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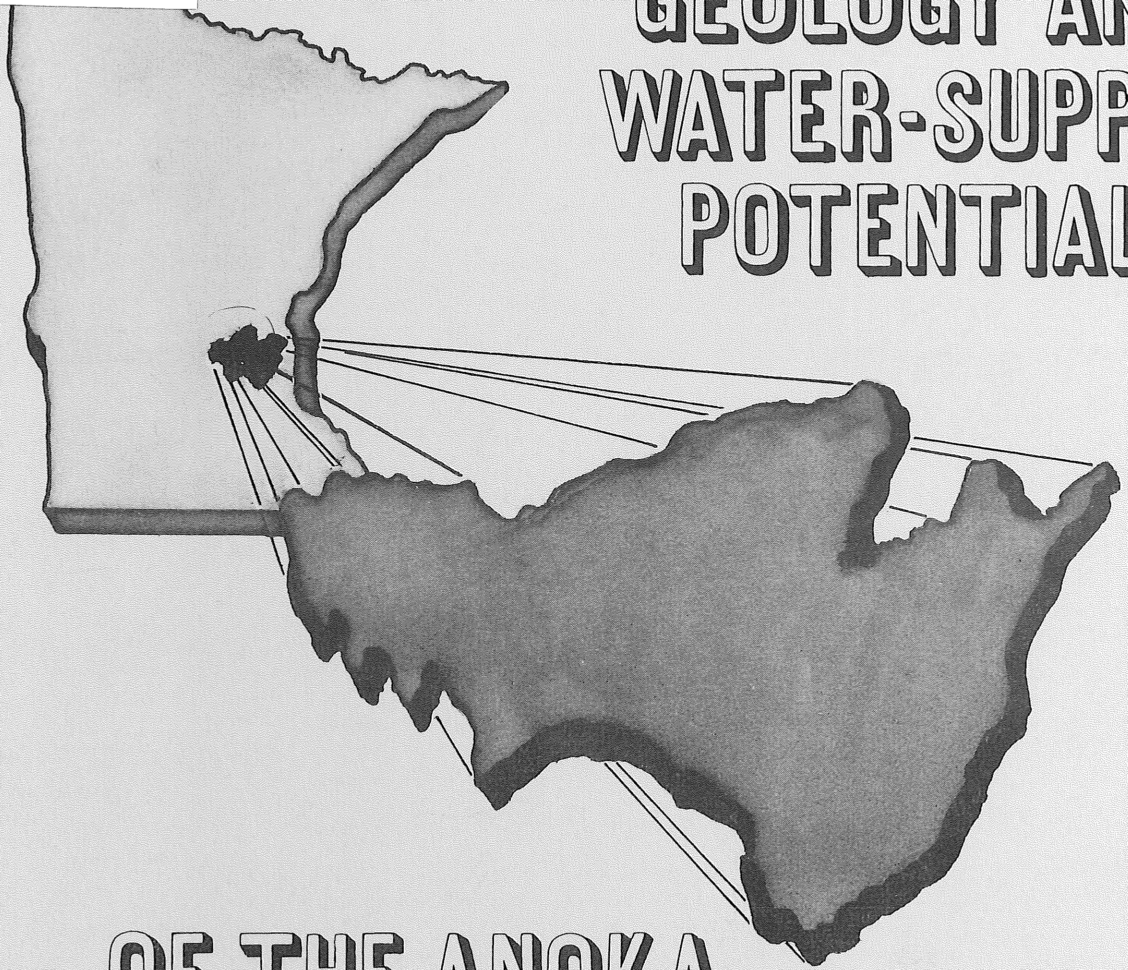
TECHNICAL PAPER NO.6

GEOLOGY AND WATER-SUPPLY POTENTIAL



OF THE ANOKA SAND-PLAIN AQUIFER, MINNESOTA

prepared cooperatively

MINNESOTA

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF WATERS

U.S. DEPARTMENT OF INTERIOR

GEOLOGICAL SURVEY

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MINNESOTA DEPARTMENT OF NATURAL RESOURCES
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GEOLOGY AND WATER-SUPPLY POTENTIAL OF THE ANOKA SAND-PLAIN AQUIFER, MINNESOTA

by

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Prepared cooperatively by the

MINNESOTA DEPARTMENT of NATURAL RESOURCES,
Division of Waters
and the
U.S. DEPARTMENT of INTERIOR,
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CONTENTS

ILLUSTRATIONS

GEOLOGY AND WATER-SUPPLY POTENTIAL OF THE ANOKA SAND-PLAIN AQUIFER, MINNESOTA

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ABSTRACT

Intensified land development on the Anoka sand plain necessitates a better understanding of the hydrogeology of the surficial outwash deposits of the area. The Anoka sand-plain aquifer consists of outwash attributable to two different ice lobes. Predominant grain size of the upper outwash decreases and sorting coefficient increases from west to east. Till or lake deposits underlie most of the surficial outwash. In some areas, these deposits are absent and the aquifer is directly underlain by bedrock, mainly sandstone. Preliminary study indicates that parts of the aquifer may yield several hundred to more than 1,000 gallons of water per minute to properly developed large-diameter wells. Storage in the aquifer is estimated to be 2,000 billion gallons and annual withdrawals approaching 250 billion gallons may be sustained. More detailed analysis is essential for proper management and optimum use of the resource.

INTRODUCTION

The Anoka sand plain (of Cooper, 1935 and Farnham, 1956) and associated valley-train deposits along the Mississippi River constitute an area of about 1,300 square miles of surficial outwash in east-central Minnesota (fig. 1). Being a hydrogeologic unit, the outwash is herein referred to as the Anoka sand-plain aquifer. As used in this report, the name "Anoka sand plain" includes the valley-train deposits. Because of the proximity of the sand plain to the expanding Minneapolis-St. Paul metropolitan area, its hydrogeologic significance merits consideration.

Water withdrawals from the Anoka sand-plain aquifer are largely from small-diameter wells, 20 to 50 feet deep, which yield less than 20 gpm (gallons per minute). Yields of up to several hundred gallons per minute are generally obtained from confined drift aquifers, which underlie the surficial outwash (drift thickness ranges from about 50 to 300 feet), or from Paleozoic and Precambrian sandstones, which underlie the eastern two-thirds of the study area.

Intensified land use on the Anoka sand plain will increase water requirements. As this area is subjected to the inevitable stresses of development, the appraisal and wise management of its water resources becomes increasingly important. The Anoka sand-plain aquifer, being unconfined, requires particularly careful attention to protect it against uncontrolled storage depletion, diminution of recharge, and pollution by man's activities.

The purposes of this study are to describe the geology of the Anoka sand-plain aquifer and to provide a first approximation of its water-yielding capability. The report is based

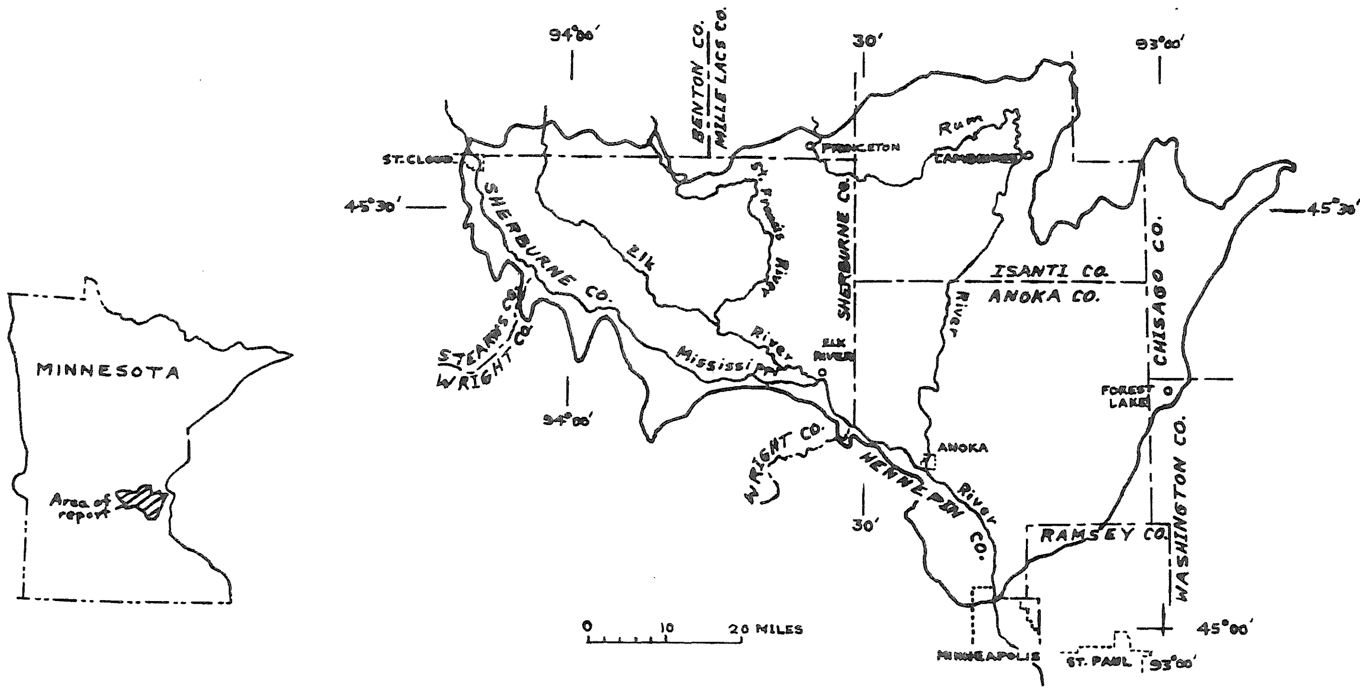

Figure 1. - Location and extent of the Anoka sand plain.

primarily on about 200 test holes augered by the U.S. Geological Survey as a part of regional water-resource investigations (Lindholm and others, 197_). Some auger-hole data in the extreme southern part of the study area were obtained from Minnesota Highway Department records. This study is not a comprehensive evaluation of the aquifer but provides basic geologic and hydrologic information for future investigators, water planners, users, and managers.

GEOLOGY

East-central Minnesota was subjected to several ice advances during Pleistocene glaciation (Wright and Ruhe, 1965), resulting in a variety of glacial deposits and geomorphic features. The Anoka sand plain was recognized by Cooper (1935) as being primarily of glacio-fluvial origin. The surface of the sand plain is flat to moderately undulating and slopes generally southward. Major topographic highs are "till islands" protruding above the general outwash surface, whereas lows are typically areas mantled by organic soils.

The sand plain is bounded in large part by red-brown or gray till (fig. 2). Red-brown sandy till was deposited by ice of the Superior lobe, which entered the area from the northeast. Gray silty till was deposited by ice of the Grantsburg sublobe, which later entered the area from the west.

For purposes of defining the Anoka sand-plain aquifer, its lower limit is chosen as the uppermost relatively

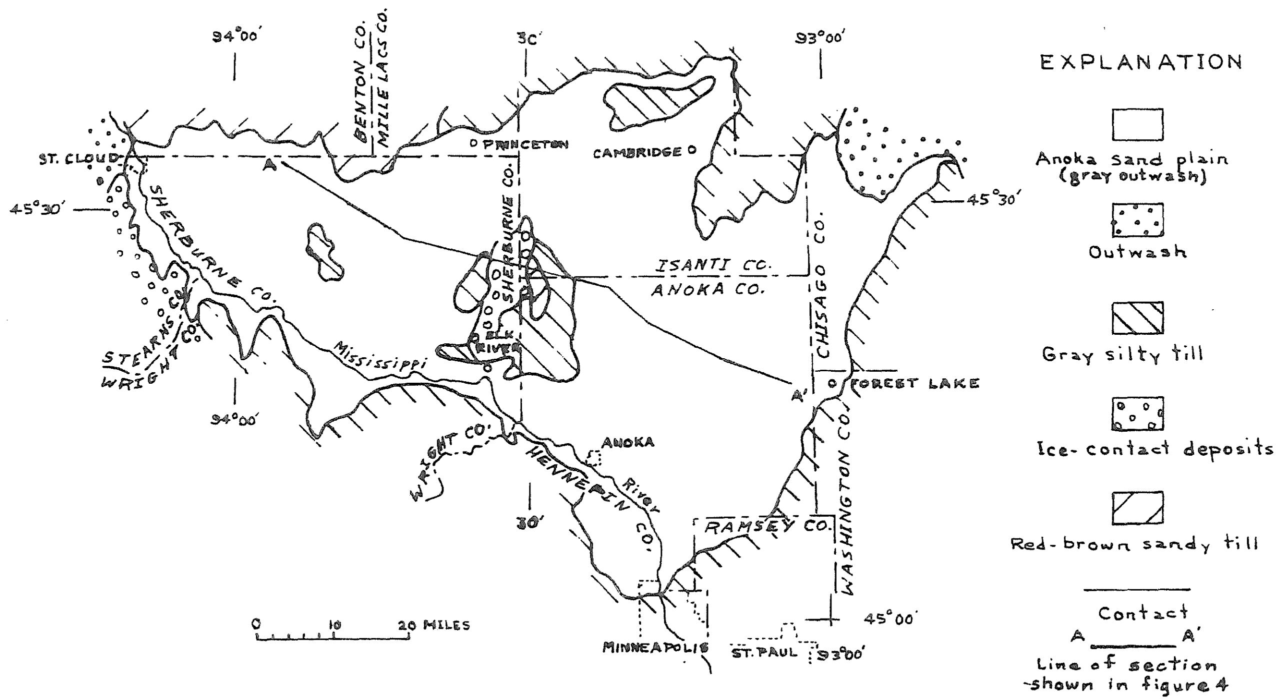

Figure 2. - Surficial geology of the Anoka sand-plain area.

impermeable unit thicker than 5 feet. Red-brown sandy till immediately underlies the aquifer in most of the area (figs. 3 and 4). Gray silty till forms the underlying unit in several areas, and red-brown lake deposits, chiefly clay and silt, underlie much of the eastern part of the aquifer. In some areas, the aquifer is directly underlain by bedrock, mainly sandstone, forming a more permeable lower boundary for the aquifer.

Outwash deposits were associated with the retreat of each ice lobe. The lower outwash unit, red sand of Superior lobe origin, is discontinuous in the eastern two-thirds and absent in most of the western third of the study area. The sand ranges in thickness from 0 to about 50 feet. Test augering and sieve analyses indicate that no predictable textural variations occur within this unit. Most of the red sand is medium grained (diameters 0.25 to 0.50 mm), with lesser amounts of fine or coarse grains. It is generally well sorted; the sorting coefficients (square root of the ratio of the 75-percentile grain size to the 25-percentile grain size) of nine samples range from 1.25 to 3.42 and have a median of 1.44.

Younger outwash deposited by proglacial streams as they followed the southwestwardly retreating ice front of the Grantsburg sublobe (Cooper, 1935) forms the upper unit of the sand plain. This unit is continuous over virtually the entire sand plain and is commonly 20 to 60 feet thick. Below the water table the outwash is predominantly gray, whereas above

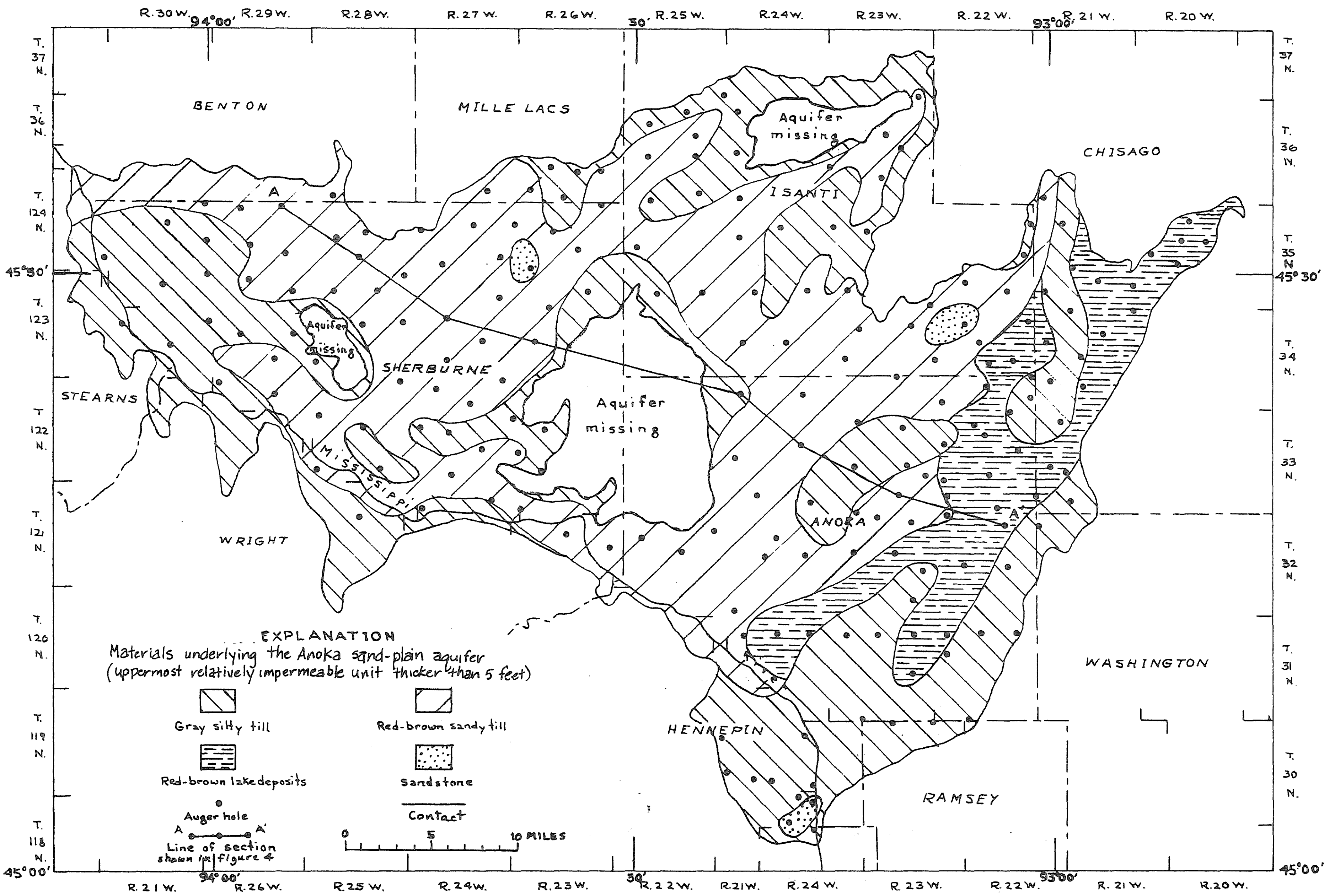

Figure 3. - Distribution of materials underlying the Anoka sand-plain aquifer.

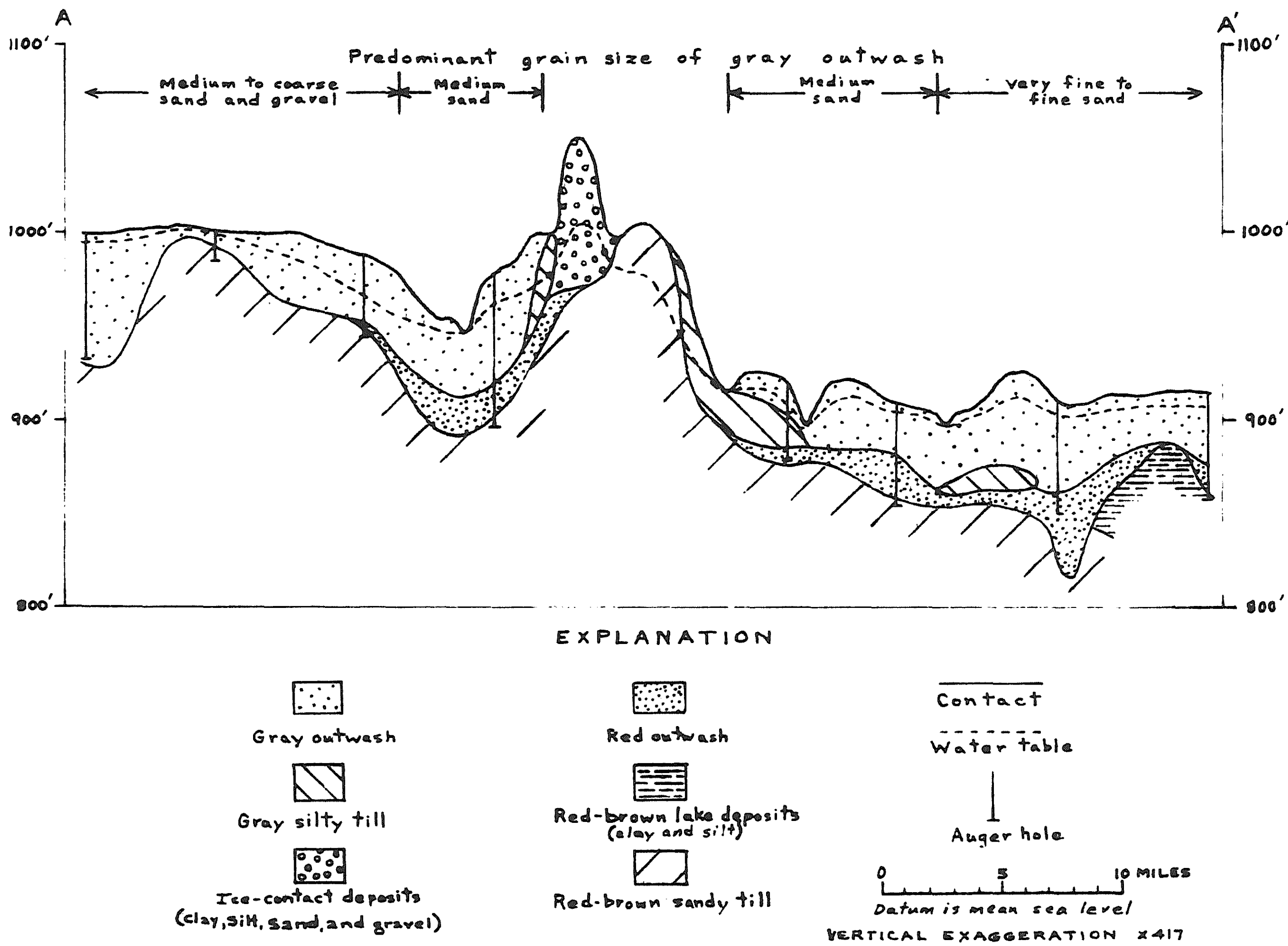

Figure 4. - Section illustrating stratigraphic relationships of the Anoka sand plain.

the water table, it is generally oxidized to a yellow-brown color. Although surficially the outwash is predominantly very fine to fine sand over most of the area (Cooper, 1935; Farnham, 1956), distinct textural variations are evident in the subsurface (fig. 4). Test augering and sieve analyses indicate that the gray outwash in the western third of the area and along the Mississippi River is predominantly medium to very coarse sand (diameters 0.25 to 2.0 mm) and contains considerable amounts of gravel. The sorting coefficients of nine samples range from 1.30 to 3.36 and have a median of 1.93. Sand in the central third of the area is predominantly medium (diameters 0.25 to 0.50 mm). The sorting coefficients of 11 samples range from 1.11 to 2.74, and have a median of 1.40. In the eastern third of the area, sand is predominantly very fine to fine (diameters 0.125 to 0.25 mm). The sorting coefficients of 19 samples range from 1.05 to 1.71 and have a median of 1.30.

WATER-SUPPLY POTENTIAL

Areal variations in saturated thickness of the Anoka sand-plain aquifer (vertical distance between the water table and the uppermost relatively impermeable unit thicker than 5 feet) are delineated in figure 5. Elongate trends of the thicker outwash areas probably indicate the location of major late Pleistocene drainageways. Based on saturated thickness and an overall specific yield of 0.25, the aquifer is

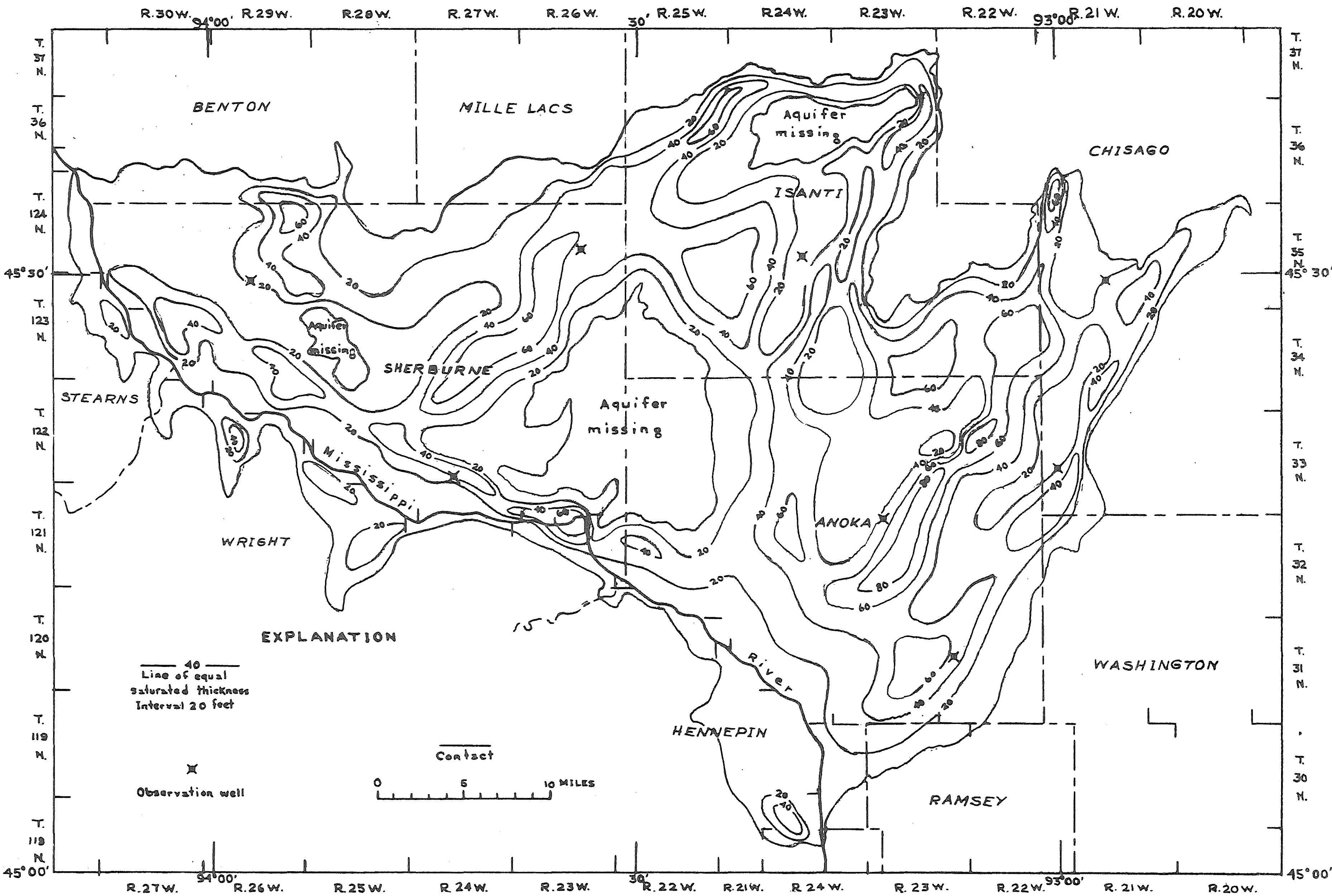

Figure 5. - Saturated thickness of the Anoka sand-plain aquifer.

estimated to store 2,000 billion gallons of recoverable water.

Theoretical short-term yields to wells completed in the aquifer are mapped in figure 6. These values are derived from saturated thickness, estimated hydraulic conductivity (typically, 50 to 200 feet per day), and the following assumptions: (1) the aquifer is homogeneous and of infinite areal extent; (2) the overall storage coefficient is 0.15 for a pumping period of 1 day (this is less than the long-term or specific-yield value of 0.25 because of the delay in gravity drainage); (3) wells are 16 inches in diameter, 100 percent efficient, and open to the full saturated thickness of the aquifer; and (4) drawdown in a well after 1 day of pumping is equal to two-thirds of the original saturated thickness. The assumed drawdowns were adjusted for decreases in saturated thickness caused by dewatering of the unconfined aquifer (Jacob, 1944). Well yields were calculated by the nonequilibrium equation of Theis (1935).

About 20 percent of the Anoka sand plain is underlain by surficial outwash capable of yielding more than 500 gpm of water to individual large-diameter wells. In about 45 percent of the area, expected well yields are less than 100 gpm. Although the outwash is generally finer textured in the eastern part of the aquifer, thicker saturated sections result in potential well yields comparable with those in the western part. Actual well yields at any given location may differ from those shown in figure 6 because of lithologic heterogeneity

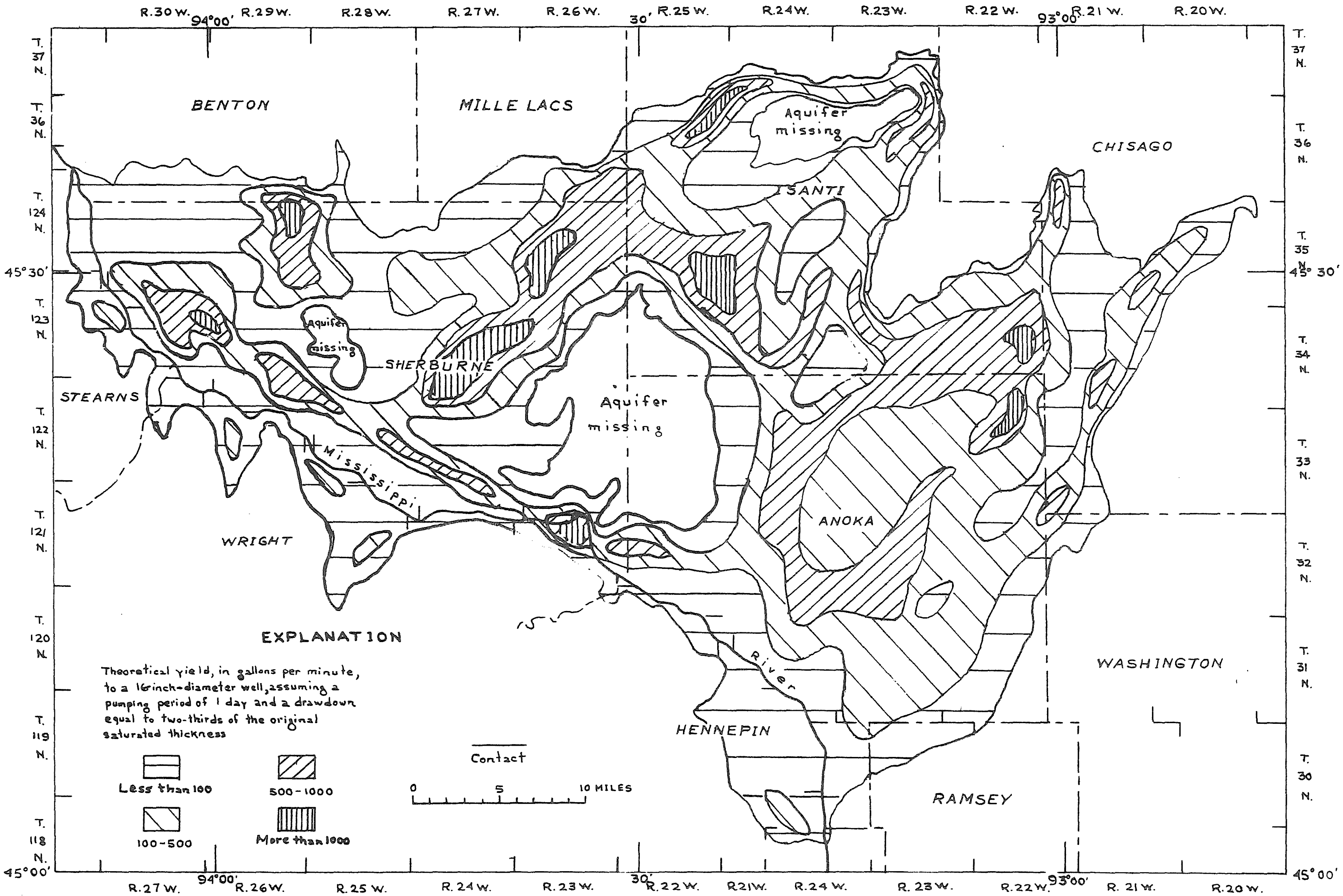

Figure 6.--Theoretical yields to a well completed in the Anoka sand-plain aquifer.

in the aquifer, effects of hydrologic boundaries, and well efficiencies of less than 100 percent. Few large-yield wells are completed in the aquifer to substantiate these estimated yields. However, the method of determination used in this study has proved valid in appraising other surficial outwash aquifers in Minnesota (Lindholm, 1971).

Sustained yield from the Anoka sand-plain aquifer depends upon the amount of natural recharge and discharge in the ground-water system, as well as its capability to yield water to wells. Recharge to the aquifer is from precipitation, whereas discharge is largely as base flow and evapotranspiration. Water-level records for 1970-71 (long-term records not available) from eight observation wells completed in the aquifer (fig. 5) were used to estimate recharge. Precipitation during those years at the Cambridge State Hospital station was 12 percent above normal, based on the period 1932-71. The average annual sum of water-level rises, derived from the differences between peaks and extrapolated recession limbs of the water-level hydrographs, was 4.2 feet. By adjusting this value downward by 12 percent, to account for the above normal precipitation, and assuming that the specific yield of the aquifer is 0.25, then average annual recharge to the aquifer is about 250 billion gallons. Some part of this quantity is the practical sustained yield of the aquifer, or the amount of water that might be withdrawn annually without a long-term loss in storage. To even approach withdrawals of this magnitude without causing adverse effects on the ground-water system, detailed analysis of the system would be needed to optimize development of the aquifer.

In addition to its own water-supply potential, the Anoka sand-plain aquifer is important with regard to underlying aquifers. Underlying sandstone units form part of the northwestern flank of the Twin Cities artesian basin, from which large quantities of water are withdrawn. Direct hydraulic connection between the surficial and bedrock aquifers occurs in some areas. Although the red-brown sandy till in much of the area forms the lower boundary of the surficial aquifer, it may be sufficiently permeable to permit a significant amount of vertical leakage down to underlying aquifers. Any development affecting the quantity or quality of water in the Anoka sand-plain aquifer could, therefore, affect quantity or quality in underlying aquifers. Because of the complexities of the total hydrologic system, additional data and a model study might be necessary to adequately evaluate the response of the system to ground-water development.

CONCLUSIONS

The Anoka sand-plain aquifer consists largely of gray outwash (Grantsburg sublobe origin) directly underlain in much of the area by red outwash (Superior lobe origin). Although the gray outwash is generally well sorted, it is progressively better sorted and finer grained from west to east. The subsurface textural variations suggest a western source of the gray outwash and support a glacio-fluvial origin, as described by Cooper (1935). Red-brown till, gray till, and red-brown lake deposits, form the lower boundary of most of the Anoka sand-plain aquifer. Some areas of direct hydraulic connection exist between the surficial outwash and underlying bedrock aquifers.

In places, large quantities of water are potentially available from the aquifer. Although saturated thickness and estimated well yields vary widely throughout, the aquifer as a whole is a valuable, little developed, source of water.

Additional, more detailed, study of the hydrologic system is necessary to best develop the Anoka sand-plain aquifer. Basic to further study would be the acquisition of more data concerning hydraulic properties of the aquifer and adjacent geologic units; location and effects of hydrologic boundaries; ground-water recharge, discharge, and movement; and ground water - surface water relationships. With this information, the hydrologic system could be analyzed by a model to aid in its practical development and management.

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