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GROUND WATER FOR IRRIGATION IN THE VIKING BASIN, WEST-CENTRAL MINNESOTA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 23-75

Prepared in cooperation with the
West-Central Minnesota Resource Conservation and
Development Committee and the
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M. S. McBride

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16. Abstracts

The Viking Basin consists of six glacial outwash areas in Douglas, Ottertail, and Todd Counties, west-central Minnesota. Total area is 340 square miles (880 square kilometres). Soils are sandy and excessively well-drained. Crops grown on the outwash would benefit from supplemental irrigation. Irrigation supplies can be obtained from wells in the surface outwash aquifer in significant parts of the large outwash areas near Carlos and Parkers Prairie and the small outwash area near Clotho. Irrigation supplies are unlikely in the outwash areas near Alexandria, Urbank, and Rose City. Major use of ground water for irrigation may lower ground-water levels sufficiently to affect lake and marsh levels and streamflow out of the irrigation areas. Water from the outwash is of excellent chemical quality for irrigation.

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By M. S. McBride

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CONVERSION FACTORS

For use of readers who 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 (in)	25.40	millimetres (mm)
feet (ft)	.3048	metres (m)
miles (mi)	1.609	kilometres (km)
square feet (ft^2)	.09290	square metres (m^2)
acres	.4047	hectares (ha)
square miles (mi^2)	2.590	square kilometres (km^2)
feet per second (ft/s)	.3048	metres per second (m/s)
feet squared per second (ft^2/s)	.09290	metres squared per second (m^2/s)
gallons per minute (gal/min)	6.309×10^{-5}	cubic metres per second (m^3/s)
cubic feet per second (ft^3/s)	.02832	cubic metres per second (m^3/s)

GROUND WATER FOR IRRIGATION IN THE VIKING BASIN, WEST-CENTRAL MINNESOTA

by Mark S. McBride

ABSTRACT

The Viking Basin consists of six separate but close-together areas underlain by surficial glacial-outwash aquifers in Douglas, Otter Tail, and Todd Counties, west-central Minnesota. The total area is 340 mi^2 (square miles) or 880 km^2 (square kilometres). Soils developed on the outwash are generally sandy and excessively well drained. Crops grown on the outwash would benefit from supplemental irrigation. The outwash is underlain by 300 to 400 ft (feet) or 90 to 120 m (metres) of glacial drift, consisting largely of clay till but locally containing buried sand and gravel aquifers capable of yielding large quantities of water to wells. Igneous and metamorphic bedrock beneath the till is not a source of water.

Well yields greater than 1,000 gallons per minute (0.06 cubic metre per second) can be obtained from the surface outwash aquifer in about one-third of the outwash area near Carlos (28 mi^2 or 73 km^2) and in about half of the outwash area near Parkers Prairie (190 mi^2 or 490 km^2). Extensive irrigation with ground water in the Carlos area would lower average water levels from 2 to 8 ft (0.6 to 2.4 m) in the developed area. Average water levels in the irrigated part of the Parkers Prairie area would decline 1 to 3 ft (0.3 to 1 m). Environmental effects would include lowering the levels of lakes and marshes and reducing streamflow out of the areas.

An area south of Alexandria (83 mi^2 or 210 km^2) is underlain by outwash generally less than 40 ft (12 m) thick. The surface outwash aquifer here can supply enough water for irrigation in only a few places. One irrigation system now operates from a well in a buried outwash aquifer; test drilling may reveal more such aquifers.

Outwash in an area near Clotho (15 mi^2 or 39 km^2) is locally more than 80 ft (24 m) thick. About 3 mi^2 (8 km^2) of this area is irrigable and can probably be supplied with water from the outwash. An area south of Urbank (14 mi^2 or 36 km^2) has generally less than 40 ft (12 m) of surface outwash; a few irrigation supplies may be obtainable where the outwash is thickest. In an area southeast of Rose City (13 mi^2 or

34 km^2), outwash is generally less than 20 ft (6 m) thick, and no irrigation from the outwash seems possible.

Water from the outwash is of excellent chemical quality for irrigation. The outwash aquifer is easily contaminated from the surface. however, and a significant danger exists of nitrate contamination of drinking-water supplies.

INTRODUCTION

The Viking Basin occupies about 340 mi^2 (880 km^2) in Douglas, Otter Tail, and Todd Counties (fig. 1). It consists of six individual areas underlain by surficial outwash aquifers, all formed at the same time and in the same manner, but now separated from one another by regions where only clay till appears at the surface. The six areas of outwash will be referred to in this report as the Carlos, Parkers Prairie, Alexandria, Clotho, Urbank, and Rose City outwash areas, after the principal town in or near each.

The outwash occupies depressions in the surface of a thick sequence of clay tills. Because the soils of the basin are thin, sandy, and lie above well-sorted clean sand, their water-holding capacity is low. Midsummer rainfall is erratic and usually scanty; thus, crop yields are generally low and partial crop failures are frequent.

The study was made to determine the location, quality, and availability of ground water in the surficial outwash, and to predict the probable effects of extensive use of ground water. The information in this report will be of value in planning the use of ground water for irrigation to supplement natural rainfall or for industrial purposes.

The Carlos and Clotho outwash areas are drained by the Long Prairie River, the only sizable stream in the Viking Basin. The Wing River and several smaller creeks drain the Parkers Prairie outwash area. The Alexandria, Urbank, and Rose City outwash areas have no large streams.

In general, the surface drainage of the basin is poorly developed, both because the outwash is highly permeable and because the landscape is relatively young.

Although tourism and light industry are important, farming is the principal source of income in the basin. At present (1974), 14 farmers irrigate, most of them having started within the last 5 years.

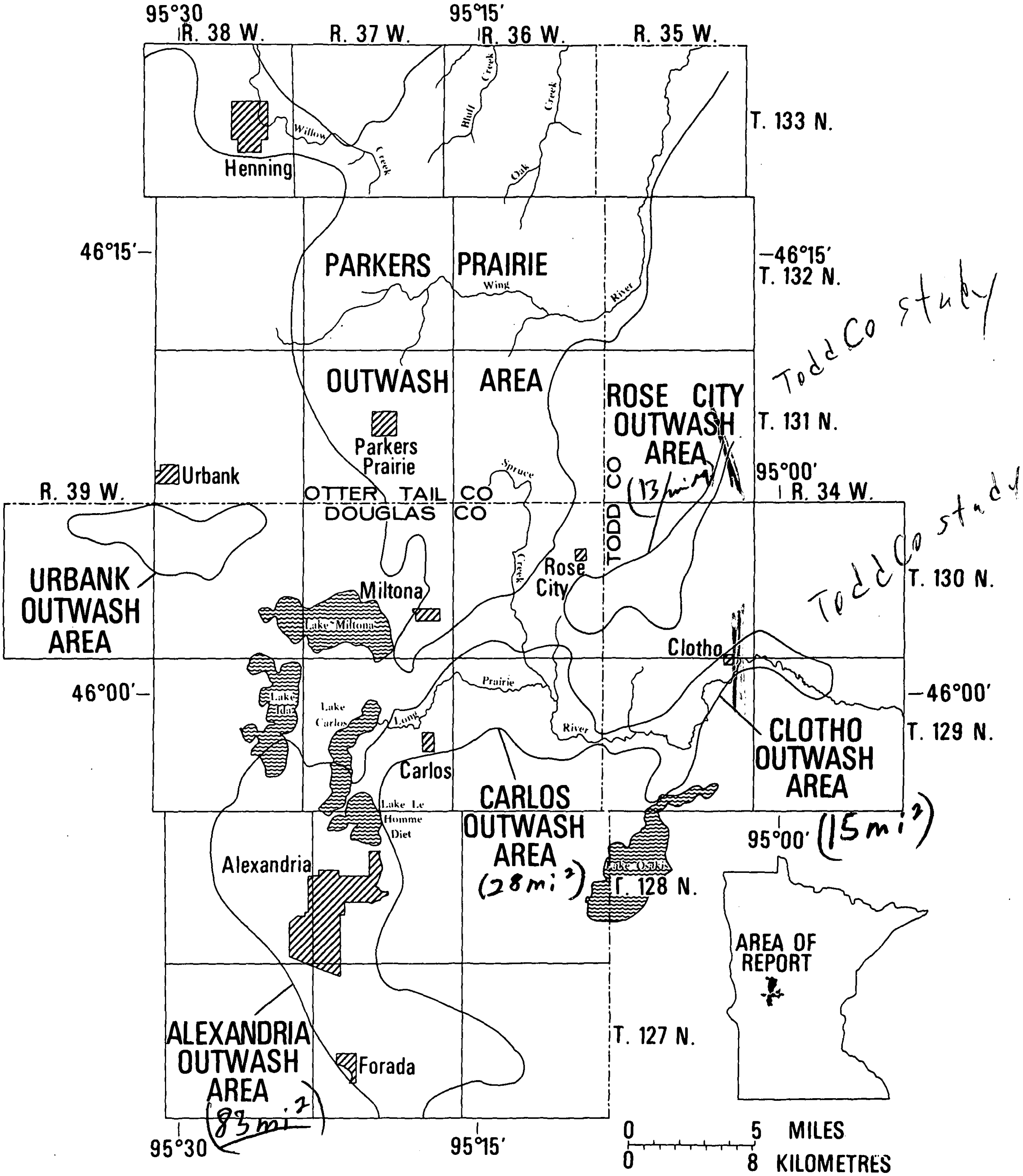

Figure 1.--Extent of Viking Basin and location of outwash areas

This study was made in cooperation with the West-Central Minnesota Resource Conservation and Development Committee and the Division of Waters, Soils, and Minerals, Minnesota Department of Natural Resources.

METHODS OF INVESTIGATIONS

The extent and thickness of the outwash was determined from records of wells and by test drilling. More than 200 test holes were drilled with a power auger, some to depths of nearly 100 ft (30 m). Twenty-one observation wells were also installed with the auger; water levels in these were measured weekly or bi-weekly by a local observer. One aquifer test was made.

Sand samples taken from many of the test holes were analyzed for particle-size distribution. Chemical quality of the ground water was also analyzed.

In the fall of 1973, streamflow measurements were made at 11 places along the Long Prairie and Wing Rivers and Spruce Creek to determine the contribution of ground water to streamflow. Periodic measurements of streamflow were made at six sites from October 1971 to October 1973 to determine variation in streamflow.

The surface geology was mapped in selected areas, principally to delineate the extent of the outwash sand.

Digital models were constructed to simulate ground-water flow in the two major outwash areas. After the models were adjusted to simulate the present ground-water system satisfactorily, they were used to predict the effects of extensive ground-water development.

PREVIOUS INVESTIGATIONS

Upham (1888) was the first to describe the general geology of the study area in a report which included some information on ground-water conditions. Allison (1932) also described the general geology of the area, giving somewhat more detail on depth and chemical composition of ground water. The Viking Basin lies within the Crow Wing and Chippewa watersheds, which were reconnoitered by Lindholm and others (1972) and by Cotter and others (1968), respectively.

TEST-HOLE NUMBERING SYSTEM

The system of numbering test holes and wells is based on the U.S. Bureau of Land Management's system of subdivision of the public lands. The Viking Basin is in the fifth-principal-

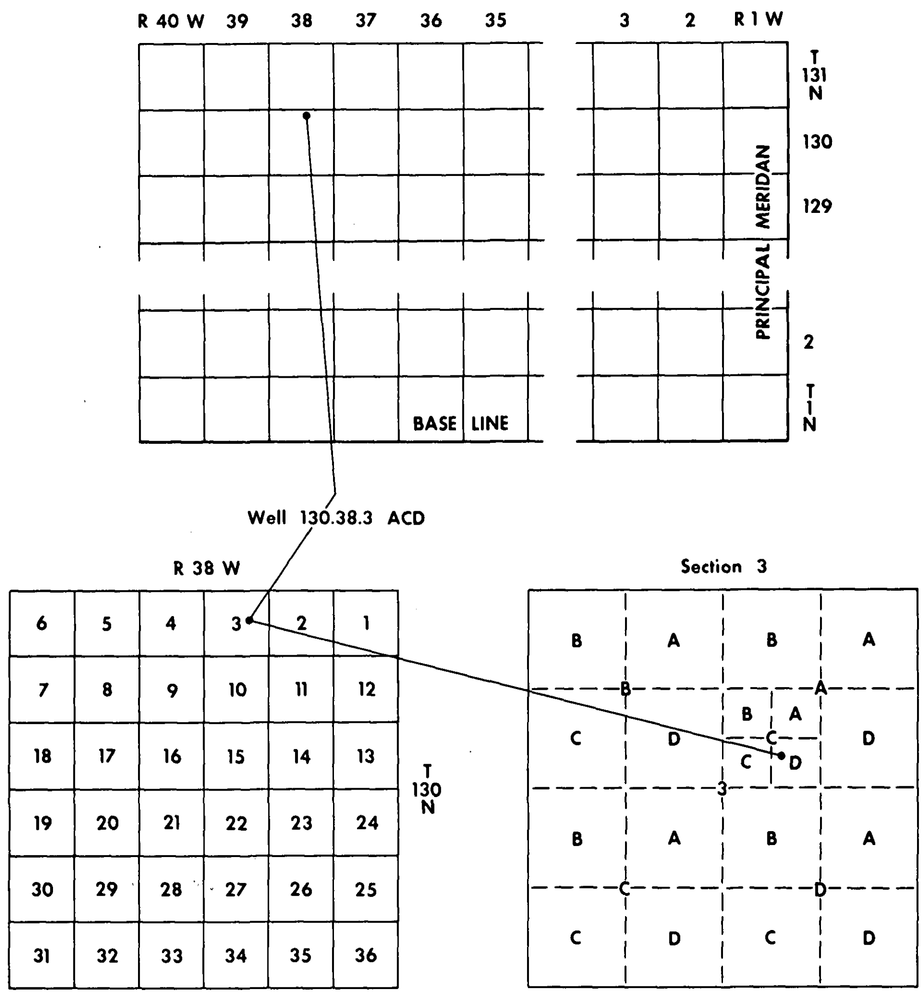

Figure 2.--Well and test-hole numbering system

meridian and base-line system. The first segment of a well or test-hole number indicates the township north of the base line; the second, the range west of the principal meridian; and the third, the section in which the test hole is situated. The letters A, B. C, and D, following the section number, indicate the well location within the section. The first letter denotes the 160-acre (65-ha) tract, the second the 40-acre (16-ha) tract, and the third the 10-acre (4-ha) tract. The letters are assigned in a counterclockwise direction, beginning in the northeast quarter.

Figure 2 illustrates the method of numbering. Thus, the number 130.38.3 ACD identifies a well or test hole located in the SE¼SW¼NE¼ sec.3, T.130 N., R.38 W.

OCCURRENCE OF GROUND WATER

Ground water may be defined as water which lies within the saturated zone beneath the earth's surface. The upper limit of the saturated zone is the water table, an imaginary surface along which the water's pressure is the same as that of the atmosphere.

Precipitation is the ultimate source of ground water in the Viking Basin. Water from rainfall or melting snow seeps vertically downward through the soil zone and through the unsaturated sand beneath it. When it reaches the water table, it becomes ground water.

Ground water tends to move horizontally toward lakes and marshes, where it is discharged by evapotranspiration, or toward streams, where it sustains streamflow during periods of fair weather. Some ground water flows out of the basin into adjacent sand-plain areas.

Under natural conditions, the ground-water system is in a state of dynamic equilibrium. That is, although the water is constantly in motion, a balance is maintained between recharge, discharge, and storage within the system.

Ground water occurs in the voids between grains of geologic materials. Porosity is the fraction of the volume of a material which consists of voids. Porosity of geologic materials may range from less than 1 percent in hard metamorphic rocks to more than 90 percent in organic lake sediments. Sands similar to those in the Viking Basin have porosities in the range of 25 to 50 percent. Because some water clings to the particles, not all ground water can drain to wells. Specific yield is defined as the percentage of total volume of saturated material that consists of water that can be recovered by gravity drainage. Specific yields of sand and gravel aquifers are generally in the range of 15 to 25 percent.

Flow of ground water is governed by Darcy's law, which states that the rate of flow, in terms of volume of water per unit time, is proportional to hydraulic conductivity, hydraulic gradient, and the area across which flow occurs.

Hydraulic conductivity is a measure of how readily ground water can flow through a material. It depend on the size, shape, and drgree of interconnection of the pore spaces. As used in this report, hydraulic conductivity is defined as the flow of water in cubic feet per second (ft^3/s) or cubic metres per second (m^3/s) through a cross-sectional area of 1 ft^2 or 1 m^2 under a hydraulic gradient of 1.0. Hydraulic conductivity has the units of a velocity when reduced to lowest terms and is expressed in this report in feet per second (ft/s) or metres per second (m/s). Most sands and gravels have hydraulic conductivities in the range 0.0001 to 0.1 ft/s (0.00003 to 0.03 m/s). Most silts and clays have hydraulic conductivities less than 0.0000001 ft/s (0.00000003 m/s).

Hydraulic gradient is the loss in head divided by the distance that ground water flows in losing that head. In most water-table aquifers, the hydraulic gradient is nearly equal to the slope of the water table. Hydraulic gradient is generally expressed as a dimensionless decimal fraction. For example, if a water table has a slope of 1 ft in 2,000 ft (or 1 m in 2,000 m), the hydraulic gradient is 1/2000 or about 0.0005.

An aquifer is a body of geologic material, generally of high hydraulic conductivity, which can yield useful amounts of water to wells. The ability of an aquifer to conduct water is often expressed in terms of transmissivity, which is the product of its hydraulic conductivity and saturated thickness. Transmissivity is expressed in units of feet squared per second (ft^2/s) or metres squared per second (m^2/s).

An artesian aquifer has a confining bed of low hydraulic conductivity lying above it, and the water is under pressure. In a well completed in an artesian aquifer, water rises above the top of the aquifer. If the water rises above the land surface, the result may be a flowing well. A water-table aquifer is not confined. Its upper boundary is the water table.

Thickness of saturated material in the aquifer changes with variations in water-table altitude. The level of water in wells in water-table aquifers is generally close to that of the water table.

Water in the basin occurs under both artesian and water-table conditions. The surface outwash is a water-table aquifer, although, in a few places, thin beds of clay or silt may confine the water beneath them. Most bodies of sand and gravel within the glacial clay till are artesian aquifers.

Initially, water pumped from a well in a confined aquifer results from expansion of the water and compression of the solid part of the aquifer. A small part of the water pumped from a water-table aquifer results from these same effects, but the largest part is derived from drainage of the upper part of the aquifer as the water table is lowered. Pumping creates a cone of depression around the well, with water levels lowered most at the well and progressively less outward from the well. The extent of the cone of depression, which is to say the greatest distance at which drawdown can be detected, depends on whether the aquifer is artesian or water-table, the thickness and permeability of the aquifer, the rate of pumping, the storage characteristics of the aquifer, and the time since pumping began.

If pumping continues for a sufficiently long time, the cone of depression will spread until water is diverted toward the well from lakes, streams, or marshes. The levels of lakes and marshes may be lowered, and the volume of evaporation from them thus reduced. Ground water that ordinarily discharges to streams may be captured. In addition, the amount of water transpired by plants may be decreased. If the total of the reductions in evaporation, transpiration, and streamflow equals the discharge of the well, then the cone of depression stabilizes, and no more water is taken from storage within the aquifer.

HYDROGEOLOGY

Bedrock

Bedrock is 300 to 400 ft (90 to 120 m) deep in most of the area and does not crop out (Lindholm and others, 1972). It consists of complex metamorphic and igneous rocks (Sims, 1970) of which the geology is poorly known. It is unlikely that significant quantities of water can be obtained from the bedrock.

Glacial Drift

Two principal types of glacial drift occur in or near the Viking Basin. Till is a poorly sorted mixture of gravel, sand, silt, and clay deposited directly by glacial ice. Stratified drift is clean, well-sorted sand and gravel, deposited by meltwaters. Stratified drift may be subdivided into outwash and ice-contact deposits. Outwash is deposited as plains of low relief at some distance from the glacier. Ice-contact deposits, generally manifested as hills or irregular topography, was deposited in direct contact with the glacial ice. Most of the drift in the Viking Basin was deposited during the latest or Wisconsin stage of glaciation. Some buried drift may be pre-Wisconsin in age.

Early in the Wisconsin stage, ice advanced into the area from the northeast. Along its edge it deposited the Alexandria moraine, a broad hilly belt which runs north-south through Douglas and Otter Tail Counties.

The present land surface was formed in late Wisconsin time, when ice advanced from the west approximately as far as the Viking Basin. The Alexandria moraine retained a high, hilly form but was mantled with younger till. As the ice melted and retreated, about 12,000 years ago, a large quantity of water was released, laden with debris from the glacier. Silt and clay were carried out of the area by the running water; but sand and gravel, less easily moved, were laid down as outwash in depressions in the till, thus forming the Viking Basin.

Till

Till underlies surficial outwash in the Viking Basin; in furrounding areas, it lies at the surface. The hydraulic conductivity of the till is very low; measurements elsewhere in Minnedsota suggest a value of about 10^{-8} ft/s ($3x10^{-9}$ m/s). The till supplies little water to wells, although good aquifers may be enclosed within it. Till near the surface is commonly weathered to buff or orange; below the surface, unweathered till retains its original bluish-gray color. The till is commonly described as "blue clay" or "gray clay" on drillers' logs. Grain-size analyses, however, commonly show sand, silt, and clay in roughly equal proportions.

Buried Aquifers

Sand and gravel aquifers occur locally within the till. These represent outwash or ice-contact deposits which were buried by till from later glacial advances. In most places, buried aquifers a few feet thick and capable of supplying enough water for a farm can be found within the till. At some places, wells have been drilled several hundred feet to bedrock without penetrating sufficient outwash to provide a satisfactory supply. Large supplies have been obtained from buried aquifers in other places, however. The village of Parkers Prairie has a well (131.37.22 BBB) which penetrated 23 ft (7.0 m) of surface outwash, 82 ft (25 m) of till, and 24 ft (7.3 m) of sand and gravel. This well has produced as much as 330 gal/min (0.7 ft^3/s or 0.021 m^3/s). A well to the northwest, at 132.37.30 ACA, is 200 ft (60 m) deep and supplies enough water from a buried aquifer to operate a center-pivot irrigation system. The location of a buried aquifer can sometimes be inferred from logs of nearby wells. Usually, however, test drilling is necessary.

Buried aquifers are normally artesian, and water in wells will commonly rise to within 30 ft (9 m) of the land surface, even from deep aquifers. Depth to water in wells may be more than 30 ft (9 m) in upland areas.

Some wells in buried aquifers flow; for example, several in sections 25 and 36, T.130 N., R.36 W., south of Rose City. Well 130.36.36 DBC produces a fountain more than 2 ft (0.6 m) high from a 1 in (25 mm) opening in the top of the casing; it is reported to have flowed for more than 50 years.

Surface Outwash Aquifer

Outwash lies at the surface in six separate areas as shown in figure 1. The thickness of the outwash deposits and the configuration of the water table within them are shown in plates 3 and 4, respectively.

Carlos Outwash Area

Outwash in this area (28 mi^2, 73 km^2) is generally thick. About half the area is underlain by more than 40 ft (12 m) of outwash. The maximum thickness is more than 110 ft (34 m) northeast of Carlos. Because the water table lies below the land surface, saturated thickness (fig. 5) is less than total thickness. Saturated thickness is more than 40 feet (12 m) in about one-third of the area.

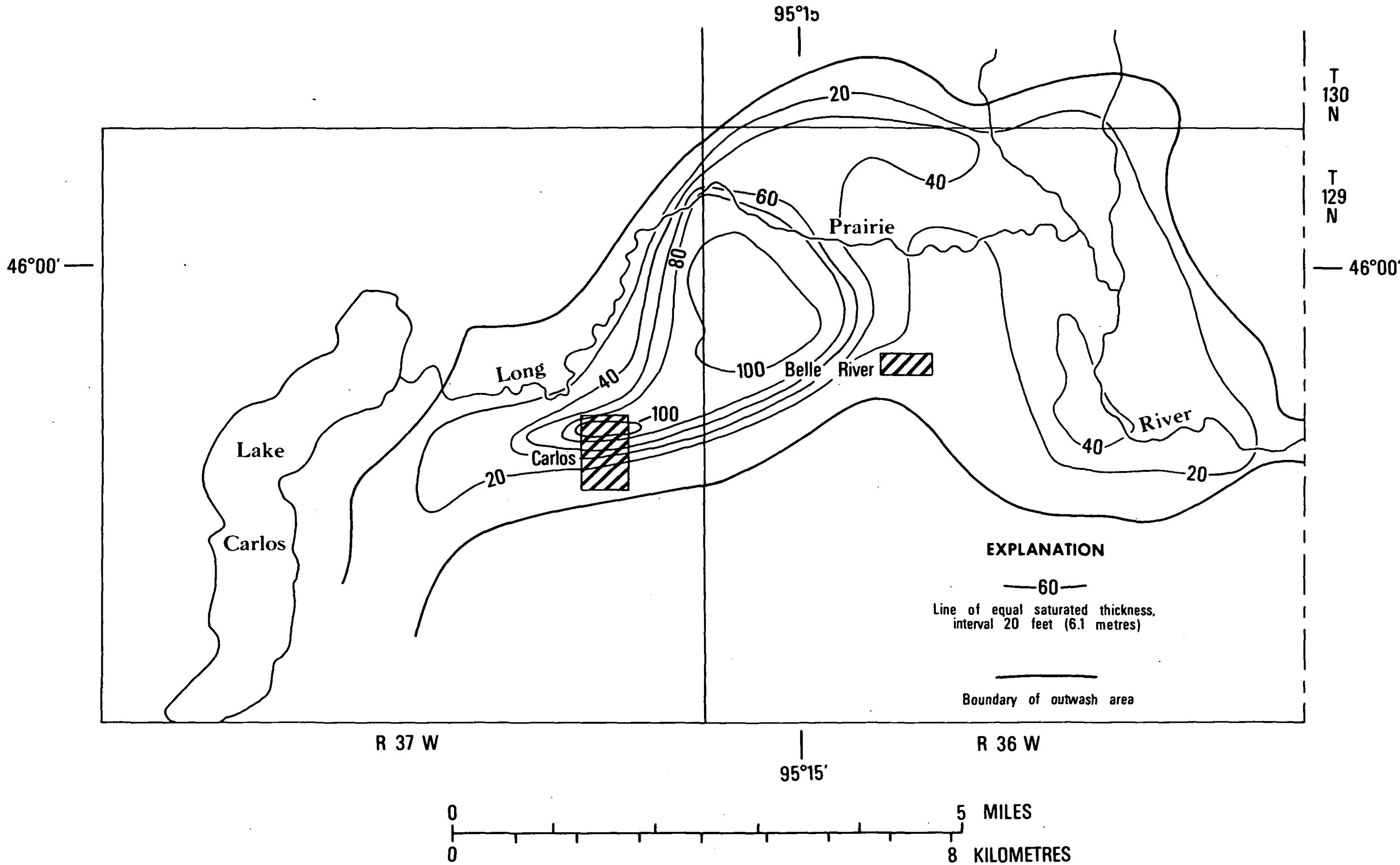

Figure 5.--Saturated thickness of surface outwash aquifer in Carlos outwash area

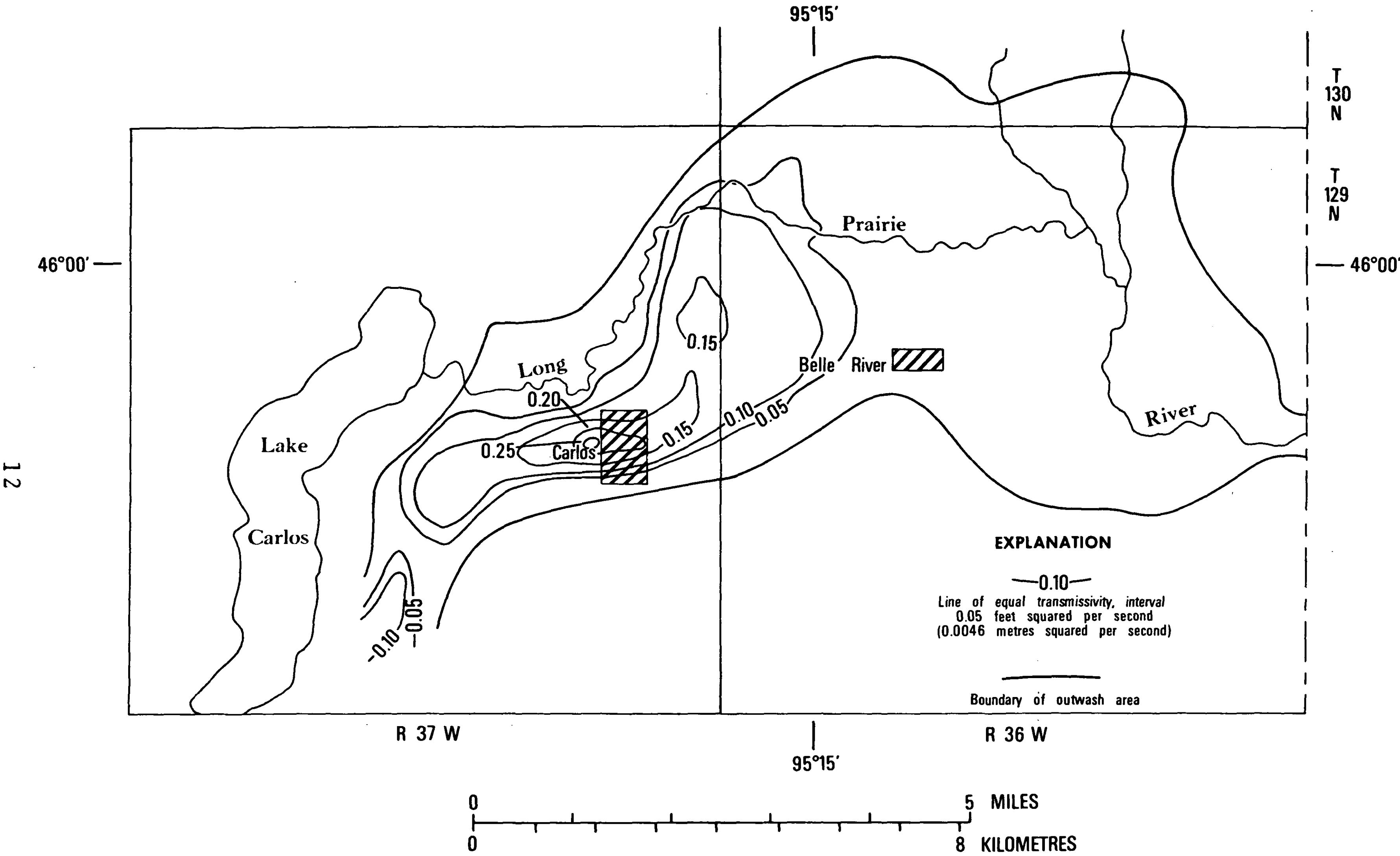

Figure 6.--Transmissivity of surface outwash aquifer in Carlos outwash area

This outwash was deposited when the edge of the Des Moines-lobe ice was in the vicinity of Alexandria. Meltwater was discharged down the present valley of the Long Prairie River, leaving outwash along the river in the Carlos area and for many miles downstream.

Medium-to-coarse sand is dominant in the outwash (table 1). Median grain size (the size having half the particles finer, half coarser) ranged from 0.47 to 1.6 mm for five samples. The sand is clean and well sorted and its hydraulic conductivity is high.

A map of the transmissivity of the surface outwash aquifer is shown in figure 6. Saturated thickness of the outwash is shown in figure 5. The highest values of transmissivity are northeast of Carlos, principally because of the thick saturated section there.

To relate transmissivity values to ground-water yield, a map of theoretical potential well yields was made (fig. 7) based on Theis's model of the hydraulics of wells (Todd, 1959). These yields represent the maximum practical pumping rates for wells operated for 30 days out of the year, 24 hours per day, with drawdowns limited to two-thirds of the saturated thickness. At this limit, about 90 percent of the maximum possible discharge is obtained. It is impractical to operate at greater drawdowns because the pumping depth will increase out of proportion to the increase in well yield. In making figure 7, it was also assumed that:

1) All wells have a diameter of 24 in (610 mm).
2) All wells have an efficiency of 100 percent.
3) The specific yield of the aquifer is 20 percent.
4) Interference between wells is negligible.

In the calculations, correction was made for the decrease in transmissivity resulting from lowering of the water table (Jacob, 1944).

Note that this map is valid only for one specific set of pumping conditions. If a well were pumped year-round, for example, the maximum yield would be less than that indicated on the map. Also, the map is intended only to show general areas where yields are greatest. Because of local variations in transmissivity, yields of individual wells may be more or less than indicated on the map.

Table 1.-Particle-size distribution (in percent by weight)
[Particle sizes in millimetres]

<table>
<tr><th></th><th></th><th></th><th></th><th colspan="4">Sand</th></tr>
<tr><th>Test Hole Location</th><th>Depth (feet)</th><th>Clay (0.004)</th><th>Silt (0.004-0.0625)</th><th>V. fine (0.0625-0.125)</th><th>Fine (0.125-0.25)</th><th>Medium (0.25-0.5)</th><th>Coarse (0.5-1)</th></tr>
<tr><td colspan="8">Carlos outwash area</td></tr>
<tr><td>129.36.15BB</td><td>55</td><td colspan="2">2.5</td><td>1.5</td><td>4.1</td><td>7.3</td><td>24.1</td></tr>
<tr><td>129.36.15BB</td><td>85</td><td colspan="2">2.2</td><td>1.6</td><td>5.9</td><td>20.7</td><td>25.6</td></tr>
<tr><td>129.36.18CC</td><td>2</td><td colspan="2">1.7</td><td>1.5</td><td>11.4</td><td>20.7</td><td>30.0</td></tr>
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<tr><td>129.37.23BB</td><td>7</td><td colspan="2">.8</td><td>1.5</td><td>13.1</td><td>37.4</td><td>28.5</td></tr>
<tr><td colspan="8">Clotho outwash area</td></tr>
<tr><td>129.35.16BB</td><td>7</td><td colspan="2">1.6</td><td>5.9</td><td>23.0</td><td>26.1</td><td>26.9</td></tr>
<tr><td colspan="8">Parkers Prairie outwash area
Northwest part of area</td></tr>
<tr><td>131.37.15BB</td><td>15</td><td>4.3</td><td>8.9</td><td>3.9</td><td>8.6</td><td>8.6</td><td>6.5</td></tr>
<tr><td>132.37.13DA</td><td>25</td><td colspan="2">.6</td><td>.6</td><td>5.4</td><td>21.5</td><td>21.2</td></tr>
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<tr><td>132.37.27AC</td><td>30</td><td>8.7</td><td>14.1</td><td>5.6</td><td>14.8</td><td>23.1</td><td>17.7</td></tr>
<tr><td>133.37.23CC</td><td>34</td><td colspan="2">3.0</td><td>3.7</td><td>15.4</td><td>10.5</td><td>24.1</td></tr>
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<tr><td colspan="8">Southeast part of area</td></tr>
<tr><td>130.36.3AA</td><td>30</td><td colspan="2">3.4</td><td>4.2</td><td>20.6</td><td>32.2</td><td>19.9</td></tr>
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<tr><td>131.36.27DA</td><td>20</td><td>6.4</td><td>22.1</td><td>8.3</td><td>16.8</td><td>9.5</td><td>6.2</td></tr>
<tr><td>131.36.33BD</td><td>10</td><td>3.2</td><td>12.5</td><td>4.4</td><td>17.7</td><td>25.6</td><td>24.5</td></tr>
<tr><td>131.36.33BD</td><td>40</td><td>6.9</td><td>11.2</td><td>3.4</td><td>11.3</td><td>23.0</td><td>17.4</td></tr>
</table>

Gravel					
V. coarse (1-2)	V. fine (2-4)	Fine (4-8)	Medium (8-16)	Coarse (16-32)	Median grain size (mm)
15.8	13.1	12.4	19.2	--	1.6
16.5	13.4	10.1	4.0	--	.85
11.2	9.4	11.7	2.3	--	.70
13.4	11.8	13.1	9.4	--	.94
10.6	5.0	3.0	--	--	.47
7.4	4.4	4.8	--	--	.42
1.3	1.9	8.9	40.5	6.6	6.3
13.1	9.1	5.1	12.0	11.4	1.0
6.8	4.6	4.7	4.5	46.3	9.0
8.2	4.6	2.5	.7	--	.31
30.4	11.8	.4	.7	--	.83
14.5	10.5	4.4	--	--	.64
9.5	5.5	4.6	--	--	.40
3.3	10.2	13.2	6.0	7.7	.40
--	.6	.3	.9	8.4	.14
4.6	1.6	.2	--	--	.33
20.6	6.9	.7	--	--	.67
7.7	5.2	3.2	1.6	--	.34
9.5	8.4	9.5	11.4	--	.68
8.2	8.7	6.4	--	--	.57
3.5	2.5	1.9	--	--	.12
13.2	10.5	6.1	.9	--	.54
3.2	11.3	15.0	1.2	--	.22
7.6	4.1	.5	--	--	.35
11.6	6.9	4.7	3.6	--	.41

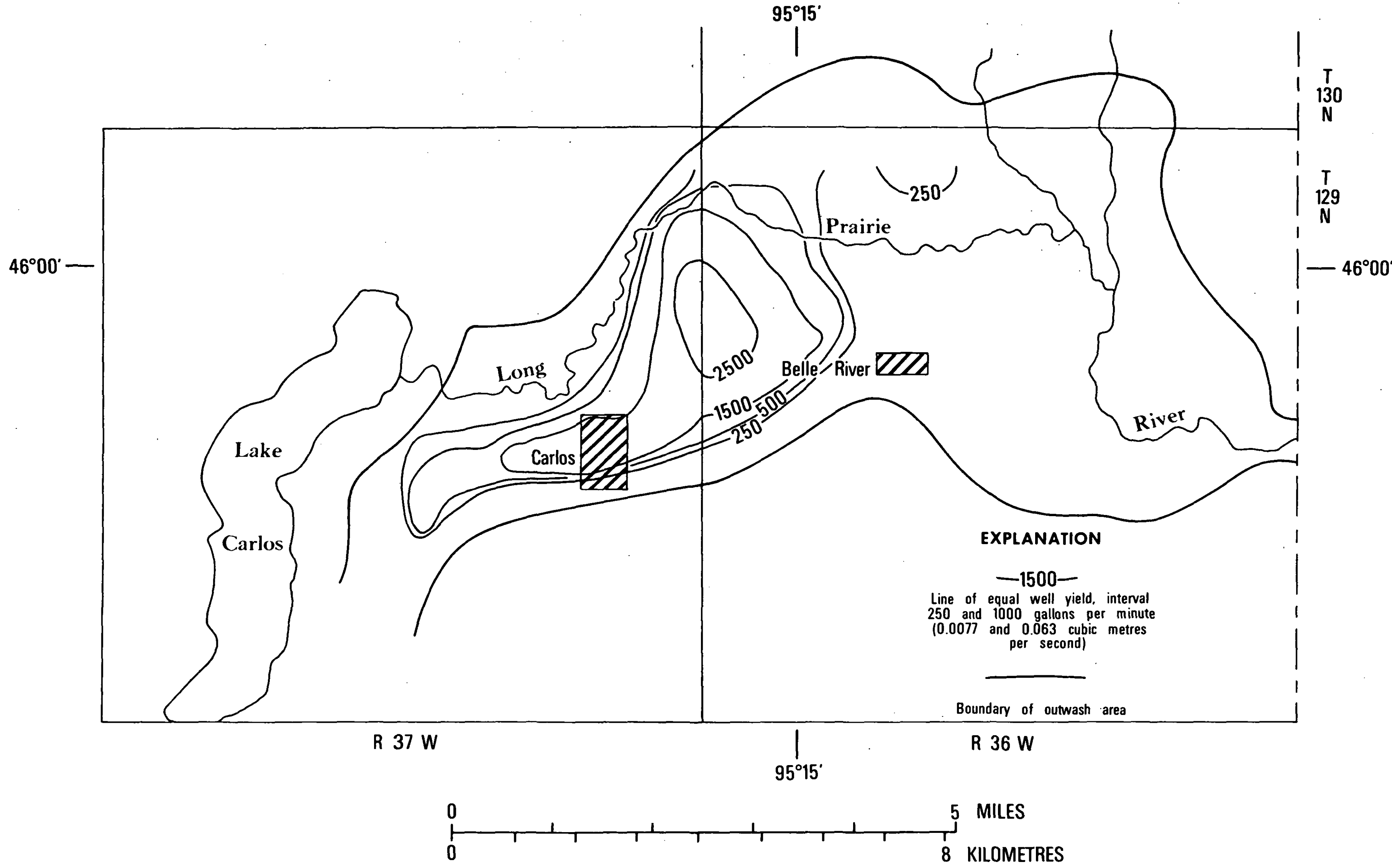

Figure 7.--Theoretical potential well yields from surface outwash aquifer in Carlos outwash area

General directions of ground-water movement are shown in Plate 4 . Water-table altitude is least near the Long Prairie River and Spruce Creek. Ground water moves toward these streams, where it is discharged. On October 1-2, 1973, streamflow was measured at four sites along the Long Prairie River to determine the rate of ground-water discharge (table 2). Between the first site, at the source of the river, and the last, slightly more than halfway through the Carlos outwash area, the increase in streamflow was 5.6 ft^3/s (0.16 m^3/s). Total ground-water discharge in the area, including that into Spruce Creek, was estimated to average 12 ft^3/s (0.34 m^3/s).

The water balance of the surface outwash aquifer is summarized in table 3. Water moving in the ground-water system is largely recharge from precipitation and is largely lost to the Long Prairie River and Spruce Creek. The total gain, 16 ft^3/s (0.45 m^3/s), represents the rate at which water enters the ground-water system. An additional 15 ft^3/s (0.42 m^3/s) enters the area by way of the Long Prairie River and 10 ft^3/s (0.28 m^3/s) by way of Spruce Creek. This surface water presently passes through the area without becoming part of the ground-water system. In principle, then, a total of 41 ft^3/s (1.1 m^3/s) could be extracted for use. This would require that natural evapotranspiration and streamflow out of the area be reduced to zero, assuming that none of the water was returned to streams or to the ground. In practice, it will probably never be practical or desirable to extract water at more than a fraction of this rate.

Parkers Prairie Outwash Area

This is the largest of the outwash areas and covers 190 mi^2 (490 km^2). More than half the area is underlain by outwash more than 40 ft (12 m) thick. The average thickness of the deposit is about 50 ft (15 m); the maximum exceeds 100 ft (30 m). Saturated thickness is more than 40 ft (12 m) in one-third of the area (fig. 8).

The east edge of the glacial ice lay along the west side of the Parkers Prairie area when the outwash was formed. Meltwater discharged eastward but was diverted by high ground lying east of the present outwash area. A large part of the water flowed northeast along a number of small, parallel drainages, leaving the area by way of the broad northeastward-trending band of outwash at the north end of the area. Parallelism of these drainages was caused in part by drumlins (elongate streamlined hills formed by glacial ice overriding masses of till) which

Table 2.--Discharge of Long Prairie River in

Carlos outwash area, October 1-2, 1973

Location	Discharge		Remarks
	ft^3/sec	m^3/sec	
$NW\frac{1}{4}SW\frac{1}{4}$ sec.15, T.129 N., R.37 W.	15.2	0.431	Lake Carlos outlet
$SW\frac{1}{4}SE\frac{1}{4}$ sec.14, T.129 N., R.37 W.	18.2	0.516	0.5 mile (0.8 km). NW of Carlos
$NW\frac{1}{4}SW\frac{1}{4}$ sec. 6, T.129 N., R.36 W.	18.8	0.533	
$SW\frac{1}{4}NW\frac{1}{4}$ sec. 9, T.129 N., R.36 W.	20.8	0.590	0.7 mile (1 km) N of Belle River

Table 3

Approximate water balance of surface outwash aquifer in Carlos outwash area

Gains	ft^3/s	Percent of total
Recharge	12	75
Inflow across boundaries	4	25
Total	16	100
Losses		
Evapotranspiration	3	19
Outflow across boundaries	1	6
Seepage into streams	12	75
Total	16	100

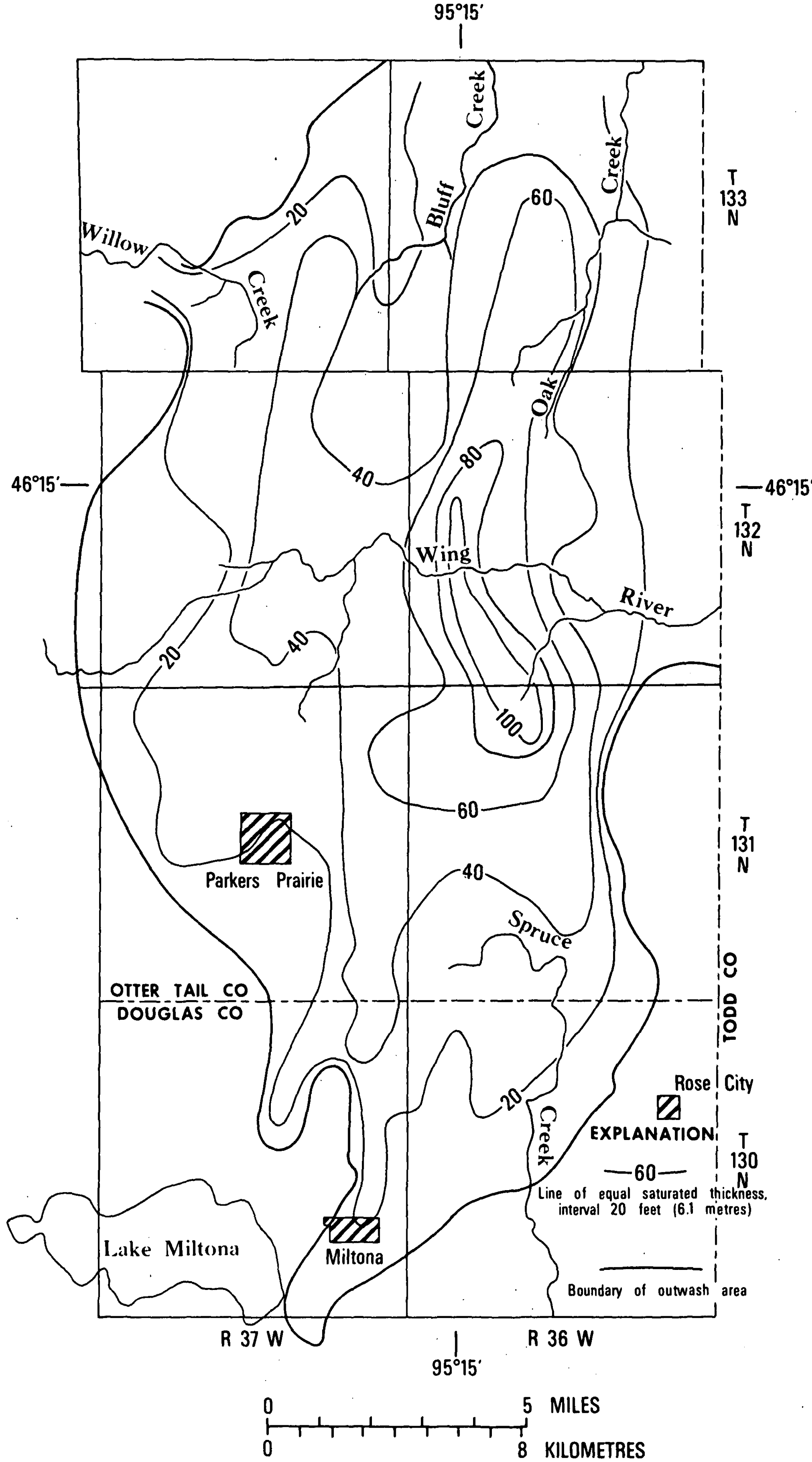

Figure 8.--Saturated thickness of surface outwash aquifer in Parkers Prairie outwash area

are oriented northeast-southwest. A small part of the water flowed down the present course of the Wing River. Some water probably escaped to the northwest toward Henning, down the small valley now occupied by Willow Creek.

Another part of the water flowed south down the valley of Spruce Creek, as indicated by the size of this valley, which averages 0.3 mi (0.5 km) wide and is 40 ft (12 m) deep where it leaves the outwash area. The valley is large out of proportion to the size of the stream and could not have been eroded by the present Spruce Creek in the relatively short time since the outwash was deposited.

Grain-size relations in the outwash reflect the direction of meltwater movement. Six sand samples were taken north of a line extending northeast from Parkers Prairie (table 1). Thirteen were taken south of that line, most from within 2 mi (3 km) of the east border of the area. These sets of samples represent, roughtly, the parts of the outwash area that were closest to and farthest from the ice front, respectively. Plainly, the outwash in the northwest part of the area is much coarser and, consequently, more permeable than that in the southeast. Exceptionally coarse outwash, north and west of Parkers Prairie, close to the west border of the area, includes water-rounded stones as much as 1 ft (0.3 m) in diameter.

Transmissivity of the outwash is shown in figure 9. Highest transmissivity, more than 1.0 ft^2/s (0.093 m^2/s), is northeast of Parkers Prairie. Note that the maximum transmissivity in the Carlos outwash area was 0.25 ft^2/s (0.023 m^2/s) and that one-third of the Parkers Prairie outwash area has transmissivity greater than this value.

Theoretical potential well yields (fig. 10) are generally large. Yields exceeding 500 gal/min (0.528 ft^3/s or 0.0150 m^3/s) can be obtained from the surface outwash in most of the area. The same assumptions made in calculating yields for the Carlos outwash area apply here.

Movement of ground water in the area is complex (plate 4). Altitude of the water table is greatest north and west of Parkers Prairie. Movement outward from this high is in three general directions. Some ground water moves northeast and passes out of the area into an adjoining sand plain. In the central part of the area, ground water moves east and discharges to the Wing River. In the southern part, most ground water discharges to Spruce Creek. A smaller amount discharges in a marshy area immediately south of Miltona and passes off by small streams to Lake Miltona or the Long Prairie River.

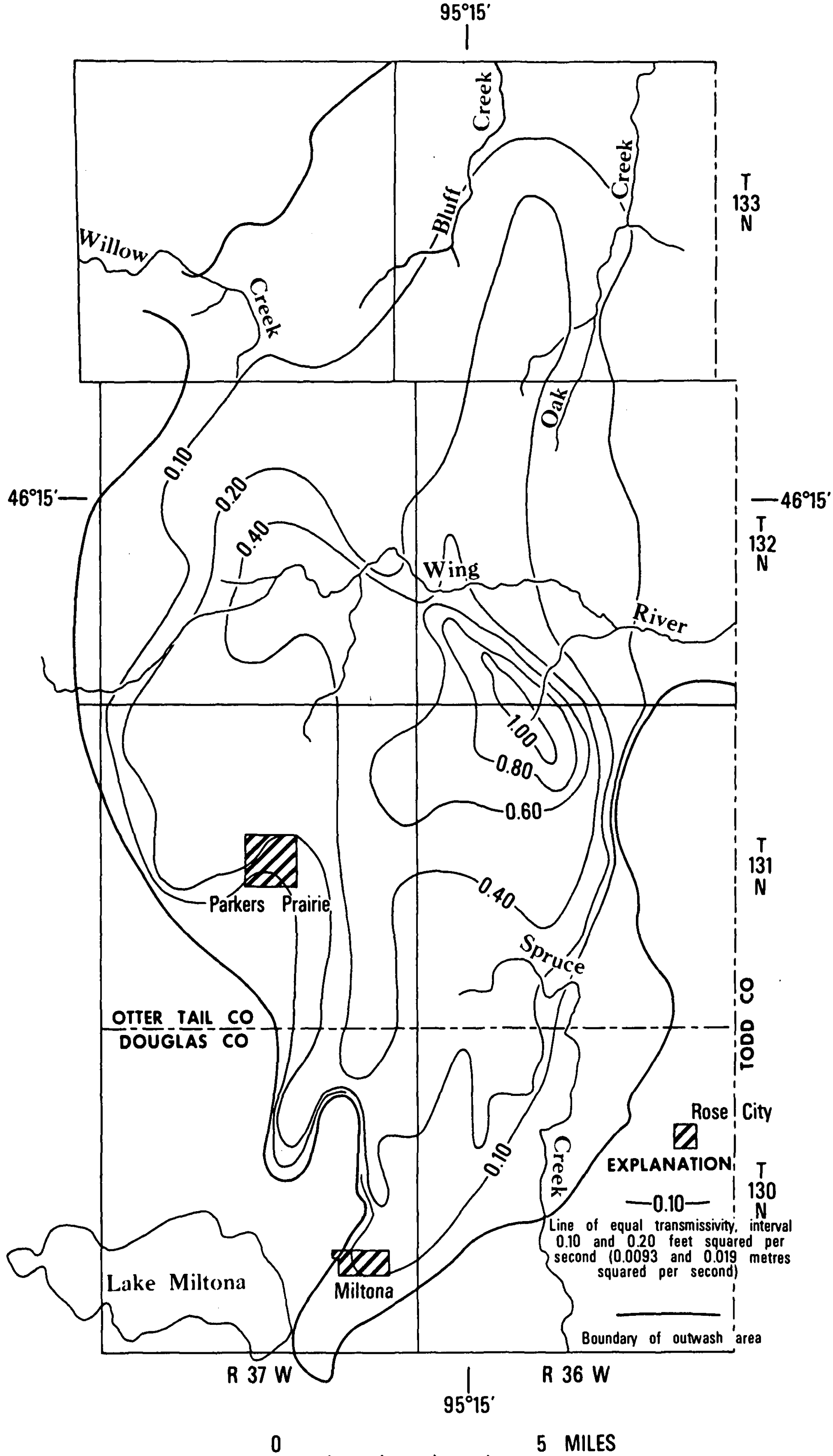

Figure 9.--Transmissivity of surface outwash aquifer in Parkers Prairie outwash area

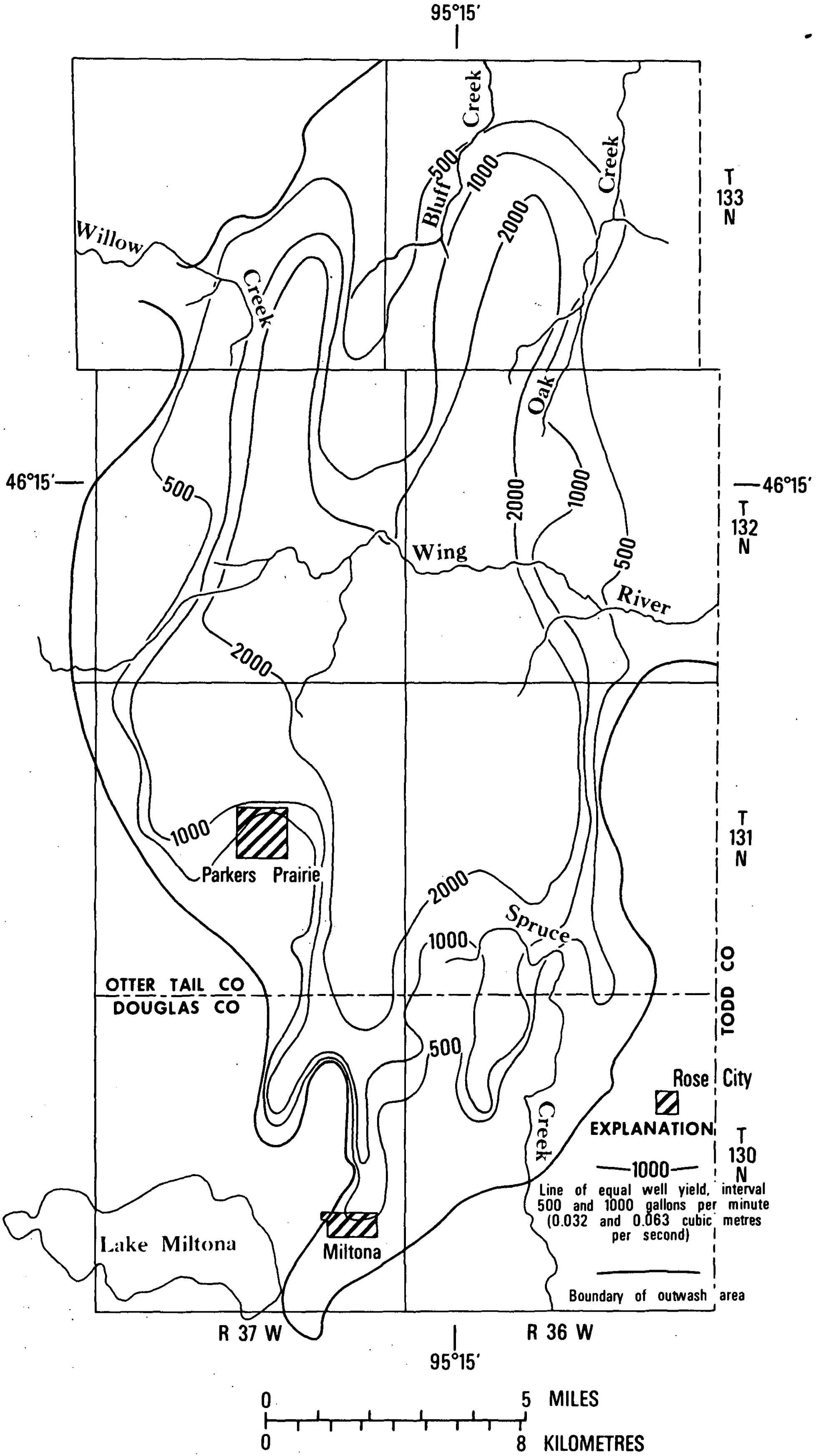

Figure 10.--Theoretical potential well yields from surface outwash aquifer in Parkers Prairie outwash area

On the basis of periodic stream discharge measurements made during 1971-73, combined average base flow for the five principal streams of the area is estimated as 42 ft^3/s (1.2 m^3/s) (table 4). Total base flow out of the area, including minor streams, is estimated as 50 ft^3/s (1.4 m^3/s).

The water balance of the surface outwash aquifer is summarized in table 5. Recharge comes from precipitation. Losses are largely to evapotranspiration and streams, in roughly equal amounts.

Alexandria Outwash Area

The Alexandria outwash area covers 83 mi^2 (210 km^2), under which most of the outwash is less than 40 ft (12 m) thick. In most places, the saturated section of the surface aquifer is thin and will probably not supply enough water for irrigation. Locally, enough water may be obtained from multiple wells, lakes or pits, or buried aquifers. An irrigation system in SE¼SE¼ sec.26, T.127 N., R.37 W., in the southeastern part of the area, uses three wells finished in the surface outwash. Slightly to the north, in SE¼NE¼ sec.23, T.127 N., R.37 W., a center-pivot system is operated from a single well in a buried aquifer. Deep test drilling might discover equally productive buried aquifers in other parts of the area.

Outwash is thickest in the northern part of the area where maximum thickness is more than 80 ft (24 m). Although much of this part of the area is urbanized, limited supplies of water for irrigation may be obtainable. A narrow strip of outwash more than 40 ft (12 m) thick extends north from Forada. This seems to be a former stream channel, cut into the till by glacial meltwater and later filled with outwash sand and gravel.

Clotho Outwash Area

This area extends along the Long Prairie River for 11 mi (18 km) downstream from the Carlos outwash area and covers 15 mi^2 (39 km^2). A strip down the center of the area, averaging about 0.5 mi (0.8 km) wide, is underlain by outwash more than 40 ft (12 m) thick and in places, more than 80 ft (24 m). (See fig. 3.) The outwash sand is similar to that in the Carlos area (table 1). The irrigable land, most of which can probably be irrigated from wells, is limited to a few square miles by marshes and by steep hills bordering the river valley.

Table 4.--Estimated average base flow of streams in the Parkers Prairie outwash area.

Stream	Site Location	Average Base-Flow Discharge	
		ft^3/sec.	m^3/sec.
Spruce Creek	NE$\frac{1}{4}$NW$\frac{1}{4}$ sec.28, T.130 N., R.36 W.	10	0.28
Willow Creek	SE$\frac{1}{4}$SW$\frac{1}{4}$ sec.26, T.134 N., R.38 W.	6	0.2
Bluff Creek	NW$\frac{1}{4}$NW$\frac{1}{4}$ sec.27, T.134 N., R.36 W.	2	0.06
Oak Creek	SW$\frac{1}{4}$NE$\frac{1}{4}$ sec.34, T.135 N., R.36 W.	5	0.1
Wing River	SW$\frac{1}{4}$SW$\frac{1}{4}$ sec.3, T.133 N., R.35 W.	19	0.54
	Total	42	1.18

Table 5

Approximate water balance of surface outwash aquifer in Parkers Prairie outwash area

	ft^3/s	Percent of total
Gains		
Recharge	95	100
Losses		
Evapotranspiration	40	42
Outflow across boundaries	5	5
Seepage into streams	50	53
Total	95	100

Urbank Outwash Area

Most of this area (14 mi^2, 36 km^2) has surface outwash less than 40 ft (12 m) thick. A few irrigation supplies may be obtainable where outwash is thickest.

Rose City Outwash Area

This area covers 13 mi^2 (34 km^2). Maximum outwash thickness is slightly more than 20 ft (6 m); furthermore, where the outwash is thickest, the surface is largely marsh. Chances of obtaining sufficient water for irrigation from the surface outwash seem remote.

WATER QUALITY

Most of the dissolved chemical constituents in ground water come from the porous materials through which the water passes. The kind and amount of dissolved constituents depend on the composition and grain size of the porous materials and on the length of time that the water spends in contact with them.

Water in both surface and buried aquifers in the Viking Basin is a mixed type in which calcium, magnesium and bicarbonate are the principal ions (table 6). These three major ions come from solution of carbonate minerals, principally calcite and dolomite, within the drift. Large concentrations of calcium and magnesium make the water generally hard.

Suitability of water for irrigation depends on the composition and concentration of dissolved constituents. Most water-quality problems in irrigation water result from excessive salinity (dissolved solids), sodium, or boron.

Salinity is commonly expressed in terms of the specific conductivity of the water. As water dissolves more salts, its ability to conduct electricity increases. The U.S. Salinity Laboratory Staff (1954) classifies waters with conductivities between 250 and 750 micromhos/cm as having medium salinity hazard. Conductivity of waters in the Viking Basin is summarized in table 7. Conductivity of ground water was measured when samples were collected for analysis; water from wells thought to be contaminated were eliminated from the summary. Conductivity of water from streams, ditches, and lakes was surveyed in October 1973. The salinity hazard of water in the Viking Basin is not great.

Table 6.--Chemical analyses of ground water in the Viking Basin Results in mg/ except, temperature, sodium-adsorption ratio, specific conductance, and pH. Agency making analysis: MHD, Minnesota Department of Health; USGS, U.S. Geological Survey)

Well location	Depth of well (ft)	Source of water	Date of collection of sample	Temperature (oC)	Analysis by	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)
127.37.23DDA	--	Surface outwash aquifer	10-26-72	13.0	USGS	76	20	1.9	3.2	252
128.37.17BAB	90	Buried drift aquifer	10-26-72	11.0	USGS	75	33	3.6	2.0	392
128.37.18DDD	118	Buried drift aquifer	6-64	--	USGS	84	40	7.6	2.1	398
129.36.15BBB	--	Surface outwash aquifer	11-13-73	11.0	USGS	82	19	3.8	3.5	312
129.36.18CBB	29	Surface outwash aquifer	11-13-73	10.0	USGS	85	27	2.6	1.8	275
129.37.13AAC	--	Surface outwash aquifer	10-26-72	7.5	USGS	130	48	20	3.7	419
129.37.23ADB	--	Buried drift aquifer	--	--	MHD	84	32	10	1	354
130.36.4CBB	--	Surface outwash aquifer	9-17-73	12.0	USGS	49	19	2.3	2.0	204
130.36.21CDD	--	Spring	9-19-73	12.0	USGS	84	27	6.8	1.9	414
131.36.20BCC	27	Surface outwash aquifer	9-13-73	10.0	USGS	70	22	1.7	1.2	258
131.37.8CCD	48	Surface outwash aquifer	9-18-73	8.5	USGS	8.7	29	7.0	4.6	133
131.37.22BBB	129	Buried drift aquifer	6-64	--	USGS	59	24	3.6	2.0	290
132.36.18DAA	38	Surface outwash aquifer	9-18-73	9.5	USGS	76	19	5.4	3.3	315
132.36.34CBC	--	Surface outwash aquifer	10-27-72	10.5	USGS	66	20	1.4	2.2	285
132.37.16BCD	21	Surface outwash aquifer	9-18-73	14.0	USGS	65	21	2.8	2.1	256
132.37.36ABB	31	Surface outwash aquifer	9-19-72	9.5	USGS	95	29	4.0	2.2	395
133.36.18CCC	--	Surface outwash aquifer	9-12-73	11.0	USGS	84	23	3.5	1.6	378
133.36.33BBB	16	Surface outwash aquifer	9-12-73	10.0	USGS	89	26	3.3	1.3	324
133.37.23CCB	20	Surface outwash aquifer	11-13-73	11.5	USGS	45	14	6.4	1.4	112

Table 6.--(Continued)

Sulfate (SO_4)	Chloride (Cl)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Fluoride (F)	Nitrate & Nitrite $(NO_3+NO_2$ as N)	Boron (B)	Dissolved Solids (residue on evaporation at 180°)	Hardness: Total	Hardness: Noncarbonate	Sodium-Adsorption ratio	Specific Conductance (micromhos/cm at 25°C)	pH
19	8.7	22	0.04	1.1	0.2	12	0.05	318	270	65	0.1	350	7.7
9.1	4.0	5.1	4.0	.2	.4	.01	.24	328	320	2	.1	700	7.4
21	25	--	1.4	.15	.1	.2	.02	432	372	--	1.0	705	7.5
33	4.4	13	2.1	.82	.1	.10	0	293	280	27	.1	545	7.3
19	12	21	.03	.03	.1	8.6	.03	355	320	98	.1	603	7.6
81	52	25	.02	.02	.3	27	.14	684	520	180	.4	1270	7.3
5.1	10	--	1.3	.06	.13	--	--	420	320	--	1.3	635	7.1
25	3.1	9.7	.09	.06	.1	2.6	.03	248	200	33	.1	450	7.8
2.5	1.0	21	0	.12	0	.47	.02	328	320	0	.2	550	7.8
11	11	20	.18	.03	.1	6.6	.05	311	270	54	0	480	7.7
30	3.1	6.4	.03	.08	0	.13	.01	198	140	2	.3	280	9.1
13	6.8	--	2.40	.21	.1	0	.01	282	246	--	.6	465	7.5
34	4.1	12	.10	1.10	.1	.16	.06	342	270	10	.1	480	8.2
9.4	1.9	11	.08	.14	.1	3.4	.03	294	250	13	0	540	7.5
16	4.1	14	.03	.16	.1	9.0	.02	299	250	39	.1	440	8.1
15	15	16	2.10	.37	.3	.13	.04	404	360	33	.1	590	7.6
3.6	2.6	22	3.80	.43	.2	.25	.05	341	300	0	.1	510	7.4
12	12	18	.06	.04	.1	8.6	.05	367	330	64	.1	610	7.5
14	9.0	7.4	.04	.083	.2	.05	.02	185	170	70	.2	231	8.4

Table 7.--Electrical conductivity of water in the Viking Basin

(Data are in micromhos per centimetre)

	Minimum	Mean	Maximum
Ground water	231	520	705
Streams and ditches	220	460	540
Lakes	170	230	300

Excessive sodium in irrigation water is undesirable. Sodium in high concentration tends to replace calcium and magnesium in the soil, reducing the soil's workability and ability to absorb water. Sodium hazard may be measured by the SAR (sodium-adsorption-ratio), as defined as

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

where ion concentrations are expressed in milliequivalents per litre. For the range of salinities in the Viking Basin, the U.S. Salinity Laboratory Staff (1954) considers waters with SAR less than 6 to have low sodium hazard. The maximum SAR shown in table 6 is 1.3; thus, problems with sodium in Viking Basin irrigation waters are unlikely.

Boron is a necessary plant nutrient, but excessive amounts are toxic. Plants vary widely in their sensitivity to boron. The U.S. Salinity Laboratory Staff (1954) rates irrigation water with boron concentration less than 0.22 mg/l (milligram/litre) as excellent for even the most sensitive plants. Most crops likely to be raised in the Viking Basin are not sensitive to boron. The maximum boron concentration shown in table 6 is 0.24 mg/l; thus, danger from boron seems unlikely in the Viking Basin.

Suitability of water for irrigation depends on soil and climatic conditions as well as on the water itself. Plants extract and evaporate water from the soil, leaving behind most of the salts that were dissolved in the water. Unless these salts are removed, they build up in the soil, eventually rendering it worthless. Irrigators in western States must often apply excess water to flush salts from the soil; they then remove this water with artificial drainage systems. The necessary flushing should occur naturally in the Viking Basin, with natural recharge supplying the flushing water and streams the drainage.

Iron and manganese are not normally harmful to plants, but their presence is undesirable for other uses. The Minnesota Department of Health recommends that drinking water contain not more than 0.3 mg/l iron, and 0.05 mg/l manganese (P. B. Johnson, oral commun.). Of the 19 analyses (table 6), 7 exceed the limit for iron, and 15 exceed the limit for manganese. Limits of 0.2 mg/l for both iron and manganese are suggested for water used in canning or freezing vegetables (U S. Federal Water Pollution Control Adm., 1968). These limits for iron and manganese are exceeded by 7 and 6 analyses, respectively. Treatment is thus necessary before water from many wells can meet standards for drinking and food preservation.

Because of its permeability and surface exposure, the outwash aquifer is easily contaminated. Of the constituents analyzed, nitrate is the most indicative of contamination. Excessive nitrate may cause methemoglobinemia ("blue-baby disease") in infants (U.S. Public Health Service, 1962). The Minnesota Department of Health recommends a limit of 10 mg/l (as N) for drinking water (P. B. Johnson, oral commun.). Two analyses exceed this limit and several others come close. Nitrate probably does not occur naturally in Viking Basin ground waters in concentrations above a few milligrams per litre. Nitrate contamination of ground water is thus fairly common in the Viking Basin; the same is true in other sand plains in Minnesota. Sources of possible nitrate contamination include fertilizers, feedlots, and septic tanks. The latter two are of particular concern because they are concentrated sources and are often located close to farm wells.

Substances other than nitrate may contaminate ground water. Examples include bacteria, seepage from landfills, industrial wastes, and agricultural chemicals. Although they were not analyzed for in the present study, it may be desirable to consider such substances in designing future ground-water quality monitoring programs.

EFFECTS OF DEVELOPMENT OF THE SURFACE OUTWASH AQUIFER

A model of a ground-water system is a device or mathematical construction that simulates the flow of ground water through the hydrologic system. Models are useful in predicting pumping effects on a ground-water system before the pumping occurs. Digital models were constructed for the Carlos and Parkers Prairie outwash areas. The models, mathematical in nature, need a digital computer for their application.

Digital Models

The models used in this study solve a partial differential equation describing nonsteady flow of a compressible fluid in an elastic non-homogeneous porous medium. The equation can be written

$$\frac{\partial}{\partial x}\left(T\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(T\frac{\partial h}{\partial y}\right) = S\frac{\partial h}{\partial t} + W(x,y,t)$$

where T is transmissivity (L^2/T)

h is hydraulic head (L)

S is storage coefficient (dimensionless)

t is time (T)

W is a source function in terms of volume flux per unit area (L/T)

The computer program used to make model calculations was developed by Pinder and Bredehoeft (1968) and later modified by Trescott (1973) using certain features derived from Prickett and Lonnquist (1971). The principal function of the program is to calculate distribution of head in the aquifer for each grid cell of a rectangular grid at the ends of a small number of time steps, which commonly range from a few days to a few years. Model output after a selected number of time steps includes maps and tables showing head and drawdown for each cell. A mass balance, an accounting of the various gains and losses of water affecting the aquifer, is also calculated.

No model perfectly mimics the functioning of an aquifer. Furthermore, however good the model, its results cannot be more accurate than the information it is fed. The results presented in this report should form a useful guide to development and planning, but they are subject to improvement as more information and better modeling techniques become available.

Assumptions of models

Certain assumptions are made in the models. They simplify input and expedite the computer solution.

1) Flow of ground water is assumed to be entirely horizontal. This is justified by the fact that the aquifer is typically several hundred times as wide as it is thick.

2) The rate of recharge is assumed to be constant throughout the modeling period. A rate of 6 in (150 mm per year) was used for both the Carlos and Parkers Prairie models. It was based on the study of observation-well hydrographs from the Viking Basin and nearby sand plains.

3) Evapotranspiration is assumed to occur at the rate of 6 in (150 mm) per year when the water table is at the land surface. The rate is reduced linearly with lowering water table, reaching zero at 4.0 ft (1.2 m) below the land surface. The rate is assumed to be constant throughout the year.

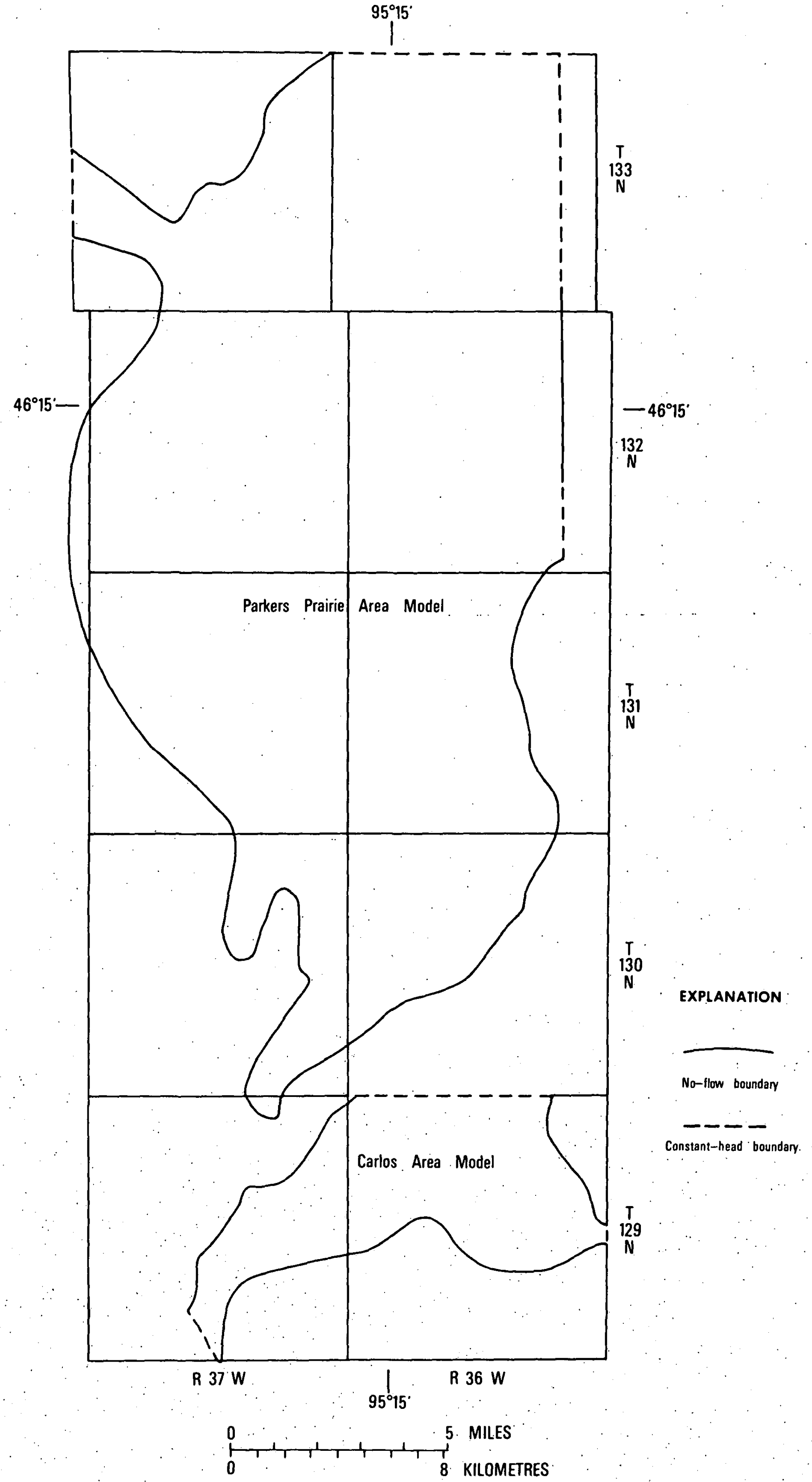

Figure 11.--Boundary conditions used in digital models

4) Streams are modeled as if they were bodies of water lying above the aquifer and separated from it by a layer of material having low hydraulic conductivity. Their levels are assumed to be constant. Water is modeled as flowing into or out of streams, depending on whether head in the aquifer is greater or less than in the streams.

5) Hydrologic boundaries are assumed to be either no-flow or constant-head. Boundary conditions used are shown in figure 11. The edges of the sand plains, where outwash sand is in contact with till, are modeled as no-flow boundaries. Constant-head boundaries are used where the sand plain being modeled joins another sand plain (for example, the north boundary of the Parkers Prairie outwash area) or where boundary conditions are uncertain (as at the north boundary of the Carlos outwash area). Constant-head boundaries are used on the assumption (justified by the model results) that they lie in regions where drawdowns are negligible.

Results for Carlos Outwash Area

The model of the Carlos outwash area used a grid simulating cells 1,000 by 500 ft (305 by 152 m) over the central part of the area. Simulated cells in the outer, less significant parts of the model were made as large as 2,000 by 1,000 ft (610 by 305 m). Time steps were made a uniform 365 hours. Larger time steps were tried in an attempt to speed the solution, but this created mathematical problems which prevented the model from reaching a solution.

After the digital model of the Carlos outwash area satisfactorily simulated the steady-state distribution of head under conditions of no pumping, a pumping function was introduced to simulate hypothetical future irrigation development of the aquifer. Postulated pumping centers are shown in figure 12 and in subsequent illustrations. Each of the pumping centers represents one or more irrigation wells, and was located on the basis of the suitability of land for irrigation and the availability of water from the surface outwash. Almost certainly, the actual development of the aquifer will differ from this hypothetical development.

Figure 12 shows the modeled declines in water level resulting from continuous pumping of 3.24 ft^3/s (1,450 gal/min or 0.0917 m^3/s) from each center for 30 days. To place this pumping rate in perspective, pumpage would equal 1 ft (0.3 m) of water over 193 acres (78 ha) of land. Pumpage might be this great during a severe drought, but in most years it would be less.

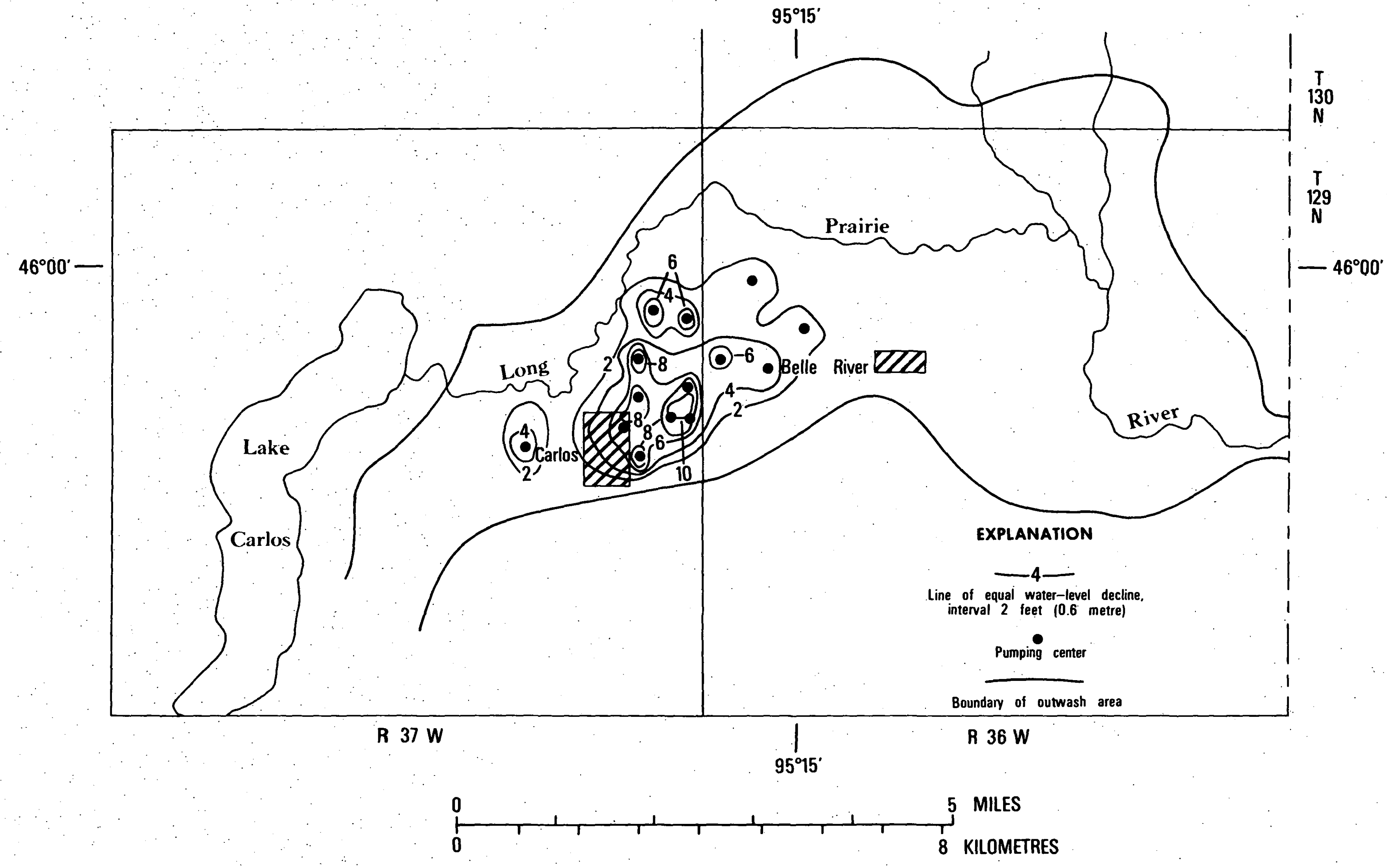

Figure 12.--Modeled declines in water level in Carlos outwash area caused by pumping each center at 3.24 cubic feet per second (1,460 gallons per minute or 0.0917 cubic metres per second) for 30 days

Maximum water-level decline predicted by the model is more than 10 ft (3 m). Figure 12 shows only those declines at some distance from wells. Levels in the wells would be several tens of feet lower.

When pumping stops, water levels recover. Residual water-level declines after 335 days of recovery--that is, at the beginning of the following year's irrigation season--were predicted to be between 2 and 4 ft (0.6 and 1.2 m) over most of the irrigation area (fig. 13). In making figure 13, the water table was assumed to be at static level before pumping. Thus, residual declines shown are for the first year. A second year's pumping would begin with the water table somewhat lower than the first year's prepumping level. Residual declines then, would be cumulative from year to year.

In an area of heavy pumping, water levels decline in a sawtooth pattern (fig. 14). They tend to stabilize as water is captured from natural discharge areas or is induced into the aquifer from streams and lakes. Levels then oscillate about an average (dashed line) lower than the prepumping level but are subject to further gross decline. The aquifer system is then in dynamic equilibrium, or has reached steady-state conditions. Figure 14 is, of course, idealized. Actual ground-water levels will also be affected by variations in precipitation, tending to rise in wet years and to decline in dry years.

Average steady-state water-level declines may be approximated by simulating pumping at a constant rate which removes as much water in a year as irrigation does during the annual irrigation season. Because the duration of irrigation pumping was assumed to be 30 days out of the year, the constant pumping rate needed to determine the long-term average steady-state water-level declines is:

$$(30/365)\ (3.24) = 0.27\ ft^3/s\ (120\ gal/min\ or\ 0.0076\ m^3/s)$$

Under steady-state conditions resulting from pumping each center at 0.27 ft^3/s (0.0076 m^3/s) (fig. 15), average water levels in the entire irrigation area would be more than 2 ft (0.6 m) below prepumping levels and, in one area, more than 8 ft (2 m) below. Under this regime, the numerous small marshes and ponds would probably be dry several months out of the year.

To test the effects of lowering pumping rates, steady pumping at each center was simulated to be 0.18 ft^3/s (80 gal/min or 0.0051 m^3/s) and 0.09 ft^3/s (40 gal/min or 0.025 m^3/s), two-thirds and one-third, respectively, of 0.27 ft^3/s (0.0076 m^3/s).

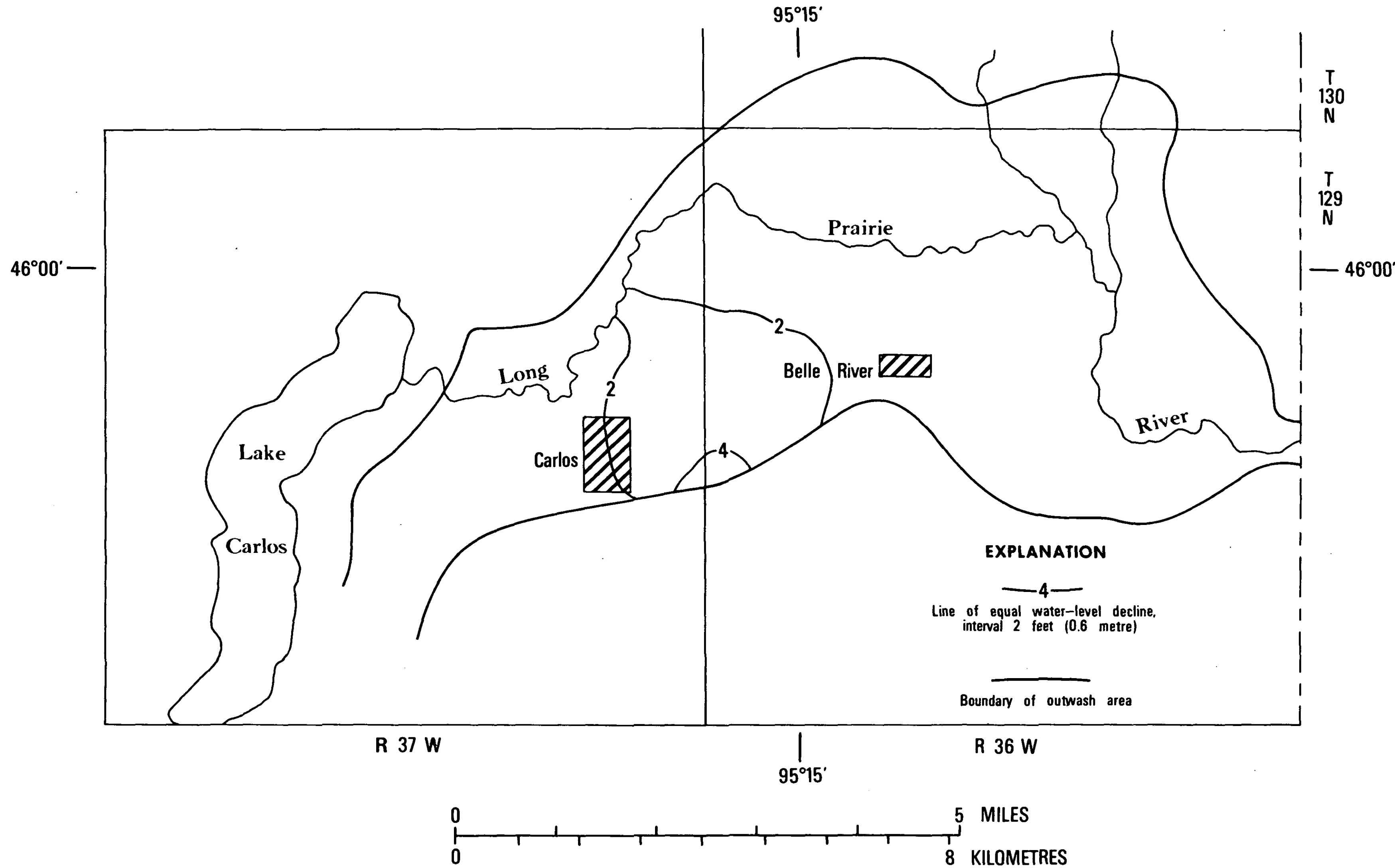

Figure 13.--Modeled declines in water level remaining in Carlos outwash area after 335 days recovery

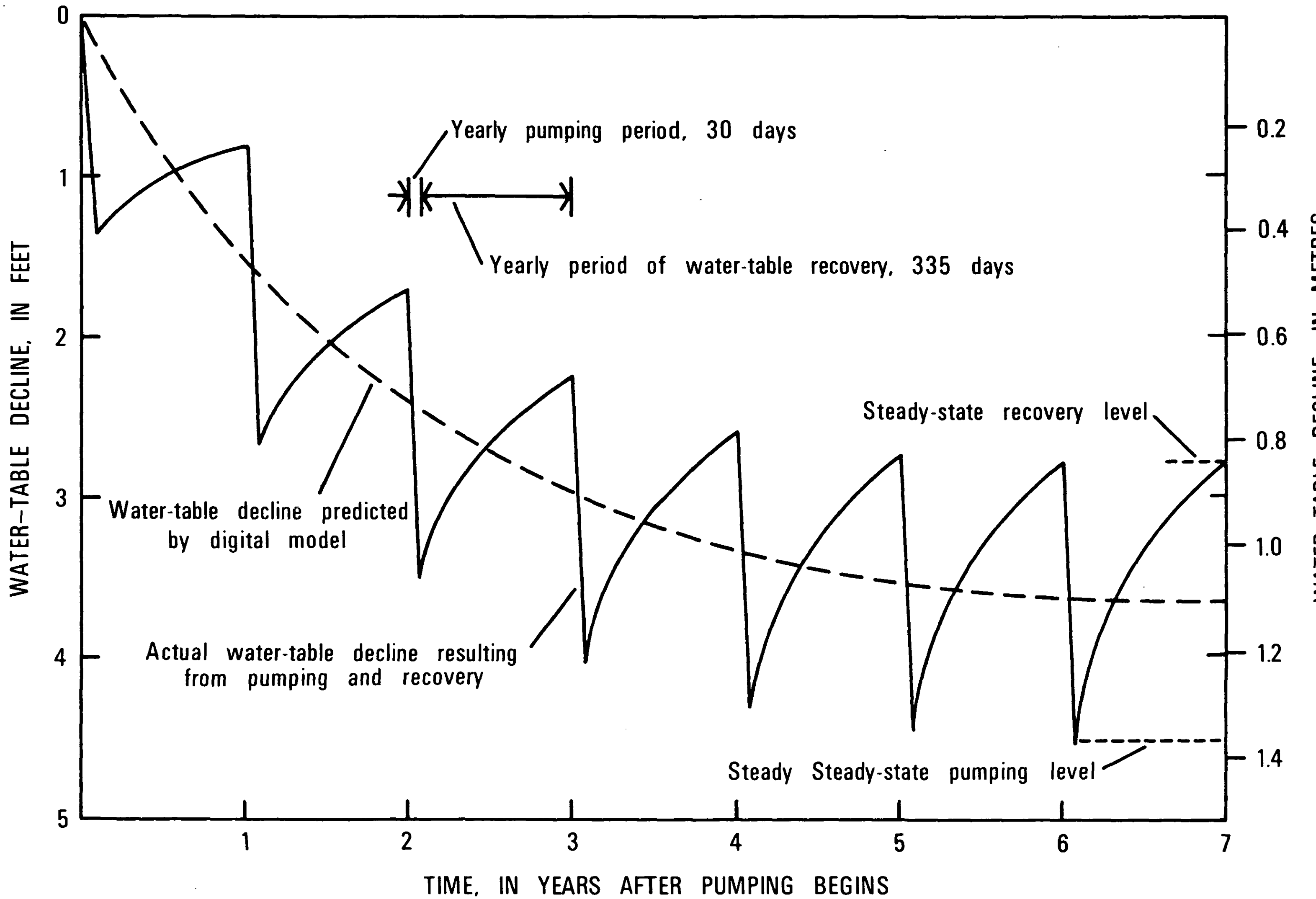

Figure 14.--Relation between water-level declines predicted by digital model and actual cycles of pumping and recovery

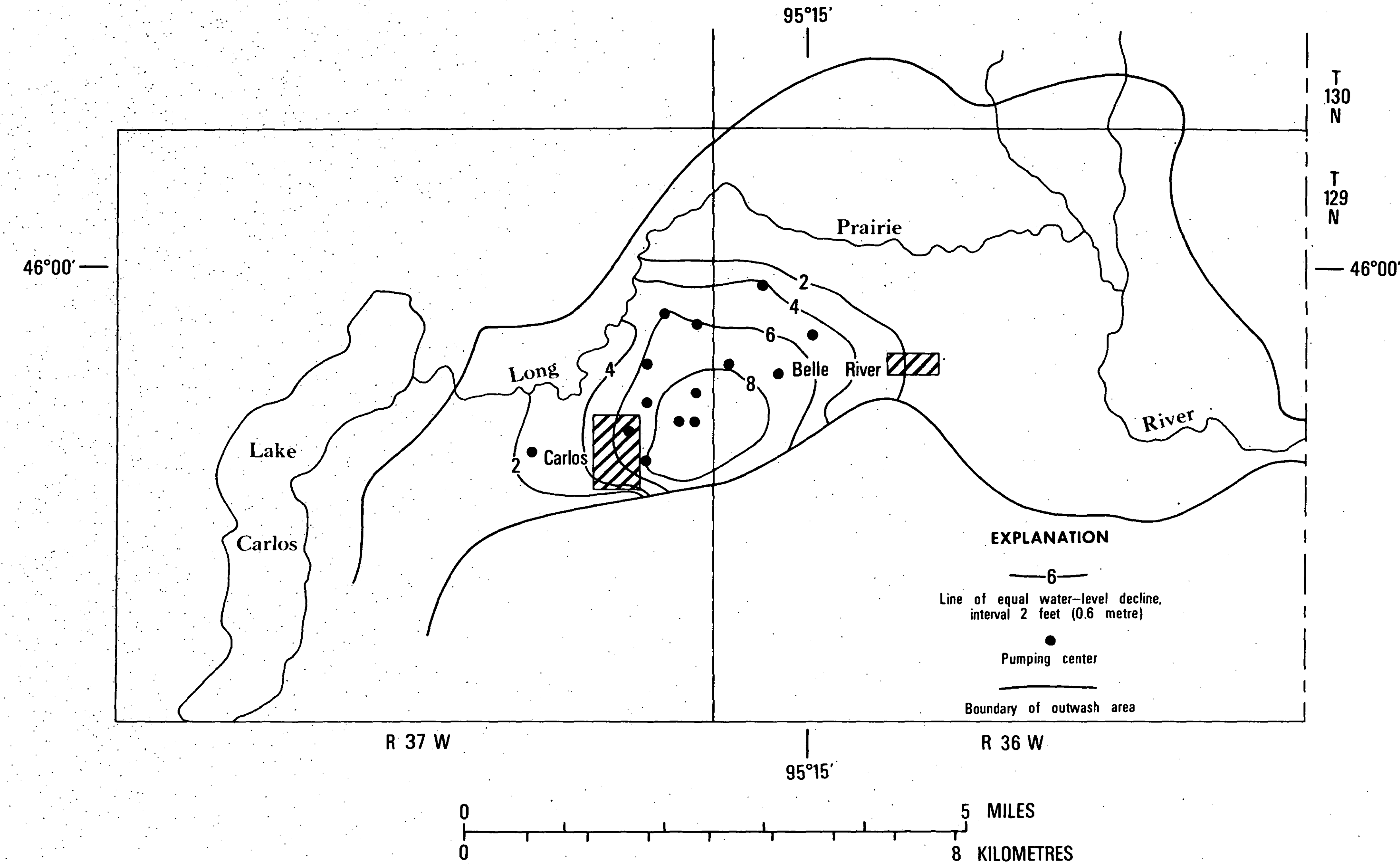

Figure 15.--Steady-state water-level declines in Carlos outwash area resulting from pumping each center at 0.27 cubic feet per second (120 gallons per minute or 0.0076 cubic metres per second)

Maximum water-level declines (fig. 16 and 17) were indicated to be 5 ft (1.5 m) and 3 ft (1 m), respectively. At both rates, declines over a significant part of the irrigation areas were indicated to be 2 ft (0.6 m) or more, enough to diminish marshy areas. At all three pumping rates, steady state was reached within a few years of simulated time. The exact time is not meaningful, because real wells would be drilled over a period of years, rather than all at once. It is plain, however, that adjustment of the aquifer to pumping stresses is rapid.

The source of the water pumped by the wells is of considerable interest. For all three steady-pumping rates, water balances calculated by the model (table 3) show that most water is derived from the Long Prairie River by reducing natural ground-water discharge into the river. The amount salvaged from reduced evapotranspiration is negligible. Base flow in the river near Carlos is approximately 18 ft^3/s (0.51 m^3/s) (table 2). At the maximum steady-pumping rate described above, 0.27 ft^3/s (0.076 m^3/s), pumpage from the 14 centers was 3.78 ft^3/s (0.107 m^3/s). On the average, over the year, the river's base flow would be reduced about one-fifth.

The model shows effects of pumping on the river to be delayed. For example, the total rate of pumping for the 14 pumping centers in figure 12 is 45.36 ft^3/s (1.284 m^3/s), or about 2.5 times the river's base flow. The model water balance shows, however, only about 1.5 ft^3/s (0.042 m^3/s) being obtained by decreasing discharge to the river during the 30-day irrigation season. The remainder comes from water stored within the aquifer. In the real aquifer, depleted storage would be replenished gradually and the effect on the river would gradually decrease with time. It should be noted that this conclusion applies strictly only to the distribution of pumping centers used in the model, in which no well is less than 0.5 mi (1 km) from the river. A well very close to the river could obtain most of its water from the river rather than from storage after only a few hours or days of pumping.

Results for Parkers Prairie Outwash Area

The Parkers Prairie area model used grid cells 2,652 by 1,336 ft (808.3 by 407.2 m) in size. Uniform time steps of 2,190 hours were used.

Pumping in the Parkers Prairie outwash area was simulated according to the same pattern as in the Carlos outwash area. Because the assumptions and qualifications are the same for both areas, the treatment here will be much more brief.

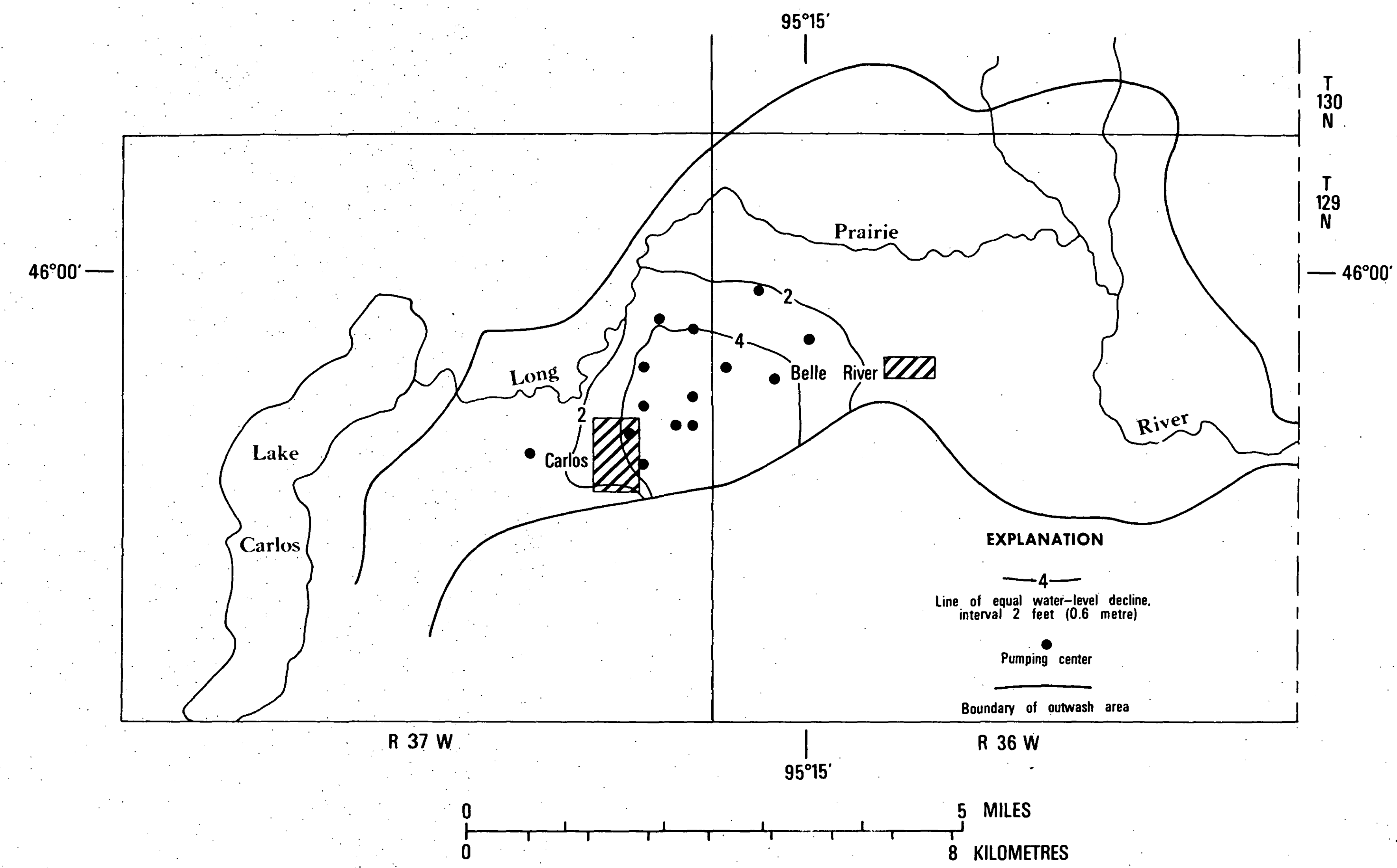

Figure 16.--Steady-state water-level declines in Carlos outwash area resulting from pumping each center at 0.18 cubic feet per second (80 gallons per minute or 0.0051 cubic metres per second)

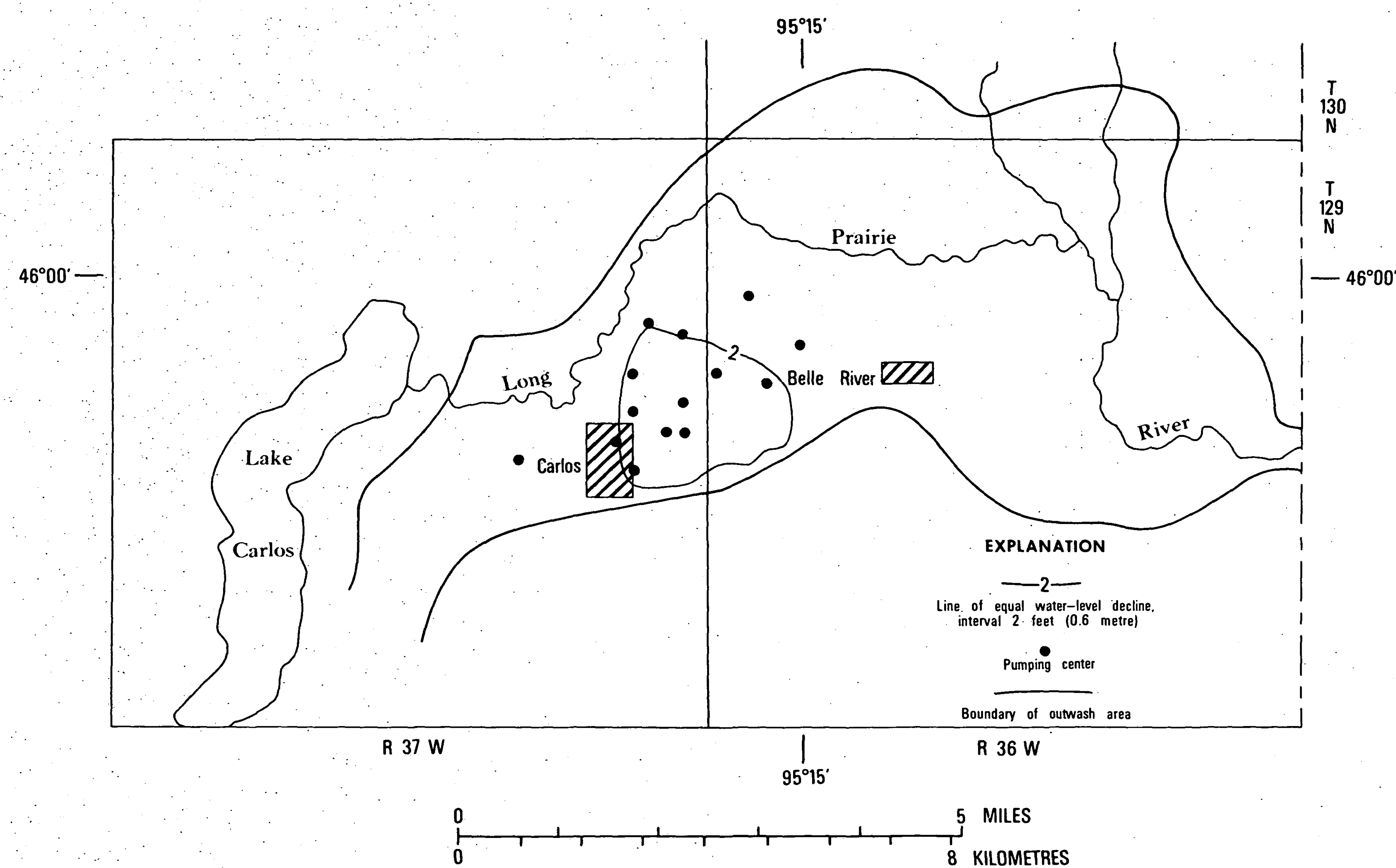

Figure 17.--Modeled steady-state water level declines in Carlos outwash area resulting from pumping each center 0.09 cubic feet per second (40 gallons per minute or 0.0025 cubic metres per second)

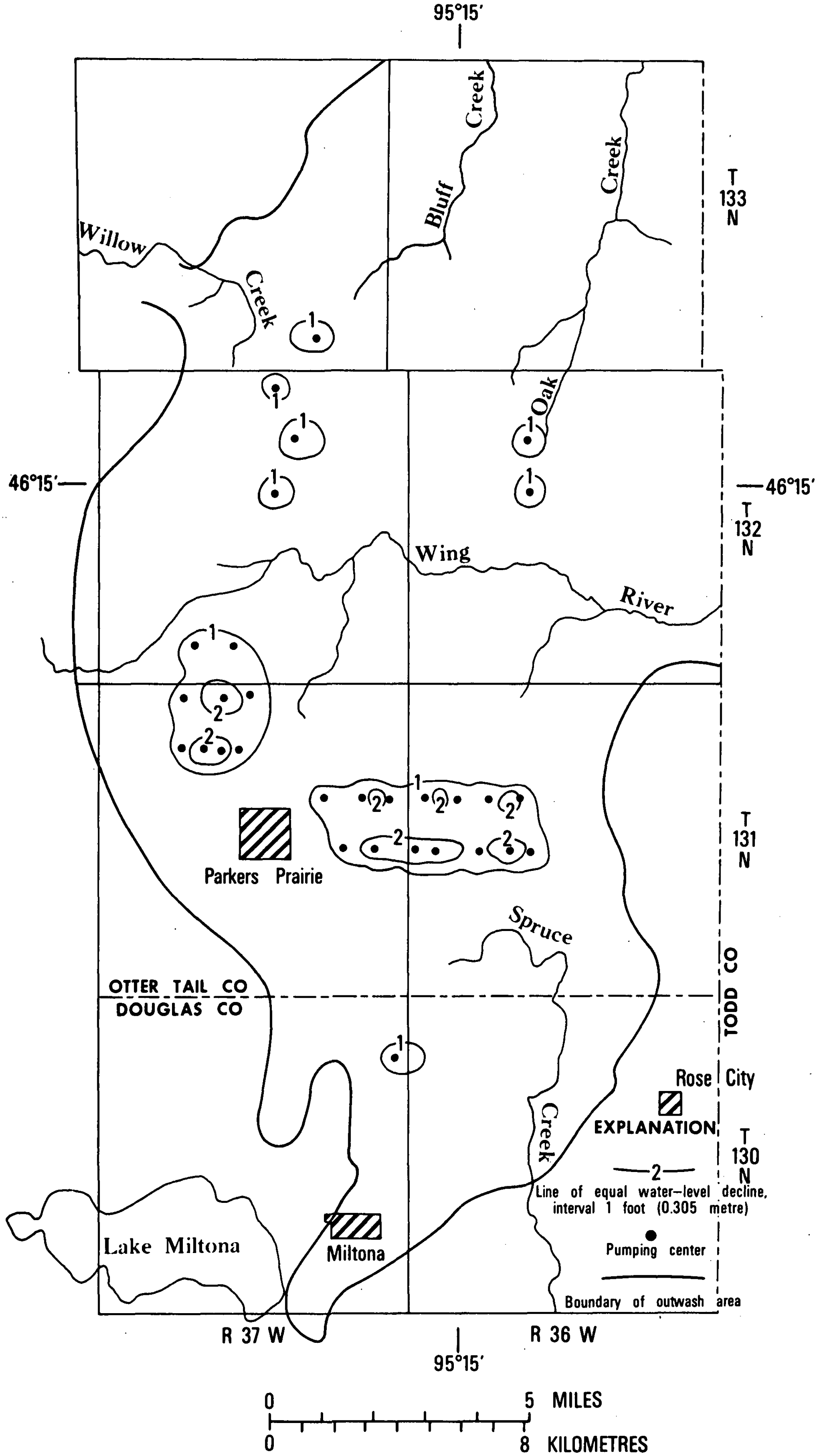

Figure 18.--Modeled declines in water level in Parkers Prairie outwash area resulting from pumping each center at 3.24 cubic feet per second (1,460 gallons per minute or 0.0917 cubic metres per second) for 30 days.

Pumping at the rate of 3.24 ft^3/s (1,460 gal/min or 0.0917 m^3/s) was simulated at 29 centers for a period of 30 days (fig. 18). Except close to the wells, the model showed water-level declines of little more than 2 ft (0.6 m). The total pumping rate for all centers was 93.96 ft^3/s (2.66 m^3/s). During the 30-day pumping period, the model showed about 8 ft^3/s (0.2 m^3/s) to be derived from reduced ground-water discharge into streams, 1 ft^3/s (0.03 m^3/s) from reduced evapotranspiration, and the remainder from aquifer storage. The value for reduced ground-water discharge is the total for all streams in the area, not for any single stream.

Residual water-level declines 335 days after pumping ends were shown as less than 1 ft (0.3 m) everywhere in the model area.

To simulate the long-term average effects of irrigation pumping, pumping was simulated at all centers at 0.27 ft^3/s (120 gal/min or 0.0076 m^3/s) until modelled water levels reached steady-state conditions (fig. 19). This was reached after only a few years of simulated pumping. Practically all the area was shown to be affected by pumping, but water-level declines were at most about 3 ft (1 m). Only in relatively small areas of closely spaced pumping centers did the model show declines greater than 2 ft (0.6 m).

To simulate long-term effects of lower rates of pumping, simulated pumping rates of 0.18 ft^3/s (80 gal/min or 0.0051 m^3/s) (fig. 20) and 0.09 ft^3/s (40 gal/min or 0.0025 m^3/s) (fig. 21) were applied to all pumping centers until steady state was attained. Average water-level declines were shown to be slight in both cases. At the higher rate, the model showed declines were greater than 1 ft (0.3 m) only where pumping centers were closest; at the lower rate, declines were shown as less than 1 ft (0.3 m) practically everywhere.

In contrast to the Carlos area model, the Parkers Prairie area model showed reduced evapotranspiration to be a significant source of the water pumped. This is because a greater part of the Parkers Prairie outwash area is marsh land. Under steady-state conditions, the model showed that about half of the water pumped would be derived from reduced evapotranspiration and half from reduced ground-water discharge into streams. This conclusion is strictly valid only for the distribution of pumping centers used in the model, but it indicates what may be expected from actual development. As in the Carlos area, the actual effects of pumping on streamflow and marsh water levels will probably tend to be spread throughout the year rather than concentrated during the pumping season. Table 5 summarizes the water balance.

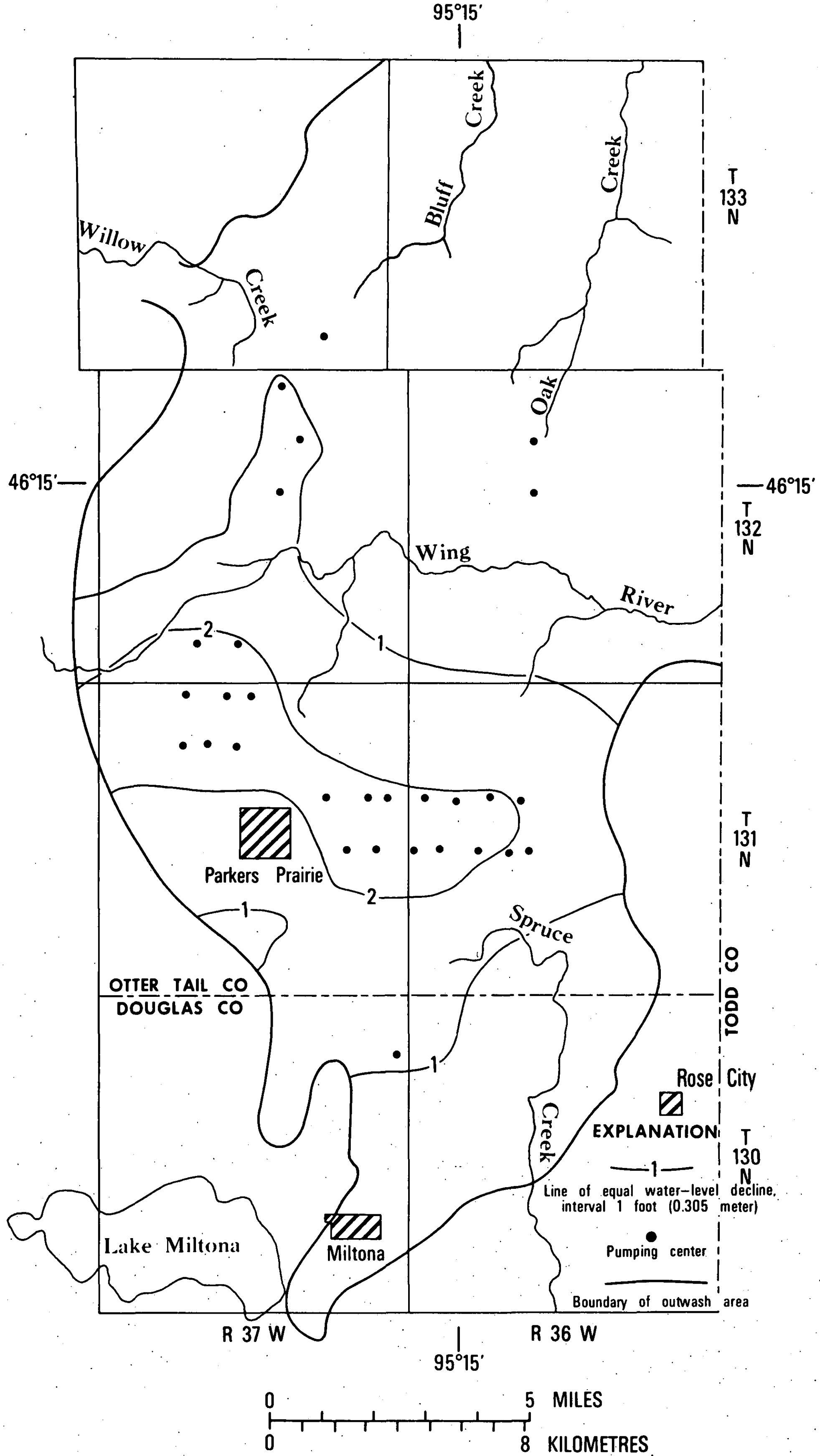

Figure 19.--Modeled steady-state water-level declines in Parkers Prairie outwash area resulting from pumping each center at 0.27 cubic feet per second (120 gallons per minute or 0.0076 cubic metres per second).

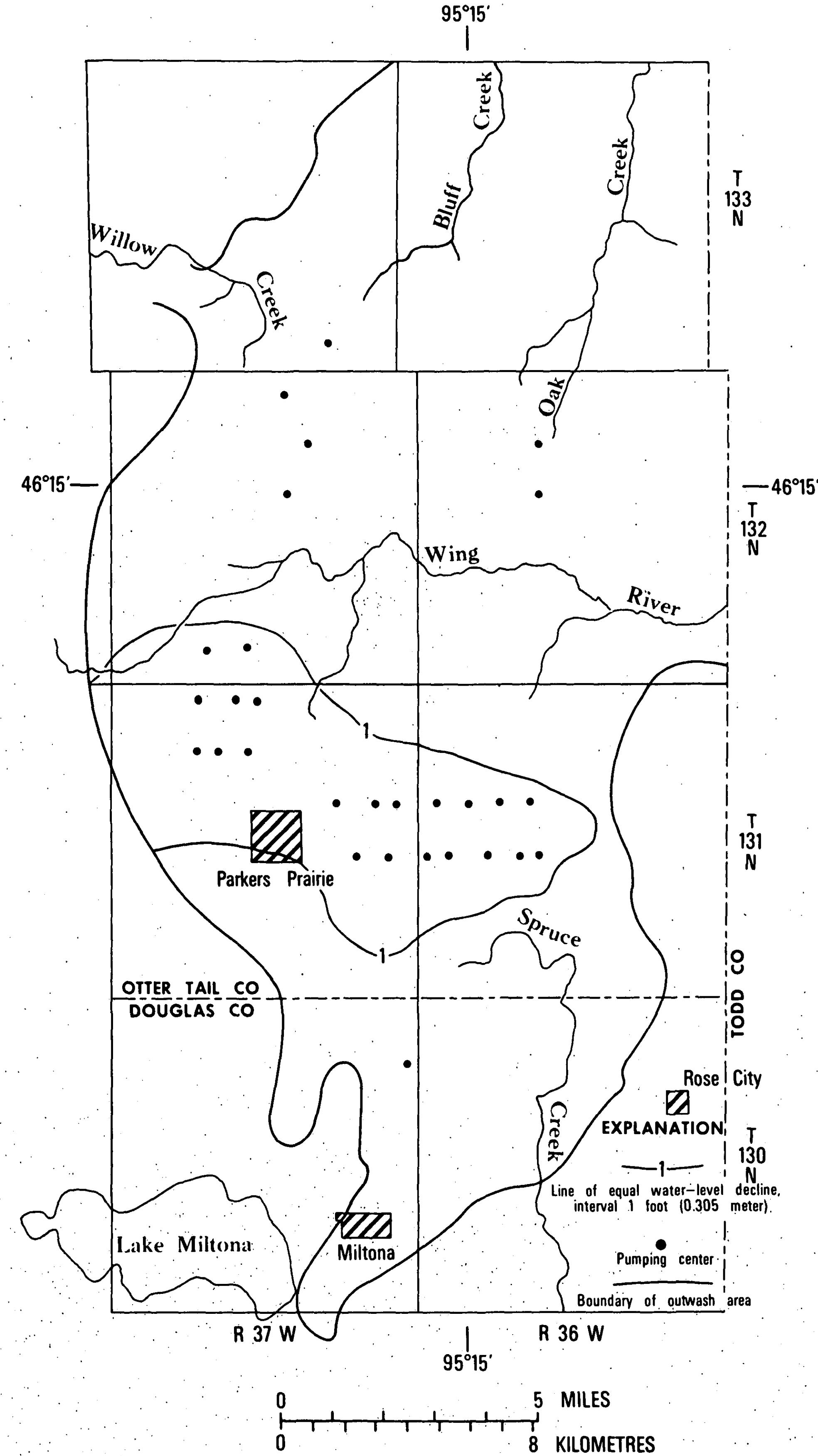

Figure 20.--Modeled steady-state water-level declines in Parkers Prairie outwash area resulting from pumping each center at 0.18 cubic feet per second (80 gallons per minute or 0.0051 cubic metres per second).

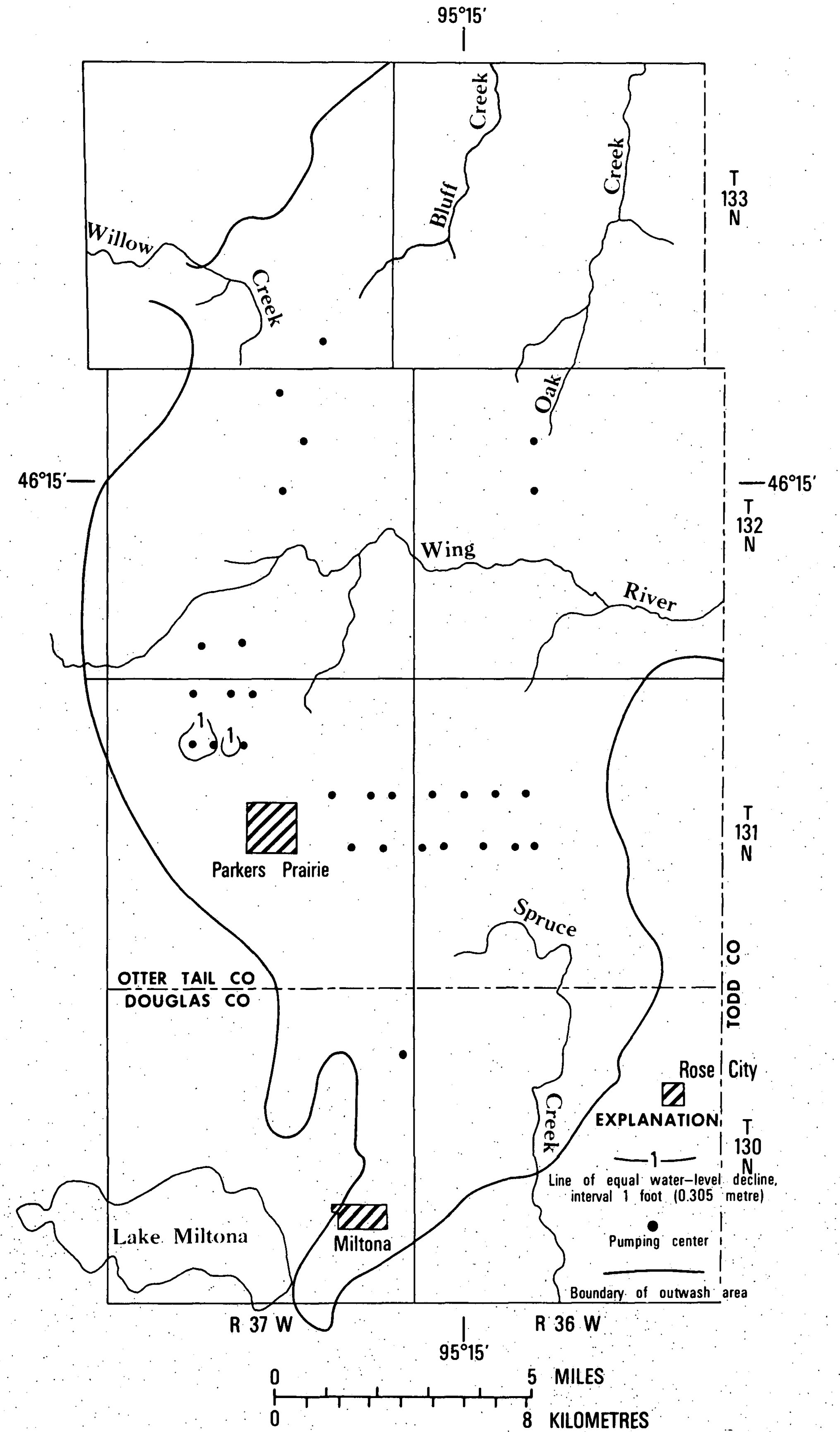

Figure 21.--Modeled steady-state water-level declines in Parkers Prairie outwash area resulting from pumping each center at 0.09 cubic feet per second (40 gallons per minute or 0.0025 cubic metres per second).

CONCLUSIONS

The surface outwash aquifer whose extent defines the Viking Basin is variable in saturated thickness and hydraulic conductivity. The Carlos and Parkers Prairie outwash areas have the greatest potential for development as wells capable of yielding more than 1,000 gal/min (2.23 ft^3/s or 0.0631 m^3/s) could be constructed in large parts of both areas. Most of the Clotho outwash area can probably be irrigated from wells in the surface outwash aquifer.

In the Alexandria, Urbank, and Rose City outwash areas, saturated thickness is too small to support irrigation at most places, although locally a few supplies may be obtainable. In places, buried aquifers within the drift can supply large quantities of water. The extent and thickness of such aquifers can be determined only by test drilling.

Ground water is of excellent chemical quality for irrigation. Concentrations of salinity, sodium, and boron are too low to pose any likely danger to irrigated crops. The surface aquifer is easily contaminated, however, and significant danger exists for nitrate contamination of drinking-water supplies.

Extensive use of water from the surface outwash aquifer will cause declines in ground water, marsh, and lake levels, as well as decreases in streamflow. Digital modeling showed that declines in water levels in the irrigated part of the Carlos outwash area under heavy development may be expected to range from 2 to 8 ft (0.6 to 2.4 m). During the irrigation season declines will be considerably greater close to wells. Corresponding modeled declines in the Parkers Prairie outwash area range from 1 to 3 ft (0.3 to 1 m). Excessive decreases in streamflow during the irrigation season can be avoided if wells are kept at a sufficient distance from streams.

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