UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-LEVEL DECLINES IN THE MADISON AREA, DANE COUNTY, WISCONSIN

Open-File Report 78-936

Prepared in cooperation with the
Madison Water Utility

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CONVERSION FACTORS

The following factors may be used to convert the inch-pound units published herein to the International System of Units (SI):

Multiply inch-pound units	By	To obtain SI units
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
foot (ft)	0.3048	meter (m)
gallon (gal)	0.003785	cubic meter (m^3)

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ABSTRACT

The water supply for the city of Madison, Wisconsin, and for surrounding municipalities is obtained from the ground-water reservoir that underlies the area. This ground-water reservoir is composed of an upper aquifer and an underlying sandstone aquifer. High-capacity water-supply wells pump from the sandstone aquifer.

Pumping from the sandstone aquifer has resulted in hydrologic changes. The water level has dropped in both the upper aquifer and underlying sandstone aquifer, and the flow of water in streams has been reduced.

The effects of anticipated pumping were examined with the use of a digital model. The maximum water-level decline from the beginning of pumping until 1975 was about 75 feet in the sandstone aquifer and 10 to 20 feet in the upper aquifer. Additional declines between 1975 and 2000 were computed to be 10 to 30 feet in the sandstone aquifer and 5 to 10 feet in the upper aquifer. The average annual streamflow of the Yahara River at the McFarland gaging station was reduced 32 percent from the beginning of pumping to 1975. An additional 7 percent reduction in streamflow was computed for the period 1975 to 2000.

INTRODUCTION

The water supply for the city of Madison and for surrounding municipalities is obtained from the ground-water reservoir. This reservoir is composed of an upper aquifer and an underlying sandstone aquifer.

Extensive pumping of the sandstone aquifer has resulted in water-level declines. The Madison Water Utility and other water-oriented groups have expressed concern over these declines.

The purpose of this report is to estimate water-level declines in the area as a result of pumping and to predict those that may be produced by the year 2000 under anticipated development, using the steady-state model previously developed and calibrated (McLeod, 1975).

Location and Extent of Study Area

The study area is Dane County, 1,233 mi^2 in south-central Wisconsin (fig. 1). The aquifer system was modeled throughout the county, with particular attention given the Madison area, where development has been greatest.

HISTORY OF GROUND-WATER WITHDRAWAL

Withdrawal of water from the sandstone aquifer began in 1882 and has increased steadily to the present, 1977 (fig. 2). Water was first withdrawn when the city of Madison began its public water-supply system. The total capacity of the system at that time was less than 1 Mgal/d (Weidman and Schultz, 1915, p. 293). By comparison, average daily pumpage from the sandstone aquifer in 1975 by users in the Madison area was 42.1 Mgal/d, with the Madison Water Utility averaging 30.2 Mgal/d.

FUTURE GROUND-WATER WITHDRAWAL

Projected trends estimated by the Madison Water Utility indicate that pumpage in the area will increase to 59.8 Mgal/d by the year 2000. This estimate is somewhat lower than previous ones (Black and Veatch, 1974, p. 3; McLeod, 1975, p. 31).

Estimated future pumping trends have been altered because of changing attitudes toward water use. The Madison Water Utility recently began a water-conservation program among its customers that has shown positive results, and it plans to continue this program.

WATER-LEVEL DECLINES CAUSED BY GROUND-WATER WITHDRAWAL

Water Level in the Sandstone Aquifer

The gradual increase in pumping from the sandstone aquifer has caused a gradual decline of water levels in wells tapping it (fig. 3). In 1882, the static water level in deep wells near the Madison Water Utility main pumping station located in downtown Madison between Lakes Mendota and Monona was approximately 5 ft above the level of Lake Mendota. By 1975 the static water level in deep wells near the station had declined to 70 ft below lake level. Water levels have declined similarly in deep wells located on the east side of Madison at Oscar Mayer & Co. Smaller declines have been observed in other deep wells on the east and west sides of Madison (McLeod, 1975, p. 13).

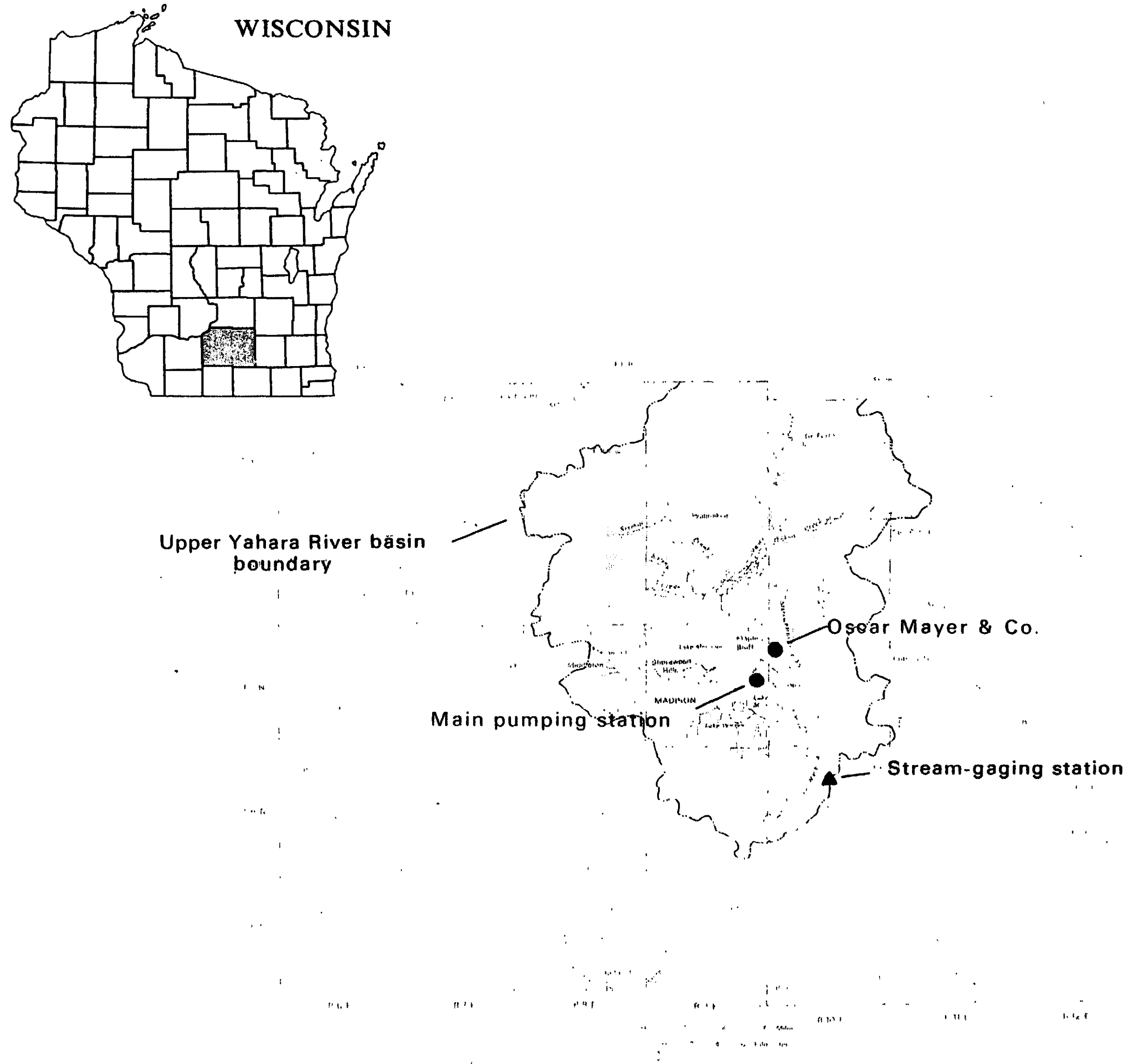


Figure 1. Location of study area.

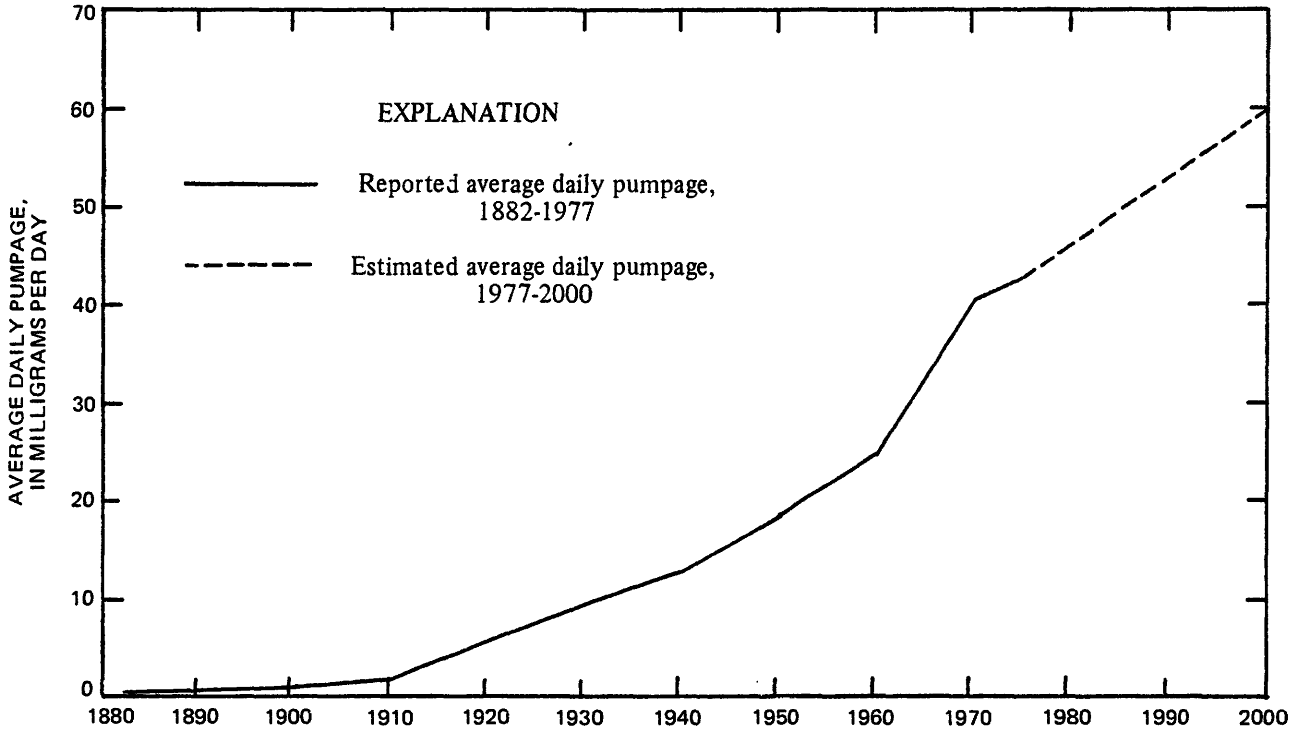


Figure 2. Ground-water withdrawal from the sandstone aquifer, 1882-2000.

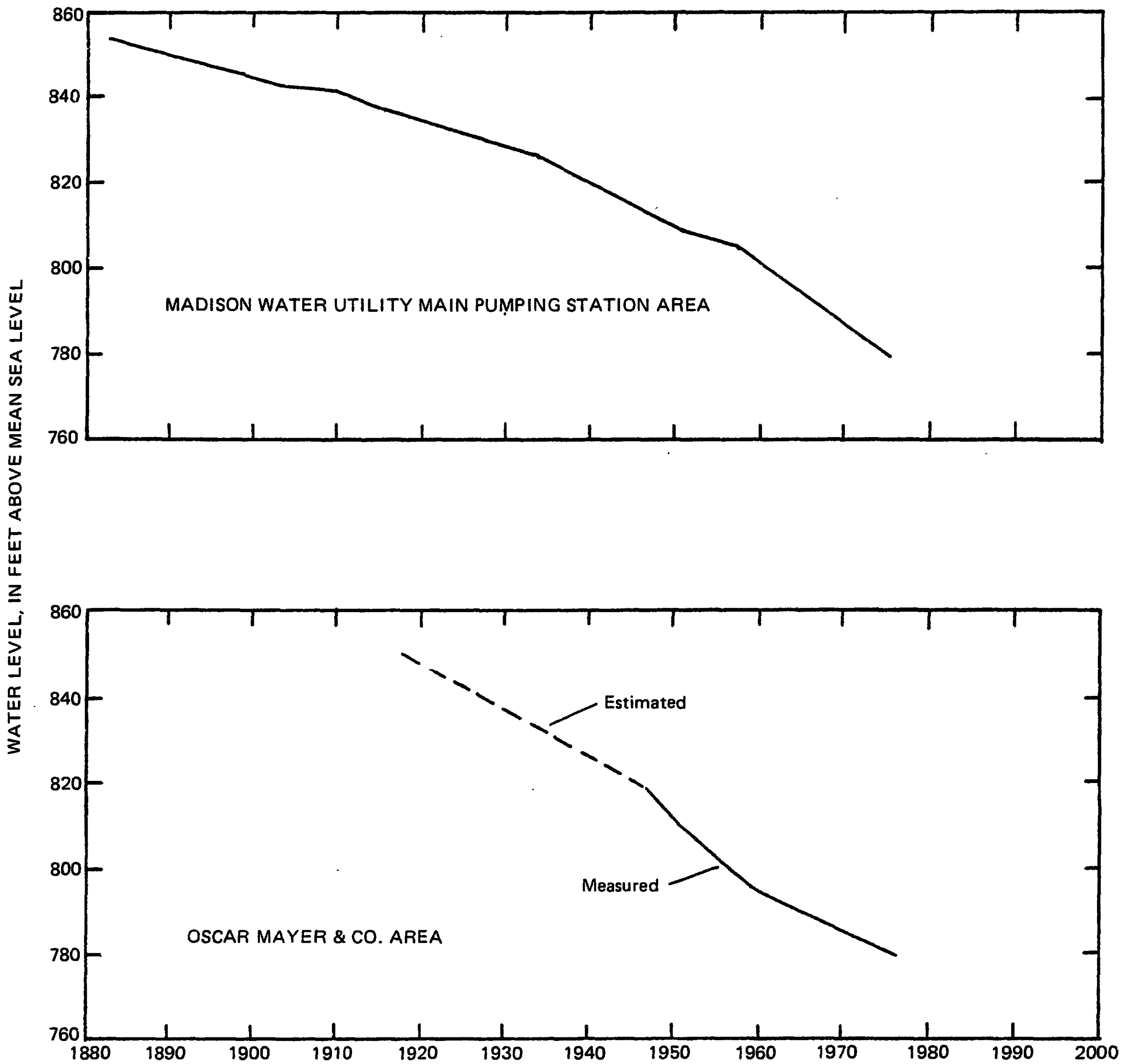


Figure 3. Water-level trends in the sandstone aquifer, 1882-1975. (Location of main pumping station and Oscar Mayer Co. shown in Figure 1.)

Drawdowns in the sandstone aquifer by 1950 and 1975 were simulated with the model on the basis of pumpage and pumping locations supplied by the Madison Water Utility. Results of these simulations are presented in figures 4 and 5. Historical drawdown at specific locations is noted to give the reader an indication of the reasonableness of the computer-simulated drawdowns.

The drawdown contours are elongated to the northeast-southwest through the Madison area. This is due to the orientation of pumping in that direction and to the configuration of the aquifer system. Drawdown to the northwest and southeast has been reduced by leakage to the sandstone aquifer from the thick unconsolidated deposits in the deeply buried preglacial Yahara River valley (McLeod, 1975, p. 22).

Water Level in the Upper Aquifer

Historic water-level data for the upper aquifer are sparse in areas where the water level has declined. However, for the period 1969-71 there is fair water-level data in the areas of downtown Madison and the University of Wisconsin campus. The water level in these areas at that time was generally 10 to 20 ft lower than the water level under prepumping conditions. Presumably this drawdown was gradual as pumping increased from the sandstone aquifer.

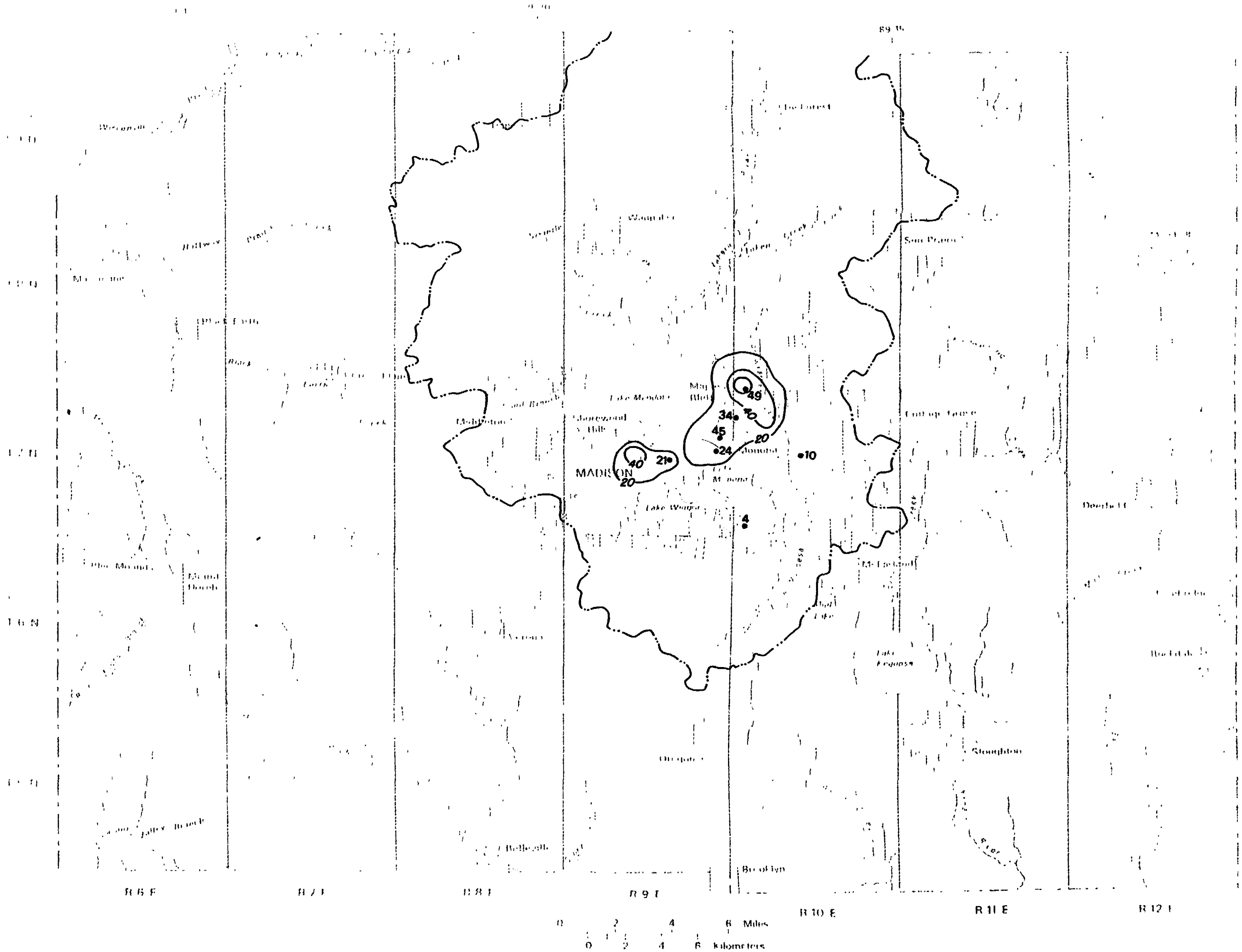
Drawdowns in the upper aquifer by 1950 and 1975 were simulated with the model (figs. 6 and 7). These simulations show that drawdown in the upper aquifer has been much smaller than that in the sandstone aquifer at corresponding locations. The difference is caused by low vertical permeabilities in the aquifer system.

Streamflow

The relatively small decline in water levels in the upper and sandstone aquifers indicate that the ground-water reservoir has been able to maintain a state of equilibrium between recharge and discharge in spite of pumping stresses. The balance is maintained by a reduction in natural discharge to wetlands, lakes, and streams.

Reductions in natural discharge to streams due to pumping are not readily apparent on streamflow hydrographs. However, it has been demonstrated using double-mass curve techniques that yearly reductions in streamflow of the Yahara River at the outlet from Lake Waubesa (fig. 1) could be approximated by the yearly amounts of pumped ground water exported from the basin as treated sewage effluent (Young, 1965; Fetter, 1977).

Flow diversions above selected points on the upper Yahara River for 1950 and 1975, as computed by the model, are given in table 1. Diversions were greatest within the Lake Mendota and Lake Monona watersheds. This was expected because pumping was greatest in these areas.



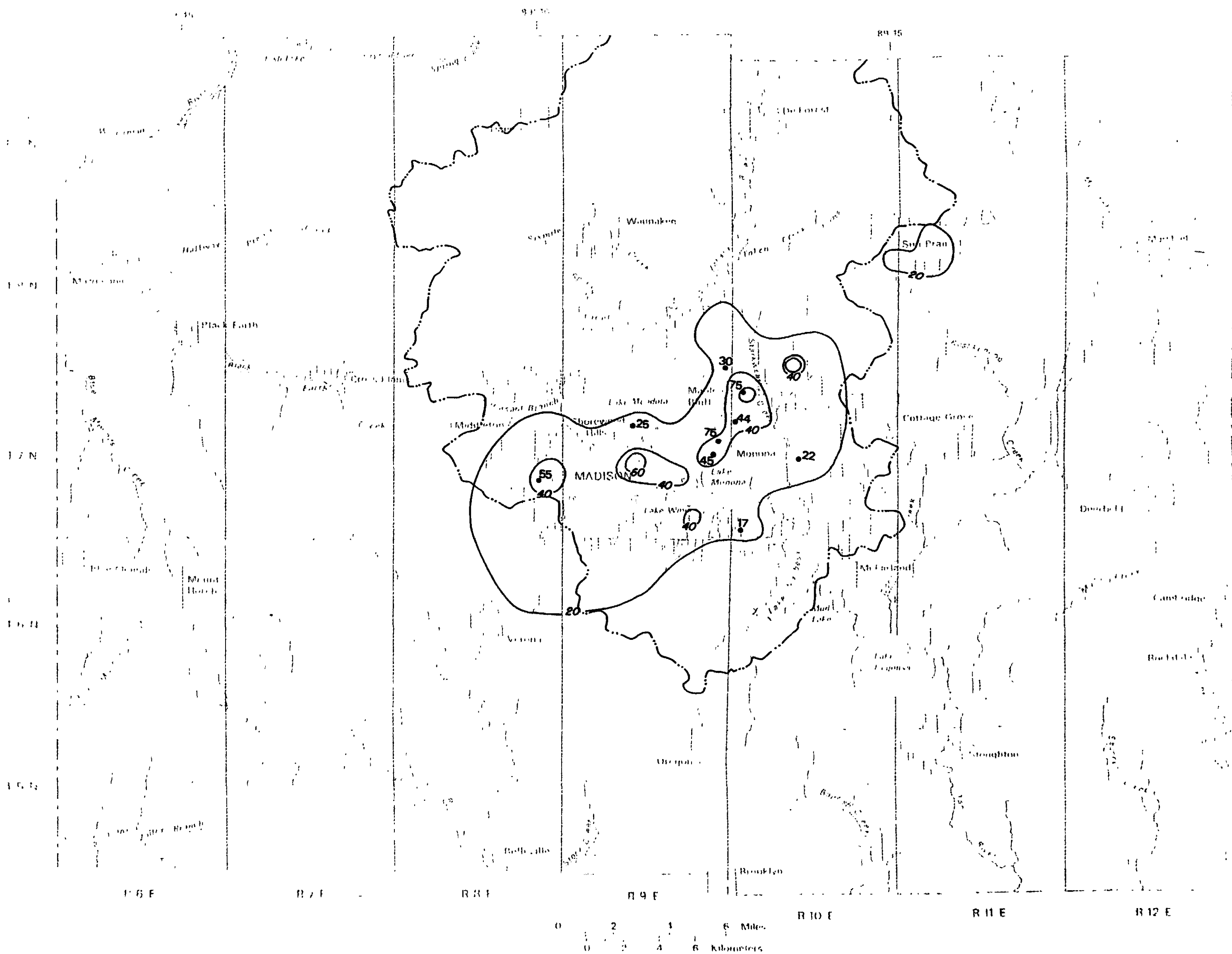
EXPLANATION

Upper Yahara River basin boundary

•10 Measured drawdown, in feet

—20— Line of equal drawdown, approximately located. *Interval 20 feet*

Figure 4. Model-simulated drawdown in the sandstone aquifer from 1882 to 1950.



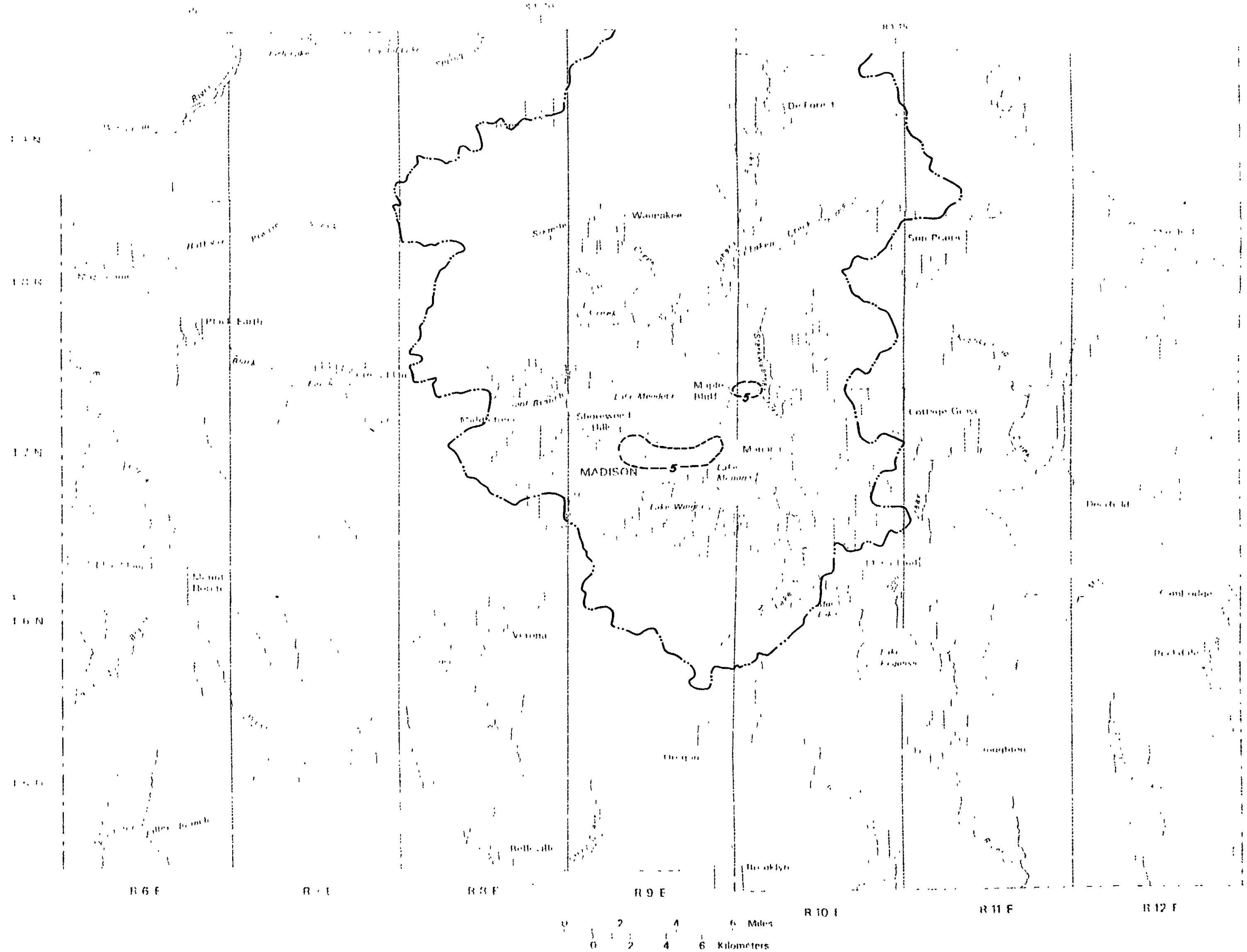
EXPLANATION

Upper Yahara River basin boundary

Measured drawdown, in feet

Line of equal drawdown, approximately located. *Interval 20 feet*

Figure 5. Model-simulated drawdown in the sandstone aquifer from 1882 to 1975.

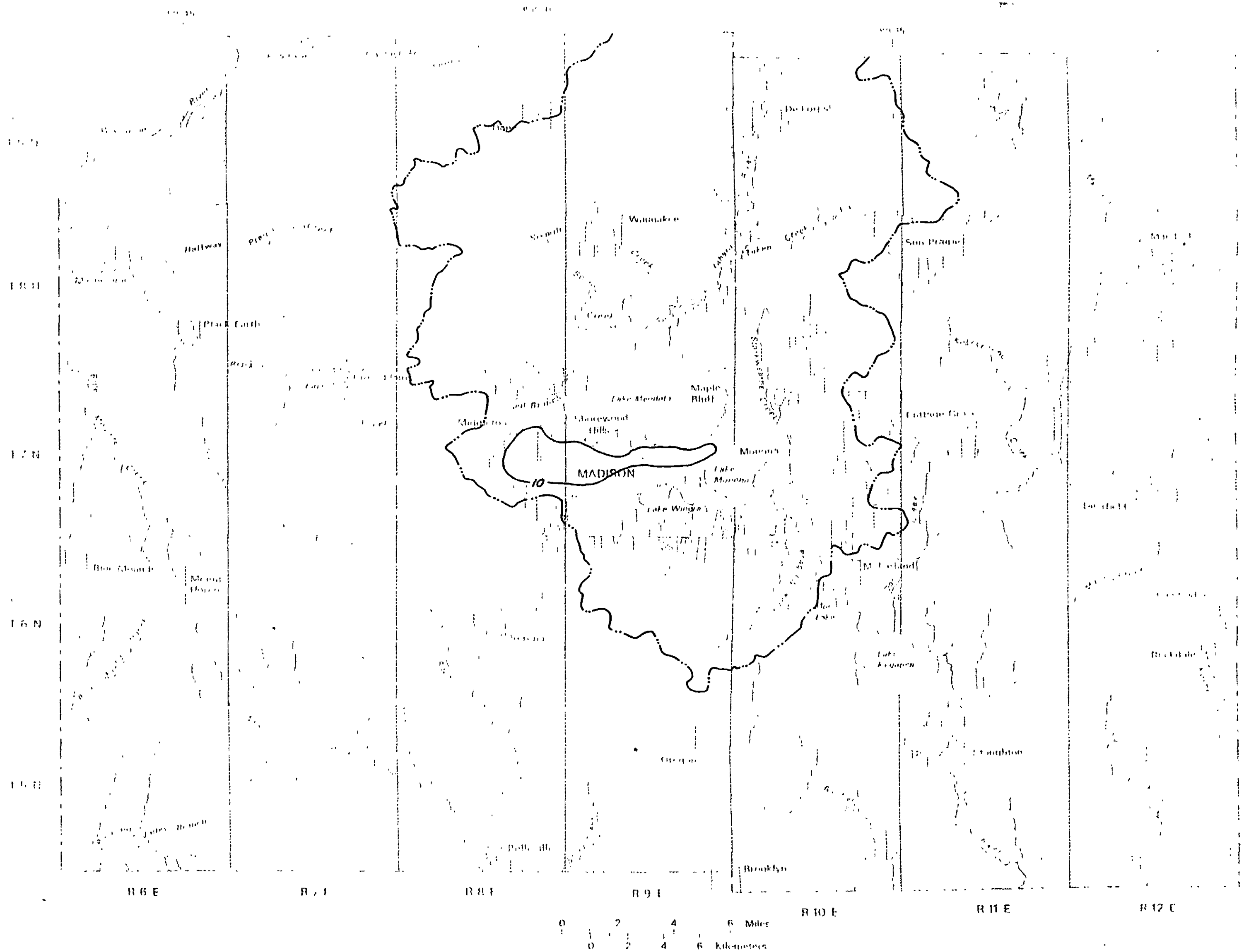


EXPLANATION

Upper Yahara River basin boundary

5 — Line of equal drawdown, approximately located. *Interval 10 feet with 5 feet supplemental contours*

Figure 6. Model-simulated drawdown in the upper aquifer from 1882 to 1950.



EXPLANATION

Upper Yahara River basin boundary

10 — Line of equal drawdown, approximately located. *Interval 10 feet with 5 feet supplemental contours*

Figure 7. Model-simulated drawdown in the upper aquifer from 1882 to 1975.

Table 1.--Model-simulated streamflow diversions above selected points on the upper Yahara River

Year	Lake Mendota Inlet (Mgal/d)	Lake Mendota Outlet (Mgal/d)	Lake Monona outlet (Mgal/d)	Lake Waubesa outlet (Mgal/d)	
1950	0.6	7.4	15.7	[1]0	[2](14.1)
1975	2.3	16.6	31.6	34.9	(36.1)
2000	3.8	19.3	38.5	42.7	

[1]Treated effluent was discharged into Lake Waubesa before December 1968.

[2]The numbers in parentheses are the yearly amounts of pumped ground water measured at the sewage-treatment plant.

The computer-simulated flow diversion above the outlet from Lake Waubesa for 1975 agreed very closely with the amount of pumped water exported from the basin as sewage effluent that year. This close match adds to the credence of the computed values.

The data in table 1 do not include water gained from reductions in ground-water evapotranspiration caused by lowering the water table. Therefore, it is not likely that actual changes would greatly exceed those that were computed.

Effects on Adjacent River Basins

The results of the model-simulated streamflow reductions suggest that ground water has been diverted from adjacent basins into the upper Yahara River basin. The amount of water diverted into the basin was estimated as the difference between the amount pumped from within the basin and the computed streamflow reduction at the gaging station. The amount of diverted water to the upper Yahara River basin estimated in this manner was 1.2 Mgal/d in 1950 and was 3.6 Mgal/d in 1975, or approximately 10 percent of the water pumped within the basin (table 2).

The diversion of ground water from adjacent basins to the upper Yahara River basin could not be verified with the available data. However, encroachment of the drawdown cone in the sandstone aquifer into adjacent river basins, clearly in evidence by 1975, is a good indication that ground water was being captured from these basins.

Table 2.--Ground-water pumpage in the upper Yahara River basin and computed water sources

Year	Total within-basin pumpage (Mgal/d)	Computed quantity of pumpage diverted from streams, wetlands, and lakes in basin (Mgal/d)	Computed quantity of pumpage diverted from adjacent basins (Mgal/d)
1950	17.5	16.3	1.2
1975	38.5	34.9	3.6
2000	54.3	42.7	11.6

ESTIMATING FUTURE CHANGES

Water-level declines by the year 2000 were simulated with the model. Proposed pumping rates and locations were supplied by the Madison Water Utility.

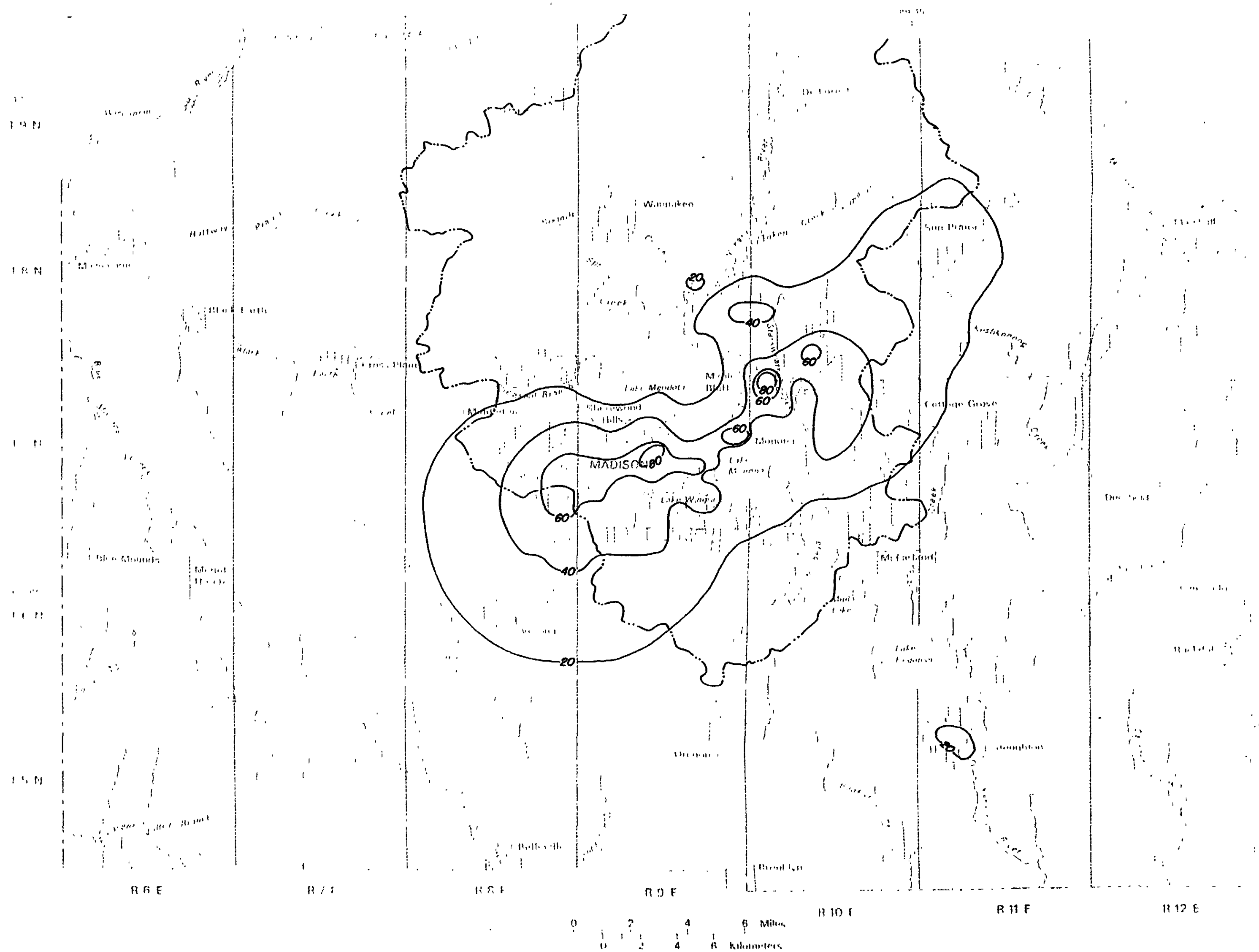
Simulated drawdowns in the sandstone and upper aquifers are shown in figures 8 and 9. The contours of drawdown reflect the same general shape as that constructed for 1975. Maximum declines continue east and south of Lake Mendota and on the southwest side of Madison. The water level in the sandstone aquifer in these areas will probably be 10 to 30 ft lower than that during 1975. The level in the upper aquifer in these areas will probably be 5 to 10 ft lower than that during 1975.

The computed diversion of streamflow past the Yahara River gaging station was 42.7 Mgal/d (table 1). The mean annual flow past the gaging station under natural conditions was estimated to have been 108 Mgal/d, based on streamflow records during 1931-76 adjusted to account for the diverted flow. Using these estimates, by 2000 a reduction in mean flow of 39 percent can be expected at the gage. This compares with an estimated 32 percent flow reduction in 1975.

Ground-water diversion from adjacent basins was computed to be 11.6 Mgal/d by 2000 (table 2). Thus, by the year 2000, 21 percent of the pumped water in the basin could be derived from outside the basin, if pumpage trends follow the estimated plan.

SUMMARY AND CONCLUSIONS

Water-level declines and streamflow changes in the Madison area that have resulted from pumping ground water were estimated with the aid of a digital-computer model. Drawdowns in the sandstone and upper aquifers and



EXPLANATION

Upper Yahara River basin boundary

20 — Line of equal drawdown, approximately located. *Interval 20 feet in sandstone aquifer and 10 feet in upper aquifer*

Figure 8. Predicted drawdown in the sandstone aquifer by 2000.

EXPLANATION

Upper Yahara River basin boundary

—10— Line of equal drawdown, approximately located.
Interval 20 feet in sandstone aquifer and 10 feet in upper aquifer

Figure 9. Predicted drawdown in the upper aquifer by 2000.

flow diversions from the Yahara River by 1950, 1975, and 2000 were computed. The results indicate that the aquifer system can supply the water needs of the area in the future.

There is uncertainty in the predicted drawdowns, largely because of a lack of historic data available for calibrating the model. Drawdown in the sandstone aquifer was estimated from intermittent observations at six to eight locations. Drawdown in the upper aquifer was estimated on the basis of recorded observations at construction sites. The only long-term streamflow data available was at the lower end of the basin, below Lake Waubesa.

A program to monitor long-term ground-water levels, springflow, and streamflow in the upper Yahara River basin would provide better data for model calibration. A reliable model can be used to study alternative plans for continued development of the sandstone aquifer.

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