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A Preliminary 'Least Cost' Study of Future Groundwater Development in Northeastern Illinois

by A. F. MOENCH and A. P. VISOCKY

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A PRELIMINARY 'LEAST COST' STUDY OF FUTURE GROUNDWATER DEVELOPMENT IN NORTHEASTERN ILLINOIS

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SUMMARY

The cost of raw and treated groundwater produced in quantities sufficient, in most cases, to meet the projected demand to 2020 was estimated for each township in the six-county area of northeastern Illinois. Three sources of groundwater were considered: the shallow sand and gravel aquifers, the shallow dolomite aquifers, and the deep sandstone aquifers.

Pumpage from the two shallow aquifers was limited to their known potential yields. The water in the deep sandstone aquifers could be withdrawn at any desired rate, but when the water level declined to the top of the main producing aquifer (Ironton-Galesville Formation) pumpage had to be reduced to the amount necessary to maintain a constant water level. The behavior of the water levels in this aquifer was determined with the help of a digital simulation model.

Unit costs of wells, pumps, power, and rehabilitation were obtained for each aquifer in each township. These included both amortized capital costs and operation-maintenance-repair costs (in 1970 dollars). The costs of storage and distribution to consumers were not considered. The demand for each 10-year period from 1980 to 2020 was satisfied, where the supply was sufficient, in such a way as to minimize the cost subject to the constraints on supply.

The cost of treating the raw water in order to raise the quality to a level comparable to treated Lake Michigan water was estimated. It was assumed that all groundwater would be treated in like manner.

Results showed that raw water varied in cost from as little as 2 cents per 1000 gallons to as much as 14 cents per 1000 gallons depending upon the depth to the deep sandstone water. The unit cost of treated water varied from 22 to 53 cents per 1000 gallons, the lower costs applying to the largest users because of the economy of scale in treatment. Also because of this economy of scale, the cost of treated water tended to decrease with time; the cost of raw water increased with time. Fourteen townships were found to be deficient in groundwater in 2020, by a total of 147 million gallons per day, and will have to find alternative sources.

INTRODUCTION

Initial analysis of the water resources in northeastern Illinois (Lake, McHenry, Kane, Du Page, Cook, and Will Counties) yielded figures on groundwater supply and water demand by township at 10-year intervals from 1980-2020. The groundwater studies encompass all of the six counties except those portions supplied by Lake Michigan water. Results showing projected groundwater deficiencies were summarized by Schicht and Moench (1971). Their study set the stage for a more detailed analysis which takes into consideration economic aspects of groundwater development in the area.

The purpose of this report was to estimate the average cost of producing groundwater and treating it to make it comparable in quality with treated Lake Michigan water. The groundwater resource was divided into three sources: 1) sands and gravels of the glacial till, 2) Silurian dolomite, and 3) deep sandstone Cambrian-Ordovician aquifers. Sources 1 and 2 are referred to in this report as the shallow aquifers and source 3 as the deep sandstone aquifers. The underlying Mt. Simon aquifer was not considered as a source in this study.

The study was conducted under the following general assumptions. The demand was to be satisfied by using the cheapest available groundwater within a township. Pumpage from the shallow aquifers was to be limited to their potential yield. Water could be continuously withdrawn (mined) from the deep sandstone aquifers until the pumping water level reached the top of the Ironton-Galesville Formation, the most productive portion of the deep sandstone aquifers. When this occurred the pumpage from the deep sandstone was reduced so the pumping water level remained at the top of the Ironton-Galesville Formation which lies at depths of 900 to 1300 feet below land surface. As pumpage is reduced any deficiency in meeting the demand must be satisfied by importation of water from Lake Michigan or by some other alternative source.

In this report, the northeastern Illinois area was analyzed by townships *(see figure* 4) and 10-year time increments as used in the earlier report by Schicht and Moench (1971). For ease in computation, the potential yields of aquifers and the groundwater demands obtained for the earlier study were rounded to the nearest million gallons per day (mgd) for each township. Also to facilitate computation each township was considered to be independent of the others. The possibility of overland transport from nearby townships was therefore not considered.

In this study, the costs (adjusted to 1970 dollars) per million gallons per day of raw water produced were obtained on an annual basis for each source. The costs included the necessary operation, maintenance, and repair (OM&R) expenditures and capital expenditures (amortized over the expected life of the particular component at an interest rate of 6 percent). Since future studies will compare costs of alternative sources, costs which are common to all sources such as storage and distribution facilities were omitted from this analysis. In addition, costs of land acquisition, consultants' fees, taxes, and insurance were omitted because similar expenses might be expected for delivery of surface water.

The model was so designed that the unit cost of raw water produced from the shallow aquifers remains constant with time; however, the unit cost of water produced from the deep sandstone aquifers increases with each time increment as the water levels decline. The amount by which the water must be raised was obtained for the center of each township with the aid of a digital simulation model (Prickett, 1969). This is the hydraulic lift which was used to calculate the cost coefficients for the deep sandstone aquifers. The water-level decline based on the digital simulation model was discretized in a step-wise fashion so that the water levels in any 10-year period were constant. This simplified the analysis in that the costs which are dependent upon lift are linearly related to demand for each 10-year period of interest.

The cost of treatment was considered separately from the other cost components since waters from all groundwater sources are treated together as one source. It was recognized that there are differences in the quality of water depending upon location. However, for the purposes of this study, it was assumed that the cost of treatment is the same everywhere. Treatment costs for each year of interest included operation, maintenance, and repair expenditures which are based upon the demand at the time increment of interest and capital expenditures which are based on the future demand of 20 years hence. The purpose of using the future demand was to account for capacity expansion. For demands rounded to 1 mgd the township was assumed to have a single treatment plant. For demands greater than 1 mgd it was assumed there will be two treatment plants.

This study was conducted under the general direction of Dr. William C. Ackermann, Chief of the Illinois State Water Survey, and H. F. Smith, Head of the Hydrology Section. Water Survey personnel assisted in the project in several ways: R. J. Schicht provided valuable guidance throughout the study; R. A. Sinclair wrote the main computer program; T. A. Prickett and C. G. Lonnquist designed the basic digital simulation program for the deep sandstone aquifers; and R. T. Sasman provided useful pumpage and cost data. The authors are appreciative of the helpful discussions with many Survey personnel, in particular J. P. Gibb and K. P. Singh.

UNIT COSTS

The average annual cost of obtaining a million gallons per day of raw water from each of the three groundwater sources was obtained by summing the unit costs of wells, pumps, power, and rehabilitation. These vary from township to township over the six-county area as well yield, well depth, and dynamic lift vary. Cost figures were adjusted to 1970 dollars through the use of Engineering News-Record construction cost indices. Treatment costs take into consideration the economy of scale and hence are the only unit costs which vary with quantity.

Component Unit Costs

Wells. The average capital costs of wells in the three aquifers were determined from graphs published by Gibb and Sanderson (1969) where the average depth of the wells and required well diameters based on expected well yields are known. It has been assumed that all wells would be drilled to the bottom of the aquifer to be developed.

Average well depth required for each aquifer in each township was determined from data available in the files and reports of the Illinois State Water Survey. (In certain townships the average thickness of the Silurian dolomite was less than 25 feet in which case the aquifer was omitted from the study.) Average well yields were obtained from results of earlier studies by the State Water Survey published in *Water for Illinois, a Plan for Action* (1967). In addition, average well yields were used to estimate the number of wells in the shallow aquifers needed to produce 1 mgd. The deep sandstone aquifer was assumed capable of yielding 1 mgd to each well in the six-county area. To allow for peaking supply the number of wells per million gallons per day was increased by 50 percent, and to include standby wells the number of wells was increased by an additional 20 percent.

Annual costs of wells were obtained by amortizing the capital costs at a 6 percent interest rate over their expected life. Life expectancy was established as 25 years for a sand and gravel well and 50 years for a Silurian dolomite or deep sandstone well. Derived expressions used to calculate the annual well costs in dollars per million gallons per day from each source are:

sand and gravel $$C_{W1} = 117\ WC_1/WY_1 \qquad (1)$$

Silurian dolomite $$C_{W2} = 95\ WC_2/WY_2 \qquad (2)$$

deep sandstone $$C_{W3} = 3.97\times10^{-3}\ d^{1.87} \qquad (3)$$

where WC_1 and WC_2 are the well costs in dollars (Gibb and Sanderson, 1969), WY_1 and WY_2 are well yields in gallons per minute (gpm), and d is the depth to the bottom of the deep sandstone aquifer in feet.

Pumps. The cost of pumps was also obtained from Gibb and Sanderson (1969) whose formula requires knowing well yield and lift. It was assumed that only submersible pumps would be used. (Gibb and Sanderson's graph was modified upward for pumps requiring lifts of over 800 feet since more data became available for high lifts.) Lift was estimated for the shallow aquifers by adding to the depth to static water level the drawdown plus 100 feet (to raise the water to storage tanks). The drawdown was calculated from average well yields and specific capacities. In certain instances the computed drawdown exceeded the available drawdown and it was then necessary to reduce the well yield. For the deep sandstone aquifer, the lift was computed with the aid of the digital simulation model described by Prickett (1969).

The cost of switches, wiring, and miscellaneous appurtenances was estimated to be about 50 percent of the cost of the pumps. The cost of pumps was therefore increased by a factor of 1.5. The capital cost of pumps was amortized over a 10-year life at 6 percent interest. Derived expressions used to calculate the annual pump costs in dollars per million gallons per day in each source are:

sand and gravel	$C_{P1} = 1715\ L_1^{0.658}/WY_1^{0.459}$		(4)
Silurian dolomite	$C_{P2} = 1715\ L_2^{0.658}/WY_2^{0.459}$		(5)
deep sandstone	$C_{P3} = 75\ H^{0.721}$	when $H > 800'$	(6)
	$= 83\ H^{0.658}$	when $H < 800'$	

where L_1, L_2, and H are the lifts in each aquifer in feet and WY_1 and WY_2 are the well yields in gallons per minute in the sand and gravel and Silurian dolomite aquifers, respectively.

Power. Water is pumped from the dynamic water level in the ground to an elevation of 100 feet above land surface to provide a distribution pressure of about 43 pounds per square inch (psi). The cost of power for pumpage was taken at a flat rate of 8 mills per kilowatt-hour (kwh). This rate was obtained from a schedule provided by Commonwealth Edison wherein it was estimated that at least 100,000 kwh/month would be consumed by water utility companies in each township. This included power consumption by treatment plants.

Annual electric power costs can be closely approximated by the straight line relation shown in figure 1. This was derived with the aid of State Water Survey Technical Letter 9 (1968) with the assumptions of 50 percent wire-to-water efficiency and a pumping rate of 1 mgd. Electric power costs are related to lift as fo11ows:

$$C_E = 18.3\ H \qquad (7)$$

where C_E is the annual cost in dollars and H is the lift in feet.

Rehabilitation. It was assumed that Silurian dolomite wells would require rehabilitation (acidizing) on the average of once every 25 years. Rehabilitation of wells with yields of 100, 200, 300, 400, and 500 gpm were estimated to cost $500, $1000, $1500, $2000, and $2500, respectively. This resulted in a small additional annual cost per million gallons per day, C_R, of some $250 for most townships.

Total Unit Cost of Raw Water

The unit cost of untreated water from a given source was obtained by summing the unit costs of the separate components as follows:

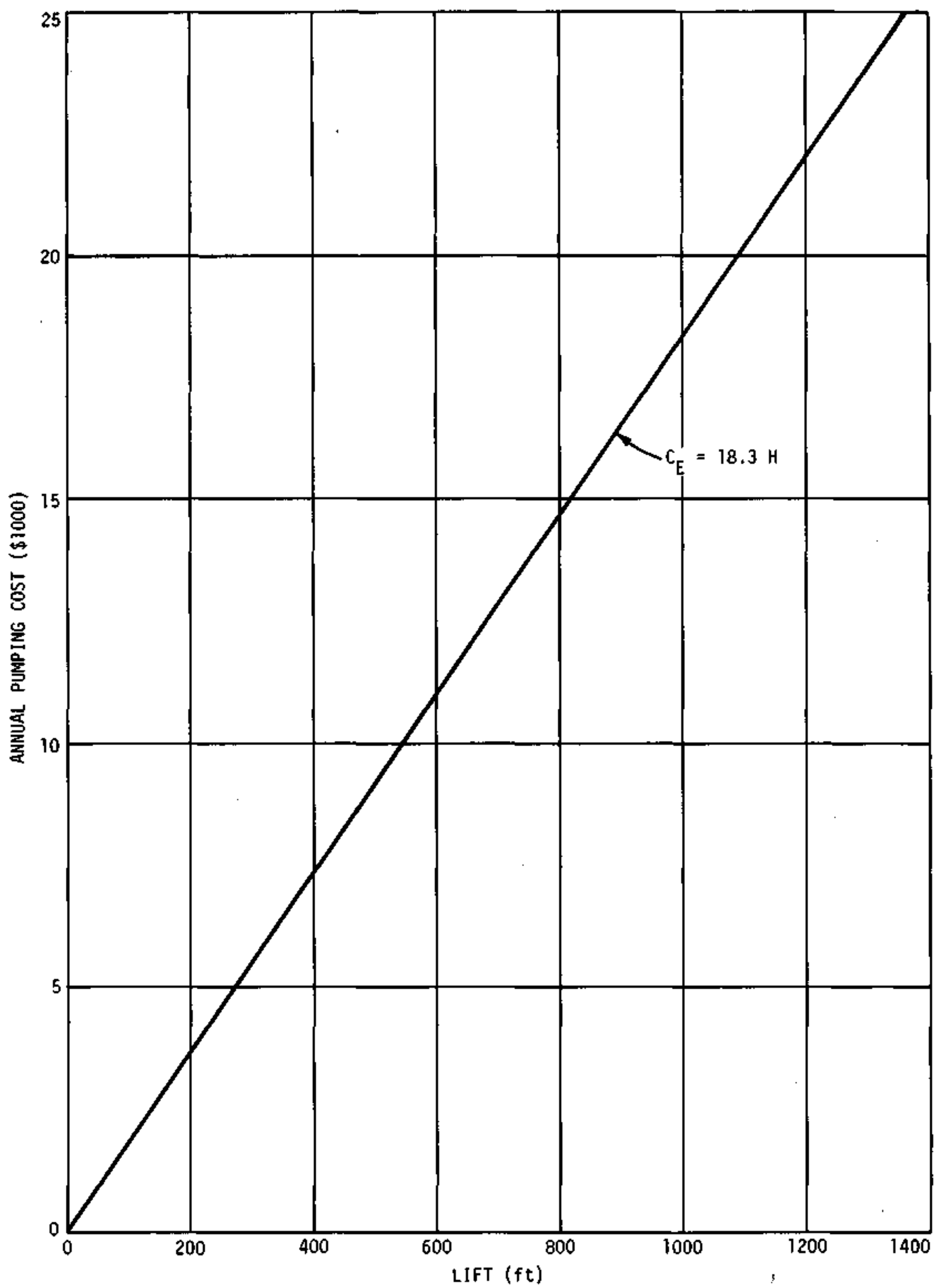

Figure 1. Annual pumping cost per mgd versus lift

$$C_1 = C_{W1} + C_{P1} + C_E \quad (8)$$

$$C_2 = C_{W2} + C_{P2} + C_E + C_R \quad (9)$$

$$C_3 = C_{W3} + C_{P3} + C_E \quad (10)$$

where C_1, C_2, and C_3, are the total annual unit costs in dollars per million gallons per day of raw water produced from sand and gravel, Silurian dolomite, and deep sandstone aquifers, respectively.

Treatment Cost

The cost of treatment to remove undesirable constituents was estimated with the aid of several reports and was adjusted to 1970 dollars. Figure 2 shows the capital cost of treatment plants determined on an annual basis by amortization over an expected 25-year plant life at 6 percent interest. Cost data given by Langdon (1966), Howson (1962), and annual reports for Beardstown and Joliet were used in making the cost estimates. Langdon (1966) presents several case histories which give first costs for plants of differing types of treatment and differing capacities. Howson (1962) shows investment costs versus capacity in which he used data for some 15 softening plants. The estimated investment costs of groundwater treatment plants were greater than but parallel to those indicated in State Water Survey Technical Letter 11 (1968).

Annual operation, maintenance, and repair costs estimated for treatment plants were also greater than but parallel to those given in Technical Letter 11. The reports of Langdon (1966) and Howson (1962), and data for Hinsdale, Elgin, and Champaign were used to construct the curve shown in figure 3. Apparently, figures 2 and 3 differ from Technical Letter 11 because the latter included treatment plants that do not improve the quality of water to the extent required in this report.

The expression used to calculate treatment cost when demand in the year of interest is greater than 1 mgd is:

$$C_T = 2\ [28.2\ (\frac{FD}{2})^{0.625} + 91.3\ (\frac{D}{2})^{0.666}] \quad (11)$$

where C_T is the annual treatment cost in \$1000 for demands *D* and future demands (20 years hence) *FD*. It can be seen from equation 11 that the unit cost of

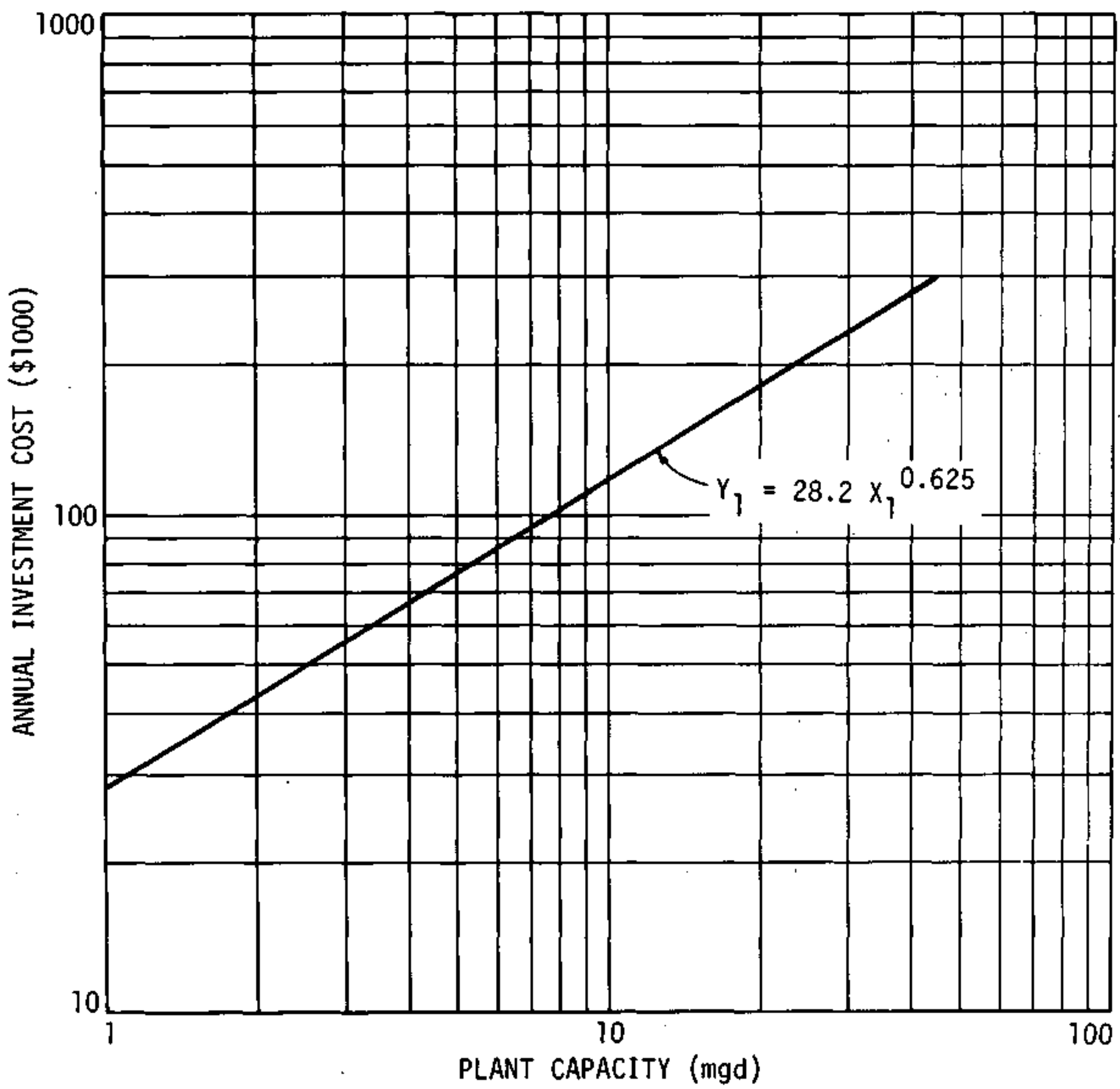

Figure 2. Annual investment costs of treatment plants versus plant capacity

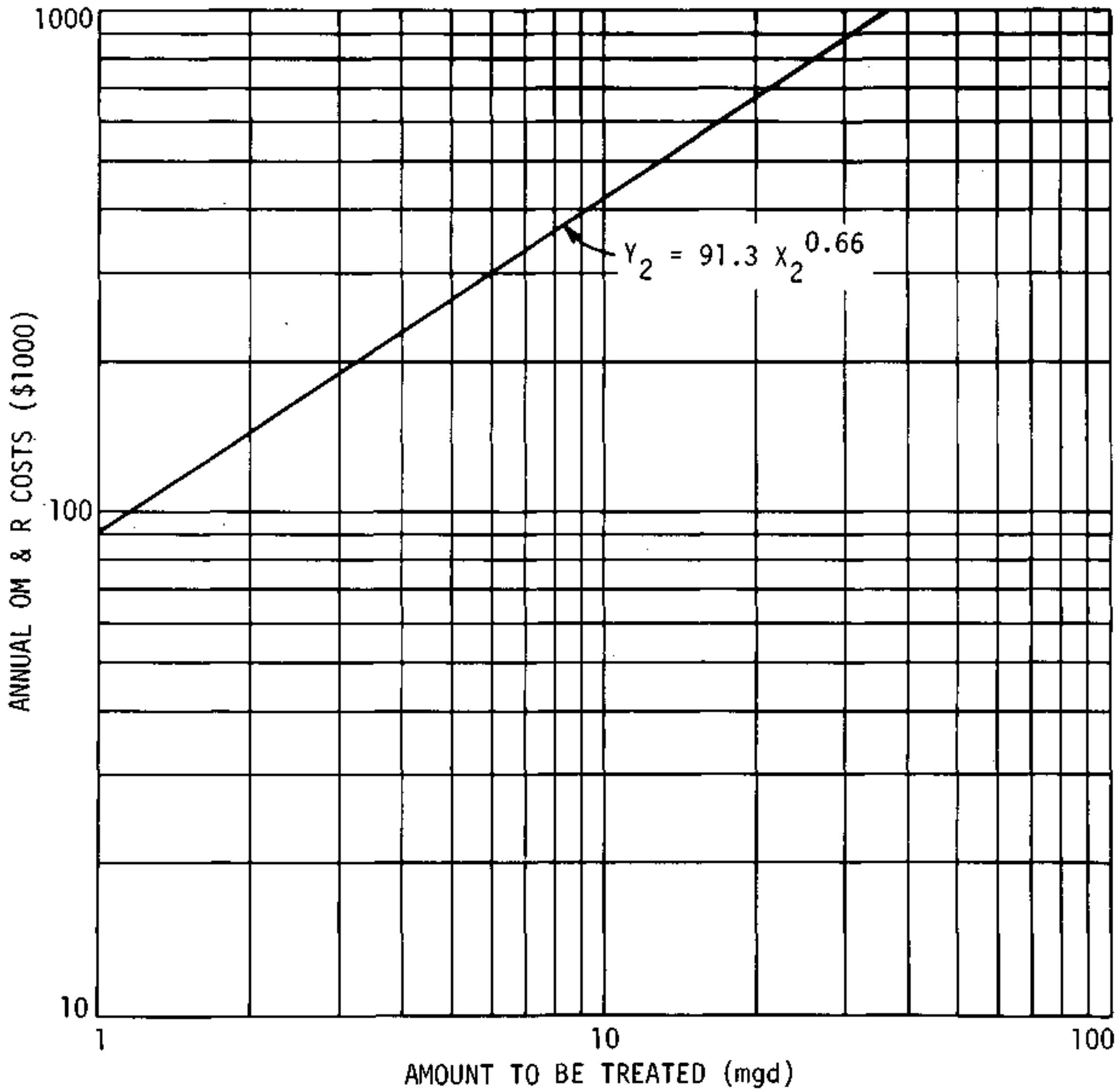

Figure 3. Annual operation, maintenance, and repair costs of treatment plants versus amount treated

treatment decreases as demand increases. The 2020 groundwater demand was used as the future demand for the years 2010 and 2020.

The annual treatment cost C_T can be converted to the unit cost of dollars per million gallons per day by dividing by *D.*

LEAST COST COMPUTATIONAL PROCEDURE

The procedure for obtaining the total cost of producing groundwater and delivering the treated water to storage tanks above land surface is outlined briefly in the introduction. Appropriate data for each township including potential yields, demands, and the necessary information for computing unit costs for each of the three groundwater sources were punched on IBM cards. The formulas derived for computing annual costs of wells, pumps, power, rehabilitation, and treatment were included in the main computer program. Data for depth to water in the deep sandstone were obtained from the aquifer simulation model.

Since all the unit costs were constant for any 10-year period, it was a simple matter to determine the cheapest source. The demand was satisfied by using the least expensive source first to its full potential before going on to the next cheaper source. Invariably the shallow aquifers were developed before using the more expensive deep sandstone water. Only the cost of untreated water was considered in this step since the unit cost of treatment is the same for all sources. This procedure was carried out for each township for each 10-year interval from 1980 to 2020.

Computations pertaining to water levels in the deep sandstone were carried out with the aquifer simulation model. Needed pumpage from the deep sandstone aquifers was determined as outlined above to satisfy demand in each township and inserted into the aquifer simulation model. When pumping water levels declined to the top of the Ironton-Galesville Formation, pumpage was reduced automatically. The magnitude of the deficit was determined by comparing total groundwater pumpage and total demand.

The 'least cost' solution to satisfying the demand in any period of interest and in any particular township was obtained by minimizing the untreated water cost, *CMIN*, which is expressed as follows:

$$CMIN = C_1Q_1 + C_2Q_2 + C_3Q_3 \quad (12)$$

C_1, C_2, and C_3 are the unit costs defined by equations 8-10 and Q_1, Q_2, and Q_3 are the amounts of water in million gallons per day to be withdrawn from sand and gravel, Silurian dolomite, and deep sandstone aquifers, respectively. Equation 12 is subject to the requirements that the demands D be satisfied and that the potential yields B_1 and B_2 of the sand and gravel and Silurian dolomite aquifers, respectively, not be exceeded. These requirements expressed mathematically are:

$$Q_1 + Q_2 + Q_3 = D \quad (13)$$

$$Q_1 \leq B_1 \quad (14)$$

$$Q_2 \leq B_2 \quad (15)$$

After finding $CMIN$, Q_3 is the quantity which is used in the digital simulation model of the deep sandstone aquifers to simulate pumpage for the next 10-year period. In instances where the water level has declined to the top of the Ironton-Galesville Formation, Q_3 is automatically reduced and equation 13 cannot be satisfied. An additional quantity (the deficit) is then necessary to satisfy the demand.

RESULTS AND DISCUSSION

Figure 4 shows the study area divided into townships numbered 1 – 104. Also shown are the boundaries of the Metropolitan Sanitary District and the area presently being supplied by Lake Michigan water.

The unit costs of raw and treated groundwater are shown for each township for each year of interest in table 1. Also shown are the groundwater demands so that a direct comparison of demand and cost can be made for each township. Zero demand is indicated wherever the entire township is assumed to be supplied by lake water or wherever rounding to the nearest million gallons per day results in the elimination of demands of less than 0.5 mgd. Table 1 also gives the potential yields, rounded to the nearest million gallons per day, for the two shallow aquifers.

It can be seen from table 1 that raw water unit costs either remain constant or increase with time as, water levels decline in the deep sandstone aquifers. The unit costs of treated groundwater, however, tend to decrease with increasing demand

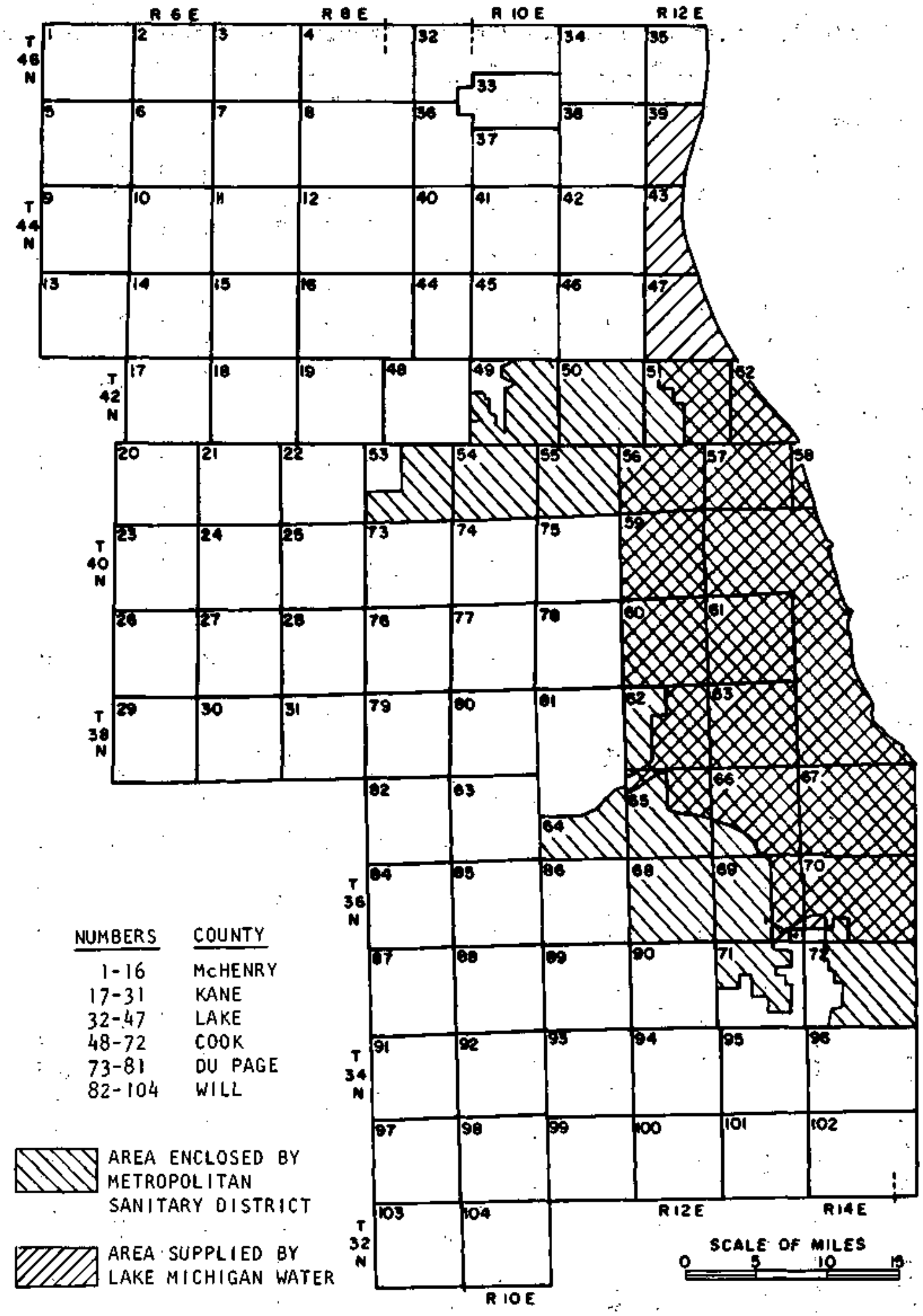

Figure 4. Map of study area showing numbered townships, the Metropolitan Sanitary District and the area supplied by Lake Michigan water

Table 1. 'Least Costs' of Raw and Treated Groundwater, 1980-2020*

Township	B_1 (mgd)	B_2 (mgd)	1980 D (mgd)	1980 Costs Raw	1980 Costs Treated	1990 D (mgd)	1990 Costs Raw	1990 Costs Treated	2000 D (mgd)	2000 Costs Raw	2000 Costs Treated	2010 D (mgd)	2010 Costs Raw	2010 Costs Treated	2020 D (mgd)	2020 Costs Raw	2020 Costs Treated
McHenry County																	
1	2	4	1	3	40	1	3	44	2	3	38	3	3	32	3	3	32
2	0	6	0			0			0			1	3	36	1	3	36
3	1	6	0			0			0			1	3	40	2	3	36
4	2	7	0			1	2	43	2	2	39	3	3	32	4	3	29
5	3	0	0			1	3	40	1	4	44	2	4	39	3	4	32
6	0	0	0			0			1	5	45	2	5	40	3	6	34
7	1	6	1	3	35	1	3	40	1	3	43	2	3	38	3	3	32
8	2	8	1	2	35	1	2	35	1	2	39	1	2	39	2	2	35
9	4	0	2	2	39	3	2	33	4	2	30	5	3	27	6	3	25
10	2	3	0			0			1	2	39	1	2	39	2	2	35
11	1	5	3	3	35	4	3	33	6	3	29	9	4	24	12	5	23
12	2	8	2	2	39	3	3	35	4	3	30	5	3	27	6	3	25
13	2	0	0			0			0			0			0		
14	1	5	0			0			0			1	3	36	1	3	36
15	1	6	1	2	39	1	3	39	2	2	37	2	2	37	3	3	31
16	2	6	5	2	29	7	3	26	9	3	24	12	4	23	15	5	22
Kane County																	
17	1	0	1	4	37	1	4	37	1	4	41	1	4	41	2	5	38
18	1	0	0			1	4	45	1	4	53	3	6	38	6	7	30
19	2	0	6	4	29	8	5	27	10	7	27	12	8	26	15	9	25
20	1	0	0			0			0			0			1	4	37
21	1	0	0			0			1	4	47	2	5	42	4	7	33
22	2	0	10	6	26	13	7	25	15	9	25	18	10	24	23	9	26
23	2	0	0			0			0			1	4	37	1	4	37
24	1	0	0			0			1	4	47	2	5	42	4	7	32
25	2	2	4	3	31	5	4	29	6	5	29	7	5	27	9	6	26
26	2	0	0			0			0			1	4	37	1	4	37
27	1	0	0			1	4	44	2	5	43	3	5	36	5	6	30
28	1	5	5	3	29	7	3	26	9	4	25	10	5	25	14	6	23
29	2	0	0			0			0			1	4	37	1	4	37
30	1	0	1	4	44	1	4	47	3	6	37	4	5	33	6	6	28
31	0	4	15	5	23	18	7	23	22	8	22	26	9	24	29	9	25
Lake County																	
32	0	6	0			1	2	35	1	2	35	1	2	35	1	2	35
33	0	3	1	3	35	1	3	39	1	2	43	2	2	37	3	2	31
34	0	4	0			1	2	39	1	2	43	2	2	37	3	2	31
35	1	1	5	3	29	6	4	28	8	5	27	10	6	26	13	7	25
36	1	3	2	3	38	2	3	38	3	3	32	3	3	32	4	3	29
37	0	3	4	3	30	4	3	31	6	4	28	7	5	27	9	6	26
38	0	4	2	2	39	3	2	33	4	2	30	5	3	28	6	4	27
39	0	0	0			0			0			0			0		
40	0	4	1	2	35	1	2	35	1	2	35	1	2	35	1	2	35
41	0	5	2	3	40	3	3	34	4	3	31	5	3	28	7	4	25
42	1	4	6	3	38	8	3	27	13	5	25	20	7	23	31	9	22
43	0	0	0			0			0			0			0		
44	0	3	1	3	43	2	3	40	3	3	36	4	4	32	7	6	27
45	0	4	2	3	40	3	3	35	4	3	32	6	5	29	9	6	26
46	0	4	2	2	41	3	2	36	5	3	32	8	5	28	15	7	24
47	0	0	0			0			0			0			0		
Cook County																	
48	1	3	2	4	39	2	4	41	3	4	35	4	4	31	5	5	29
49	0	5	8	5	28	13	7	25	17	8	24	21	9	24	26	8	25
50	1	4	14	5	22	16	7	24	17	8	24	18	9	24	19	8	25
51	0	2	0			0			0			0			0		
52	0	0	0			0			0			0			0		
53	2	1	4	4	35	7	6	30	10	8	27	14	9	25	19	10	27
54	0	3	6	5	30	8	7	29	11	8	26	14	9	25	18	9	27
55	0	4	13	5	23	15	8	24	17	9	24	18	8	25	21	8	26
56	1	4	0			0			0			0			0		
57	0	3	2	3	36	2	3	36	2	3	36	2	3	36	2	3	36
58	0	1	0			0			0			0			0		
59	1	4	0			0			0			0			0		
60	0	5	0			0			0			0			0		
61	0	5	0			0			0			0			0		
62	0	7	7	3	24	7	3	25	8	3	24	9	4	24	9	4	24
63	0	5	3	3	31	3	3	31	3	3	31	3	3	31	3	3	31
64	0	4	2	3	42	4	3	31	5	4	31	7	6	28	10	7	26
65	0	5	1	3	40	2	3	38	2	3	40	3	3	32	4	3	28
66	0	5	3	2	32	4	2	29	4	2	30	5	2	26	6	3	26
67	0	1	1	4	36	1	4	36	1	3	36	1	4	36	1	3	36
68	0	0	4	6	38	8	9	32	12	11	30	16	12	29	22	14	28
69	0	5	5	2	30	8	4	26	10	6	26	13	7	25	16	8	24
70	0	4	1	3	35	1	3	35	1	3	35	1	3	35	1	3	35
71	0	5	7	3	27	11	5	26	15	8	26	21	10	25	29	12	25
72	0	7	17	5	21	21	7	22	25	9	23	29	11	23	35	11	24

Table 1 ***(Concluded)***

Township	B_1 (mgd)	B_2 (mgd)	1980 D (mgd)	1980 Costs Raw	1980 Costs Treated	1990 D (mgd)	1990 Costs Raw	1990 Costs Treated	2000 D (mgd)	2000 Costs Raw	2000 Costs Treated	2010 D (mgd)	2010 Costs Raw	2010 Costs Treated	2020 D (mgd)	2020 Costs Raw	2020 Costs Treated
Du Page County																	
73	2	2	1	2	48	3	2	35	5	3	30	7	5	28	10	7	26
74	1	3	5	3	31	9	6	28	13	7	24	18	9	24	24	8	25
75	0	4	15	5	22	20	9	23	24	9	24	26	8	25	29	8	25
76	0	3	4	3	32	6	4	29	8	6	28	11	7	26	14	9	25
77	0	5	11	4	25	17	7	23	24	9	22	30	9	24	38	8	25
78	0	5	20	7	21	23	9	23	24	9	24	25	9	24	25	8	24
79	0	5	3	2	36	6	3	28	8	4	27	12	6	24	15	7	24
80	0	5	6	3	29	10	5	26	15	7	24	20	8	23	26	9	24
81	0	7	14	4	21	16	6	22	16	7	23	17	7	23	18	8	23
Will County																	
82	0	5	1	5	36	1	4	41	1	4	41	2	4	37	2	5	37
83	0	6	2	3	40	3	3	34	4	3	31	5	3	28	7	4	25
84	0	6	2	3	39	3	3	36	4	3	34	7	3	26	11	4	22
85	0	5	5	3	29	6	3	28	9	4	26	12	6	24	15	7	24
86	0	5	1	2	51	3	2	40	6	3	33	12	7	26	24	9	23
87	0	8	1	5	45	2	5	44	3	6	41	5	6	32	9	6	26
88	0	7	17	5	21	19	6	22	23	8	22	27	9	22	32	9	23
89	0	5	1	2	46	3	2	35	4	2	33	7	4	27	11	6	25
90	0	5	2	2	41	3	2	37	5	2	32	9	6	27	16	8	24
91	0	7	7	5	27	7	6	28	8	6	27	9	8	27	10	8	27
92	0	6	0			1	3	43	2	3	41	3	3	34	5	3	27
93	0	5	0			0			1	2	39	1	2	39	2	2	35
94	0	5	0			0			1	2	43	1	2	43	3	2	31
95	0	5	2	2	43	3	2	40	6	3	32	12	7	26	22	9	24
96	0	6	2	2	37	2	2	39	3	2	33	4	2	29	5	2	26
97	4	1	1	5	37	1	5	38	1	5	38	1	6	38	1	6	38
98	1	3	0			0			0			1	4	36	1	4	36
99	0	5	0			0			0			1	2	35	1	2	35
100	0	5	0			0			1	2	42	2	2	37	3	2	31
101	0	5	0			0			1	2	42	1	2	42	3	2	31
102	0	6	0			0			0			1	2	35	1	2	35
103	4	2	0			0			0			0			0		
104	1	6	0			0			0			1	5	38	1	6	39

**Costs are in cents per 1000 gallons; township numbers are those shown in figure 4;*
B_1 = potential yield of sand and gravel aquifers; B_2 = potential yield of Silurian dolomite; D = demand

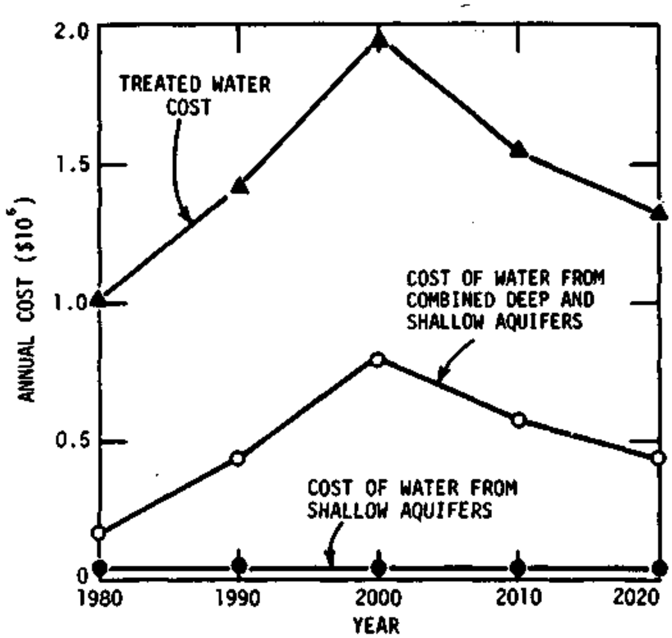

Figure 5. *Annual groundwater coat for township 77 in Du Page County* because the cost of treatment which is sensitive to the economy of scale is by far the most significant cost component. In townships where deficiencies occur *(shown in table 3)* the unit costs usually increase again as groundwater pumpage declines.

It should be emphasized that costs shown here are for the purpose of comparison only. Conclusions should not be drawn as to the cost a municipality, for example, would have to pay. It is probable, however, that under most circumstances the cost of treated groundwater will be less expensive than available Lake Michigan water. The Chicago Water Department at the time of this writing charges 27.5¢/1000 gallons (at the limits of the city of Chicago) for water purchased by municipalities within the boundaries of the Metropolitan Sanitary District. Incorporated areas or municipalities not within the Sanitary District might be permitted to purchase water from the city of Chicago but at rates that would have to be negotiated (J. W. Jardine, personal communication, 1971).

A plot of total annual groundwater cost versus time for a township (number 77 on figure 4) in the center of Du Page County is given in figure 5 as an example of how costs from the different sources might vary.

In this example, the annual cost of shallow aquifer water (1imited in this case to Silurian dolomite water) is obtained by multiplying the constant annual unit cost of $7150/mgd by a potential yield of 5: mgd. The demand in 1980 is 11 mgd, hence only 6 mgd of deep sandstone water is needed. The annual unit cost of deep sandstone water in this year is $23,000/mgd. This is multiplied by 6 mgd and added to the cost of shallow aquifer water to obtain the 1980 value of the cost of raw water from combined sources. In the year 2000 the annual unit cost of deep sandstone water has increased to a maximum of $45,100/mgd and the demand has increased to 24 mgd (or 19 mgd of deep sandstone water). By 2020 the demand is 38 mgd but the pumpage from the deep sandstone has to be cut' back to 10 mgd; this results in the deficiency shown in table 3. This deficiency must, of course, be satisfied by obtaining water from another source at an added cost.

Annual treatment costs are obtained through the use of equation 11 and added to the cost of raw water to obtain the treated water costs shown in figure 5. The total annual cost of producing untreated groundwater in township 77 varies from 17 percent of the treated water cost in 1980 to 41 percent of the treated cost in 2000, and back to 35 percent of the treated cost in 2020. On the average in the entire six-county area the cost of untreated water varies from 10 to 20 percent of the cost of treated water.

The average annual cost in the six-county area exclusive of treatment is $12,000/mgd for the sand and gravel aquifer and $10,000/mgd for the Silurian dolomite aquifer. For the deep sandstone aquifer the average annual cost ranges from $18,700/mgd in 1980 to $31,700/mgd in 2020.

The percent of the total cost that can be attributed to the various components associated with each source is shown in table 2. It is apparent from table 2 that the cost of power is the most important component of the deep sandstone aquifers. The cost of pumps is an important component of all three sources. The cost of wells is of lesser importance except when considering the sand and gravel aquifer where well construction is relatively expensive.

Table 2. Average Percentage of Raw Water Cost Associated with Each Component for Each Source

Component	Sand and gravel	Silurian dolomite	Deep sandstone 1980	Deep sandstone 2000	Deep sandstone 2020
Wells	36	10	17	12	10
Pumps	39	49	28	31	32
Power	25	38	55	57	58
Rehabilitation	0	3	0	0	0

Table 3 shows the magnitude of the groundwater deficiencies from 2000-2020. The sum total of these deficiencies is approximately half the sum total of the deficiencies shown for the same years in the report by Schicht and Moench (1971). This is because the greater distribution of deep sandstone pumping centers that was used in this study provides more efficient use of the aquifer. Instead of the 21 pumping centers used in the earlier report, there is now one for each of the townships where there is a necessity to pump deep sandstone water. Although the township deficiencies for 2020 total 147 mgd, it should still be possible to meet the entire 2020 demand with importation of groundwater from other townships. In 2020 there will remain at least 140 mgd of shallow aquifer. water within the six-county area, and deep sandstone water will still be available in many townships.

Table 3. Magnitude of the Groundwater Deficiencies from 2000-2020

Township number	Deficiencies (*mgd*) 2000	2010	2020
22			10
31		6	11
49		5	12
50		4	4
53			6
54			8
55			9
72			9
74			12
75	8	12	17
77		13	23
78	4	8	9
80			8
88			9
Total deficit	12	48	147

CONCLUSIONS

The model described in this report is based on gross average figures for each township in the study area and cannot be applied to specific schemes of development. However, it is felt that the study has resulted in valid comparisons of costs of raw and treated groundwater over space and time. The cost of raw water increases from 1980 to 2020 as water levels decline. For 2020 raw water averages about 6¢/1000 gallons, ranging from 2-14¢/1000 gallons throughout the six-county area. The cost of treated water in most cases decreases with time because of the economy of scale in treatment. For 2020 treated water averages about 29¢/1000 gallons, ranging from 22-39¢/1000 gallons (a maximum of 53¢/1000 gallons occurs in 2000). The cost of treatment, which is unfortunately the least well known component of cost, has the greatest effect upon the cost of the final product. Variations or errors in the cost of raw water are unlikely to influence significantly the cost of treated water. When large quantities are used, treated groundwater will probably be cheaper for most townships than the most readily available source of surface water.

The total groundwater deficit in 2020 amounts to 147 mgd, but this depends upon the condition that water levels not decline below the top of the Ironton-

Galesville Formation. A higher limit to the pumping level would, of course, result in greater computed deficits. The 14 townships which become deficient in groundwater in 2020 will have to pay more for water in order to meet the demand. Besides the use of Lake Michigan water, other alternatives exist such as importing groundwater from nearby townships, recycling treated effluent, and possibly utilizing treated water from the deep Mt. Simon aquifer. These alternatives will be explored in subsequent reports.

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