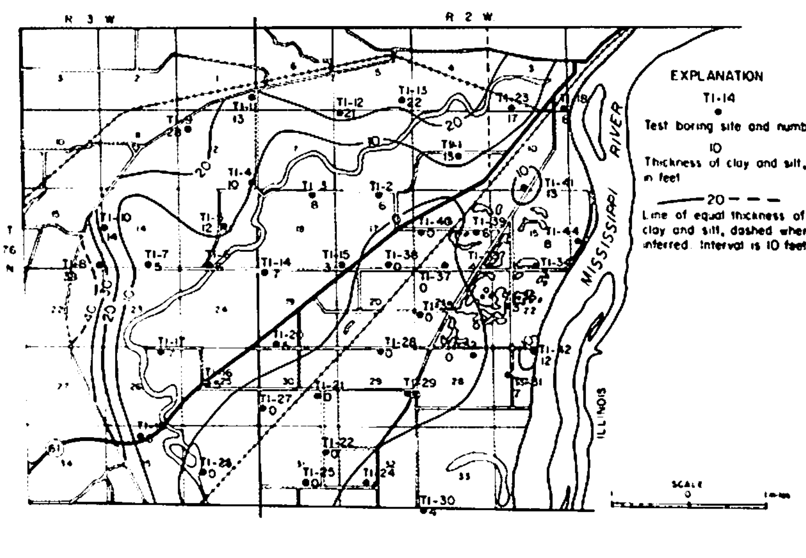


Figure 10.—Distribution and thickness of surface clay and silt.

Hydrologic Properties

Saturated Thickness

The saturated thickness of the aquifer varies with the position of the water table and the depth to bedrock. In October 1964, when the water table was at a low position, the saturated thickness ranged from about 40 to 140 feet (fig. 11). During high water-table conditions such as occurred during May 1965, the saturated thickness is increased several feet. The saturated thickness generally is between 120 and 140 feet in approximately 87 percent of the area. However, in the northeastern part of the Island, where the bedrock is high, the saturated thickness is between 40 and 60 feet.

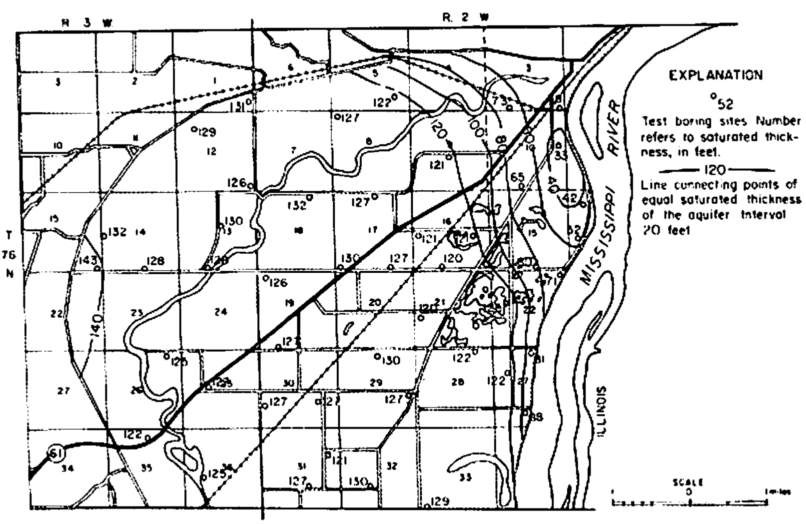


Figure 11.—Saturated thickness of the alluvial aquifer, October 1964.

Transmissivity

The great variability in the aquifer's composition and saturated thickness leads to variations in transmissivity throughout the Island. Several methods were used to estimate transmissivity; they are as follows: 1) analysis of flow nets of the principal well-field areas; 2) information from a pumping test; 3) estimation of the hydraulic conductivity of the aquifer materials from well-log data; 4) extrapolation of adjusted hydraulic conductivity data across the Island; and 5) verification of the transmissivity in a selected area by an analytical method.

The transmissivity of a "large sample" of an aquifer can be determined by a flow-net analysis, if the ground-water flow is steady-state and the flow rate can be estimated (Bennett, *in* Ferris, 1962, p. 139). These requisite conditions for constructing and analyzing flow nets are present in the vicinity of the two major pumping centers on the Island. The water-table maps (pl. 3) indicate that: 1) the 525-530-foot contours around the pumping centers are fairly stable during periods of low river stage; and 2) all ground-water flow across the 525-530-foot contours is toward the pumping sites; therefore the flow rate can be approximated by inventorying the pumpages. Flow nets were constructed and analyzed for a portion of the water-table map for April 9, 1964, which was a stable period just before expansion of the municipal well field (fig. 12).

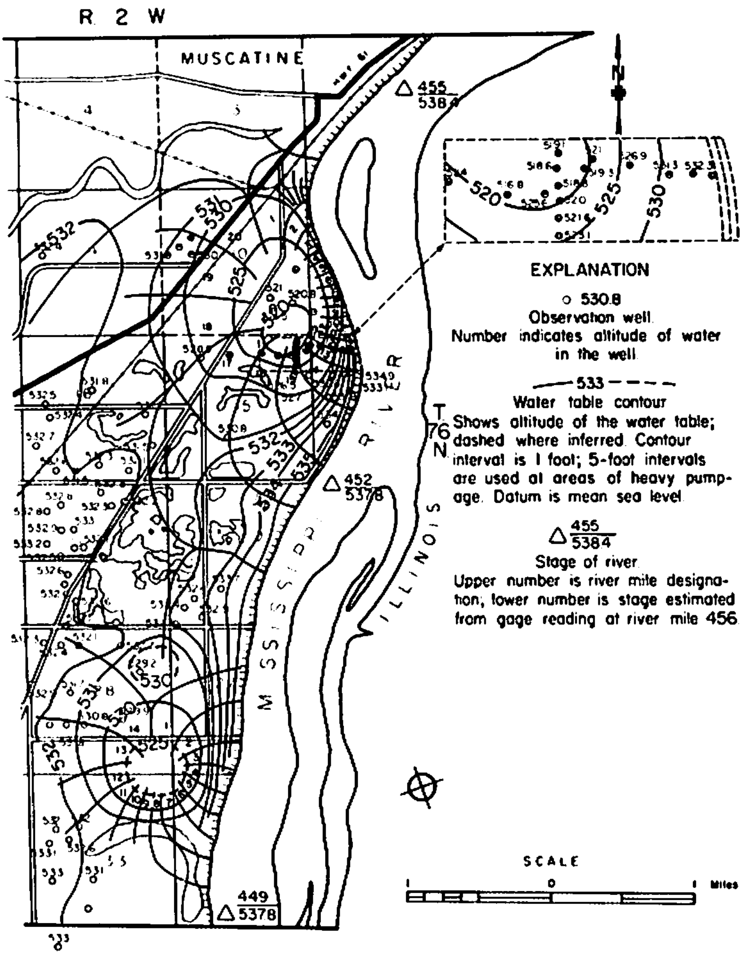


Figure 12.—Portion of water-table map for April 1964, showing a flow-net analysis to determine the transmissivity of the aquifer in the principal well-field areas and the percentage of water induced from river.

Computations

A. Analysis of upper cone, between the 525-530 foot water-table contours (after Bennett, *in* Ferris, 1962, p. 139):

$$T = \frac{Q \cdot nd}{nf \cdot h} = \frac{1.98 \times 10^6 \times 1}{20 \cdot 5} = 19{,}800 \text{ ft}^2/\text{day}$$

Where: T = transmissivity of aquifer in cubic feet per day per foot width of aquifer (ft^2/day)

Q = flow through full thickness of aquifer in cubic feet per day (ft^3/day), which is equal to the average daily pumpage during 1964 by City of Muscatine and Grain Processing Corp. = 14.8×10^6 million gallons per day or about 1.98×10^6 cubic feet per day (fig. 6a)

nd = number of potential drops between the 525-530 contours = 1

nf = number of flow channels = 20

h = total potential drop between the 525-530 contours = 5 feet

The average saturated thickness and the average dewatering between the 525-530 contours are about 57 feet and about 8 feet, respectively. Therefore, the average dewatering is 8/57 of total saturation which is about 14 percent. Thus the pre-pumping or adjusted transmissivity is:

$$T = 19{,}800 \times 1.14 = \text{approx. } \underline{22{,}600} \text{ ft}^2/\text{day}$$

Percent of water induced from river = 17/20 flow paths = 85%

B. Analysis of lower cone, between the 525-530 foot water-table contours:

$$T = \frac{Q \cdot nd}{nf \cdot h} = \frac{1.6 \times 10^6 \times 1}{14 \times 5} = 22{,}860 \text{ ft}^2/\text{day}$$

$Q = 1.6 \times 10^6 \text{ ft}^3$

nd = 1

nf = 14

h = 5

The average dewatering between the 525-530 contours is about 7/120 of total saturation, which is about 6 percent.

Therefore, the pre-pumping or adjusted transmissivity is:

$$T = 22{,}860 \times 1.06 = \text{about } \underline{24{,}000} \text{ ft}^2/\text{day}$$

Percent of water induced from river = 11/14 flow paths = 80%

The computations shown indicate that the transmissivity of the aquifer is about 22,600 ft^2/day in the vicinity of the Grain Processing Corp. and Municipal Power Plant well fields and about 24,000 ft^2/day in the vicinity of the Monsanto well field.

Additional transmissivity data for a much smaller "sample" of the aquifer were obtained from a pumping test conducted on City Well No. 13 (NW, SW, sec. 14, T. 76N., R. 2W) by Stanley Consultants, Inc. The transmissivities determined at 6 observation wells ranged from 24,500 ft²/day to 28,500 ft²/day and averaged about 26,500 ft²/day (G. Tavener, Stanley Consultants, Inc.; written commun., 1968).

The transmissivity determinations were used in adjusting hydraulic-conductivity values that had been assigned arbitrarily[1] to aquifer materials collected from test holes in the vicinity of the well fields. The adjusted hydraulic conductivity (K) of the three principal size grades of aquifer material are:

very coarse sand and gravel; (Kg)	= 500 ft/day
medium to coarse sand; (Ks)	= 150 ft/day
fine to medium sand; (Kf)	= 40 ft/day

These adjusted hydraulic conductivity values, well-log data from the test holes, and the saturated-thickness map (fig. 11) were used to estimate the transmissivity at the test-hole sites that are shown in plate 1. Guided by the map showing the distribution of coarse material in the aquifer (fig. 7), these site transmissivity data were used to make a transmissivity map of the Island (fig. 13). This map shows that the transmissivity of the aquifer ranges from about 20,000 ft²/day to about 39,500 ft²/day.

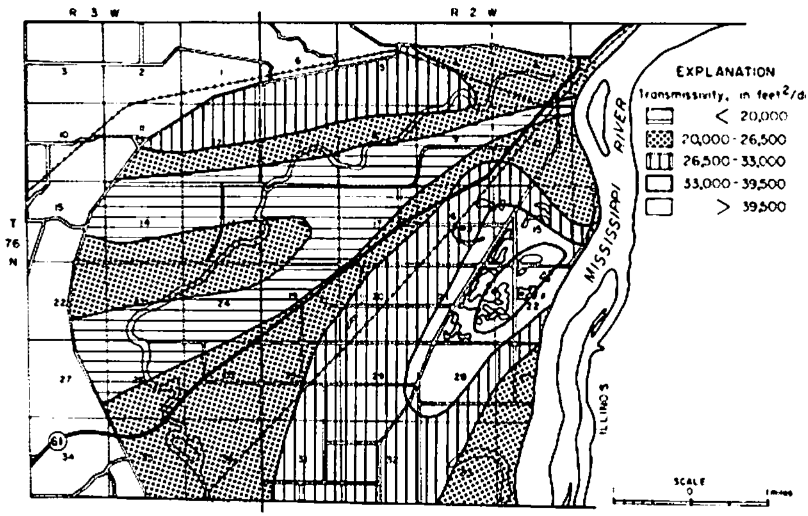


Figure 13.—Transmissivity of the alluvial aquifer, Muscatine Island, Iowa.

[1] Based on analyses made by the Hydrologic Laboratory of the U. S. Geological Survey (Morris & Johnson, 1967).

Although the transmissivities shown on figure 13 are estimates, a method is available to independently verify the transmissivity of an extensive interior area in the vicinity of the town of Fruitland. This method is commonly called Jacob's steady-state, uniform recharge method and is described by Ferris and others (1962, p. 131). The necessary data to use this method are obtained from: 1) water-table maps, which indicate a fairly stable position of the ground-water receiving stream (Muscatine Slough); and 2) observation well 76-2-30cba, in which the altitude of the average water level is 534.2 feet above sea level (table 1). The pertinent equation by Jacob is:

$$T = W\left(\frac{ax}{h_o} - \frac{x^2}{2h_o}\right)$$

$$= 1.37 \times 10^{-3}\left(\frac{12{,}000 \times 6800}{3.2} - \frac{(6800)^2}{2(3.2)}\right)$$

$$= 25{,}000 \text{ ft}^2/\text{day}$$

where:

T = transmissivity, in ft^2/day

W = average rate of precipitation recharge to the water table (assumed to be constant) = 6 inches/year (see subsequent section on recharge) = 1.37×10^{-3} ft/day.

a = distance from stream to ground-water divide = 12,000 feet

x = distance from stream to observation well = 6800 feet

h_o = elevation of the water table at the observation well with respect to the average stream level = 3.2 feet.

Table 1. Average monthly and annual water levels, in feet below land surface, in wells 76-3-25ddd and 76-2-30cba (data from plate 4).

	Well 76-3-25ddd			Well 76-2-30cba				
Year								
Month	1964	1965	1966	1967	1968	1969	1970	1971
January	—	11.20	8.35	12.06	11.60	13.25	12.40	11.30
February	—	11.05	8.75	12.18	11.92	12.75	12.65	11.40
March	11.05	10.92	9.07	12.75	12.16	12.42	12.65	11.40
April	10.70	9.65	9.26	12.15	12.37	12.22	12.20	11.50
May	10.15	8.10	8.65	11.65	12.30	12.09	11.25	11.75
June	9.95	6.95	8.30	11.75	12.40	12.00	11.05	12.10
July	10.00	7.30	9.00	11.85	12.70	11.30	11.00	12.40
August	10.25	7.75	9.66	12.00	13.05	11.05	10.60	12.60
September	10.55	7.65	10.28	12.15	13.25	11.30	10.15	12.97
October	10.92	7.05	10.60	12.20	13.29	11.66	10.10	13.32
November	11.20	8.10	10.77	11.05	13.44	11.85	10.80	13.60
December	11.35	8.80	10.96	11.11	13.50	12.10	11.10	13.50
Average annual	10.61	8.71	9.47	11.91	12.66	12.00	11.33	12.32
Transferred to								
well no. 76-2-30cba[1]	12.35	10.44	11.20					

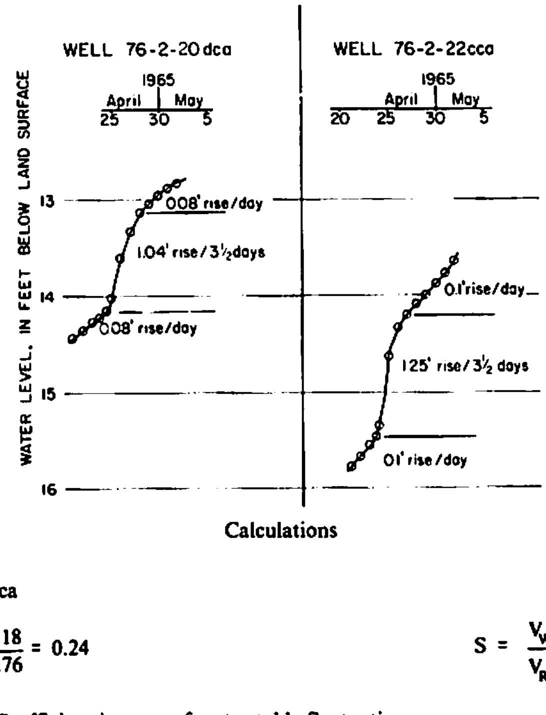
Average water level for 8 year period of record = 11.8 feet.

Average water-level altitude = 534.2 feet above sea level.

[1] On basis of overlapping records during 1966 (see plate 4)

Storage Coefficients

The storage coefficient in the zone of water-table fluctuation was calculated from data derived from hydrographs of wells 76-2-20dca and 76-2-22cca. In April 1965, when the river stage was rising toward its record peak, the water levels in both wells were rising at a constant rate. During this time, a rainfall of 2.16 inches in a 3-hour period was measured at the Iowa State Agricultural Experiment Station, near the town of Fruitland. In response to this storm, the water levels in both wells rose at accelerated rates for several days, after which they returned to the original rate. The accelerated rates are attributed to the rainfall, and the data are used to calculate the storage coefficient (fig. 14).[1] The coefficients of 0.20 and 0.24



Calculations

Well 76-2-20dca

$$S = \frac{V_w}{V_R} = \frac{0.18}{0.76} = 0.24$$

Well 76-2-22cca

$$S = \frac{V_w}{V_R} = \frac{0.18}{0.90} = 0.20$$

S = Storage Coefficient in zone of water-table fluctuation.
V_W = Volume of precititation, in ft³/ft² (ft). = 2.16 inches = 0.18 feet
V_R = Volume of water-level rise attributed to ppt., in ft³/ft² (ft).; which is:

1.04 ft - 0.28 ft = 0.76 in well 76-2-20dca
1.25 ft - 0.35 ft = 0.90 in well 76-2-22cca

Figure 14.—Hydrographs of wells 76-2-20dca and 76-2-22cca showing determination of storage coefficient of the aquifer in the zone of water-table fluctuation.

[1] Assumption was made that most rainfall reached the water table, because the soil was at field capacity, ET was minimal during this cool, cloudy period, and no runoff from the flat, sandy soil was noted.

determined at the two sites are believed to be maximum values, because the upper 25 feet of the alluvium at these sites (this includes the zone through which the water table fluctuates) is predominately gravel and very coarse sand. In areas where fine to medium sand is the predominant grain size, such as the area west of Highway 61, the storage coefficient in the water-table zone is somewhat less—possibly on the order of 0.15 to 0.18. The average Island-side storage coefficient in the zone of water table fluctuation is assumed to be about 0.21.

To summarize, the transmissivity of the aquifer ranges from about 20,000 ft^2/day in the western part of the Island to about 39,500 ft^2/day in the eastern part. The storage coefficient is believed to range from about 0.15 in the western part to 0.24 in the eastern part. In fact, the highest transmissivities and storage coefficients are located between the two 30 percent lines in the eastern part of figure 7.

Ground-Water Storage

Based on a conservative average storage coefficient of 0.15 and saturated thickness given in figure 11, the amount of ground water in storage at any given time is about 100 billion gallons. This amount represents about seven times the 1970 withdrawal amount and is an indication that the aquifer has the reserve capacity to withstand several years of deficient recharge.

Hydrologic Boundaries

The hydrologic boundaries of the alluvial aquifer that affect and influence the functioning of the hydrologic system of the Island are: 1) water table, 2) Mississippi River, 3) bedrock floor, 4) Muscatine Slough, and 5) glacial till along the valley sides. The water table is discussed in a subsequent section; discussion of the other boundaries follows.

Mississippi River

The Mississippi River, which is the eastern border of Muscatine Island, is a continual line source or recharge boundary to the alluvial aquifer (pl. 3). As such, the river has a major impact on the water levels, water withdrawals, and quality of water on the Island--particularly in a mile-wide strip adjacent to the river. The two principal characteristics of the river that are the cause of this impact are the river stage and the chemical quality of the water.

The stage of the Mississippi, opposite Muscatine Island, during low and moderate flows is controlled by Lock-and-Dam 17 (fig. 2). The normal or flat water stage of the pool is 536 feet above sea level (fig. 15). When the river discharge exceeds 10,000 cfs (cubic feet per second), a gradient is established in the pool which increases with increasing discharge. The median stage, which is the stage equaled or exceeded 50 percent of the time

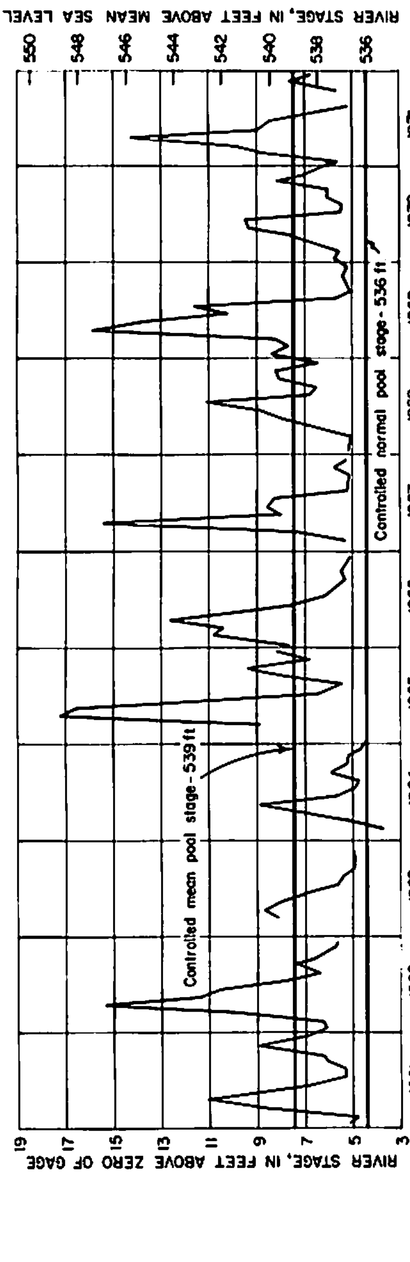


Figure 15.—Monthly mean stage of Mississippi River at Muscatine gage—1961 through 1971.

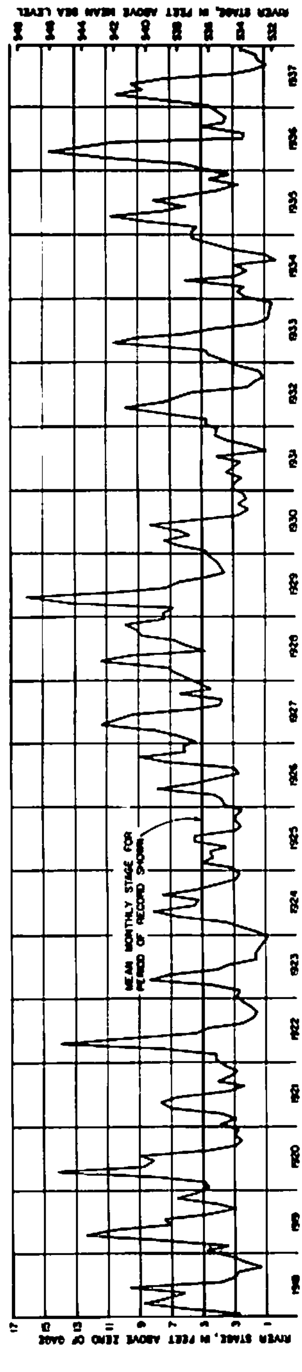


Figure 16.—Monthly mean stage of Mississippi River at Muscatine gage—1918 through 1937.

during the navigation season, is 539 feet; the gradient at this stage is about 0.3 foot per mile. The stage data obtained from Corps of Engineers, Rock Island District, were used in the preparation of water-table maps (pl. 3).

Before construction of the lock-and-dam system, the uncontrolled stages of the river during low-flow periods were substantially lower (fig. 16). The significance of the controlled stage on the hydrology of the Island can best be seen by comparing the hydrographs in figures 15 and 16. Since Lock-and-Dam 17 became operational in 1937, the mean stage of the river is about 3 feet higher, and the low-flow stages are as much as 5 feet higher. These increased stages result in increased recharge to the alluvial aquifer.

Because the river is a source of recharge to the aquifer, the quality of the river water influences the quality of water in the aquifer. Accordingly, some chemical-quality data of river water that had been collected at Davenport (about 28 river miles upstream) are presented in table 6. The chemical-quality relationship between water in the river and aquifer is discussed in a subsequent section.

Bedrock Floor

The floor under the alluvial aquifer is limestone bedrock under most of the Island, except the northeastern corner where up to 25 feet of low-permeability shale caps the limestone (pl. 1). The limestone unit is the Cedar Valley Limestone of Devonian age, which is an aquifer underlying a large area in eastern Iowa (Steinhilber and Horick, 1970). Regionally, this aquifer's hydraulic conductivity is considered to be low, because it usually yields only small supplies of water to wells; locally, however, where the unit is extensively fissured, it yields moderate to large supplies. The water from this rock unit invariably is extremely hard, ranging from 350 to 450 mg/1, (milligrams per liter), and contains concentrations of iron in excess of 2 mg/1.

The Cedar Valley Limestone at some localities under Muscatine Island is considered a recharge boundary for the following reasons:

1. The buried valley system carved into the Cedar Valley Limestone under Muscatine Island and surrounding area is the lowest part of the bedrock aquifer system. As such, Muscatine Island probably is a principal discharge area for the limestone aquifer, depending on relative head relations between the alluvial and limestone aquifers and the stage of the Mississippi River.

2. The pressure head of water in the limestone bedrock at the Sampson Street municipal standby well field (see pl. 2 for location) is about one-half foot higher than the head in the alluvial aquifer during periods when City Well 11 is idle. The water table in this area is slightly depressed because it is the northwest edge of the drawdown cone around the municipal power-plant well field. When City Well 11 is pumping, the water level in bedrock well 76-2-10bcb2 is drawn down, indicating discharge into the alluvial aquifer (pl. 4).

3. Water-level data indicate the pressure head in the bedrock is related to the stage of the river. In well 76-2-14bbc, open only in the limestone in the area where shale caps the limestone bedrock, the water level rises and falls in response to river stage changes. At well 76-2-10bcb2, in an area where shale is not present, a subdued rise in ground-water level correlates with the river stage rise at a time when no other recharge is evident.

4. Although the regional permeability of the Cedar Valley Limestone is low, the permeability at some localities under Muscatine Island probably is significantly higher than it is under the surrounding uplands. Experience elsewhere in eastern Iowa indicates that in some areas the permeability of limestones that occur under buried valleys are unusually high. However, the permeabilities of limestones are not uniform; therefore, the permeability of the Cedar Valley Limestone under the Island may be quite variable.

5. Chemical-quality data, to be discussed in a subsequent section, indicates movement of water from the limestone bedrock to some alluvial wells in the municipal and GPC well fields.

The above indicates that water can move from the limestone bedrock into the alluvial aquifer in places where the limestone is in direct connection with the alluvium, is permeable, and where the relative head conditions are favorable. Favorable head conditions occur in areas where the water table is depressed by pumpage from the alluvial aquifer; this is so particularly during periods of prolonged high stages of the Mississippi River.

Muscatine Slough

Muscatine Slough functions as an effective line sink that receives ground-water discharge from the aquifer (pl. 3). Because it is cut only slightly into the aquifer, ground-water development on the Island could lower the water table below the bottom of the slough. Under those conditions, the slough would cease to be a significant hydrologic boundary.

Glacial-till Valley Walls

The glacial till in and beneath the bluff line that forms the north and west boundaries of the alluvial aquifer is composed principally of sandy, gravelly clay. This material, which has a very low hydraulic conductivity, functions as a barrier to any significant ground-water movement into or out of the Island. However, the broad bedrock valley that heads in the area west of the Island under the till (Plate 1) may contain outwash sand. If so, water may be moving down the bedrock valley and discharging into the alluvial aquifer. Under existing hydrologic conditions, however, any discharge from the buried valley can affect only that part of the aquifer that lies between the slough and the bluffs.

Sources and Quantity of Recharge and Discharge

The position and configuration of the water table of the alluvial aquifer is the result of a summation of the recharge and discharge processes on the

Island. Changes in the position and configuration of the water table indicate variations in recharge and discharge and changes in man-made stresses on the system. Portrayal of the water table during different periods of time is indispensable in understanding the discharge-recharge relations on the Island. Accordingly, water-table maps, shown in plate 3, were prepared from water-level data collected periodically at the sites shown in plate 2. When it became evident that more information on the water table in the area south of Muscatine County was needed, additional water-level data were collected at a few sites in Louisa County (pl. 3f). In addition to the water-table maps, hydrographs of water levels in a few alluvial wells are shown in plate 4 to portray daily fluctuations of the water table at specific sites.

Water Table

The principal elements of the water table that are common to all maps (pl. 3) are: 1) a ground-water ridge or divide that trends through the center of Muscatine Island approximately parallel to Muscatine Slough; 2) a ground-water trough adjacent to and paralleling the river; 3) two large cones of depression in the water-table trough located beneath the municipal and industrial well fields; 4) slope of the water table from the bluffs to the slough, and from the ground-water ridge westward and northwestward to the slough and eastward to the ground-water trough; 5) slope of the water table from the river to the ground-water trough; and 6) the stage of the Mississippi River, which at all times is higher than the water table anywhere on the Island except for a narrow strip near the river in Louisa County.

The hydrologic relations are as follows: 1) the ground-water ridge is a recharge area, whose position is maintained mainly by precipitation as it conforms to the area where surface clay is absent; 2) the river is a major line source that continually transmits water to the ground-water trough; 3) Muscatine Slough and the ground-water trough, which contains the two large cones of depression of the water table are discharge areas--the slough receives water by down-gradient flow from the direction of the bluffs and from the direction of the ground-water ridge; the trough receives water from the ground-water ridge in addition to water from the river.

Comparison of the maps for April and October 1964 and March 1965 (pl. 3) shows a relatively stable condition of the water table during this period of the investigation. Examination of the large cones of depression shows that they retained approximately the same size and shape, though the center of one cone did become slightly deeper. Also, the area of ground-water diversion[1] for the three periods is approximately equal. Thus, in

[1] Area where ground-water flow has been diverted from one direction to another by a stress on the ground-water system, such as pumping.

spite of deficient precipitation and streamflow the cones were virtually stabilized, and the continuous heavy pumping did not significantly lower the water table.

The water-table map for May 1965 (pl. 3) shows a significant rise in the water levels under the entire Island. Not only was precipitation abundant, more than 7 inches in April, but the greatest flood of record occurred on the Mississippi River in April. The combination of heavy precipitation and the extreme river stage caused a significant rise in the water table--at least 3 feet under Muscatine Island and as much as 14 feet at one location near the river (fig. 17). The October 1965 water table (pl. 3) was very high because of near-record September precipitation combined with antecedent wet conditions.

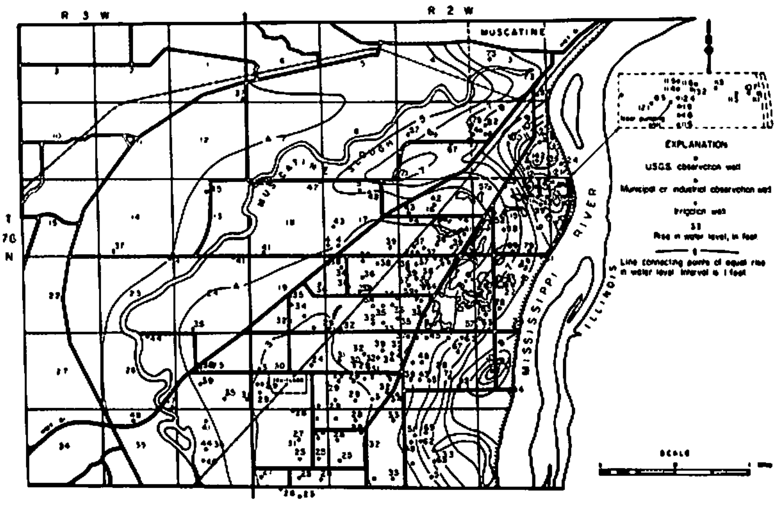


Figure 17.—Rise in water levels on Muscatine Island between March and May 1965.

The water-table altitude during October 1968 is representative of near-normal precipitation and average streamflow. The March and August 1971 water-table maps are representative of below-normal precipitation, but above-average spring streamflow. These three maps show the effects of increased pumpage from the expanding municipal well fields; the cone of depression in the northeast corner had migrated southward toward the gravel pit area, and a new cone had developed in the center of the Island. The areas of ground-water diversion around the Monsanto field and Grain Processing Corporation and municipal fields, however, remained virtually the same (figs. 18 and 19).

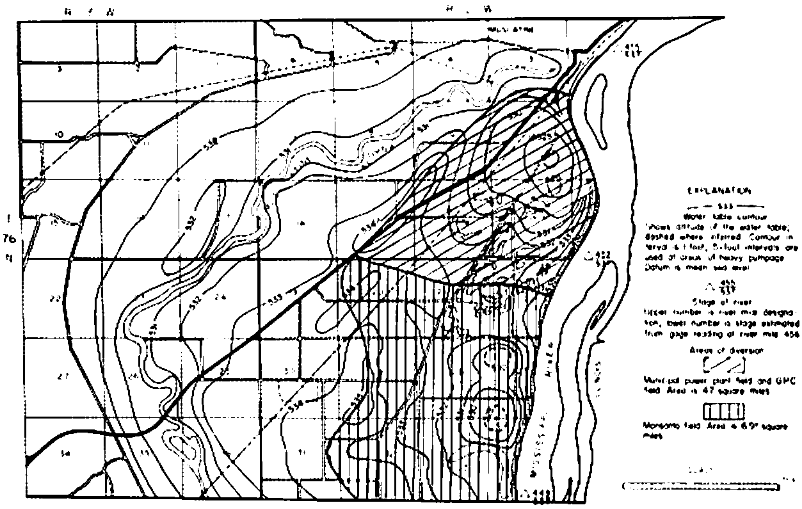


Figure 18.—Altitude and configuration of the water table on October 6, 1964, showing the areas of ground-water diversion of the major pumping centers.

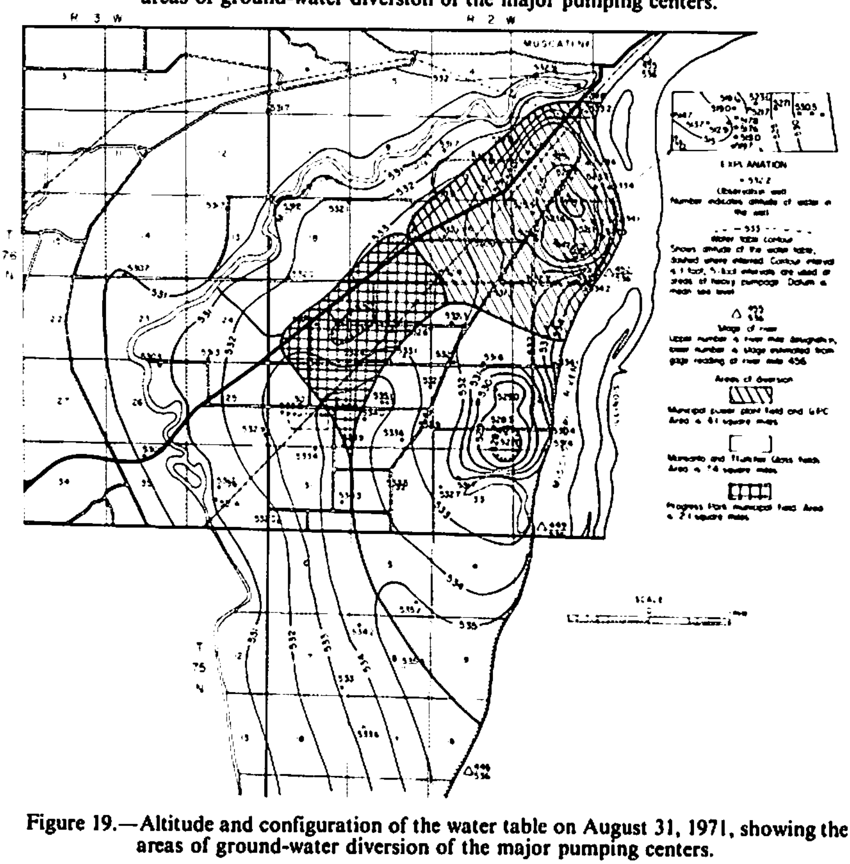


Figure 19.—Altitude and configuration of the water table on August 31, 1971, showing the areas of ground-water diversion of the major pumping centers.

Recharge to the Aquifer

Recharge to the alluvial aquifer is by precipitation, infiltration of river water, seepage from the underlying bedrock, and seepage from the till under the bluffs. The latter is not an important source; the till can transmit only very small quantities of water because of its extremely low permeability. If the bedrock valley entering Muscatine Island from the west contains significant outwash sand, some recharge may enter the alluvial aquifer by underflow. However, any recharge from the direction of the bluffs is intercepted by Muscatine Slough, so that the area east of the slough doesn't receive any recharge from the bluffs.

Recharge by precipitation occurs in the spring and fall, if the amount of rainfall is sufficient. April and May and, sometimes, June are the principal months of recharge; October and November are months of occasional recharge (fig. 3 and pl. 4). It is important to note that deficiencies in precipitation in either April or May limit recharge to the aquifer, even with excess June precipitation (see precipitation and water-level data in 1967, fig. 3 and pl. 4). Occasionally summer precipitaion in excess of crop requirements recharges the aquifer enough to balance the discharge and, thus, the water table remains fairly stable as in 1967, or even occasionally rises as in 1969. These events, however, are rare.

The average annual net recharge to the aquifer by precipitation was estimated to be about 6 inches or 105 mgy per square mile. This estimate was determined from the rise in water level during the spring and fall recharge periods in two alluvial wells (76-3-25ddd and 76-2-30cba) located in the recharge area (pl. 4). The average annual rise in water level, multiplied by the storage coefficient of the zone of water-table fluctuation, was used to approximate the average annual net recharge (table 2). This figure for recharge is used throughout the Island, even though it may be somewhat high in those areas covered with surficial silt.

Induced infiltration of water from the Mississippi River provides large quantities of recharge to the aquifer in the vicinity of the river. This infiltration is the principal source of water that sustains the heavy pumpage in the northeastern and southeastern parts of Muscatine Island. The flow-net analysis of the April 1964 water table indicates that at that time 80 to 85 percent of the water withdrawn from the aquifer at the major pumping centers was derived from the river (fig. 12). In 1964, when the pumpage by the City, Grain Processing Corporation, Monsanto Company, and Thatcher Glass Company averaged about 28 mgd, approximately 23 mgd was derived from the river. During 1971, when about 35 mgd was withdrawn from the same pumping centers, the amount induced from the river is estimated to have been about 29 mgd. In addition, a small amount of river infiltration replaces part of the evaporation losses in the gravel pit area during the period April through October. During that period, evaporation from the water-table ponds (gravel pits) was estimated to total about 340 million gallons, which is an average of about 0.93 mgd for the year. An estimated 70 to 80 percent of that amount, or about 0.7 mgd, is derived from the river. Thus, the total annual amount of infiltration that was induced from the river in 1971 was about 30 mgd.

Additional significant recharge to the aquifer results from extreme hydrologic events, such as floods. Comparison of the March and May 1965 water-table maps shows that the May water table was much higher. The increase is the result of the record flood on the river which occurred in April, plus heavy precipitation which also occurred during that time. The amount, in feet, that the water table was raised over the entire area between March and May and the extent of the area along the river that shows the greatest response to the high river stage is shown in figure 17. The volume of recharge from this extreme hydrologic event is calculated to be over 3.6 billion gallons. More important, at least 40 percent of the water, or about 1.5 billion gallons, was trapped in the ground-water trough and adjacent area. Most of this water eventually reached the centers of pumping; thus, that one recharge event provided a volume of water equal to about two months of municipal and industrial pumpage.

Table 2. Net[1] recharge by precipitation.

Year	Water-level rise (ft)		
	Spring	Fall	Total
1964	1.3e		1.3
1965	3.0e	1.5	4.5
1966	1.3		1.3
1967	1.3	1.6	2.9
1968	0.2		0.2
1969	2.5		2.5
1970	1.8	2.1	3.9
1971	0.6		0.6
	average annual		2.2

Average water-level rise/year = 2.2′

Average storage coefficient = 0.21

Average recharge by precipitation = 2.2′ x 0.21 = approx. 0.5 feet = approx. 6 in.

Average recharge per mile^2 = 27.9 x 10^6 ft^2 x 0.5 ft x 7.5 gal/ft^3 = 105 mgy/mile^2 or approx. 0.3 mgd/mile^2

[1] Recharge in excess of discharge during spring and fall recharge periods

e. Estimated

Water-level data discussed previously indicate that seepage from the bedrock occurs within the combined cones of depression around the Grain Processing Corp. and the municipal power plant well fields. A generalized water budget for the area of influence around these well fields will give a reasonable estimate of the amount of this seepage. In 1964, this area of ground-water diversion, as evidenced by the water-table maps for April and October 1964, was essentially stabilized (pl.3). Moreover, the hydrograph of well 76-3-25ddd shows that there was no net gain or loss in storage in the aquifer during 1964 (pl. 4). Thus, the total pumpage from the two well fields during 1964 had to be derived from river infiltration and other types of recharge within the 4.7 square-mile area of diversion (fig. 18). The pumpage from the area averaged about 14.8 mgd; induced infiltration from the river was 85 percent of the pumpage, or about 12.6 mgd. Thus, 2.2 mgd had to be derived by other forms of recharge. The amount of net recharge during 1964 by precipitation on the area of diversion was (from table 2 and fig. 18):

$1.3\ \text{feet}^3/\text{ft}^2/\text{year} \times 0.21 \times 7.5\ \text{gallons}/\text{ft}^3 \times 27.9 \times 10^6\ \text{ft}^2/\text{mile}^2 \times 4.7\ \text{miles}^2 \div 365\ \text{days}/\text{year} = \text{about } 0.7\ \text{mgd}.$

Therefore, in that area the recharge by seepage from the bedrock during 1964 was about 1.5 mgd. Calculations for other periods of near-stability indicate that recharge by seepage from the bedrock in the same area is about 1 mgd during years of above-average precipitation to about 2 mgd during periods of below-average precipitation. Data are not available to determine if the bedrock is a source of recharge elsewhere on the Island. Hydrochemical data, discussed subsequently, suggest that, under the hydrologic conditions and stresses extant in 1971, the bedrock was not a source of recharge other than in the area described above.

Discharge from the Aquifer

Discharge from the alluvial aquifer occurs as a continual flow of water from the high-water-table areas (the central ground-water ridge, banks of Mississippi River and the bluffs area) to discharge areas (Muscatine Slough and the ground-water trough) in response to a head differential in the system. When recharge equals discharge, the system is in dynamic equilibrium and the water table remains stable. Such a condition was approached during the spring and summer of 1967 (pl. 4). However, when recharge is less than the discharge, the water table lowers as water is removed from storage. During these periods, which are usually after spring recharge and occasionally after fall recharge, the hydrographs show a characteristic recession of the water level. The hydrographs of the two wells situated on the ground-water divide show that the rate of decline of the lower portions of the recession curves has not changed much from 1964 to 1971 (pl. 4). This indicates that hydrologic conditions in the center of the

Island have been fairly stable during the study period. A change in the slope of the recession curve would indicate a change in hydrologic conditions or an additional stress on the system in the interior area. A change did occur in the area known as Progress Park (see pl. 2), where ground-water withdrawals were initiated by the City in 1971. However, the area of ground-water diversion around this new field had not, by September 1971, encompassed the area where observation well 76-2-30cba is located (fig. 19).

The principal form of discharge from the alluvial aquifer is pumpage by the various water users on the Island. This form of discharge has increased from the few million gallons per day that was pumped before 1940 to about 37 mgd in 1970. However, approximately 80 to 85 percent of the total pumpage is river water that is induced toward the industrial and municipal pumping center situated near the river.

Down-gradient ground-water flow from the bluffs and from the ground-water ridge in the center of the Island is discharged by seepage into Muscatine Slough. Because the water in the slough is pumped into the Mississippi River by Muscatine-Louisa Drainage District No. 13, the amount of ground water discharged by seepage could be determined if pumpage records were kept by the Drainage District. Such records, however, are not available for the period of this investigation. The average amount of ground water moving down gradient to the slough, however, can be estimated by applying the generalized Darcy equation:

$$Q = TIL$$

where Q/L = average discharge per lineal foot length of channel, in $ft^3/day/ft$

T = average transmissivity, in ft^2/day (from fig. 13)

I = average hydraulic gradient from bluffs to slough and from ground-water divide to the slough, in ft/ft (from pl. 3)

The amount moving to the slough is estimated by this method to be about 7 ft^3/day per foot of channel length. Therefore, approximately 330,000 ft^3/day (2.5 mgd) is moving toward the 9-mile reach of the slough in Muscatine County. However, not all ground water moving toward the slough during the growing season is discharged into the slough. An unknown, but significant, amount is discharged by transpiration from the dense vegetation growing along the slough and by evaporation of seepage from the banks of the slough.

Discharge by evaporation directly from the water table takes place in the gravel pits. Evaporation rates in the locality are estimated to average about 6 inches per month from April through October (based on pan evaporation data collected by the National Weather Service at Iowa City and Burlington). Thus, the estimated evaporation from the approximately 300 acres of pits is about 340 million gallons per year. This is equivalent to about 1.6 mgd during the seven-month evaporation period, or 0.9 mgd throughout the year. Discharge by evaporation from the water table elsewhere on the Island probably is very slight, because the water table during the summer months is generally more than 8 to 10 feet below land surface. However, during exceptionally wet periods, such as 1965, the water table is within 2 to 5 feet of the land surface at many places. During these periods, significant amounts of water may be discharged from the aquifer by evaporation.

In summary, average recharge and average discharge appear to be close to equilibrium according to the calculations that have been made. For an average year, assuming no net gain or loss in storage and a total pumpage of 37 mgd, the recharge by river infiltration would be about 30 mgd, by precipitation about 9 mgd, and by seepage from the underlying bedrock about 1.5 mgd. The calculated recharge is about 40.5 mgd. Discharge, for the same year, would be 37 mgd by pumpage, 2.5 mgd by seepage to the slough, and 0.9 mgd by evaporation, for a total of 40.4 mgd. For a year of above-average precipitation, there would be a net gain in storage, which is shown by a net rise in water levels in observation wells. Conversely, for years of below-normal precipitation, there would be a net loss in storage.

Chemical Characteristics

Chemical analyses of water from the municipal and some industrial wells completed in the alluvial aquifer are available for various dates since 1933. Some of these are presented in table 4. In order to widen the coverage, additional water samples were collected from the shallow and deep U. S. Geological Survey observation wells during November 1964 and March 1965. The analyses of these samples are presented in table 5. All analyses indicate that the chemical constituents of the water with the occasional exception of iron, manganese, and nitrate, were within the recommended limits established for drinking water (U. S. Public Health Service, 1962). Water samples were also collected from all wells for bacterial analyses; these were reported satisfactory by the Iowa State Hygienic Laboratory.

Distribution of Selected Constituents

Hardness.—The hardness of water from the alluvial aquifer ranges from about 50 to more than 400 mg/l (milligrams per liter). The distribution of the hardness is shown in figures 20 and 21. These maps indicate that 1) the hardness of water in both deep and shallow wells in the area between the bluffs and slough, is usually over 200 mg/l and more than 400 mg/l in places, 2) the hardness of water in the deep wells east of the slough usually is less than 150 mg/l, and 3) the hardness in the shallow wells east of the slough generally is less than 100 mg/l in the ground-water divide area, and between 100 and 200 mg/l elsewhere, except at the pumping centers.

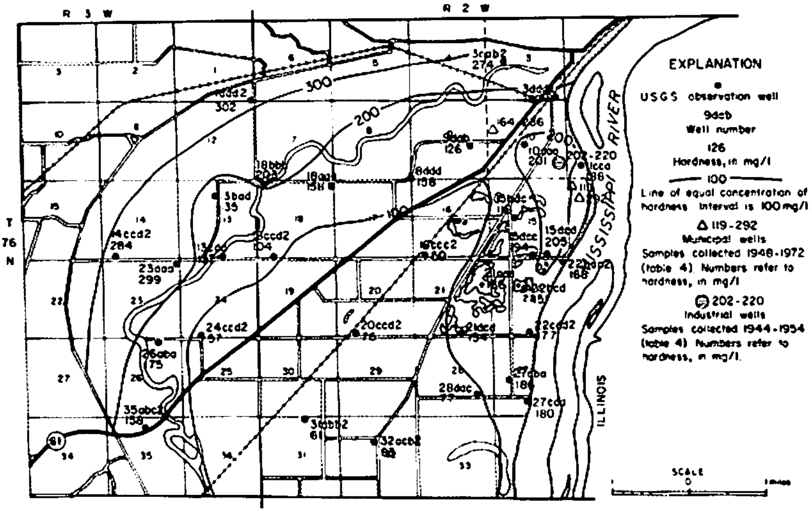


Figure 20.—Distribution of hardness in water from shallow wells in the alluvial aquifer.

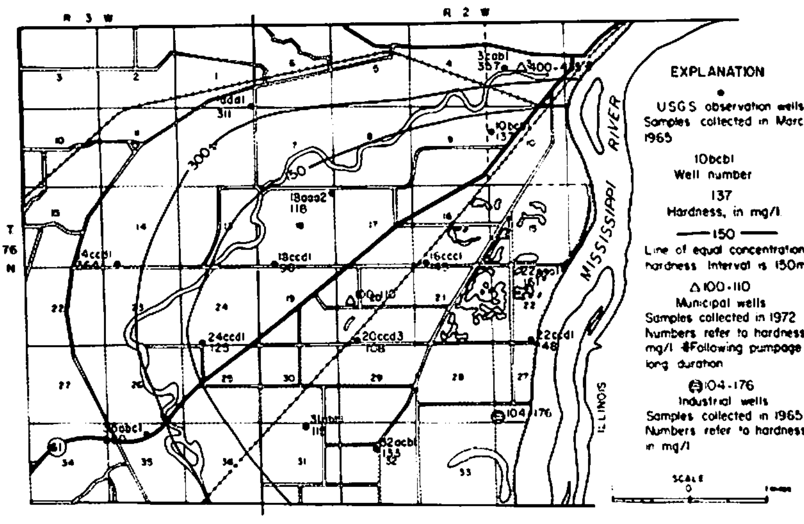


Figure 21.—Distribution of hardness in water from deep wells in the alluvial aquifer.

At the northeastern pumping center, the hardness is quite variable in both space and time (table 3). The hardness in this well field ranges from about 160 to 300 mg/l and averages about 200 mg/l. Most wells there show a progressive increase in hardness of water with time. Wells located close to the river exhibit a hardness that is consistent with the hardness of river water (compare tables 3 and 6). Water from wells located along the northern part of the well field and in the Sampson Street well field is consistently harder and has exhibited a more progressive increase in hardness than water from most other wells (table 3). These observations are an additional indication that water from the bedrock, which is harder, is recharging the aquifer from an area north and west of the well field.

At the new well field (Progress Park), the hardness of water is about 100 mg/ l. This is consistent with the hardness of the water from the deep zone in the area of the ground-water divide. The lower hardness of water from this new well field is an indication that the bedrock is not, as yet, recharging the alluvial aquifer in that area.

Dissolved Solids.—The dissolved-solids concentration in water from the aquifer ranges from about 100 mg/ l in the central part of the area to almost 400 mg/ l along the western bluff line. Generally, water east of the slough contains less than 200 mg/ l dissolved solids except in the northeast corner and along the river. The distribution of dissolved solids is similar to the distribution pattern of hardness shown in figures 20 and 21.

Iron and Manganese.—A combined concentration of iron (Fe) and manganese (Mn) less than 0.3 mg/ l is recommended for public consumption. Composite water samples obtained from the municipal-power-plant well field have an iron-manganese concentration of less than 0.3 mg/ l, although a few individual wells exhibit slightly higher concentrations. Attempts to develop supplies of similar quality water elsewhere on the Island have not always succeeded. Therefore one objective of this investigation was to determine the distribution of iron and manganese in the aquifer. The distribution of iron from shallow and deep wells in March 1965 is given in figures 22 and 23.

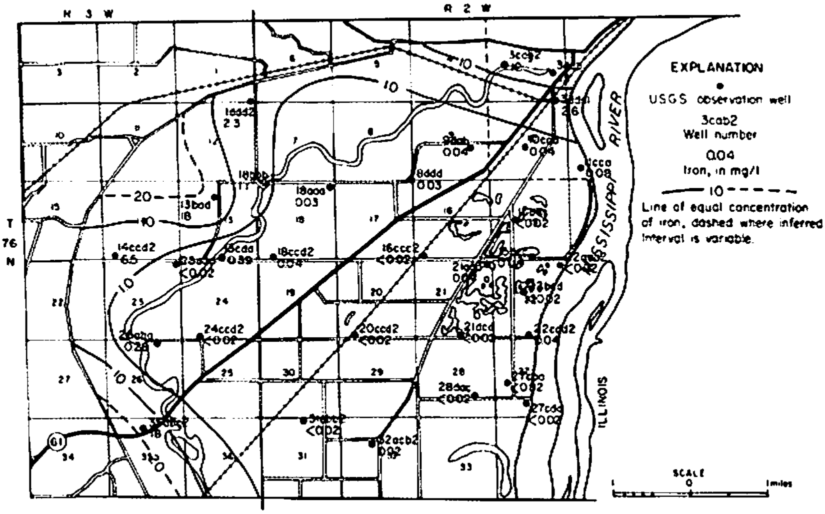


Figure 22.—Distribution of iron in water from shallow wells in the alluvial aquifer in March 1965.

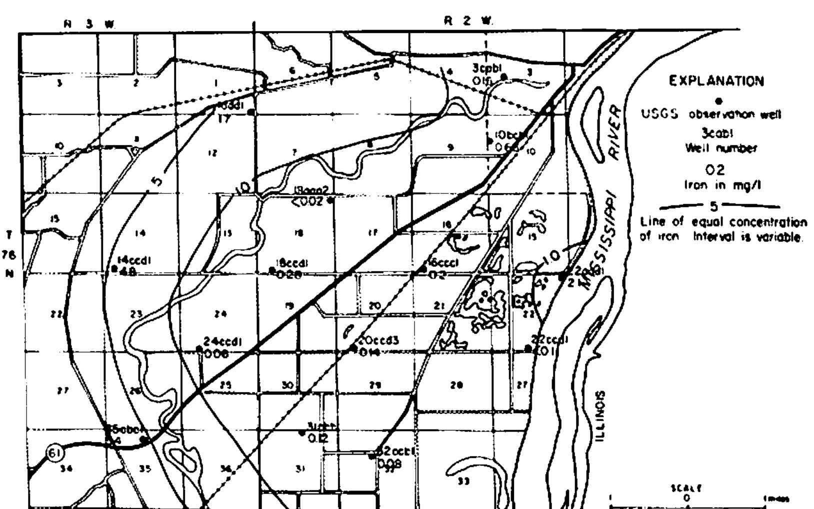


Figure 23.—Distribution of iron in water from deep wells in the alluvial aquifer in March 1965.

Table 3.—Hardness of water, in mg/l, from alluvial wells in the municipal well fields.

Well Field	Well No.	1948	1949	1952	1954	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
		Years																	
Power Plant (North and South)	1	119	151	167		180		172								196			
	2					182		188			197					292		208	
	[2]3				118	165		180								208		226	
	4					129		148								208		216	
	5						154									176		200	
	[1]6							185								174			
	8									188	188					156		192	
	9										161			190		158		148	
	[2]12												188	216		212		220	
	[1]13													196				188	
	14													228	201	200		208	
	[1]15													176				178	
	16													256				190	
	17																	188	
	18																	180	
	19																	176	
	20																	160	
	21																	216	
Hershey	7								426	406	400						435		
	10										355			196					
Sampson	11											164	168	192		234		236	
Progress Park	22																		100
	23																		110

[1] Wells located near Mississippi River.
[2] Wells located near north edge of municipal power-plant well field.

The concentration of iron is very high in both the upper and lower parts of the aquifer in the area north and west of the slough. Water from the shallow zone east of the slough generally contains less than 0.1 mg/l of iron. In the deep zone, the iron concentration is somewhat greater, but, except for the Sampson Street well field and locally, in the power-plant well field, it is less than 0.3 mg/l.

Manganese concentrations differ greatly throughout the Island, ranging from less than .05 to 8.6 mg/l. No particular distribution pattern for the manganese was discernable, except that the highest concentrations occur near the bluffs and locally in the Sampson Street and power-plant well fields.

Nitrate.—The concentration of nitrate ranges from less than 1 mg/l to 46 mg/l, which is just slightly greater than the recommended limit established by the U. S. Public Health Service. The highest concentrations occur in the shallow zone under the ground-water divide (fig. 24). Much of

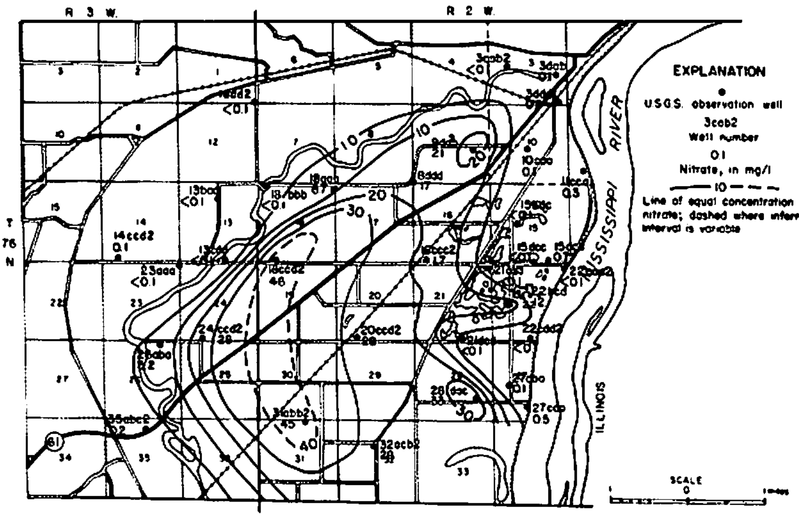


Figure 24.—Distribution of nitrate in water from shallow wells in the alluvial aquifer in March 1965.

this area of the Island has a very sandy soil that is heavily fertilized and mulched. Nitrate in the lower part of the aquifer is usually less than 1 mg/l. Analyses of water from wells 22 and 23 in the new Progress Park municipal well field, which are located in the area of high nitrate concentration but withdraw water from the deep zone, show a low nitrate concentration in 1971 (table 4).

Table 4.—Partial analyses of water from municipal and industrial wells in Muscatine Island. Constituents in mg/l.

Well number	Date of collection	Temperature (°F)	Iron (Fe)	Manganese (Mn)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved Solids	Total Hardness
Muscatine City Well #7	9-10-62	55	0.24	0.48	97	33.0	< 0.10	518	406
Muscatine City Well #8	9-11-62		.28	.05	34	3.5	1.40	223	188
Muscatine City Well #2	2-20-63	57	.06	<.05	25	6.0	0.40	248	197
Muscatine City Well #7	2-19-63	55	.80	.66	93	26.0	< 0.10	518	400
Muscatine City Well #8	3-1-63	57	.08	< .05	29	3.0	< 0.10	241	188
Muscatine City Well #9	10-31-63	57	.14	< .05	14	4.0	1.10	175	161
Muscatine City Well #10	10-30-63	58	2.00	.35	57	23.0	< 0.10	433	355
Muscatine City Well #11	8-12-64	54	.15	.36	31	2.0	1.80	206	164
Muscatine City Well #11	1-8-65	54	.20	.40	31	1.0	0.10	214	168
Muscatine City Well #12	6- -65		< .02	.12	21	5.1	3.40	207	188
Muscatine City Well #9	7-12-66	46	.06	2.20	29	7.0	1.20	235	190
Muscatine City Well #10	7-12-66	48	.06	.75	26	7.0	1.20	255	196
Muscatine City Well #11	7-12-66	54	.06	.20	41	6.0	5.80	262	192
Muscatine City Well #12	7-12-66	54	.06	.16	42	11.0	2.50	294	216
Muscatine City Well #13	7-12-66	52	.06	.12	33	8.0	3.90	264	196
Muscatine City Well #14	7-12-66	54	.06	.15	40	10.0	5.70	291	228
Muscatine City Well #15	7-12-66	53	.06	.16	47	4.0	7.40	222	176
Muscatine City Well #16	7-12-66	52	.08	.18	39	12.0	2.80	326	256
Muscatine City Well #14	5-4-67	54	.08	.12	18	6.5	1.10	233	201
Muscatine City Well #1	2-7-68	59	< .02	.14	24	6.5	0.50	242	196
Muscatine City Well #2	2-7-68	62	.06	.06	79	2.5	0.70	386	292
Muscatine City Well #3	2-7-68	54	< .02	<.05	28	7.0	2.50	241	208
Muscatine City Well #4	2-7-68	55	.06	.05	22	4.0	3.20	249	208
Muscatine City Well #5	2-7-68	55	.04	.05	25	4.0	6.60	214	176
Muscatine City Well #6	2-7-68	55	.11	.11	29	3.0	6.00	209	174
Muscatine City Well #8	2-7-68	55	.06	.06	25	2.5	7.30	191	156
Muscatine City Well #9	2-7-68	57	.06	.07	29	3.0	1.10	183	158
Muscatine City Well #11	2-8-68	52	3.50	.62	60	< 0.5	0.40	284	234
Muscatine City Well #12	2-7-68	54	.06	.06	27	6.5	0.90	247	212
Muscatine City Well #14	2-7-68	55	.14	.05	21	7.0	3.70	237	200
Muscatine City Well #2	5-28-70	—	.04	< .05	37	13.0	1.40	257	208
Muscatine City Well #3	5-29-70	—	.04	< .05	33	11.0	1.80	270	226
Muscatine City Well #4	5-29-70	—	.08	.06	37	13.0	1.20	263	216
Muscatine City Well #7	6-5-70	—	.72	.84	120	32.0	< 0.10	575	435
Muscatine City Well #8	5-28-70	—	.08	.05	38	7.0	7.10	224	192
Muscatine City Well #9	5-28-70	—	.04	.12	29	6.0	0.70	195	172
Muscatine City Well #11	6-5-70	—	2.8	.94	100	5.0	< 0.10	412	328
Muscatine City Well #12	5-28-70	—	.09	.05	34	9.0	2.70	267	220
Muscatine City Well #14	5-28-70	—	.28	.06	34	9.0	3.90	260	208
Muscatine City Well #15	5-28-70	—	.14	.06	28	6.0	1.90	211	178
Muscatine City Well #16	5-28-70	—	.40	.11	35	7.0	2.10	233	190
Muscatine City Well #17	5-28-70	—	.18	<.05	32	9.0	3.00	231	188
Muscatine City Well #18	5-28-70	—	.18	.10	32	8.0	1.80	214	180
Muscatine City Well #19	5-28-70	—	.08	.06	44	4.0	4.40	207	176
Muscatine City Well #20	5-29-70	—	.06	.14	28	2.0	1.20	186	160
Muscatine City Well #13	6-19-70	—	.12	1.50	37	11.0	0.50	236	188
Muscatine City Well #5	6-19-70	—	.02	< .05	41	9.0	5.10	259	200
Muscatine City Well #21	8-18-70	—	.10	.35	62	9.0	0.90	288	216
Muscatine City Well #22	10-1-71	—	.22	.12	34	1.0	0.90	115	100
Muscatine City Well #23	10-20-71	55	.14	.14	27	2.0	5.80	131	110
Grain Processing Corp. Well No. 1	6-29-44	62	.10	.00	23	3.5	0.09	276	202
Grain Processing Corp. Well No. 6	3-21-49	55	—	.49	85	18.0	5.70	403	298
Grain Processing Corp. Well No. 8	12-3-54	55	.00	.08	64	9.0	—	317	220
Monsanto Well #1	4-21-65	—	.50	—	—	—	—	—	176
Monsanto Well #2	4-21-65	—	.05	—	—	—	—	—	104
Monsanto Well #4	4-21-65	—	.20	—	—	—	—	—	168
Monsanto Well #5	4-21-65	—	.05	—	—	—	—	—	118
Monsanto Well #6	4-21-65	—	.05	—	—	—	—	—	106
Monsanto Well #7	4-21-65	—	.45	—	—	—	—	—	168

Table 5.—Analyses of water from U.S.G.S. observation wells on Muscatine Island. Constituents in mg/l. Well locations shown in plate 2. Analyses by Iowa State Hygenic Lab.

Well number	Date of collection	Depth (feet)	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Flouride (F)	Nitrate (NO_3)	Dissolved Solids	Hardness (calculated as $CaCO_3$)			Specific conductance (micromhos at 25° C)	pH
																		Total	Carbonate	Non-carbonate		
76-2-9dab	11-10-64	24.5	56.50	24.0	2.40	0.24	48	21.0	6.3	0.20	0	159.0	68.0	1.0	0.20	8.20	266	207	130	77	392	7.65
76-2-9dab	3-16-65		53.00		.04	<.05										21.00		126				
76-2-8ddd	11-10-64	28.2	54.00	19.0	.14	<.05	33	14.0	6.1	.2	0	68.0	76.0	6.5	.15	24.00	205	139	56	83	323	7.65
76-2-8ddd	3-16-65				.03	<.05										17.00		158				
76-2-18aaa1	11-4-64	23.2	57.00	23.0	<.02	<.05	38	16.0	5.2	.3	0	107.0	79.0	2.0	.20	7.30	240	160	88	72	343	7.50
76-2-18aaa1	3-16-65		53.00		.03	<.05										8.70		158				
76-2-18aaa2	11-4-64	65.0		15.0	.02	.62	27	12.0	3.6	.9	0	120.0	30.0	2.0	.10	.20	162	116	98	18	239	7.55
76-2-18aaa2	3-16-65		54.00		<.02	.66										<.10		118				
76-2-18bbb	11-4-64	28.3	55.00	19.0	.96	.06	36	12.0	8.9	.4	0	151.0	32.0	1.0	.45	.10	171	138	124	14	292	7.25
76-2-18bbb	3-31-65		54.00		1.10	.08										<.10		203			443	
76-3-1ddd1	11-4-64	95.3	54.50	18.0	2.60	.06	78	30.0	11.0	.9	0	364.0	30.0	6.0	.20	.20	366	311	298	13	599	7.70
76-3-1ddd1	3-31-65		53.00	19.0	1.70	.11	80	27.0	10.0	1.4	0	379.0	17.0	1.5	.20	<.10	365	311	311	0	624	7.40
76-3-1ddd2	11-4-64	27.4	54.50	21.0	1.20	.13	76	26.0	9.7	.8	0	359.0	19.0	2.0	.25	.20	348	296	294	2	567	7.50
76-3-1ddd2	3-31-65		53.50	20.0	2.30	.11	80	25.0	9.1	1.2	0	365.0	8.8	4.5	.25	<.10	355	302	299	3	584	7.50
76-3-14ccd1	11-5-64	96.4	53.50	21.0	3.30	.13	92	33.0	7.6	.6	0	415.0	44.0	3.0	.20	.10	394	366	340	26	685	7.30
76-3-14ccd1	3-31-65		53.00		4.80	<.05										<.10		364				
76-3-14ccd2	11-5-64	27.2	54.00	24.0	7.30	.14	76	22.0	5.0	.1	0	227.0	99.0	5.0	.20	.20	362	280	186	94	540	7.30
76-3-14ccd2	3-31-65		53.00		6.50	.11										.10		284				
76-3-23aaa	11-5-64	27.3	54.00	24.0	.24	.12	78	27.0	5.4	.9	0	200.0	152.0	6.0	.15	.20	405	306	164	142	585	7.60
76-3-23aaa	3-31-65		54.00	24.0	<.02	<.05	78	25.0	4.7	1.4	0	196.0	136.0	6.0	.10	<.10	430	299	161	138	585	7.60

Well number	Date of collection	Depth (feet)	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Flouride (F)	Nitrate (NO_3)	Dissolved Solids	Hardness (calculated as $CaCO_3$)			Specific conductance (micromhos at 25° C)	pH
																		Total	Carbonate	Non-carbonate		
76-3-13cdd	11-5-64	27.4	54.00	14.0	0.48	< 0.05	37	10.0	4.4	0.9	0	139.0	41.0	2.0	0.10	.30	162	134	114	20	276	7.40
76-3-13cdd	3-16-65		54.00		.39	< .05										<.10		137				
76-2-18ccd1	11-5-64	105.0	55.00	10.0	.44	.15	26	7.3	2.6	.2	0	102.0	29.0	<0.5	.05	.20	120	96	84	12	199	7.70
76-2-18ccd1	3-16-65		54.50		.28	.09										<.10		96				
76-2-18ccd2	11-5-64	27.4		18.0	.16	<.05	26	10.0	3.8	.3	0	46.0	35.0	4.0	.10	46.00	164	106	38	68	244	7.45
76-2-18ccd2	3-16-65		53.50		.04	<.05										46.00		104				
76-3-13bad	11-5-64	27.2	55.00	51.0	19.00	.45	33	14.0	8.0	.1	0	76.0	97.0	<.5	.25	.50	276	141	62	79	321	6.95
76-3-13bad	3-16-65		53.00		18.00	.48										<.01		135				
76-2-15bdc	11-16-64	26.5	57.00	9.6	.20	.08	30	9.7	3.4	1.5	0	121.0	27.0	.5	.10	<.10	139	116	99	17	234	7.70
76-2-15bdc	3-31-65		61.00	8.0	<.02	.10	34	7.8	2.9	.9	0	123.0	20.0	2.0	.10	<.10	162	116	101	15	242	8.00
76-2-10caa	3-16-65	43.5	56.00	22.0	.04	<.05	51	18.0	5.0	.4	0	210.0	37.0	1.5	.10	.10	243	201	172	29	406	7.90
76-2-11cca	11-10-64	43.3	69.50	11.0	.70	1.70	43	18.0	9.2	2.3	0	176.0	43.0	6.0	.20	.50	213	183	144	39	370	7.60
76-2-11cca	3-16-65		47.50		.08	2.10										.30		186				
76-2-22aaa1	11-16-64	74.1	54.50	18.0	7.00	<.05	46	12.0	4.6	.9	0	144.0	44.0	2.5	.10	.20	193	164	118	46	301	7.65
76-2-22aaa1	3-15-65		55.00	16.0	2.10	.15	47	11.0	4.1	.5	0	156.0	35.0	2.0	.10	<.10	194	161	127	34	313	8.00
76-2-22aaa2	11-16-64	26.6	56.00	16.0	.64	.15	50	16.0	12.0	2.6	0	229.0	24.0	9.0	.15	.20	240	192	188	4	397	7.60
76-2-22aaa2	3-15-65		61.00	16.0	<.02	<.05	48	12.0	11.0	1.1	0	216.0	6.3	8.0	.15	<.10	215	168	168	0	377	7.90
76-2-15dcc	11-16-64	26.4	59.00	14.0	.67	.10	59	17.0	4.7	1.5	0	224.0	41.0	2.5	.20	.10	249	216	184	32	402	7.95
76-2-15dcc	3-16-65		59.00		.04	<.05										<.10		194				

Well number	Date of collection	Depth (feet)	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Flouride (F)	Nitrate (NO_3)	Dissolved Solids	Hardness (calculated as $CaCO_3$)			Specific conductance (micromhos at 25° C)	pH
																		Total	Carbonate	Non-carbonate		
76-2-21aaa	11-17-64	27.4	63.50	17.0	0.23	0.70	47	14.0	2.5	1.6	0	187.0	40.0	1.0	0.05	0.30	205	176	153	23	338	7.75
76-2-21aaa	3-16-65		53.50		.04	.86										< 0.10		126				
76-2-16ccc1	11-18-64	95.3	57.00	13.0	.48	<.05	42	12.0	3.1	1.2	0	146.0	49.0	<.5	.10	.10	187	152	120	32	308	7.65
76-2-16ccc1	3-16-65		56.00		.20	.29										<.10		145				
76-2-16ccc2	11-18-64	27.4	58.00	19.0	.12	<.05	14	4.9	3.0	.7	2.4	23.0	26.0	1.0	.05	12.00	102	54	23	31	117	8.20
76-2-16ccc2	3-16-65		56.00		<.02	<.05										17.00		50				
76-2-16ccc3	11-18-64	62.0	57.50	16.0	.68	<.05	22	7.3	3.3	.9	2.4	40.0	24.0	5.5	.10	30.00	137	84	37	47	191	8.15
76-2-16ccc3	3-16-65		56.00		<.02	<.05										29.00		81				
76-2-22bcd	11-17-64	27.4	59.00	10.0	2.80	.08	40	11.0	4.5	1.7	0	122.0	43.0	4.0	.01	4.60	184	144	100	44	297	7.60
76-2-22bcd	3-31-65		58.00		<.02	<.05										12.00		151				
76-3-24ccd1	11-9-64	100.7	58.00	16.0	.40	.22	31	11.0	3.2	.3	0	122.0	40.0	<.5	.10	.20	154	124	100	24	247	7.70
76-3-24ccd1	3-31-65		56.00	16.0	.06	.24	30	12.0	2.7	.6	0	127.0	26.0	.5	.10	<.10	180	125	104	21	255	7.95
76-3-24ccd2	11-9-64	27.4	58.25	20.0	.48	.06	15	7.3	3.9	.2	0	20.0	38.0	<.5	.05	39.00	128	68	16	52	173	6.60
76-3-24ccd2	3-31-65		55.50	20.0	<.02	<.05	14	5.1	2.9	.4	0	20.0	19.0	<.5	.05	28.00	137	57	16	41	148	6.75
76-3-26aba	11-9-64	27.4	55.50	34.0	.28	7.20	32	18.0	6.4	.8	0	56.0	129.0	3.0	.20	3.70	260	154	46	108	344	6.50
76-3-26aba	3-31-65		54.00		.28	8.60										3.20		175				
76-2-22cdd1	11-17-64	93.2	53.00	14.0	.60	<.05	37	14.0	8.7	1.5	0	135.0	51.0	4.0	.05	.10	196	148	111	37	322	7.75
76-2-22cdd1	3-31-65		53.50	15.0	.10	<.05	38	13.0	5.3	.4	0	134.0	36.0	5.0	.10	<.10	216	148	110	38	318	8.05
76-2-22cdd2	11-17-64	28.2	52.00	16.0	.36	<.05	51	16.0	10.0	1.5	0	218.0	36.0	9.0	.01	.10	245	196	179	17	405	7.70
76-2-22cdd2	3-31-65		57.00	18.0	.04	<.05	50	13.0	9.8	1.2	0	206.0	14.0	6.0	.10	<.10	240	177	169	8	380	7.80

Well number	Date of collection	Depth (feet)	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Flouride (F)	Nitrate (NO_3)	Dissolved Solids	Hardness (calculated as $CaCO_3$)			Specific conductance (micromhos at 25° C)	pH
																		Total	Carbonate	Non-carbonate		
76-2-21dcd	11-17-64	28.3	65.00	19.0	0.52	<0.05	36	15.0	5.0	1.7	0	152.0	31.0	3.0	0.10	0.20	157	150	125	25	304	7.75
76-2-21dcd	3-31-65		57.00		< .02	.05										<.10		134				
76-2-20ccd1	11-18-64	89.2	58.00	18.0	1.00	<.05	18	5.3	3.2	.9	2.4	42.0	24.0	1.0	.05	19.00	118	66	38	28	149	8.30
76-2-20ccd1	3-15-65		57.00	20.0	.06	<.05	18	3.9	2.3	.4	1.2	45.0	12.0	.5	.05	19.00	102	62	39	23	147	8.50
76-2-20ccd2	11-18-64	28.0	58.00	16.0	.48	<.05	22	6.3	3.7	1.2	4.8	24.0	35.0	3.0	.05	27.00	143	80	28	52	182	8.30
76-2-20ccd2	3-15-65		56.00	17.0	< .02	< .05	24	3.9	2.6	.4	4.8	22.0	25.0	3.0	< .05	28.00	122	76	26	50	183	8.70
76-2-20ccd3	11-18-64	129.8	57.00	9.6	.36	.10	32	7.8	3.2	1.4	0	115.0	25.0	<.5	.05	<.10	136	112	94	18	224	7.20
76-2-20ccd3	3-15-65		57.00	11.0	.14	.07	34	5.8	2.4	.9	0	118.0	24.0	<.5	<.05	<.10	136	108	97	11	232	8.10
76-3-35abc1	11-18-65	95.7	54.50	24.0	5.60	.24	89	33.0	8.5	1.2	0	429.0	35.0	1.0	0.2	.30	396	358	352	6	665	7.40
76-3-35abc1	3-31-65		54.00		5.40	.29										.10		360				
76-3-35abc2	11-9-64	28.8	54.25	22.0	24.00	1.30	45	21.0	3.7	.1	0	151.0	85.0	3.0	.40	1.20	314	200	124	76	385	6.65
76-3-35abc2	3-31-65		53.00		18.00	.68										.20		158				
76-2-31abb1	11-9-64	101.5	58.00	6.4	.72	.12	35	7.8	2.7	.1	0	107.0	46.0	1.5	.05	<.10	148	120	86	34	242	7.70
76-2-31abb1	3-31-65		57.00		.12	.06										<.10		115				
76-2-31abb2	11-9-64	27.8	60.00	17.0	.85	.08	13	5.6	2.7	.3	0	9.8	37.0	<.5	.05	35.00	106	56	8	48	134	6.95
76-2-31abb2	3-31-65		57.00		<.02	<.05										45.00		61				
76-2-32acb1	11-9-64	100.3	57.00	21.0	7.40	.29	38	14.0	2.6	.2	0	127.0	44.0	1.0	.10	.50	192	154	104	50	277	7.70
76-2-32acb1	3-31-65		56.50	11.0	.08	.23	38	9.0	2.2	.4	0	127.0	29.0	<.5	.10	<.10	153	133	104	29	265	7.90
76-2-32acb2	11-9-64	27.4	59.00	15.0	.05	<.05	24	11.0	4.5	.2	0	34.0	42.0	16.0	.05	28.00	140	107	28	79	254	7.20

Well number	Date of collection	Depth (feet)	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Flouride (F)	Nitrate (NO_3)	Dissolved Solids	Hardness (calculated as $CaCO_3$)			Specific conductance (micromhos at 25° C)	pH
																		Total	Carbonate	Non-carbonate		
76-2-32acb2	3-31-65		55.00	16.0	0.02	<0.05	22	6.6	4.1	.4	2.4	40.0	17.0	7.0	0.10	28.00	132	83	37	46	205	8.35
76-2-28dac	11-17-64	32.2	57.00	17.0	3.30	<.05	18	7.3	3.7	.9	0	38.0	26.0	2.5	.05	33.00	128	76	31	45	175	7.85
76-2-28dac	3-31-65		57.00		<.02	<.05										33.00		77				
76-2-27cda	11-18-64	39.7	64.00	18.0	1.40	<.05	48	18.0	11.0	2.4	0	212.0	34.0	7.0	.10	.20	234	196	174	22	401	7.50
76-2-27cda	3-31-65		57.00		<.02	<.05										.50		180				
76-2-27cba	11-17-64	33.2	56.00	16.0	.60	.15	53	18.0	8.4	1.5	0	214.0	40.0	9.0	.05	.30	251	206	175	31	413	7.70
76-2-27cba	3-31-65		57.00		<.02	<.05										.10		186				
76-2-3ddd1	11-10-64	44.8	55.00	15.0	3.70	.40	50	16.0	10.2	2.2	0	212.0	35.0	7.0	.25	.70	242	190	174	16	395	7.30
76-2-3ddd1	3-16-65		54.50		2.60	.34										.30		162				
76-2-15dcd	11-16-64	27.4	56.00	24.0	1.70	.70	54	19.0	7.0	1.4	0	21.4	41.0	7.0	.10	2.50	269	214	175	39	413	7.90
76-2-15dcd	3-16-65		55.00		.04	<.05										.70		205				
76-2-10bcb1	11-18-64	100.1	54.00	16.0	1.00	10.00	49	16.0	5.9	1.6	0	222.0	24.0	<0.5	.10	.20	211	186	182	4	363	7.15
76-2-10bcb1	3-16-65		54.50		.68	.11										<.10		137				
76-2-3cab1	11-10-64	67.0	55.00	21.0	1.80	.76	77	24.0	10.0	1.1	0	290.0	55.0	7.5	.20	1.40	349	292	238	54	544	7.50
76-2-3cab1	3-16-65		54.00		.16	.92										<.10		357				
76-2-3cab2	11-10-64	27.4	56.00	24.0	16.00	.34	49	22.0	12.0	.1	0	173.0	84.0	13.0	.20	.60	316	213	142	71	452	6.80
76-2-3cab2	3-16-65		52.50		12.00	.35										<.10		274				
76-2-3dab	11-10-64	30.4	57.00	16.0	12.00	.75	72	23.0	15.0	1.6	0	307.0	21.0	13.0	.20	1.20	364	274	252	22	540	7.00
76-2-3dab	3-16-65		56.00		13.00	.94										.10		390				

Sulfate.—The sulfate content in the water ranges from about 25 to 150 mg/1 (tables 4 and 5). However, the higher concentrations, about 70 to 150 mg/1, are restricted principally to areas adjacent to the Slough and the area between the bluffs and the Slough. Elsewhere, the concentrations generally are between 25 and 50 mg/1, which are similar to the concentrations in the Mississippi River (table 6).

Table 6.—Partial analyses of water from Mississippi River at Davenport, Iowa. Constituents in mg/1. Analyses by Iowa State Hygienic Lab.

Date of collection	Temperature (°F)	Iron (Fe)	Manganese (Mn)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved Solids	Total Hardness (calculated as $CaCO_3$)	pH
2-15-60	34.0	0.34	0.10	27	6	1.3	248	184	7.85
4-11-60	43.0	.30	.05	25	6	1.4	213	142	8.20
7-25-60	80.0	.04	.05	24	5	.4	214	160	8.15
2-20-61	35.0	.25	.05	28	6	.3	209	164	8.30
6-19-61	74.0	.16	.05	26	5	.3	208	148	7.50
9-11-61	79.0	.22	.05	28	6	.2	204	162	7.95
12-11-61	34.0	.20	.05	31	8	1.2	246	196	8.10
3-26-62	38.0	.40	.05	25	7	1.5	189	136	7.75
5-13-63	63.0	.08	.05	35	6	1.1	197	146	8.15
1-13-64	32.0	.02	.07	34	8	3.2	264	200	7.50
8-3-64	81.0	.04	.12	47	7	1.6	239	180	7.90
4-5-65	35.0	.56	.05	22	7	1.9	172	104	8.00
Range		.02 .56	.05 .12	22 47	5 8	0.2 3.2	172 264	104 200	7.50 8.30

Interpretation of Distribution

The occurrence and distribution of the chemical constituents in the water excepting nitrate are dependent on the boundary conditions and flow system of the alluvial aquifer. Two boundaries—the river and the bedrock—have been shown to influence ground-water flow where the system has been altered or modified by ground-water withdrawals. Elsewhere on the Island, however, the influence of the materials in the unsaturated zone becomes apparent when the distribution of chemical constituents (figs. 20-23) is compared with the generalized soils map (fig. 5.) The concentrations of most chemical consituents is higher in water from the area underlain by bottomland soils, which are developed on a mixture of colluvium and alluvium; the concentrations are lower in water from the area underlain by terrace soils, which are developed only on alluvium. The higher concentrations under the bottomland soils are attributed to the leaching of calcareous, gypsiferous, and ferruginous minerals and rock flour in the colluvial materials that were derived from the till in the bluffs. The areal distribution of the chemical constituents is controlled to a great extent by the flow system in the aquifer. Muscatine Slough is a line sink; therefore, the higher concentrations of chemical constituents are restricted in their distribution to the areas between the bluffs and Slough and a narrow strip on the riverward side of the Slough. This distribution pattern should prevail so long as the ground-water divide persists in the central part of the Island.

IMPACT OF MAN'S ACTIVITIES ON THE HYDROLOGIC SYSTEM

Effects on the Water Table

Man's land-use practices and his development of water supplies altered the hydrologic system when he first moved into the area. The early effects on the water table, however, were minimal. Minor supplies of ground water were developed on small, widely scattered farms for domestic and livestock use. Only small amounts of ground water were developed by the few industries that were not supplied by the city. The municipal supply for the, then, small town of Muscatine was obtained from the Mississippi River. Although private levees were erected during the latter part of the 19th century, they were unconnected, and thus were not completely effective in preventing overland flooding. Their impact on the hydrologic system, therefore, was minimal and remained so until the Federal Government completed an integrated system in 1924.

Subsequent activities of man, however, began to have significant impact on the system; some raised the water table and some lowered it. Each activity had a characteristic impact during a specific period of time. The hydrologic conditions during four periods will be discussed. These are: from the early 1900's to 1937; from 1937 to 1946; from 1946 to 1971; and from 1971 to the near future.

Hydrologic Conditions During the Early 1900's to 1937

This period was characterized by controlled discharge of water from Muscatine Slough, uncontrolled stages of the Mississippi River, and the initiation of ground-water withdrawals for irrigation and municipal use.

The hydrologic system on Muscatine Island during that period was in a state of dynamic equilibrium quite different than it is presently. Recharge to the alluvial aquifer was principally by the infiltration of precipitation during the spring and occasionally in the fall. The amount is assumed to have been the same as presently—an average of about 6 inches per year. Additional recharge was by seepage from the Mississippi River during rising river stages, which usually occurred in the late winter and spring. Moderate rises in stage recharged a strip of aquifer near the river probably no wider than one-half mile; the highest stages recharged a strip probably more than one mile in width. Most of this recharge, however, was returned to the river during the subsequent declining river stages. Recharge by overland flooding occurred occasionally before 1924, but was prevented following the completion of the government levee from the City of Muscatine to Port Louisa. Seepage from the bedrock probably recharged the aquifer locally; the amount, however, was probably small. Seepage from the till was insignificant, as it is presently.

Discharge from the aquifer was principally by seepage into Muscatine Slough and into the Mississippi River. The discharge into the slough was a continuous process and was controlled by the pumping station that was constructed in 1916 at Port Louisa. For the first time, excess ground and surface water could be drained from the Island even during times of high flows on the Mississippi River. Ground water was discharged into the Mississippi River during falling and low river stages, which usually occurred during the summer and winter. An unknown quantity was discharged by evapotranspiration in and adjacent to the slough. The amount probably was greater than it was in 1970, because more vegetation, swamps, and ponds, existed then. Evaporation from the water table in the gravel-pit area was minimal, because the number of pits and , thus, the total area of exposed water surface was small. Discharge by pumpage was minimal. An estimated 1 to 2 mgd was withdrawn for municipal supply from the aquifer in the Muscatine area; an unknown, but small amount was withdrawn for irrigation at a few scattered locations on the Island. Hence, municipal and irrigation pumpage had little effect on the hydrologic system.

Although recharge to the aquifer equals discharge when considered over any long period of time, one or the other is predominant at any particular time. On Muscatine Island, recharge exceeds discharge usually in the spring and occasionally in the fall, therefore the water table will be at its highest position in late spring and occasionally in the fall. Conversely, the water table will be at or near its lowest position in late summer. If no recharge occurs during the fall, the water table will continue to decline very slowly throughout the fall and winter.

In the absence of water-level data, the recharge-discharge relations discussed above and records of the boundary conditions of the aquifer form the basis for generating a generalized water-table map of the Island for the period. The stage of Muscatine Slough, beginning in 1916, was held between 530 and 531 feet, except during abnormally wet conditions. The river stage from late summer to late winter most often was between 533 and 534 feet (fig. 16). Therefore, during normal to near-normal hydrologic

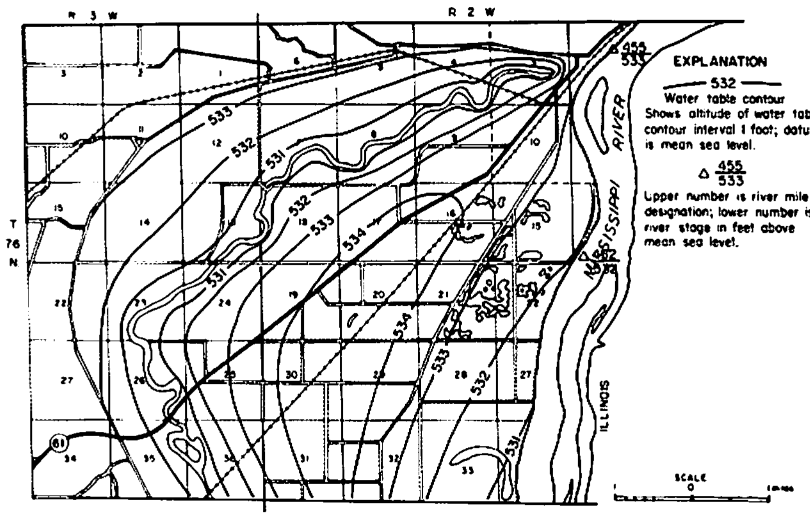


Figure 25.—Generalized water-table map, representative of late summer or winter conditions during 1900 to 1937.

conditions, a typical water-table map for late summer or mid-winter would have a configuration and position as shown in figure 25. If conditions were above or below normal, the water table would be about one foot higher or lower, respectively. During normal to near-normal spring conditions, the water table for late spring would have basically the same configuration, but it would be at least 2 to 3 feet higher than the late-summer water table.

Hydrologic Conditions During 1937 to 1946

This period was characterized by controlled stages of both river and slough, and by modest development of ground-water supplies. Withdrawals for municipal, industrial, and irrigation were just beginning to increase in the latter part of the period.

The closure of Lock-and-Dam 17 in 1937 changed one of the boundary conditions of the aquifer, and had a significant impact on the hydrology of the Island. River stages before 1937 had commonly declined to between 532 and 534 feet, and occasionally to 531 feet (fig. 16). However, starting in 1937, the river stage during low-to-moderate discharges was controlled by Lock-and-Dam 17 and seldom declined to less than 536 feet (fig. 15). Thus, the stage during the low-flow periods that generally occur during summer and winter was at least 3 feet higher than previously. The mean stage also was increased by about 3 feet.

The net effect of the changed boundary condition on the system is reflected in the water-table map shown in figure 26. This generalized map, believed to be representative of the changed conditions during late summer or late winter, shows that the water table was raised at least 3 to 4 feet and

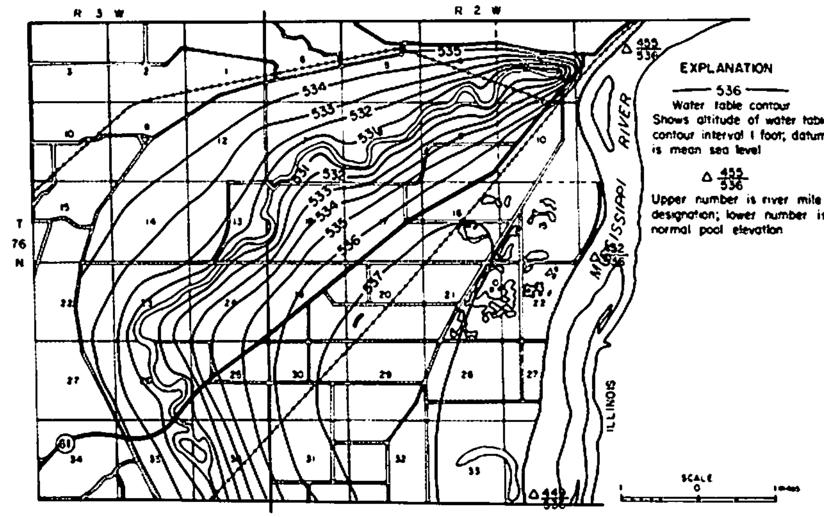


Figure 26.—Generalized water-table map, representative of late summer and winter conditions during 1937 to 1946.

the configuration was changed. The ground-water divide was shifted toward the river and the gradient toward the river was flattened and that toward the slough was steepened. This indicates that discharge to the slough was increased and discharge to the river decreased. The water table in late spring, during normal or near-normal spring conditions, would be expected to be about 2 to 3 feet higher than in late summer. Therefore, during years of normal to near-normal hydrologic conditions, the water table in the recharge area (near the ground-water divide) fluctuated between about 540 feet in late spring and about 537 feet in late summer. Thus, man's impact on the hydrologic system during this period of time was to raise the water table.

Hydrologic Conditions During 1946 to 1971

This period was characterized by very substantial increases in ground-water withdrawals for all purposes. Industrial pumpage increased from a very modest amount to more than 8 bgy; municipal pumpage increased from about 0.5 bgy to about 5 bgy; pumpage for irrigation increased from a modest amount to about 0.3 bgy. An additional 0.3 bgy of ground water was discharged by evaporation from the exposed water table in the gravel pits, which had increased in number during this period.

The impact of the large-scale withdrawals is quite evident on the water-table maps (pl. 3). Withdrawals by the City of Muscatine and GPC in the northeast corner of the Island have created a large cone of depression in the water table in that area. Similarly, withdrawals by Monsanto Co. and to a more limited extent, Thatcher Glass Co. have created a large cone in the southeastern part of the Island. In between these cones, evaporation from the gravel pits during mid-spring to mid-fall has caused a smaller depression in the water table. All three depressions combine to form a persistent elongated trough in the water table that parallels the river.

Although ground-water withdrawals are, as yet, minimal in the center of the Island, the water-table maps (plate 3) show that the water table in that area probably is several feet lower than it was during the 1937-46 period. Most of this decline is in response to the pumpage taking place at the municipal and industrial sites; water from the divide area is being diverted to provide about 15 to 20 percent of the amount being withdrawn at the major pumping centers. It is important to note that water from the divide area in Louisa County also is being diverted to the cone of depression at the Monsanto field. A small part of the water-level decline in the divide area is attributed to the withdrawals for irrigation; the amount is calculated to average only about 0.5 feet across the irrigated area.

Changes in the system can be attributed principally to the increased ground-water withdrawals during 1946-71. Thus, the impact of the withdrawals can be estimated by mapping the difference in altitude of the August 1971 water-table (pl.3) and the generalized late-summer water table during 1937-46 (fig. 26). The resultant map (fig. 27) indicates that ground-water withdrawals have caused a decline in water levels in the central part of the Island of about 1 foot near the slough to about 5 feet near the outer edges of the principal cones of depression. The declines are greater than 8 feet at the pumping centers.

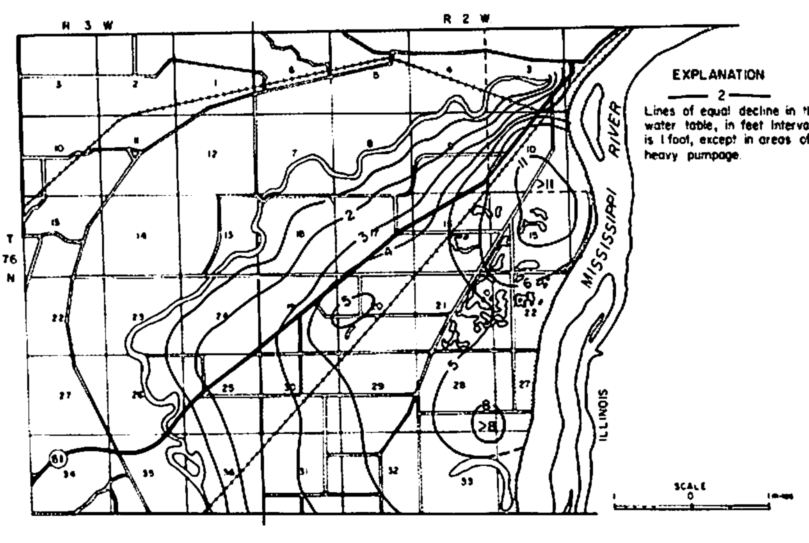


Figure 27.—Decline of the water table attributed principally to ground-water withdrawals during 1946 to 1971.

Man's impact on the system during this period of time was to lower the water table. But it is important to note that, with the exception of the areas immediately adjacent to the major pumping centers, the water table presently is not much different than it was during 1900 to 1937. A comparison of the August 1971 map, pl. 3 with fig. 25 indicates that the present decline in water levels is partially offset by the rise in water levels during 1937-46.

Present (1971) and Future Conditions

The hydrologic system in 1971 appears to be in equilibrium with the imposed stresses. With the possible exception of the Progress Park well-field area, the water table is dynamically stabilized and fluctuates in response to the relationship between net recharge and the presently stabilized ground-water withdrawals and other forms of discharge. During periods when spring recharge is minimal, the position of the water table during late summer would be similar to that on August 1971 (pl. 3). When fall recharge also is minimal to nonexistent, as it was in 1971, the water table during fall and winter would decline about another foot as indicated by the 1971 hydrograph of well 76-2-30cba (pl. 4). During periods of normal to near-normal recharge, the water table should be at least a foot higher than it was during 1971. During periods of extreme events, such as flooding on the Mississippi River and/or high spring and fall precipitation, the water table would respond as it did during 1965 (pl. 3).

The water table in the immediate area around the Progress Park well

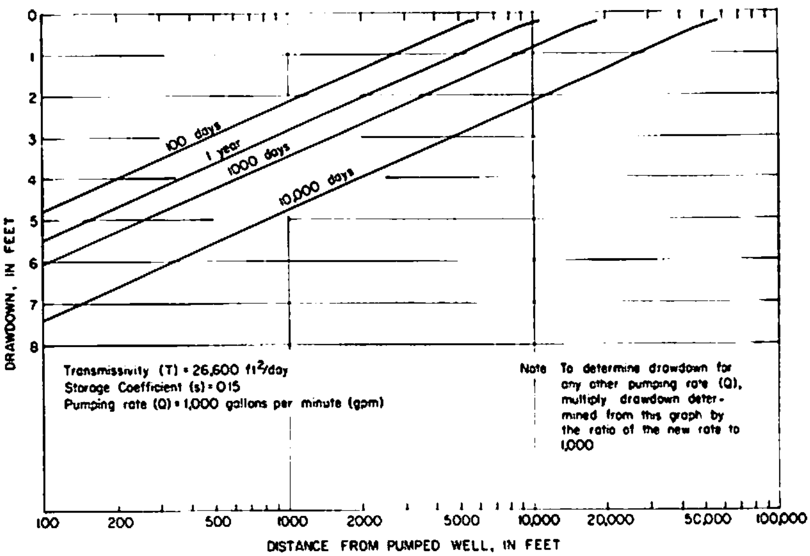


Figure 28.—Distance-drawdown graph.

field was not yet stabilized by August 1971, because withdrawals from the well field were not as yet stabilized. Total pumpage from the field then was about 240 million gallons, or about 65 percent of the planned stabilized pumpage rate of 1 mgd. The water-level decline at the end of one year's pumping at 1 mgd (about 700 gpm) can be calculated by using the distance-drawdown graph prepared from the hydrologic data of this area (fig. 28). This graph indicates that the decline of the water table in the vicinity of the well field, after one year's pumping, should be about 1.3 feet at a distance of 0.5 mile and about 0.7 foot at a distance of 1 mile. Moreover, the area of ground-water diversion for this well field under stabilized conditions probably would be about twice the area shown for August 1971 (fig. 19). Assuming no recharge from the bedrock and average recharge by precipitation (0.3 mgd/mile^2), the diversion area for this well field pumping at 1 mgd will be about 3 to 4 square miles. The diversion area and the actual decline in water levels can be readily determined by installing and measuring a few more observation wells in and around the well field.

The Island's water resources are far from being overdeveloped. Although annual withdrawals are presently about 13.5 billion gallons, about 10 to 11 bgy are derived by infiltration from the river. Thus, ground-water withdrawals on the Island amount to about 2.5 to 3.5 bgy. This is approximately equal to the average annual recharge by precipitation on the Island (about 3.2 bgy). However, not all the annual recharge moves to pumping sites; an estimated 1 bgy discharges toward the slough and gravel pit area. Therefore, about 0.5 to 1 bgy are derived from storage or from another source. If it were coming from storage, the water table would show progressive declines that would average about 0.5 to 0.8 feet per year over the Island and would be particularly greater near the major pumping centers. But, the water table is dynamically stable in the divide area (pl. 4). In fact, equilibrium is soon re-established at the pumping centers after every pumping change, particularly in the northeastern area (pl. 3). Thus, the additional water is derived from another source—the bedrock. In one locality in the northeastern area of ground-water diversion, recharge from the limestone bedrock was estimated to be about 0.4 to 0.7 bgy. The bedrock in other areas on the Island is not known to be contributing water to the alluvial aquifer under the hydrologic conditions extant in 1971. However, if conditions or stresses change, the bedrock may contribute water to the alluvial aquifer in other localities.

The amount of recharge from the bedrock may well be a factor in the maximum development of water on the Island. This amount will be dependent on the permeability distribution and the head differential between the bedrock and alluvial aquifers at a locality. The permeability distribution in carbonate rocks generally is highly random and not uniform; thus the transmissivity could be high at some site and very low at others. The pressure head in the bedrock appears to be related to the river stage, at least in proximity to the river; the water levels in the alluvial aquifer are partially dependent on pumpage. Therefore, the head differential between the two rock units at a site would be dependent on the river stage and the pumpage at the site. Because the above characteristics and relationships are not well understood at the present time, an investigation of the hydrology of the bedrock would be required before the maximum water supply could be determined.

The effect on the hydrologic system of the future development of water supplies will depend on the location of the development. Additional municipal supplies probably will be developed at the Progress Park field; therefore, water levels will decline in this general area until new equilibrium conditions are established. The amount of decline in the area around the well field can be estimated, for the period of time until stability is achieved, from the distance-drawdown graph (fig. 28). The effects of additional industrial withdrawals can be estimated in a similar manner, if the pumping site is located in an area where the transmissivity and storage coefficient of the aquifer are similar to that shown in figure 28. If the transmissivity and storage coefficient are different, new distance-drawdown curves will have to be constructed that are based on the different hydraulic characteristics.

New water-supply developments along the river will take advantage of induced recharge of river water. If the development takes place in the gravel-pit area, water levels in the pits will be lowered. Also, withdrawals in an area south of Monsanto, in Louisa County, will affect water levels on the southwest side of the Monsanto cone, because some of the recharge from the river presently moving toward the Monsanto area will be diverted. These effects, and others, can be more readily quantified if a digital model of the system can be developed. Although hydrologic conditions in the bedrock are not completely known, enough information on the system is available to attempt the development and verification of such a model.

Effects On The Chemical Quality

Land-use practices and ground-water withdrawals have had and will continue to have an impact on the chemical quality of water in the alluvial aquifer. One effect, the nitrate build-up, could become a serious problem. Another effect, an increase in hardness of the water in places, is a nuisance problem. In addition, a potential contamination problem exists in the gravel-pit area.

Build-up Of Nitrates And Other Farm Chemicals

The nitrate occurrence in the recharge area of the aquifer apparently is related to the farming practices and the hydrology of the system. Nitrate from materials used in fertilizing and mulching the sandy soil in the recharge area apparently reaches the water table and then is attenuated as it moves down gradient to discharge areas. As only the upper part of the aquifer is presently affected, the problem has not, as yet, shown up in the most recently constructed municipal wells at Progress Park field.

Analyses of water from the two wells in that field show a maximum nitrate content of 5.1 mg/l. This is an indication, however, that some high-nitrate water is reaching the wells even though the pumpage is mainly from the deeper part of the aquifer. The nitrate content of the well field supply may increase in the future as withdrawals increase and the resultant cone of depression extends out further than presently. Obviously the nitrate concentration of the water should be monitored, particularly at the end of the recharge period in the spring and in the early winter.

The nitrate build-up points up the possibility of another serious problem. Farm chemicals, such as herbicides and insecticides, may also be reaching the water table. A monitoring program would help to determine the possibility of contamination from this source.

Hardness Changes

The hardness of ground water in the northeastern part of the Island has almost doubled since the increase in withdrawals in the 1940's. The average hardness of water pumped from the old driven wells in the 1930's, before the system was heavily stressed, was about 100 mg/l. The average hardness in the same area presently is about 200 mg/l (table 3). Part of the increase is attributed to the induced recharge of Mississippi River water, which has an average hardness of about 160 mg/l (table 6). Another part is attributed to seepage of hard water from the bedrock in the vicinity of the Sampson Street well field. The hardness of the water at the new Progress Park well field is presently about 100 mg/l. This area is unlikely to be influenced by the river, but if the bedrock is permeable, the hardness may be influenced by seepage from the bedrock as the withdrawals increase.

The development of major ground-water supplies near the slough will result in noticeable increases in both hardness and iron, because the cone of depression will extend under the slough into the area of hard, high-iron water.

Potential Impact In Gravel-Pit Area

The numerous gravel pits are sites where the water table is exposed and the water system is vulnerable to contamination. As can be seen on the water-table maps, some water moves through this area toward the municipal power-plant field. Therefore, deleterious materials derived from materials dumped into the pits probably would move toward the municipal supply.

CONCLUSIONS AND RECOMMENDATIONS

1. The water resources of Muscatine Island are far from being overdeveloped. The reserves in storage, amounting to about 100 billion gallons, are not being tapped at present. Present development of about 13.5 bgy is in equilibrium with recharge from precipitation, the river, and from bedrock aquifers. Evidence is available to indicate that river recharge may support significant increases in withdrawals; however, additional studies are required for verification.

2. The large-scale withdrawals of ground water are not causing a general decline of water levels on the Island as of 1971. Withdrawals caused declines of 1 to 5 feet in the interior of the Island and more than 8 feet in the immediate vicinity of the two major pumping centers, but water levels, in 1971, were stabilized. The water level under the Island, with the exception of a 1-to 2-mile-wide strip near the river, is not much different presently than it was before Lock-and-Dam 17 was closed in 1937.

3. The distribution of hardness, iron, and nitrate in the ground water is shown on a series of maps. In general, the hardness, dissolved solids, iron, and manganese are highest in the area between the slough and the bluffs and lowest in the central part of the Island. Nitrate is highest in the central part of the Island, and its distribution shows a relationship to the area of irrigated cropland on sandy terrane of the Island. The concentration and distribution of the chemical constituents are affected by man's activities; water withdrawals are increasing the water's hardness at the major pumping centers, and farming practices appear to be the cause of a significant increase in the concentration of nitrate, and possible other farm chemicals, in parts of the ground-water system.

4. The effects of future withdrawals can best be determined by analyzing a digital model of the system. The development and verification of such a model can be based on the data in this report. In the meantime, the effects of future withdrawals can be estimated from the distance-drawdown graph presented in this report.

5. Additional observation wells installed in the alluvial aquifer near the Progress Park well field would supply needed data to verify a model of the aquifer system. Additional observation wells installed in the bedrock at about 4 to 6 scattered localities on the Island would provide needed data on the hydrology of the bedrock system.

6. A program to periodically monitor the nitrate would permit early detection of changes in concentration before the concentrations reached excessive levels. In addition, a program to determine the presence of deleterious farm chemicals in the aquifer system would permit early identification of possible contamination by these substances. Water samples for both purposes could be collected at existing wells and at the additional observation wells suggested above.

SELECTED REFERENCES

Bennett, R. R., 1962, Flow-net analysis, *in* Ferris, J. G. and others, Theory of aquifer tests: U.S. Geol. Survey Water-Supply Paper 1536-E, p. 139-144.

Ferris, J. G., 1963, Cyclic water-level fluctuations as a basis for determining aquifer transmissibility, *in* Bental, Ray, compiler, Methods of determining permeability, transmissibility, and drawdown: U.S. Geol. Survey Water-Supply Paper 1536-I, p. 305-318.

Hansen, R. E., 1972, Bedrock topography of east-central Iowa: U.S. Geol. Survey Misc. Geol. Inv. Map I-717.

Morris, D. A., and Johnson, A. I., 1967, Summary of hydrologic and physical properties of rock and soil materials, as analyzed by the Hydrologic Laboratory of the U.S. Geological Survey: U.S. Geol. Survey Water-Supply Paper 1839-D, 42p.

Norton, W. H., et al., 1912, Underground resources of Iowa: U.S. Geol. Survey Water-Supply Paper 293, p. 463-477.

Steinhilber, W. L., and Horick, P. J., 1970, Ground-water resources of Iowa *in* Water resources of Iowa: Iowa Acad. Sci. Pub., p. 29-49.

Stevenson, W. H., Brown, P. E., and Johnson, H. W., 1918, Soil survey of Iowa, Rept. No. 3 - Muscatine County: Iowa Agri. Exp. Station.

Udden, I. A., 1899, Geology of Muscatine County: Iowa Geol. Survey Ann. Rept., v. 9, p. 247-388.

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