Report

Future Water Supply

Prepared for

Waukesha Water Utility

March 2002

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Executive Summary

Purpose

This study was conducted to evaluate water supply alternatives for consideration by the Waukesha Water Utility to continue providing reliable, high quality, affordable drinking water to its customers.

Waukesha Water System

Waukesha obtains its drinking water from a sandstone aquifer (Cambrian-Ordovician) with ten active wells, each about 2,000 feet deep. The wells have a combined capacity of about 15 million gallons per day (mgd). The water system is shown in Figure E-1 (see following page).

During 2001, average day demand was about 8 mgd, and maximum day demand about 13 mgd. Anticipated increases in water demand have created the need to provide additional water supply capacity. The maximum day water demand could increase from 13 mgd to 22 mgd (or more) over the next 50 years.

The sandstone groundwater level near Waukesha is declining 5 to 10 feet per year. Groundwater level is currently about 500 feet below the ground surface, and still declining (Figure E-2). This decline increases pumping, operation, and maintenance costs.

FIGURE E-2
Water Level Decline in Sandstone Aquifer (Source: USGS)

Water produced by Waukesha's sandstone wells has high levels of hardness and low levels of iron and manganese. With the exception of radium and gross alpha, the water meets all primary drinking water standards. In recent years, radionuclides (gross alpha) and total dissolved solids levels are increasing in certain wells (Figures E-3 and E-4).

Declining water levels and water quality (radionuclides, total dissolved solids), coupled with increasing water demand, have created the need to investigate alternative water sources. The current water supply situation is not critical. However, now is a prudent time to take proactive action and plan for the future.

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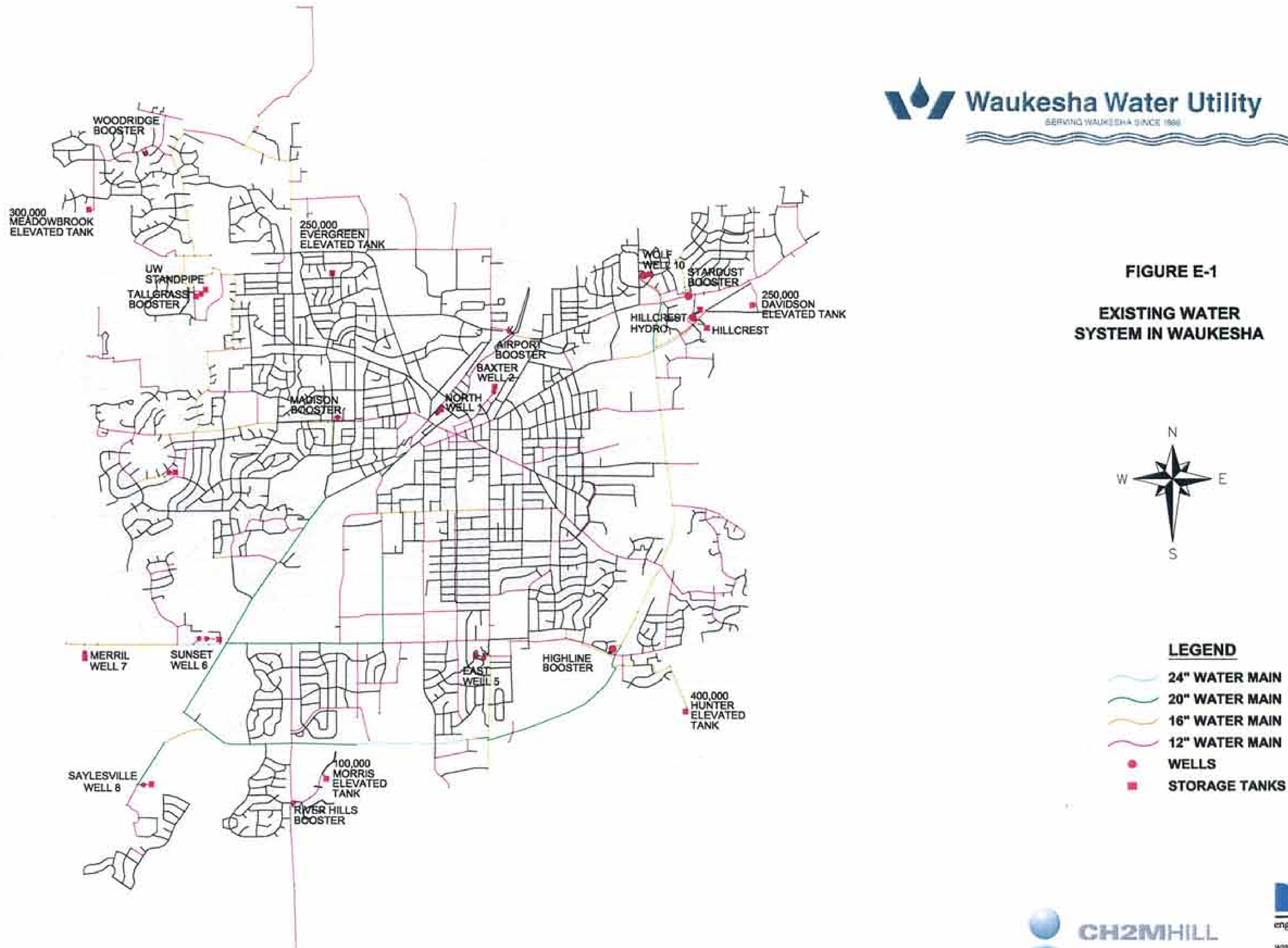

FIGURE E-1

EXISTING WATER SYSTEM IN WAUKESHA

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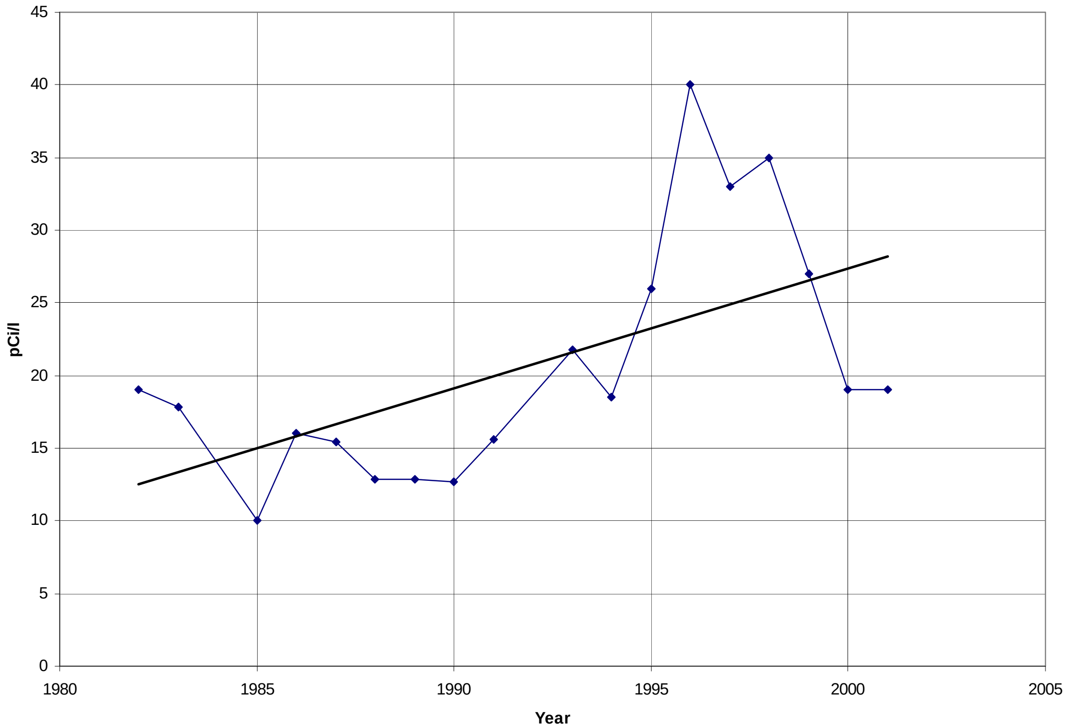


FIGURE E-3 Trends in Gross Alpha Levels
(Waukesha Water Distribution System)

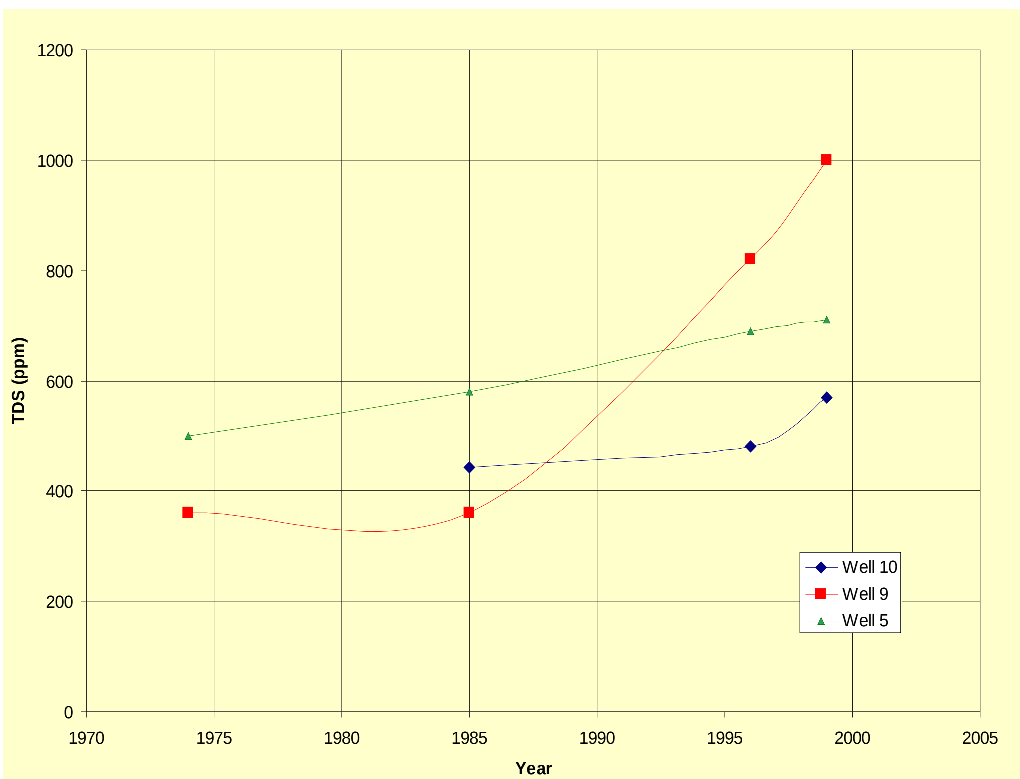


FIGURE E-4 Trends in Total Dissolved Solids

Water Supply Alternatives

Waukesha is fortunate to have a number of water supply sources available. Over 20 water supply alternatives and combinations of alternatives have been evaluated. Water supply sources require sustainable capacity for at least 50 years. This could become a peak day water demand of 22 mgd or more. After preliminary screening, the major water supply categories were:

Deep Sandstone Groundwater

- Near Waukesha
- West of Waukesha

Sandstone Well No. 3 in Waukesha

Fox River

Shallow Groundwater

- South of Waukesha
- West of Waukesha

Lake Michigan

Surface Water

- Lake Michigan
- Fox River
- Rock River

The general location of these water sources is shown in Figure E-5.

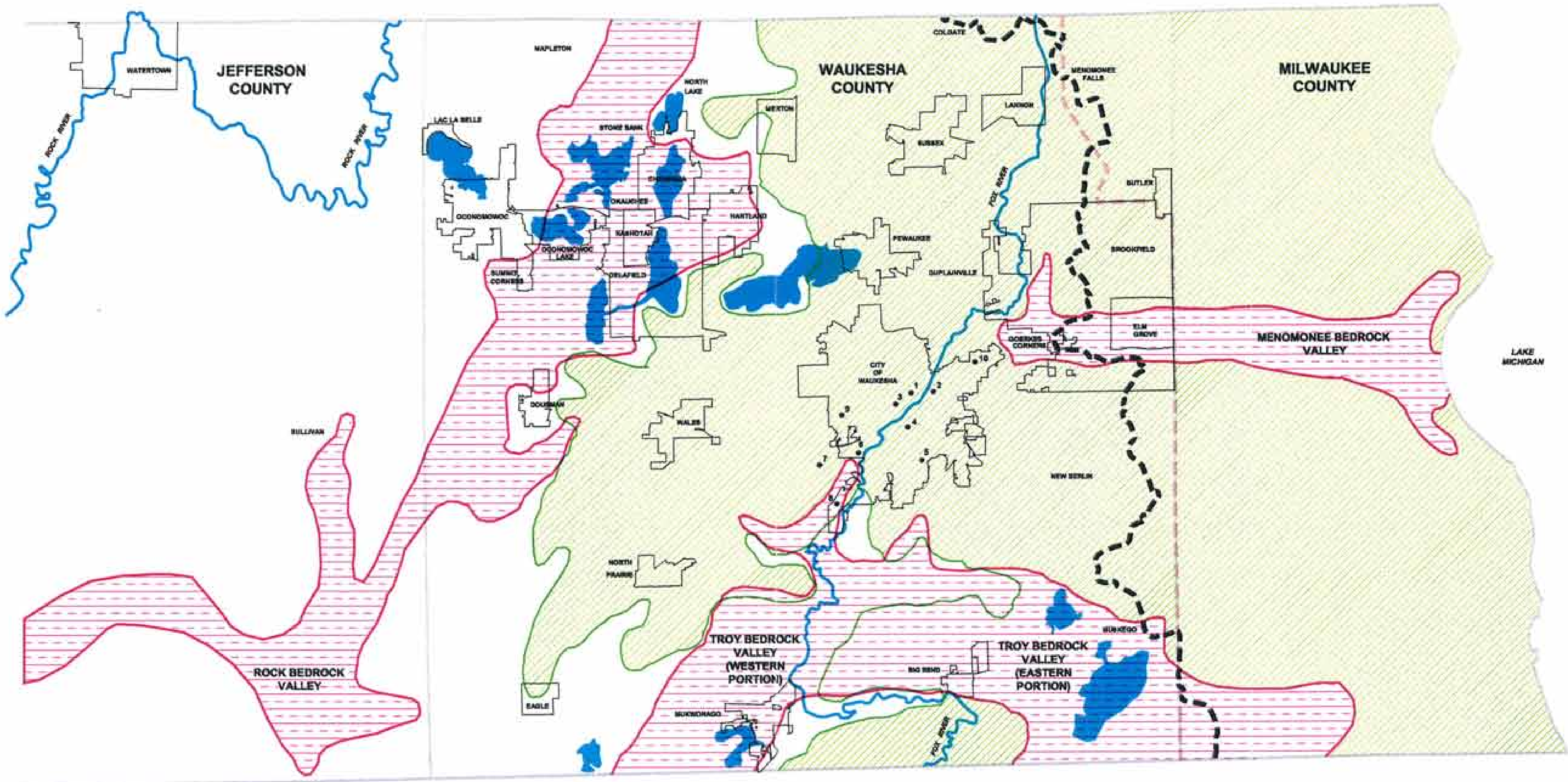
Evaluation of Alternatives

Benefits

A common set of evaluation criteria was established to measure the potential benefits of alternative water supplies. The criteria are:

- Reliability
- Regulations/Legal
- Political/Public Acceptance
- Operations and Maintenance
- Schedule
- Infrastructure

Based on these criteria, the alternatives were evaluated relative to each other by a broad group of stakeholders and a smaller group of utility personnel and consultants. The evaluation results shown on Figure E-6 were similar for each group. On the figure, graph bar height is proportional to benefits. As shown, the shallow aquifer alternatives generally have the highest benefits, followed by Lake Michigan alternatives. The sandstone alternatives had the lowest benefits.



LEGEND

- APPROXIMATE WESTERN EXTENT OF SILURIAN DOLOMITE
- APPROXIMATE LIMITS OF MAJOR BEDROCK VALLEYS
- APPROXIMATE TRACE OF SUBCONTINENTAL DIVIDE
- WATER
- CORPORATE LIMITS
- COUNTY BOUNDARIES
- 1 WAUKESHA WATER UTILITY WELL
- EXISTING LAKE MICHIGAN SERVICE AREA

FIGURE E-5

LOCATION OF WATER SUPPLIES

0 1 2 3 4000 8000

SCALE IN FEET

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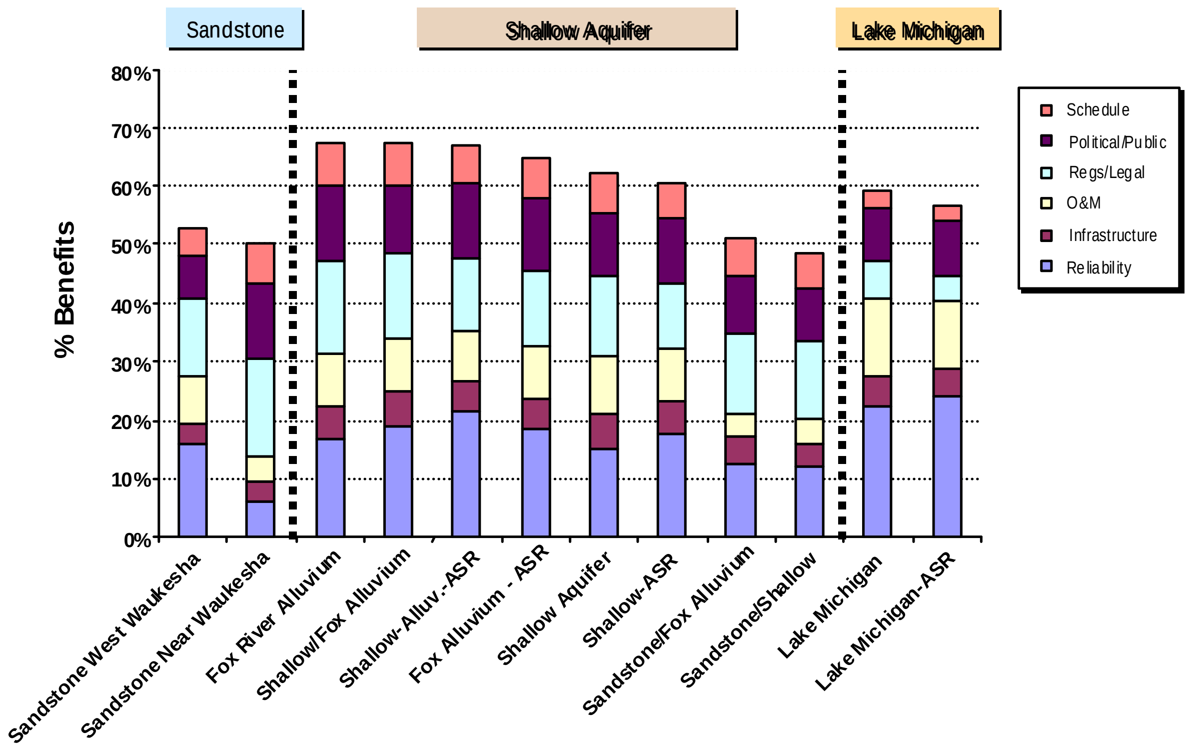

FIGURE E-6
Benefit Ranking Results

The water supply alternatives with the most benefits were the Fox River alluvium and a combination of the shallow aquifer and the Fox River alluvium aquifer. Both aquifers are south of Waukesha. Water from these aquifers would be treated and pumped to the water distribution system. A combination of two aquifers provides more reliability and flexibility for providing water than the single aquifer alternatives. The close proximity to Waukesha also reduces the amount of piping infrastructure.

Another alternative with high benefits uses the same aquifers (shallow and Fox River alluvium) combined with Aquifer Storage and Recovery (ASR). With ASR, treated water from the shallow aquifers would be stored in existing sandstone wells for use during high demand periods (Figure E-7). This significantly reduces water supply and treatment facility sizes and costs because the facilities are designed to deliver water based on average demands instead of maximum demands. This is analogous to running a factory at an 80 percent level of efficiency versus a 50 percent level of efficiency. ASR also increases water supply reliability and flexibility. Water can be provided from three sources, and environmental impacts from pumping any one groundwater supply can be minimized.

The Lake Michigan alternative provided slightly less benefit than the shallow aquifer alternative, but greater benefit than the sandstone aquifer. This alternative involves buying treated drinking water from a Lake Michigan water utility and pumping to Waukesha. The Lake Michigan alternative was rated as the most reliable and as the best in terms of operations and maintenance (O&M). However, concerns for obtaining permission for a diversion without sending wastewater back to the Great Lakes basin, and negotiating a water contract with another community caused this alternative to be ranked lowest in regulatory/legal, political/public acceptance, and schedule criteria.

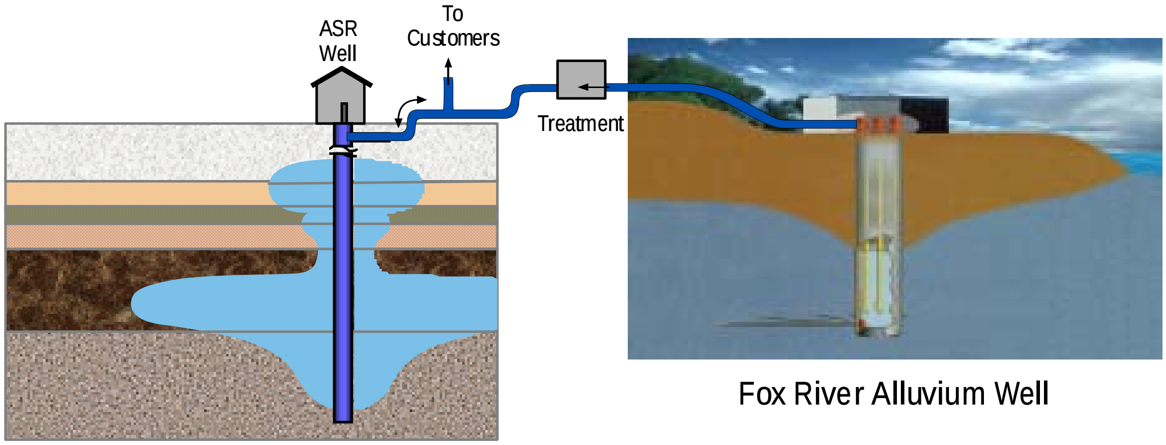

FIGURE E-7
Shallow Groundwater and ASR in Sandstone Wells

The sandstone alternative provided the least benefit. Reliability of the sandstone aquifer near Waukesha was low due to deteriorating water quality and declining groundwater levels. Most new sandstone wells would be located outside current City limits because of drawdown conditions. In addition, extensive treatment was required to deal with radionuclides and increasing levels of total dissolved solids. This created infrastructure and O&M concerns.

Placing sandstone wells west of Waukesha in the recharge area of the sandstone aquifer significantly improved reliability and reduced treatment requirements. However, this alternative was located the farthest distance from Waukesha, resulting in a need for significantly more pipeline infrastructure and concerns regarding political and public acceptance issues.

Costs

Capital and O&M costs were estimated for each alternative. A summary of these costs is presented on Figure E-8 and in Table E-1. The shallow aquifer alternatives present some of the lowest total costs. Total costs include capital costs plus 20 years of O&M costs (present worth). The lowest cost alternative is a shallow aquifer wellfield south of Waukesha and the use of ASR to store drinking water for use during high demand periods ($62 million total cost). The highest shallow aquifer alternative cost is the combination of the Fox River alluvium and shallow aquifer south of Waukesha ($83 million total cost). If ASR is combined with this alternative, the total cost is reduced from $83 million to $69 million because of the need for smaller pipes, smaller plants, and fewer wells. The Lake Michigan alternative has a total cost of $90 million. This alternative has the lowest capital cost ($42 million), but O&M costs are higher, mainly due to the cost of purchasing treated wholesale water from a Lake Michigan supplier. This alternative assumes that a permit would be issued, allowing diversion of Lake Michigan water without return to the Great Lakes basin. If return of water is required, the cost of this alternative will be double or more.

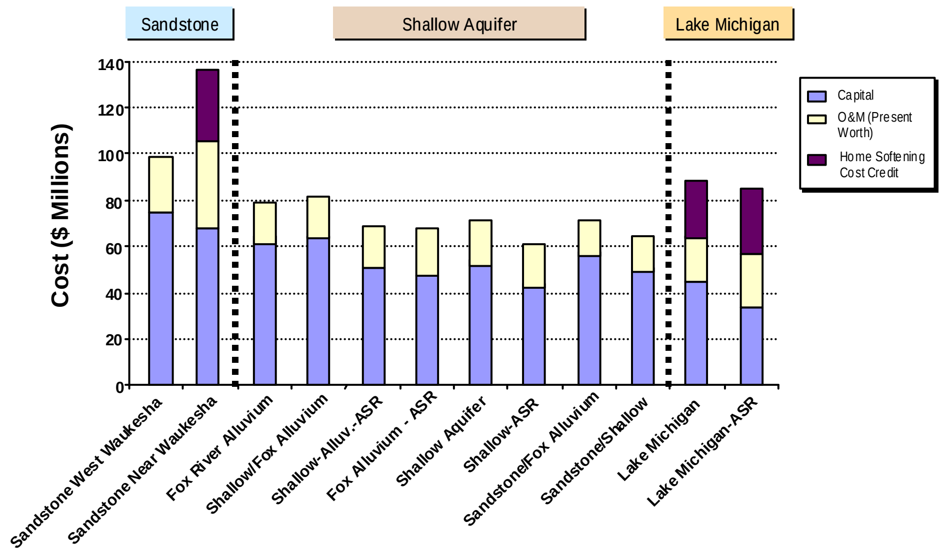

FIGURE E-8
Cost of Water Supply Alternatives

TABLE E-1
Summary Cost Estimate (in $ Millions)
Waukesha Water Supply Study

	Capital Cost[a]	O&M$/yr[b]	Increase Over Current O&M$/yr [c]	Total Cost [d]	Total Cost w/Home Softening Credit [e]
Sandstone Alternatives					
Sandstone Near Waukesha	$ 67	$ 5.9	$ 4.7	$ 135	$ 108
Sandstone West of Waukesha	$ 77	$ 1.8	$ 0.6	$ 98	
Shallow Aquifer Alternatives					
Shallow Aquifer	$ 56	$ 1.3	$ 0.1	$ 71	
Shallow Aquifer with ASR	$ 45	$ 1.5	$ 0.3	$ 62	
Fox River Alluvium	$ 62	$ 1.6	$ 0.4	$ 80	
Fox River Alluvium with ASR	$ 50	$ 1.7	$ 0.5	$ 69	
Shallow Aquifer/Sandstone	$ 51	$ 1.2	$ (0.01)	$ 65	
Fox River Alluvium/Sandstone	$ 57	$ 1.4	$ 0.2	$ 73	
Fox Alluvium/Shallow Aquifer	$ 66	$ 1.5	$ 0.3	$ 83	
Fox Alluvium/Shallow Aquifer with ASR	$ 52	$ 1.5	$ 0.3	$ 69	
Lake Michigan Alternatives					
Lake Michigan	$ 42	$ 4.2	$ 3.0	$ 90	$ 63
Lake Michigan with ASR	$ 36	$ 4.3	$ 3.1	$ 85	$ 58

[a] 2002 dollars, facilities for 22 mgd
[b] 10 mgd average day demand. Source of supply, treatment, and new transmission only
[c] Alternative O&M (column 2) minus existing O&M (10 mgd for source of supply & treatment only)
[d] Capital plus O&M present worth (20 yr, 6 percent)
[e] Subtracts capital and O&M costs of home softening (20 yr, 6 percent)

Water from Lake Michigan is naturally soft, whereas water from the shallow and sandstone aquifers is naturally hard. The shallow aquifer groundwater is a bit harder than the sandstone groundwater. Most Waukesha residents have home water softeners. If soft water from Lake Michigan was obtained, the home softeners and associated operational costs could be eliminated. The savings from providing soft water, mainly from avoiding the cost of salt purchase, is estimated at a total cost (20-year present worth) of about $27 million. If this home softening cost is subtracted from the cost of providing Lake Michigan water, the net Lake Michigan total cost is $63 million, which is almost the same as the least cost shallow aquifer alternative ($62 million).

Conclusions

Alternative Selection

The best alternatives provide high benefit at reasonable cost. The benefits and total costs for each alternative are shown on Figure E-9. The alternatives with the highest benefits and lowest costs are:

- Lake Michigan
- Shallow Aquifer

The Lake Michigan alternative cost includes the softening cost credit. It also assumes that a diversion permit would be granted which would not require returning water to the Great Lakes basin. If a diversion permit is not granted or return of water to the Great Lakes Basin is required, the Lake Michigan alternative is not viable. If a diversion permit is granted without a return flow or other requirements, Lake Michigan provides the most reliable and highest quality source of water for Waukesha and potentially other communities.

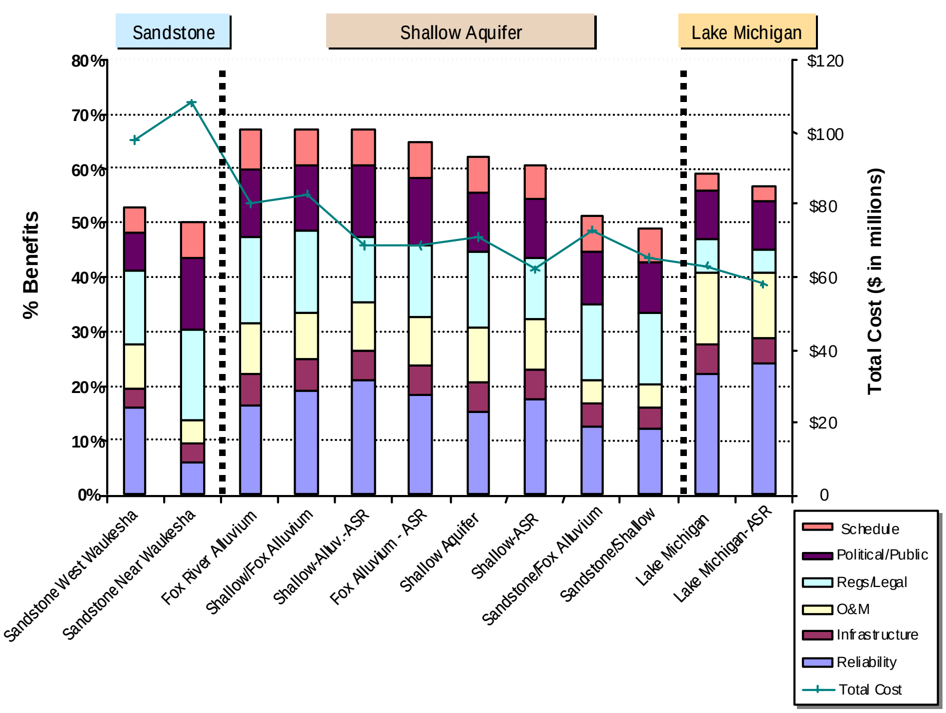

FIGURE E-9
Benefits and Costs

Of the shallow aquifer alternatives evaluated, those with the highest benefit and lowest cost are the shallow aquifer with ASR and the Fox River alluvium/shallow aquifer with ASR. The combination of Fox River alluvium, shallow aquifer, and ASR provides the most reliability and flexibility for delivering water and managing water resources. It is the preferred shallow aquifer alternative. However, future conditions and issues may change the best overall water supply source for Waukesha.

Implementation Plan

The shallow groundwater and Lake Michigan alternatives offer two excellent water supply sources for Waukesha. Implementation of a new water supply for Waukesha should proceed on a parallel path (Figure E-10).

Feasibility of the Lake Michigan supply will depend on obtaining a diversion permit where return of water to the Great Lakes basin is not required. It will also depend on negotiating a water contract with a Lake Michigan supplier. The criteria and process for evaluating the merits of a diversion are planned to be finalized in 2004 by the Council of Great Lakes Governors. However, investigations into the environmental impacts and requirements of a diversion can proceed at any time. Other activities that can proceed toward a Lake Michigan water supply include:

- Discussions with the Wisconsin Department of Natural Resources (WDNR) on regulatory requirements
- Discussions with potential Lake Michigan water suppliers
- Discussions with other communities facing similar water supply issues

FIGURE E-10
Implementation Plan

Further steps toward a shallow aquifer supply include:

- Performing hydrogeologic investigations and constructing test wells in the shallow aquifer to determine optimum well locations, sustainable capacities, and environmental impacts
- Addressing land issues, including purchases, leases, and zoning
- Discussions with other communities regarding use of the shallow aquifer and potential partnerships in a water supply system

When information on these critical issues for the water supply alternatives is available, a final decision on the best water supply source can be made.

Water is essential for life and economic vitality. Waukesha has a proud history of supplying safe and affordable water. By planning for a future water supply, Waukesha will continue to provide residents with adequate quantities of safe and affordable drinking water.

Contents

Tables

Figures

Acronyms and Abbreviations

ADD	average day demand
ASR	aquifer storage and recovery
AWWARF	American Water Works Association Research Foundation
ES	enforcement standard
gpcd	gallons per capita per day
gpd	gallons per day
GPM	gallons per minute
IJC	International Joint Commission
MCL	maximum contaminant limit
mgd	million gallons per day
O&M	operation and maintenance
ppm	parts per million
SCADA	supervisory control and data acquisition
SDWA	Safe Drinking Water Act
SEWRPC	Southeastern Wisconsin Regional Planning Commission
SWTR	Surface Water Treatment Rule
TDS	total dissolved solids
UIC	underground injection control
USEPA	United States Environmental Protection Agency
WDNR	Wisconsin Department of Natural Resources
WGNHS	Wisconsin Geological and Natural History Survey
WRDA	Water Resources Development Act

SECTION 1

Introduction

1.1 Purpose

This study was conducted to evaluate water supply alternatives for consideration by the Waukesha Water Utility to continue providing reliable, high quality, affordable drinking water to its customers.

1.2 Scope of Work

This water supply study evaluated various water supply alternatives and combinations of alternatives. Both groundwater and surface water sources were evaluated using a reliable source of water for a 50-year time frame as a goal. The drinking water should meet all primary drinking water regulations and secondary standards.

The following general tasks were performed:

- Brainstormed water supply alternatives
- Developed evaluation criteria
- Determined weighting factors for the evaluation criteria
- Screened the alternatives and eliminated those that did not meet goals
- Evaluated the alternatives based on the criteria
- Ranked the alternatives based on the criteria
- Developed capital and operating costs for each alternative
- Compared the benefits and costs of each alternative
- Provided an implementation plan for the top alternatives
- Prepared a report summarizing the findings

1.3 Waukesha Water System

Waukesha obtains its drinking water from a sandstone aquifer (Cambrian-Ordovician) with ten active wells, each about 2,000 feet deep. The wells have a combined capacity of about 15 million gallons per day (mgd). The distribution system consists of seven pressure zones, 17 million gallons of ground and elevated storage, 15 booster pump stations, and about 280 miles of water mains. The water system is shown on Figure 1-1.

During 2001, average day demand was about 8 mgd, and maximum day demand about 13 mgd. Anticipated increases in water demand have created the need to provide additional water supply capacity. The maximum day water demand could increase from 13 mgd to 22 mgd (or more) over the next 50 years.

The sandstone groundwater level near Waukesha is declining 5 to 10 feet per year. Groundwater level is currently about 500 feet below the ground surface, and still declining. This decline increases pumping, operation, and maintenance costs.

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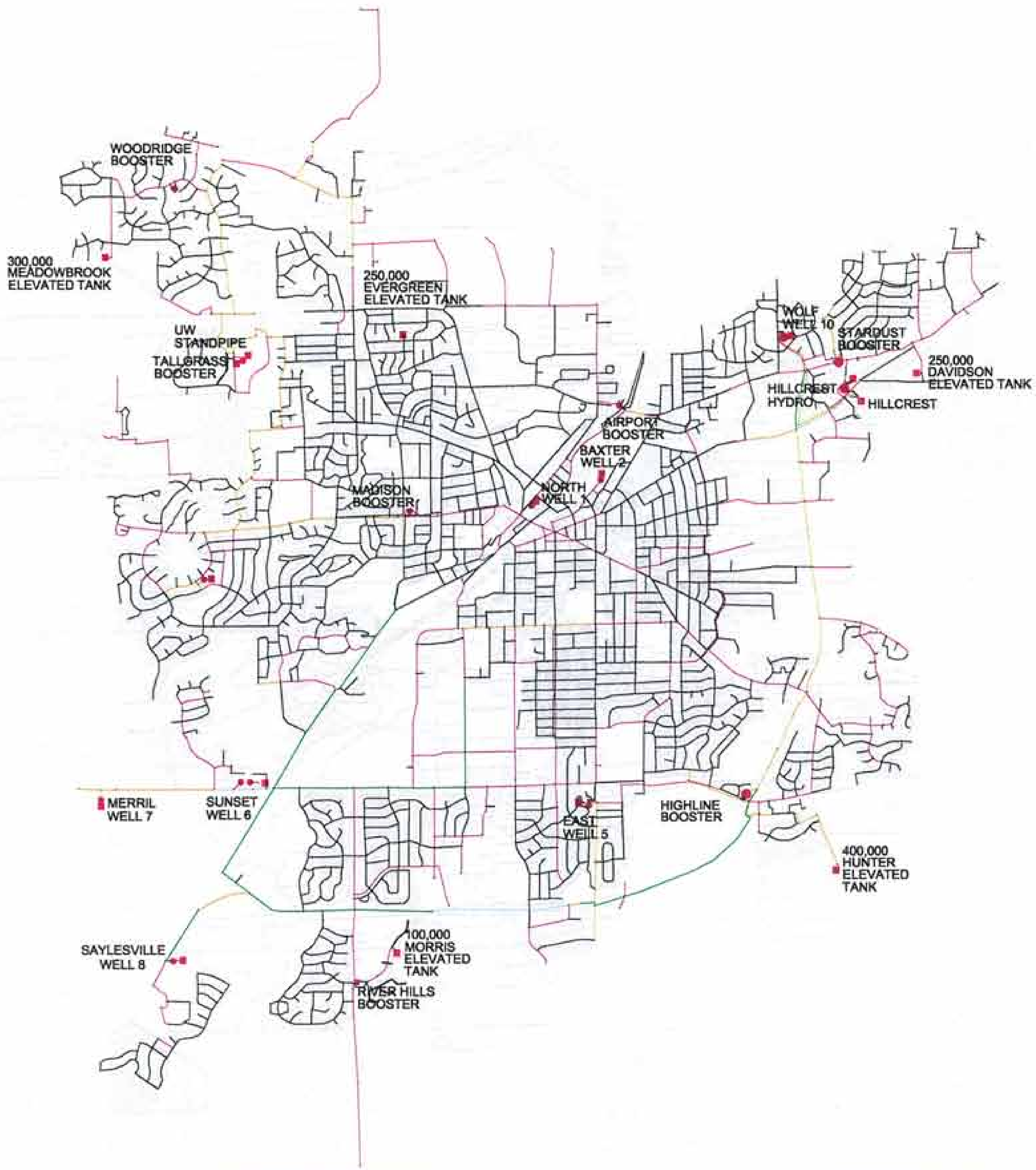

FIGURE 1-1

EXISTING WATER SYSTEM IN WAUKESHA

N
W E
S

LEGEND

- 24" WATER MAIN
- 20" WATER MAIN
- 16" WATER MAIN
- 12" WATER MAIN
- WELLS
- STORAGE TANKS

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Water produced by Waukesha's sandstone wells has high levels of hardness and low levels of iron and manganese. With the exception of radium and gross alpha, the water meets all primary drinking water standards. In recent years, radionuclides (gross alpha) and total dissolved solids levels are increasing in certain wells.

Declining water levels and water quality (radionuclides, total dissolved solids), coupled with increasing water demand, have created the need to investigate alternative water sources. The current water supply situation is not critical. However, now is a prudent time to take proactive action and plan for the future.

1.4 Planning Criteria

1.4.1 Planning Period

A 50-year planning period (to 2050) was selected to evaluate water supply sources. This planning period was selected to look toward a reliable, sustainable water supply source for the planning area. Operation and maintenance (O&M) costs for the water supply alternatives were compared over a 20-year period.

1.4.2 Water Demand Forecasts

1.4.2.1 Population Forecasts

The Waukesha Water Utility completed a Water Utility Master Plan Update in 2000. The plan established a 2000 population of about 64,000, and forecasted a 2020 Utility Service Area Boundary and population of about 78,000. Growth forecasts were established based on a 1993 land use plan and a 1999 sewer service area plan, both prepared by the Southeastern Wisconsin Regional Planning Commission (SEWRPC). Review of the Sewer Service Area Plan for the City of Waukesha and environs (1999) indicated a 2020 forecasted population range of 77,400 (under an intermediate growth plan) to 105,400 (under a high growth plan). The forecast of the Utility Master Plan lies within that range and is consistent with the SEWRPC intermediate growth plan for the service area.

The 2020 Water Service Area identified in the Utility Master Plan is shown on Figure 1-2. This boundary is very similar to the 2020 Sanitary Sewer Service Area boundary.

There have not been any population forecasts or service area estimates completed for Waukesha for year 2050. SEWRPC is in the process of updating the regional land use plan and extending the population projections, but will not have information available for use in this study. Therefore, this study will use existing forecasts of 2020 populations and service area boundaries, as used in the Utility Master Plan and as consistent with the SEWRPC sewer service area plan, to establish forecasts for the year 2050.

TABLE 1-1
Population Trends and Projections
Future Water Supply

Year	Population	Percent Change	Year	Population	Percent Change
1900	7,419	—	1980	50,365	26.9
1910	8,740	17.8	1990	56,958	13.1
1920	12,558	43.7	2000	64,000	12.4
1930	17,176	36.8	2010	71,000	10.9
1940	19,242	12.0	2020	78,000	9.9
1950	21,233	10.3	**2030**	**86,111**	**10.4**
1960	30,004	41.3	**2040**	**95,065**	**10.4**
1970	39,695	32.3	**2050**	**104,950**	**10.4**

Source: Waukesha Water Utility Master Plan, February 2000
Note: Bolded values are forecasts beyond the 2020 Water Utility Master Plan data

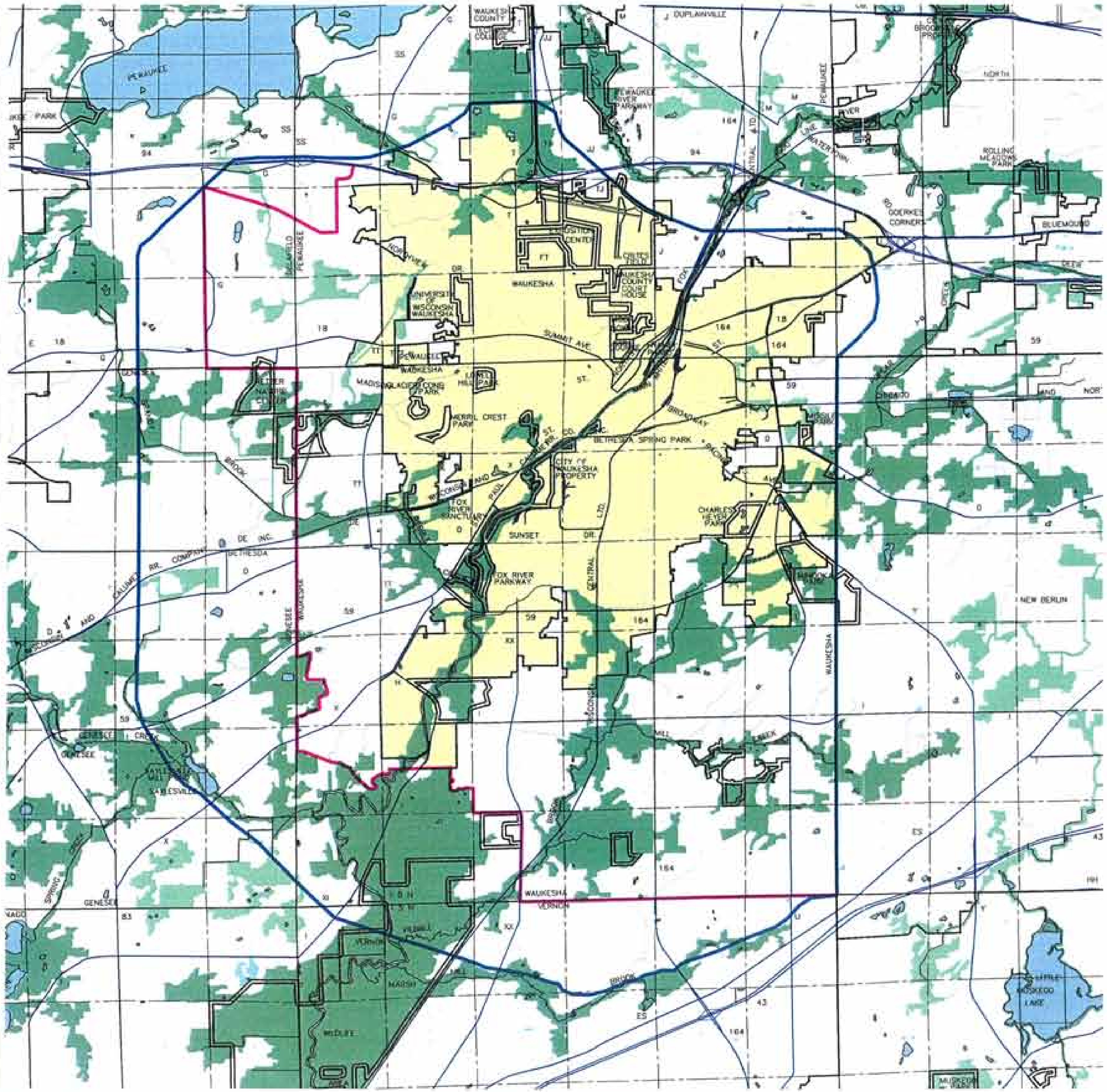

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FIGURE 1-2

FUTURE WATER SERVICE AREA

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0 .5 1 1.5 2 2.5
SCALE IN MILES

LEGEND

2050 WATER SERVICE AREA

2020 SEWER SERVICE AREA

1995 CITY BOUNARY

PRIMARY ENVIRONMENTAL CORRIDOR

SECONDARY ENVIRONMENTAL CORRIDOR

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Forecasted year 2050 population levels are presented in Table 1-1. These levels are estimated using the growth rate between 2000 and 2020 from the Utility Master Plan. Note that the 2050 population is still within the 2020 high growth plan of 105,400. This growth trend assumes continued expansion of the urban service area boundaries to adjacent township lands to the south and west.

1.4.2.2 Service Area Projection

The current Waukesha Water Utility 2020 service area developed in the Utility Master Plan is roughly consistent with an updated version of the established 2020 sanitary sewer service area. The area includes a total of about 47 square miles, within which 9.6 square miles are environmentally significant lands. This leaves a net developable land area of 37.4 acres within the 2020 water service area. If development occurred to the 2020 population level forecast of 78,000 persons, there would be an average population density of 3.26 persons per acre of developable land. Projecting that density to the 2050 population of 105,000 persons would result in an incremental land requirement of 13 square miles.

Review of the 2020 Water Utility Service Area indicates that expanding the boundary to the south and west by a maximum of 1.5 miles in each direction would result in a gross increase of 17.5 square miles (Figure 1-2). Removing the environmentally significant land would result in a net increase of about 13 square miles.

This growth concept was reviewed by the City of Waukesha Department of Community Development. The general consensus was that 50-year forecasts were very difficult. There are many political and jurisdictional issues that will likely impact the growth, development, and shape of the Waukesha service area over that period. Given the 50-year population forecasts, the department thought it was reasonable to assume that the service area would grow in a similar fashion. The general 2050 water service area is shown on Figure 1-2. It reflects Master Plan growth forecasts and the general growth pattern to the south and west of the existing service area.

There are currently some instances in which either city water or sewer service is provided, but not both. Given this trend, it is possible that in the future, the Waukesha Water Utility could become a wholesale water supplier to adjacent communities. Under this scenario, the demand forecasts and water service area could be considerably different than the service area projected. For the purposes of this service area projection, however, we will assume that the population and service area growth will coincide and move to the south and west as shown on Figure 1-2. Regional water service area forecasts will be covered in a future SEWRPC planning effort.

1.4.2.3 Water Demand

The Utility Master Plan provided similar forecasts for water demand over the 20-year period from 2000 to 2020. Historic water demand trends were reviewed and future water demand was estimated for residential, commercial, industrial, and public institutional use. Water demand trends over the past 20 years have been characterized by the steady growth of residential, commercial, and public institutional demand, with a significant decline in industrial demand. This decline has resulted in an overall reduction in ADD from a high of 9.66 mgd in 1979 to 8.15 mgd in 1998.

Based on the forecasted population growth, and the similar growth of commercial, industrial, and public institutional demand, future water demand was forecasted from 1998 to 2020. The per-capita consumption rate was generally held constant at a level similar to the last 7 years (125 gallons per capita per day [gpcd]). The per-capita consumption rate included a constant factor for unaccounted for water at 5 percent.

Forecasts for water demand beyond 2020 were made using a straight-line projection. The results are shown in Table 1-2 and on Figure 1-3. This method was compared to a method that used forecasted population and a per capita consumption rate of 125 gpcd. The results indicated very similar values for average daily pumpage. Therefore, the straight-line projection will be used for year 2050 ADD.

TABLE 1-2
Historic and Projected Waukesha Water Pumpage
Future Water Supply

Year	Average Daily Pumpage (mgd)	Maximum Daily Pumpage (mgd)	Year	Average Daily Pumpage (mgd)	Maximum Daily Pumpage (mgd)
1990			2030	**11.32**	**18.68**
1998	8.15	13.45	2040	**12.31**	**20.31**
2010	9.32	15.37	2050	**13.30**	**21.95**
2020	10.33	17.04			

Source: 1998 Master Plan, Waukesha Water Utility
Note: Bold values are forecasts beyond the 2020 Utility Master Plan data

The maximum daily pumpage was established in the Master Plan by applying a factor of 1.65 times the average daily pumpage. This factor was applied to the straight-line projections beyond 2020 to yield the values shown in Table 1-2 and on Figure 1-3.

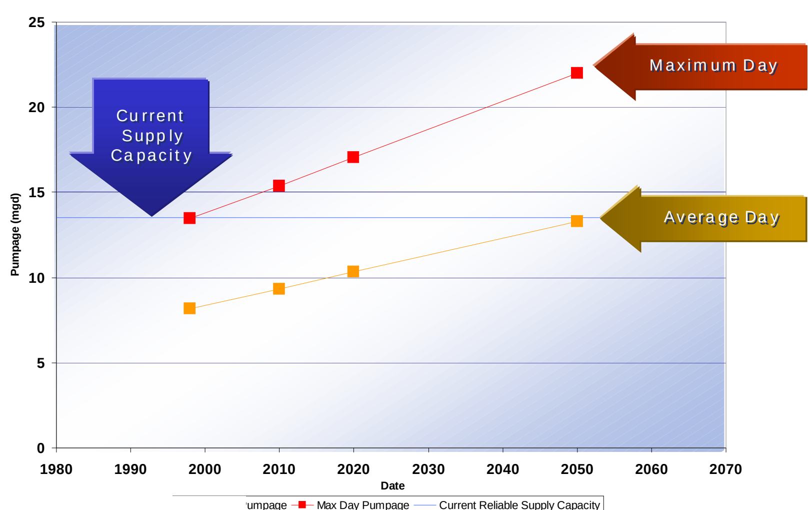


FIGURE 1-3
Water Demand Forecast

Water demand forecasts depend on many factors that cannot all be determined or controlled. The water demand projections and associated facilities represent an intermediate growth pattern. Growth could occur faster or slower based on economic, demographic, and other factors. If faster growth occurs, the water facilities described in this report will reach their capacity before 2050. Under the highest growth projection by SEWRPC, the water system capacity (22 mgd max day pumpage) would be realized around 2020.

SECTION 2

Water Supply Alternatives

2.1 Base Alternatives

The scope of work included evaluation of the following water supply alternatives:

- Sandstone aquifer
- Fox River
- Rock River
- Shallow aquifers (sand/gravel, dolomite, river alluvium)
- Lake Michigan

The general locations of these water supplies are shown on Figure 2-1.

A brainstorming meeting on September 17, 2001, identified other potential water supply alternatives including:

- Wellfield along Lake Michigan
- A dam on the Fox or Rock Rivers to create a reservoir
- Historic springs in Waukesha
- Wastewater reuse
- Milwaukee River
- Pewaukee Lake
- Quarry

Each of these alternatives will be generally described and screened for feasibility. Alternatives with fatal flaws will be eliminated from consideration.

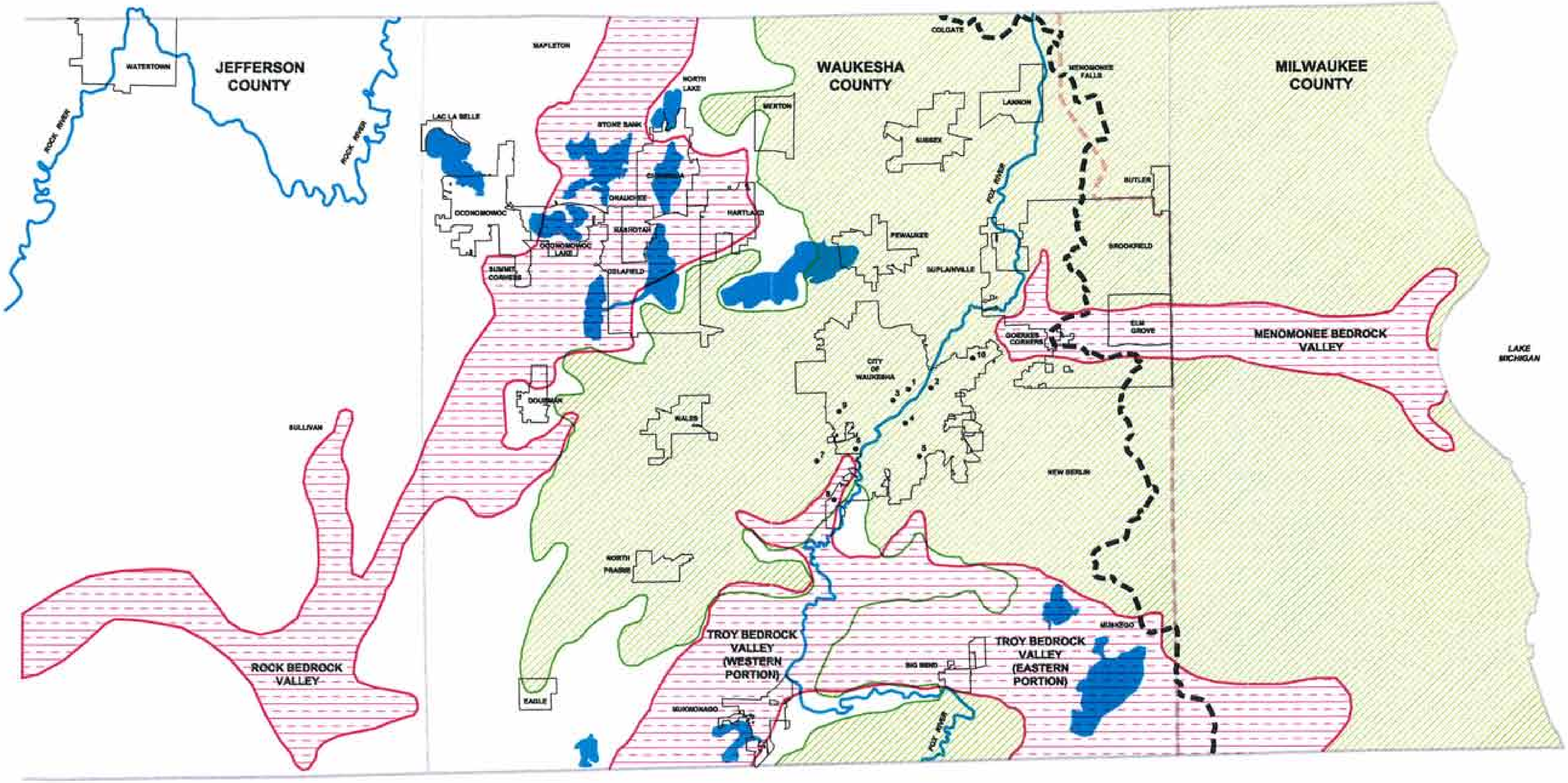
2.1.1 Groundwater Sources

2.1.1.1 Overview of Major Aquifers

The City of Waukesha and Waukesha County have three aquifers available for development of high-capacity wells. These three aquifers include:

1) The shallow aquifer, which includes the sand and gravel beds in glacial drift and the shallow Silurian dolomite aquifer;
2) The Cambrian-Ordovician aquifer, in which the Ironton-Galesville and Mount Simon sandstone are the most productive units; and
3) The alluvial deposits along major rivers and streams.

The sandstone aquifer has been the major source of water for municipal systems served by groundwater in southeastern Wisconsin, and provides most of the municipal water in Waukesha County. The sand and gravel and dolomite aquifers have traditionally been the major source of water for private wells. However, both aquifers are becoming more important sources for municipal systems in Waukesha County.



LEGEND

- APPROXIMATE WESTERN EXTENT OF SILURIAN DOLOMITE
- APPROXIMATE LIMITS OF MAJOR BEDROCK VALLEYS
- APPROXIMATE TRACE OF SUBCONTINENTAL DIVIDE
- WATER
- CORPORATE LIMITS
- COUNTY BOUNDARIES
- WAUKESHA WATER UTILITY WELL
- EXISTING LAKE MICHIGAN SERVICE AREA

FIGURE 2-1

LOCATION OF WATER SUPPLIES

0 1 2 3 4000 8000
SCALE IN FEET

N W E S

Waukesha Water Utility

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2.1.1.2 Sand and Gravel Aquifer

The uppermost aquifer consists of sand and gravel deposits in the unconsolidated glacial deposits. This aquifer is commonly called the sand and gravel aquifer. The extent of this aquifer is generally sporadic in the eastern half of Waukesha County, but it produces a significant portion of the water supply for several communities surrounding Waukesha. Several areas near the city have the potential to produce adequate quantities of water from this aquifer to meet the needs of the Waukesha Water Utility.

The sand and gravel aquifer offers many advantages, including faster local recharge, low radionuclide content, and lower costs compared to the sandstone aquifer. In spite of the advantages, development of the aquifer has been limited by the distribution of the permeable sand and gravel deposits. In most of southeastern Wisconsin, sand and gravel deposits are absent or too thin to support high-capacity wells. However, several geologic features contain channel deposits of permeable sand and gravel that can support wells producing over 1,000 gallons per minute (gpm). These geologic features include bedrock valleys, outwash deposits, and end moraine deposits. As these features cover a limited area of southeastern Wisconsin, sand and gravel aquifer wells must be sited in these specific areas to produce significant volumes of water.

2.1.1.3 Dolomite Aquifer

The regional bedrock lies below the surficial glacial deposits lies the regional bedrock. The bedrock is referred to as the Silurian dolomite. It serves as an aquifer (called the dolomite aquifer) for much of eastern Wisconsin. The dolomite itself is relatively dense and incapable of storing or transmitting significant quantities of water. The dolomite aquifer usually produces small quantities of water that are sufficient for private homes only. However, numerous zones of fractured rock exist within the dolomite, which can produce several hundred gpm from the void spaces created by the fractures and related solution cavities. It is only where the dolomite aquifer is fractured that it may produce enough water for municipal needs. The fractures tend to concentrate in regional fracture zones. The fracture zones are nearly vertical and are typically miles long, but only a few tens of feet wide.

Wells must directly penetrate a fracture zone or a related solution feature to produce significant volumes of water. In the past, fracture zones were nearly impossible to locate, and siting a high-capacity well in the dolomite aquifer was largely a hit or miss affair. This significantly limited the development of the aquifer for municipal wells. However, within the last 15 years, new geophysical techniques have been used in southeastern Wisconsin to locate regional fracture zones. This technology has made it possible to explore for high-capacity municipal wells in the dolomite aquifer. The dolomite aquifer has become an important water source for municipal wells for much of eastern Wisconsin, especially for the Cities of New Berlin and Brookfield, the Towns of Brookfield and Pewaukee, and the Villages of Germantown and Menomonee Falls (now on standby). The dolomite aquifer is only available in limited areas around the eastern, northern, and southern sides of Waukesha. Due to the restrictive requirements for siting a suitable dolomite well, it appears that the dolomite aquifer will only be able to produce a small portion of the water needed by the Waukesha Water Utility. However, the dolomite aquifer may provide water in portions of the system where other shallow sources are not available.

2.1.1.4 Sandstone Aquifer

The sandstone aquifer is a major source of groundwater for municipal supplies in southeastern Wisconsin. Most municipal water in Waukesha County comes from wells in the sandstone aquifer. All ten of the Waukesha Water Utility wells produce water exclusively from the sandstone aquifer (Figure 2-2). About 50 communities and 200 industries in southeastern Wisconsin rely on the sandstone aquifer for at least part of their water supply. The sandstone aquifer provides about 95 percent of municipal supply in Waukesha County. From 1975 to 1995, municipal demand from the sandstone aquifer increased 27 percent in Walworth County, 29 percent in Waukesha County, and 54 percent in Washington County. In 1995, at least 92 municipal wells—including those for Milwaukee, Waukesha, Ozaukee, Washington, Racine, Kenosha, and Walworth Counties—produced about 28 mgd of water from the area sandstone aquifer (Jansen and Rau, 1998).

FIGURE 2-2
Sandstone Well No. 3 in Waukesha

It is possible for the Waukesha Water Utility to develop additional well capacity in the sandstone aquifer. However, significant problems exist within the aquifer in eastern Waukesha County. These problems may make expanding the existing wellfield impractical as a long-term solution. However, it may be possible to develop additional capacity in the sandstone aquifer by developing new sandstone wells in more favorable areas.

The shallow aquifers are separated from the sandstone aquifer by the relatively impervious Maquoketa shale group. Where present, the Maquoketa Shale acts as a regional confining unit for the sandstone aquifer. Very little water seeps though the shale into the sandstone aquifer. Since the shale is present over most of eastern Waukesha County, the sandstone aquifer is confined and isolated from direct recharge in the area of heaviest demand. The sandstone aquifer in Waukesha County receives almost all of its recharge from the western portion of the county, where the Maquoketa shale is absent and surface water can infiltrate through the glacial deposits into the sandstone aquifer. A groundwater divide is present a short distance west of the Waukesha and Jefferson county border. Water entering the sandstone aquifer west of this divide flows westward, away from the City of Waukesha.

The sandstone aquifer is comprised of three major sandstone units, separated by lower permeability shale and dolomite units that act as confining layers. The sandstone units include the St. Peter, the Ironton-Galesville (also called the Wonewoc), and the Mount Simon sandstones. The sandstone aquifer consists of a series of shale, dolomite, and sandstone deposits, which are present from a depth of about 450 to about 1,500 to 3,000 feet.

The portion of the sandstone aquifer beneath the Maquoketa shale has historically been highly confined, with the hydraulic head in the aquifer being above ground level in the early years of the development of the aquifer. Heavy pumping has caused a large cone of depression. As a result, water levels in the aquifer have dropped below the base of the Maquoketa shale in much of eastern Waukesha County. In this area, the sandstone aquifer is no longer confined, which causes significant changes in the hydraulics, geochemistry, and microbiology of the aquifer.

Pumpage from the sandstone aquifer has created a large cone of depression centered on eastern Waukesha County (Figure 2-3) (SEWRPC, 1976; and Jansen and Rau, 1998). The original groundwater gradient was from west to east (SEWRPC, 1976). The cone of depression has reversed the regional groundwater gradient in Ozaukee and Milwaukee Counties (Jansen and Rau, 1998). This condition has probably existed for about 50 years and is causing water to migrate westward from under Lake Michigan to the pumping center in eastern Waukesha County.

Well capacities from the deep sandstone aquifer vary as a function of the thickness and the characteristics of several permeable units. Specific capacity values (gpm per foot of draw down) can vary from slightly less than 1 gpm/ft to over 20 gpm/ft, depending on the location and depth of the well. Typically, the sandstone aquifer is capable of supporting pumping rates of at least 500 to over 2,000 gpm to a properly constructed well.

The water quality in the sandstone aquifer has historically been good in Waukesha County. The water, although very hard, has generally been suitable for most potable purposes. The water contains naturally elevated levels of radionuclides. Most sandstone wells in Waukesha County exceed the maximum contaminant limit (MCL) for radium and gross alpha (15 pCi/l). Many wells contain low levels of arsenic. In a few wells, arsenic has been detected at levels above the new MCL (10 μg/l).

Several water quality parameters have changed in the aquifer over the last 10 to 20 years. Total dissolved solids (TDS) levels have increased in many of the deepest wells in the county (Figure 2-4). Some wells have experienced rising TDS levels that have more than doubled in 10 years and have produced brackish water. Gross alpha levels have risen significantly in most sandstone aquifer wells in Waukesha County (Figure 2-5). Typically, gross alpha levels have more than doubled over the last 20 years, and are continuing to rise. The increasing trend complicates efforts to comply with the radionuclide MCLs.

The rise in TDS levels in the aquifer appears to be related to the upward migration of water from deeper portions of the aquifer. This condition is caused by extreme vertical gradient created by the regional cone of depression. The rise in gross alpha levels may be due to related processes or to other geochemical changes in the aquifer caused by the significant decrease in head.

Beneath the sandstone aquifer lies essentially impermeable Precambrian igneous and metamorphic rocks. The Precambrian deposits are not considered to be aquifer and represent the base of the regional aquifer system.

A large normal fault, the Waukesha fault, cuts through the Precambrian rock with over 1,000 feet of vertical displacement. The fault trends northeast to southwest, and runs directly through the City of Waukesha. The sandstone aquifer is significantly thicker on the down-thrown side of the fault. The fault cuts the Cambrian through Silurian rock units with lesser displacement higher in the section. The fault forms a steep vertical step in the sandstone aquifer, with the down-thrown side on the downgradient side of the regional groundwater flow.

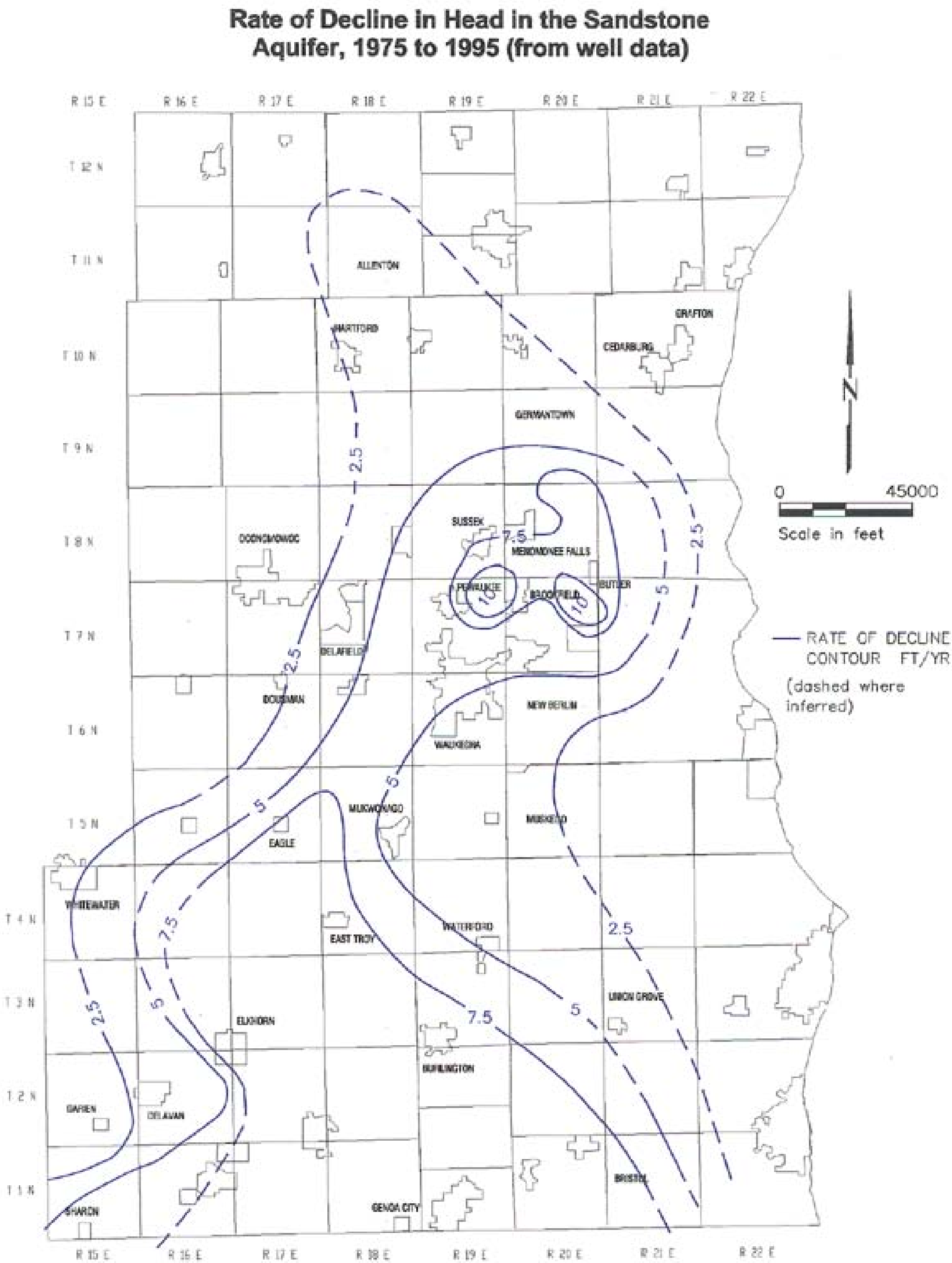

FIGURE 2-3
From Jansen and Rau, 1998

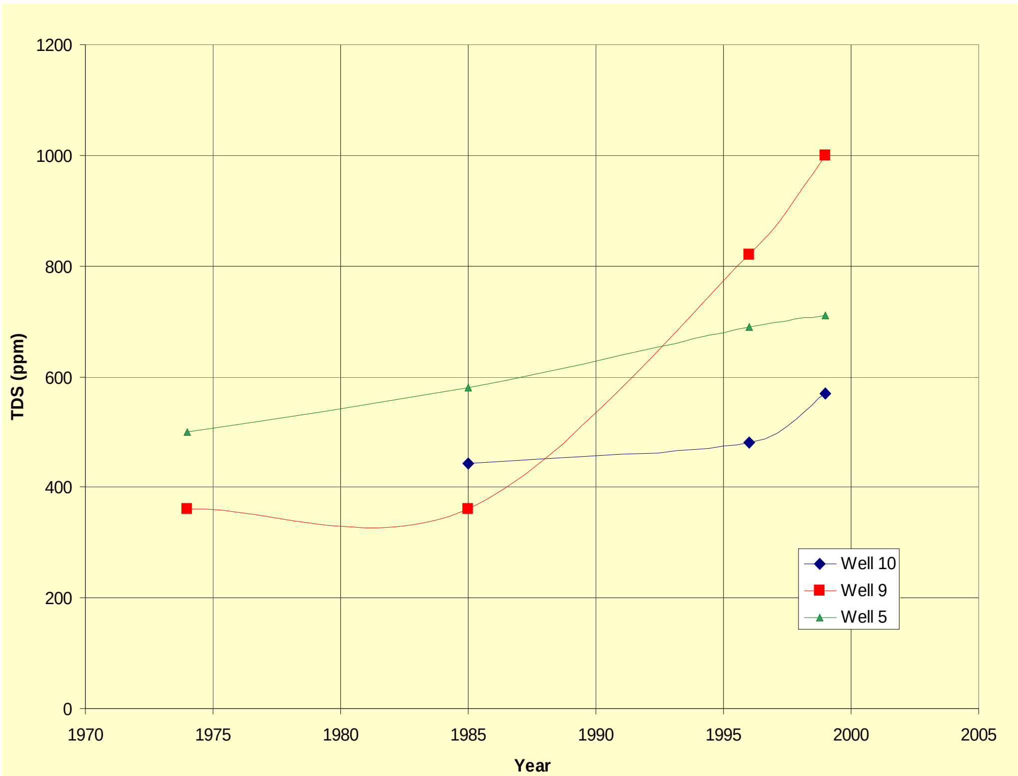

FIGURE 2-4 Trends in TDS–Sandstone Aquifer

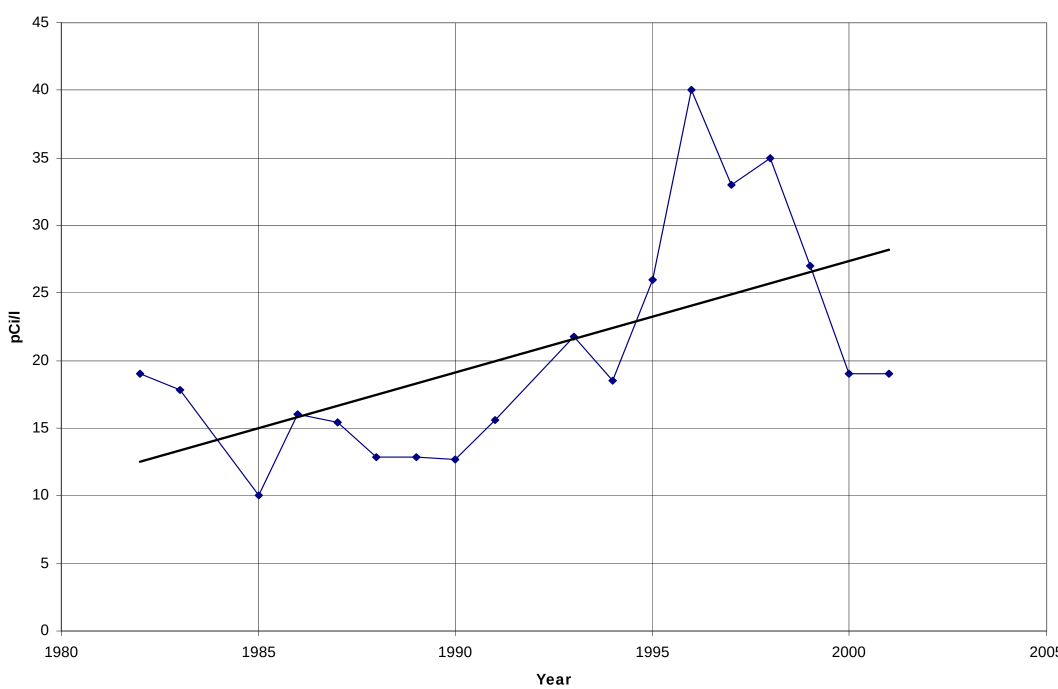

FIGURE 2-5 Trends in Gross Alpha Levels–Sandstone Aquifer

Recent geophysical and well rehabilitation studies have found that the ledge of Precambrian rock formed by the fault portion has created a zone of stagnation in the lower portion of the sandstone aquifer (AST and UWM, 2000). This portion of the aquifer predominantly contains saline water. Heavy pumpage has caused saline water to migrate upward into several of the deeper wells in Waukesha County. TDS levels have risen to troublesome levels in several wells, including at least three of the Waukesha Water Utility wells, which will make the water unusable without treatment or well rehabilitation to reduce salinity. One Waukesha Water Utility well has recently been successfully rehabilitated to significantly reduce salinity levels.

A mound of Precambrian rock has recently been detected on the up-thrown side of the fault in the northwest side of the city (AST, 2000a). An area of high conductivity groundwater was detected by surface geophysical methods. The data suggests that the area is likely to contain saline water caused by a stagnation zone behind the mound of impermeable Precambrian rock projecting into the permeable part of the aquifer.

2.1.1.5 Recharge to Aquifers

Groundwater enters an aquifer from a point of recharge and flows toward a point of discharge. Recharge areas are generally topographically high areas where water can percolate through permeable soil units down to the saturated zone of the aquifer. Discharge points are usually topographically low areas where the head in the aquifer forces water to surface discharge points, usually a stream, lake, or wetland. Water that enters the aquifer is stored in the aquifer until it reaches a discharge point. The volume of water stored in an aquifer fluctuates depending on changes in recharge and discharge. In an unconfined aquifer, changes in storage result in changes in the depth to water. In confined aquifers, changes in storage change the pressure head in the aquifer but do not change the saturated thickness of the aquifer. Most aquifers exist in a dynamic state with seasonal and longer-term changes in recharge and discharge, resulting in minor fluctuations in the storage component of the aquifer.

The concept of a dynamic equilibrium between recharge, discharge, and storage is known as the water budget. Aquifers have a limited budget of water, and if one component is changed, another component must also change to compensate. In practical terms, this means that significant changes to the recharge or discharge will result in a change in storage in the short-term and a change in discharge in the long-term. If the discharge component is increased, usually by adding pumping wells to the aquifer, the amount of water in storage is reduced around the well. If the resulting reduction in water levels can induce more recharge from surface sources, the system will reach a new equilibrium, and water levels and discharge will stabilize. If the recharge does not increase significantly, storage will continue to drop and the discharge to other sources will be reduced to accommodate the pumpage. If the pumpage is greater than the recharge, water levels will continue to decline until the wells are no longer able to maintain the pumping rate.

By this process, water pumped from wells must ultimately be replaced by increased recharge or the discharge to surface water bodies will decrease. If pumpage is great enough, discharge to surface water will eventually cease. Reduced groundwater discharge to surface water can significantly reduce water levels, particularly during periods of low precipitation.

This can result in the degradation or destruction of wetlands, deterioration of surface water quality, streams running dry for parts of the year, and lower water levels in lakes.

The same impacts can be caused by reducing the normal recharge to an aquifer. This can happen naturally, as in a drought, or due to man-made changes related to development. As areas are developed, impermeable surface area increases. The water is forced to run off these areas with essentially no infiltration. Typically, the run-off is channeled through storm drains to surface streams, and is lost as potential recharge to the aquifers. The reduction in recharge that occurs during development is a function of many factors, but reductions in the range of 30 percent are frequently estimated for typical suburban development.

In addition to reducing recharge, typical suburban development patterns often cause increased groundwater pumpage from wells. This typically results in a reduction of groundwater discharge to surface water bodies. The changes are typically subtle at first. However, if the changes are allowed to grow, negative impacts to the aquifer and environment can occur.

The magnitude and consequences of the changes depend on the characteristics of the aquifer in question. In eastern Waukesha County, the pumpage from the sandstone aquifer has exceeded recharge for decades. Because the aquifer is confined in this area, the decline in head in the aquifer has not caused a substantial increase in recharge to the aquifer, and the bulk of the water pumped has come from a loss of storage in the aquifer. This has resulted in the aquifer becoming "mined" for groundwater, with head in the aquifer declining by over 5 feet a year in much of eastern Waukesha County. Head will continue to decline in the aquifer unless pumping is reduced substantially on a regional basis. Left unchecked, the decline in head will eventually limit the volume of water that can be pumped from the aquifer. This process will eventually bring the pumping rate into balance with the recharge rate after the storage volume has been exhausted.

The decline in head in the sandstone aquifer has been accompanied by a rise in salinity in the water produced by several deep wells. The deterioration of water quality seen in the aquifer is typical for confined aquifers that are being heavily mined as water is drawn from storage from deeper parts of the aquifer. Water in the deeper parts of the aquifer has been in contact with the rock for much longer periods of time, which allows more mineral matter to be dissolved and increases the salinity of the water. This is the same pattern of regional decline and deteriorating water quality that was experienced in northeastern Illinois in the 1970s and 1980s. The trend was reversed when many large municipal water utilities changed to surface water sources and sandstone aquifer pumpage was substantially reduced.

The dolomite and sand and gravel aquifers receive more local recharge. Generally, these aquifers are covered by permeable soils, or perhaps a few feet to a few tens of feet of low permeability clay. Where the soils are relatively permeable, recharge can enter the aquifer easily. Where clay layers are present, they are generally not continuous, and areas where the clay is thin or absent are common. These areas act as "recharge windows," which allow local recharge to enter the aquifers. The ability of the dolomite and sand and gravel aquifers to recharge locally allows these aquifers to produce more water on a regional basis without significant declines in water levels. It also makes these aquifers more susceptible to local land use practices that can reduce the amount of local recharge or introduce contaminants into the aquifer. As a result, local management of the recharge areas of the dolomite and sand and gravel aquifers is much more important than for the sandstone aquifer.

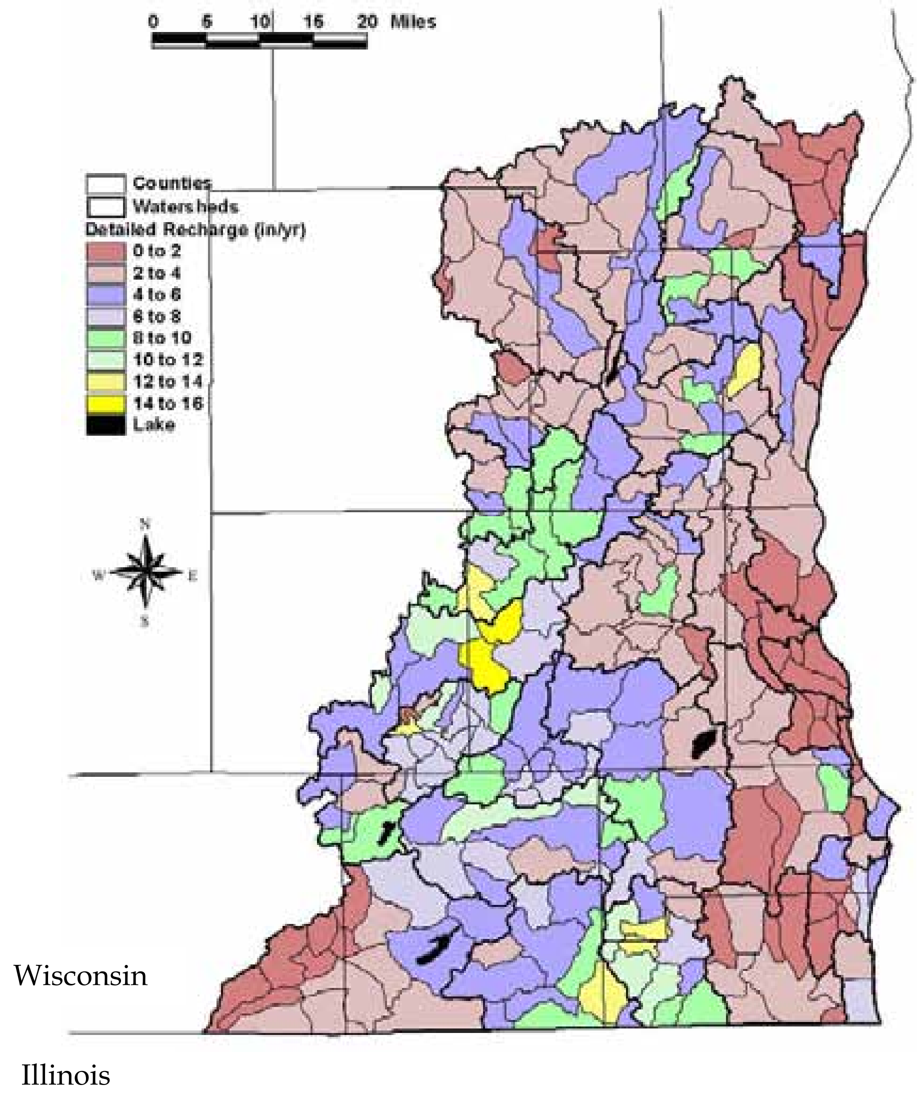

FIGURE 2-6
Recharge Rates for Southeastern Wisconsin

Given the increased importance of the sand and gravel and dolomite aquifers for meeting future water needs, proper aquifer management will be a crucial planning issue. Dr. Douglas Cherkauer has calculated groundwater recharge rates for southeastern Wisconsin. Figure 2-6 presents the estimated recharge rates (Cherkauer, 2001). Recharge varies from less than 2 inches per year, to 14 to 16 inches per year. For the purposes of comparison, the projected ADD for 2050 of 13.3 mgd could be sustained by the recharge from an area of 17.4 square miles at a recharge rate of 16 inches per year. An area of 139.7 square miles would be needed at a rate of 2 inches per year.

While it is currently not possible to quantify the volume of recharge necessary to maintain surface water, it is reasonable to assume that substantial diversions of recharge from current levels may have negative impacts to the environment and the aquifers. Given this assumption, it would seem prudent to develop management strategies to provide increased recharge to offset changes in recharge due to development and increased pumpage. Some areas in the country have started using tertiary treated effluent for groundwater recharge. This approach is relatively expensive and creates a risk of groundwater contamination.

Several water utilities around the country have been using ponds and infiltration structures to artificially enhance the recharge of stormwater. While some risk of contamination is present if not handled properly, this is a proven technology with potential application for the city. Current Wisconsin Department of Natural Resources (WDNR) well codes and stormwater codes do not encourage artificial recharge. However, after discussions with several WDNR source water protection personnel, we have learned that the WDNR recognizes the need for these technologies and is looking into the means to make them easier to implement in Wisconsin. If the region continues to increase its reliance on the sand and gravel and dolomite aquifers, artificial recharge technologies may become necessary to maintain the aquifers, as well as to preserve the quality of surface water.

2.1.1.6 River Alluvium (Fox and Rock Rivers)

The limitations of recharge to a shallow aquifer can be overcome by designing a wellfield to induce infiltration from a surface water body, such as a river (Figure 2-7). By locating a wellfield in the permeable alluvial river sands immediately adjacent to a river, groundwater that would normally discharge to the river is intercepted by the wells. If the wellfield is pumped higher than the natural groundwater flux toward the river, water will be taken initially from storage in the alluvial sand aquifer and ultimately be replenished by recharge from the river as induced by the pumpage.

The fundamental principles of this method involve using the vast volume of the permeable sand and gravel deposits adjacent to and under many rivers as a storage vessel to store water during high river stage flow for use by the wellfield. This method has the advantages of storing large volumes of water without a surface reservoir, and evening out the changes in water quality that occur in the river water.

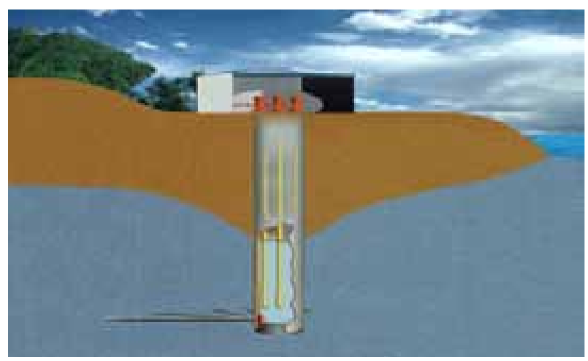

FIGURE 2-7
River Alluvium Well

These types of wellfields are usually called alluvial wellfields, although they are also called river bank filtration systems. They are commonly used in much of the Unites States, particularly where other aquifers are limited, stream flows are inadequate under low flow conditions, and surface water reservoirs are impractical or undesirable. They are also used extensively in Europe.

The volume and timing of the recharge is a function of several factors, including the groundwater flux toward the river, the permeability and extent of the alluvial deposits, the permeability of the river bed, the volume of pumpage from the wellfield, and the proximity of the wells to the river. Alluvial wellfields often consist of a line of shallow wells drilled adjacent to a river that are screened in river alluvium at depth of about 50 to 100 feet. Often, these wells are drilled in the flood plain and have casings that extend above the flood level. In some areas, horizontal collector wells are used to obtain water from under the river bed itself.

Because these wellfields can induce higher recharge rates, they often have much higher sustainable capacities than typical shallow wells. For example, the Cities of Lincoln and Omaha Nebraska operate several alluvial wellfields in the Platte and Missouri River alluvial deposits. Several of these wellfields have produced tens of millions of gallons per day for decades. Modeling studies have shown that over 90 percent of the produced water comes from induced recharge from the river. In other areas, where groundwater discharge to the rivers is higher, the percentage of river water produced by the wellfield is lower.

The capacity of individual wells within an alluvial wellfield is limited by the thickness and the permeability of the formation. In several cases, the alluvial deposits are relatively thin, which limits the length of screen that can be installed, thus limiting the capacity of the well. In other cases, the permeable deposits are relatively shallow, which limits the draw down available to a vertical wells. In these types of aquifers, higher capacity can be obtained by drilling more vertical wells or by drilling a smaller number of horizontal wells. Horizontal wells can place a much longer section of screen within a thin aquifer and can produce much more water, creating a smaller draw down over a greater area of the aquifer. Several alluvial wellfields use horizontal wells drilled directly under the river bed. Most of these wells derive the major portion of their water from the rivers.

In the Waukesha area, there are at least two potential areas for developing an alluvial wellfield. The two most promising areas are the shallow sand and gravel deposits along the Fox River immediately south of the city and the potential shallow alluvial deposits along the Fox River (Figure 2-8). Of the two areas, the Fox River alluvium appears to be the most logical option for the Waukesha Water Utility.

FIGURE 2-8
Fox River

To the south of Waukesha, the Fox River runs above a bedrock valley that is a tributary of the much larger Troy bedrock valley. Boring logs from the area indicate that the bedrock valley is filled with a series of interlayered sand and gravel rich outwash deposits and clay rich till sheets. The upper 50 feet of the unconsolidated material consists primarily of permeable sand and gravel deposits. These deposits are probably glacial outwash deposits that predate the alluvium from the present day Fox River. The Fox River alluvium is believed to be in direct contact with the outwash deposits, which has the effect of greatly expanding the extent of permeable material in connection with the river. The permeable deposits appear to extend from Sunset Drive along the Fox River all the way to the Vernon Marsh. This unit appears to be very favorable for the construction of an alluvial wellfield, and may be particularly suitable for one or more horizontal wells.

The Rock River (Figure 2-9) is also likely to be surrounded by permeable alluvial sand and gravel deposits. However, regional geologic information indicates that in the area east of Watertown, the Rock River flows through clay rich till deposits with bedrock within 50 feet of the surface. As a result, the extent of the permeable deposits is likely to be less than the deposits along the Fox River. Given that the alluvial deposits are likely to have a lower storage volume and yield less water during periods of low river flow, and given that about 15 miles of additional water main would be needed to access this source, it does not appear feasible. As a result, the Rock River alluvium will be deleted from further consideration, and further evaluation of alluvial wells will concentrate on the Fox River alluvium.

FIGURE 2-9
Rock River

2.1.2 River Water Sources – Fox and Rock Rivers

The City of Waukesha is located along the Fox River of the Mississippi River watershed. There are approximately 126 square miles of watershed upstream of the Prairie Avenue bridge in the city. The Rock River is located about 20 miles to the west-northwest of the city. There are approximately 969 square miles of watershed upstream of the City of Watertown. Both the Fox and Rock Rivers were considered as potential water sources for the Waukesha Water Utility.

The Fox River flows from the northeast to the southwest through the heart of the City of Waukesha. The watershed is rapidly developing with growth in the City of Waukesha, the City and Village of Pewaukee, the Village of Sussex, and portions of the City of Brookfield and village of Menomonee Falls. Wastewater treatment plants that discharge to the Fox River are located in the Village of Sussex, and in the Cities of Brookfield and Waukesha.

The Rock River flows to the west of the City of Waukesha. The closest segment is in Jefferson County about 3 miles west of Lac La Belle. The Rock River watershed is about 7 times the area of the Fox River Watershed and is characterized by small rural communities with associated wastewater treatment facilities. Land use is predominantly rural and natural areas including the Horicon Marsh.

2.1.2.1 River Flow

Flow records for the Fox River have been obtained at the Prairie Avenue bridge in Waukesha. This location is just downstream of the central city and upstream of the wastewater treatment plant. The average daily river flow over the past 20 years of record has been 76 mgd. That is about 27.7 billion gallons per year on average. The Waukesha Water Utility currently uses about 3 billion gallons per year. A plot of 10 years of river flow data from 1988 to 1998 is shown on Figure 2-10.

The Fox River has significant seasonal variations in flow. Summer dry weather flows drop well below seasonal averages. Figures 2-11 through 2-13 show river flow for wet, dry, and average precipitation years. Also shown is the forecasted Waukesha Water Utility water demand for the year 2050.

Review of this information indicates that the Fox River is not suitable as a single reliable source of water for the existing or future utility service area. Review of historic data indicates that adequate dry weather flow, including an allowance for base, would have been available for only 4 of the past 20 years. A supplemental reservoir such as a large lake, quarry, or aquifer storage would be required to bridge the dry weather period. The reservoir capacities required for the dry years over the 20-year period of record are shown on Figure 2-14.

Flow records for the Rock River have been obtained at Watertown. The monitoring station is located just downstream of the closest point of connection from the city of Waukesha. The average daily river flow over the past 20 years of record is 441 mgd. That is about 161 billion gallons per year on average. The Waukesha Water Utility currently uses about 3 billion gallons per year. A plot of 10 years of river flow data from 1988 to 1998 is shown on Figure 2-15.

The Rock River also has significant seasonal flow variations. Summer dry weather flows drop well below seasonal averages. Figures 2-16 through 2-18 show river flow for wet, dry, and average precipitation years. Also shown is the existing and forecasted Waukesha Water Utility water demand for 2050.

Review of this information indicates that the Rock River is not suitable as a single reliable source of water for the existing or future Utility Service Area. Review of historic data indicates that adequate dry weather flow, including an allowance for base flow, would have been available for 16 of the past 20 years. A supplemental reservoir such as a large lake, quarry, or aquifer storage would be required to bridge the dry weather period. The reservoir capacities required for the dry years over the 20-year period of record are shown on Figure 2-19.

2.1.2.2 Water Quality

Water quality data has been obtained for the Fox and Rock Rivers. Generally, the water in both rivers is suitable as a water supply with adequate treatment. Due in part to the rural and open character of the watershed, water quality is better in the Rock River.

Both the Rock and Fox Rivers are designated as recreational waters. If they were to be used as a source of drinking water, their designation would change. This could result in stricter wastewater treatment plant effluent limitations and significant compliance costs for any wastewater plant discharging into these waters.

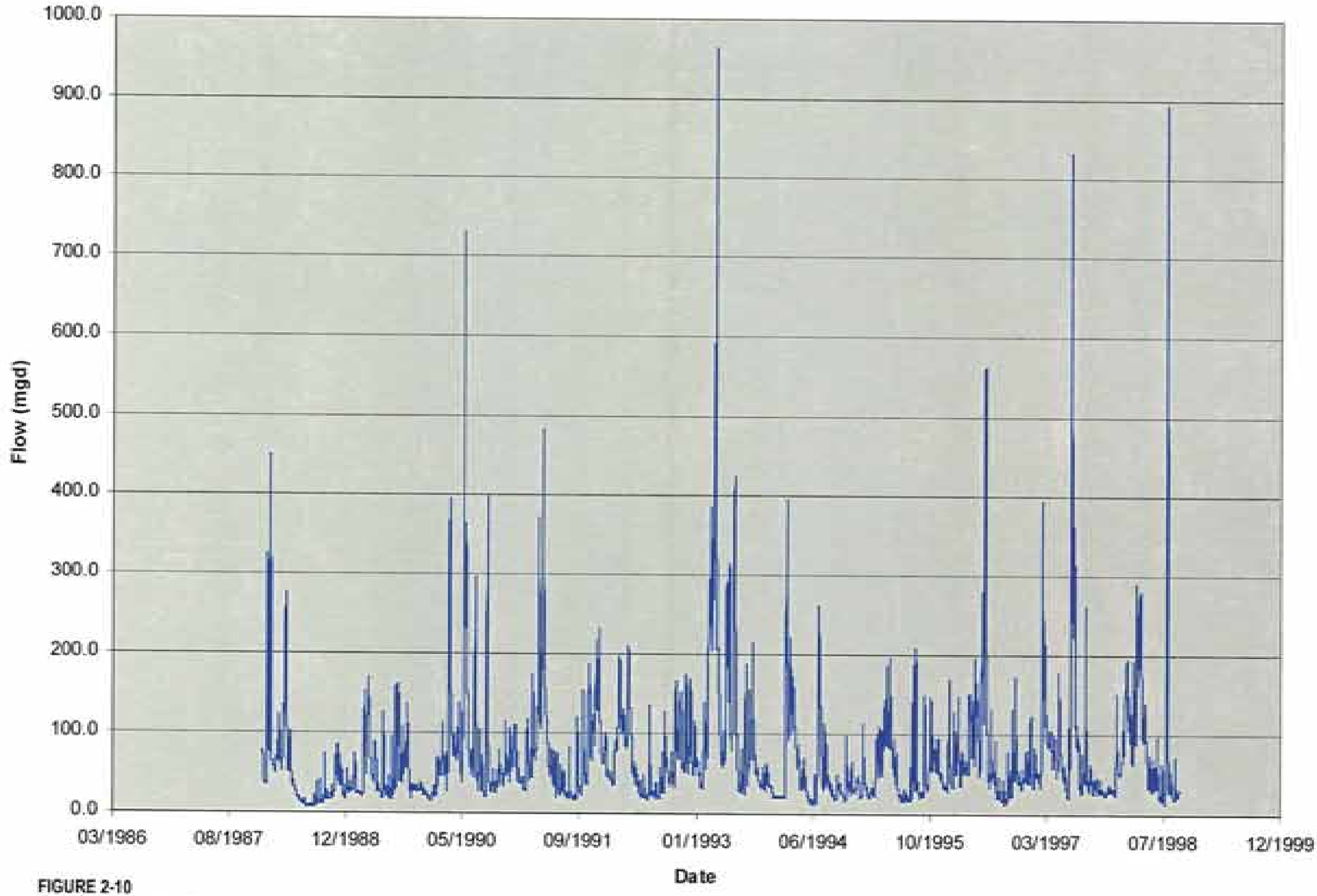

FIGURE 2-10
Fox River Historical Flow

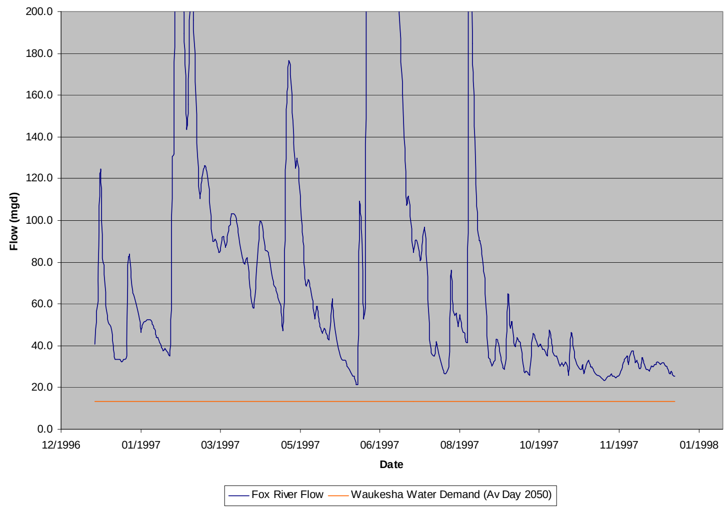

FIGURE 2-11
Fox River Flow (Wet Year)

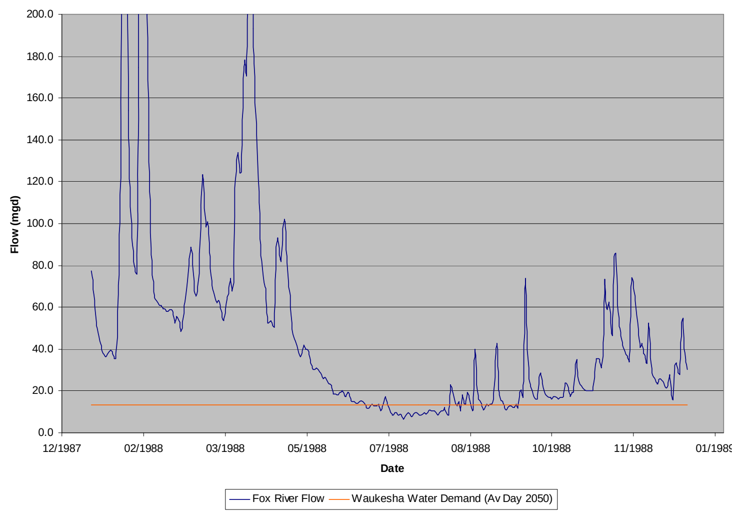

FIGURE 2-12
Fox River Flow (Dry Year)

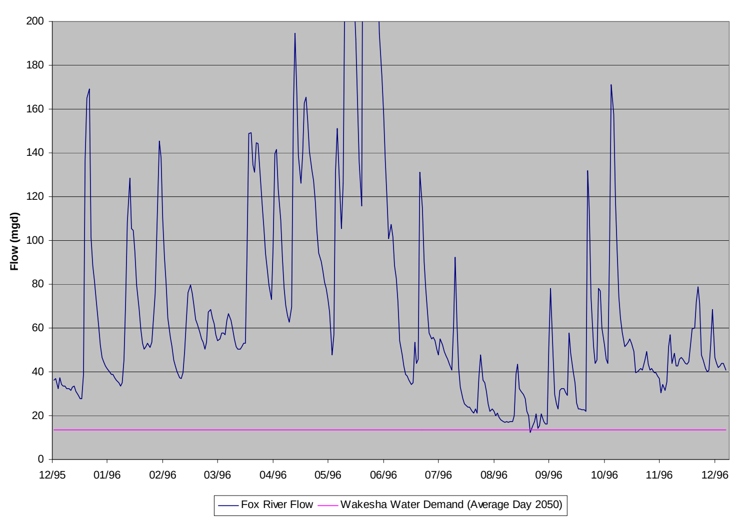

FIGURE 2-13
Fox River Flow (Average Year)

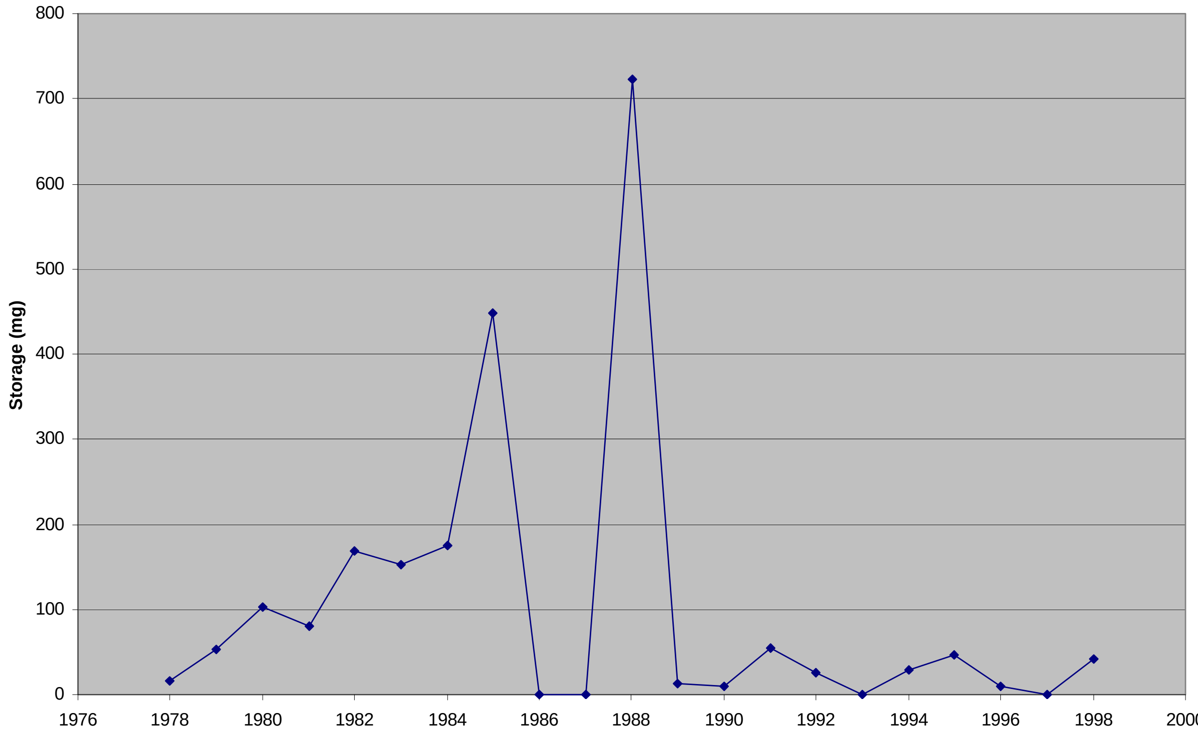

FIGURE 2-14 Reservoir Storage Required–Fox River

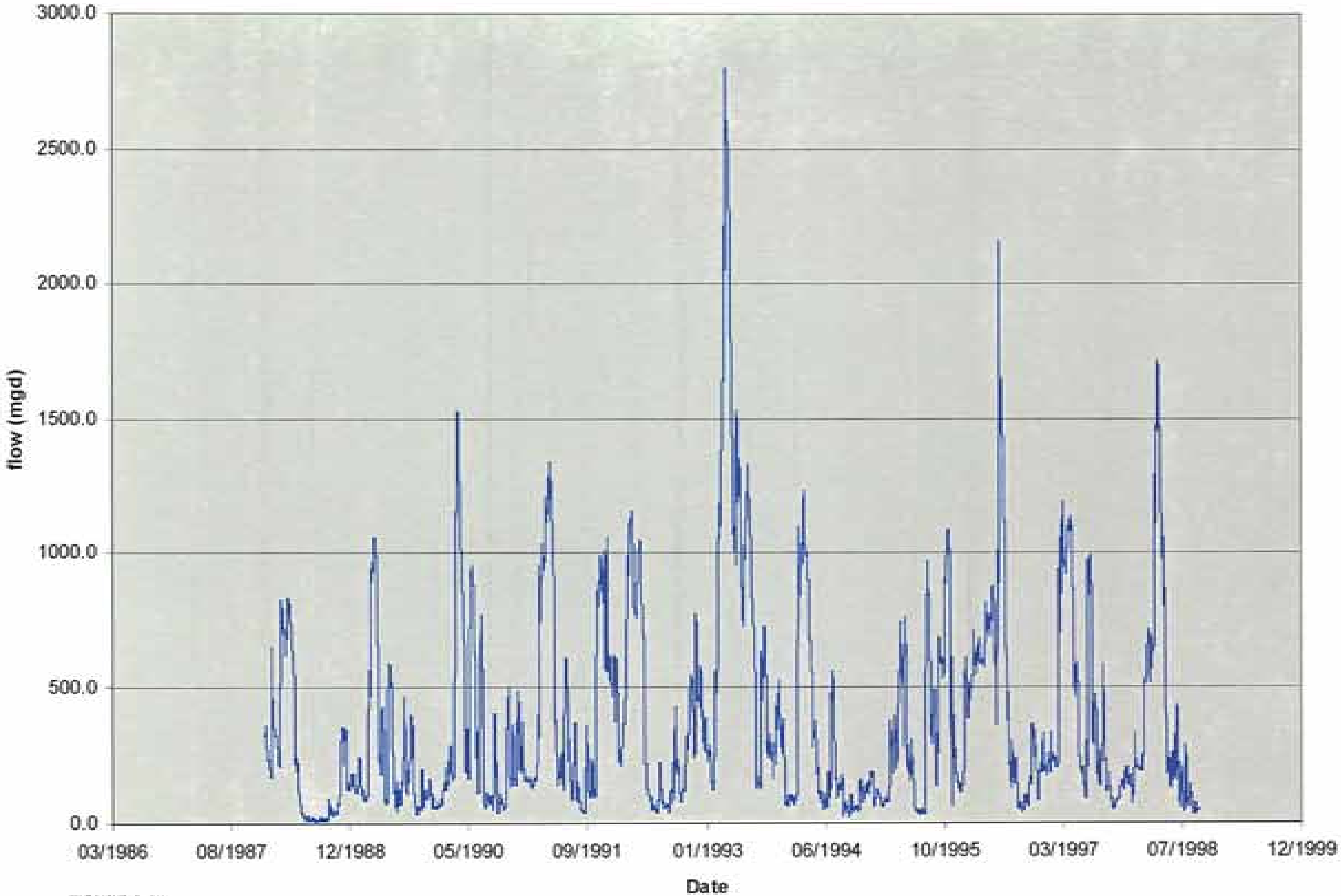

FIGURE 2-15
Rock River Historical Flow

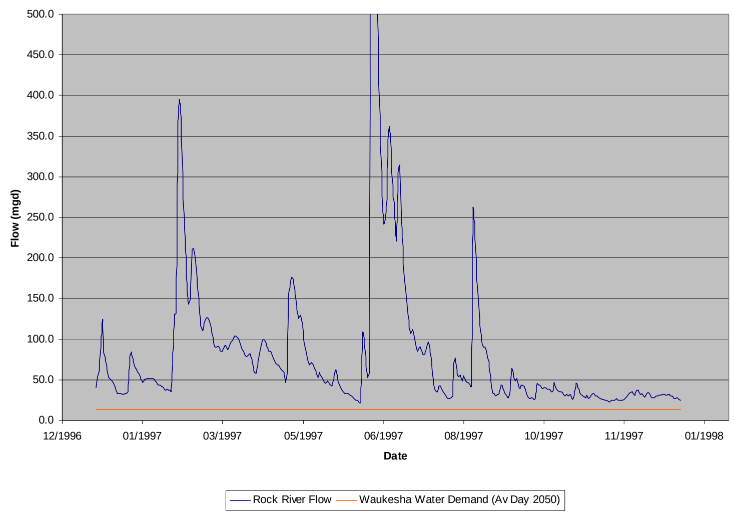

FIGURE 2-16
Rock River Flow (Wet Year)

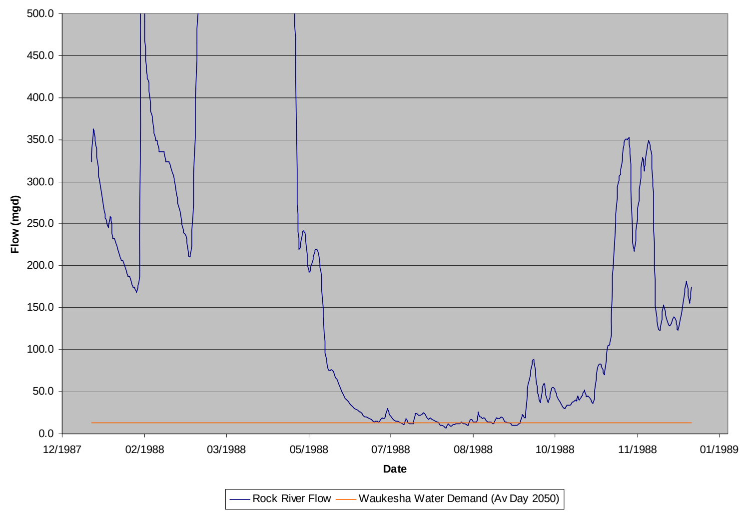

FIGURE 2-17
Rock River Flow (Dry Year)

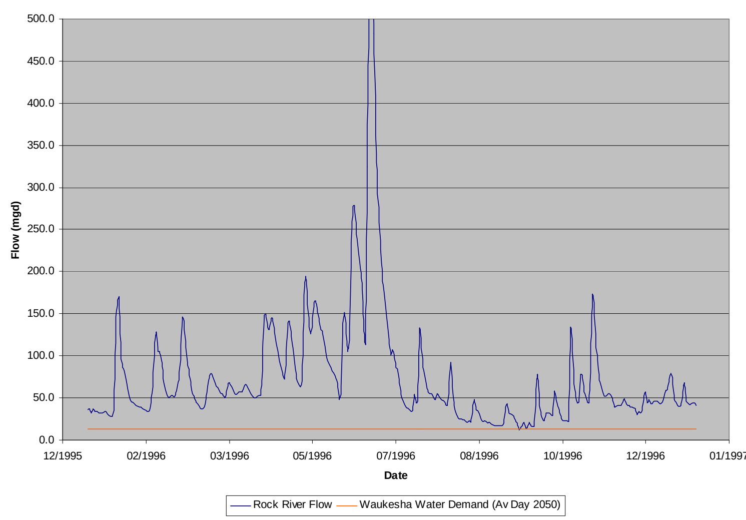

FIGURE 2-18
Rock River Flow (Average Year)

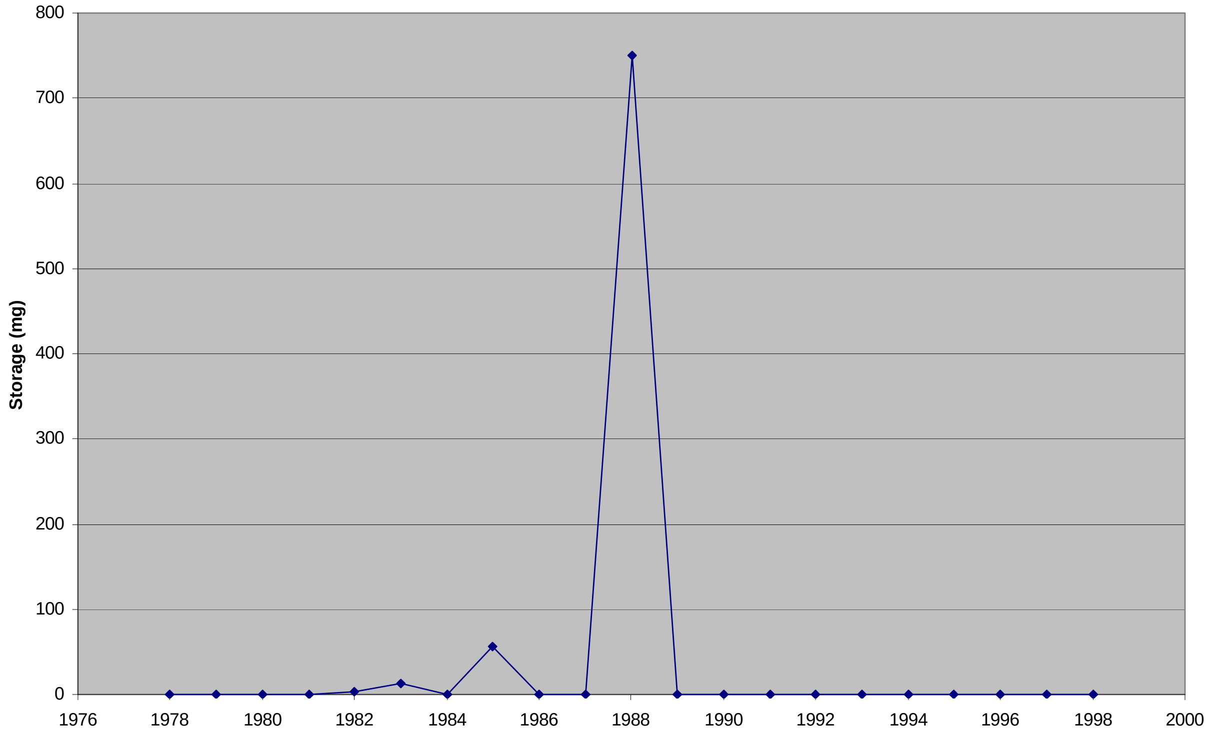

FIGURE 2-19 Reservoir Storage Required—Rock River

2.1.3 Lake Michigan

Lake Michigan is the second largest Great Lake by volume, and is the only Great Lake located entirely within the United States (Figure 2-20). The Lake Michigan Basin is an area of land where rivers, streams, and other surface waters drain into Lake Michigan. The extent of the Lake Michigan Basin is shown on Figure 2-21. The lake's drainage basin covers parts of four states and more than 45,000 square miles.

FIGURE 2-20 Lake Michigan

Hydrologically, Lake Michigan and Lake Huron are considered one lake because they are joined at the Straits of Mackinac. Lake Michigan's cul-de-sac formation results in water entering the lake, circulating slowly, and being retained for a long time before leaving through the Straits of Mackinac. It takes roughly 100 years for the water in the lake to be completely replaced.

The lake is 307 miles in length and 118 miles wide. Its maximum depth is 925 feet and average depth is 279 feet. The water surface area covers 22,300 square miles and the volume of the lake is 1,180 cubic miles, or 1.3 million billion gallons of fresh water.

FIGURE 2-21 Lake Michigan Basin (Watershed)

The elevation of the lake surface fluctuates, but is historically about 577 feet above mean sea level. Fluctuations tend to coincide with climatic changes. The lake has a 1,660-mile shoreline made up largely of sand and pebble beaches.

2.1.3.1 Lake Michigan Water Quality

Lake Michigan water quality is monitored by a number of local, state, and national agencies. Generally speaking, the quality of lake water in and around Milwaukee, Wisconsin, is good. Water of excellent quality is provided to consumers by one of a number of surface water treatment facilities in or near Milwaukee. Table 2-1 provides capacities of local treatment facilities.

TABLE 2-1
Lake Michigan Water Treatment Plant Capacities
Future Water Supply

No.	Facility Name	General Treatment Methods	Disinfection	Capacity	Available Capacity *
1	Port Washington	Rapid Sand	Chlorination	4 mgd	2 mgd
2	North Shore Water	Rapid Sand	Chlorination	16 mgd	9 mgd
3	Linnwood (Milwaukee)	Rapid Sand	Chlorination, Ozonation	276 mgd	Combined ±50 mgd
4	Howard Avenue (Milwaukee)	Rapid Sand	Chlorination, Ozonation	105 mgd	
5	Cudahy	Rapid Sand	Chlorination	6 mgd	2.3 mgd
6	South Milwaukee		Chlorination	8 mgd	4 mgd
7	Oak Creek	Rapid Sand	Chlorination	20 mgd	7.4 mgd
8	Racine	Rapid Sand	Chlorination	40 mgd	0 mgd
9	Kenosha	Membrane	Chlorination	34 mgd	15 mgd

* Available capacity is based on reported treatment plant capacity minus historic peak day or if not available, peak day from 1999 - 2000.

At the two Milwaukee treatment facilities, the Howard Avenue and Linnwood Plants, average raw water quality parameters are similar. The water is characterized by moderate hardness and alkalinity, with low color and generally low organic content.

Because the quantity available and the quality of the Lake Michigan supply are both considered excellent, the lake is often looked to as a source of supply for municipal water systems. Figure 2-22 provides the general location of the plants located within 50 miles of Waukesha.

1. Port Washington
2. North Shore Water
3. Linwood (Milwaukee)
4. Howard Avenue (Milwaukee)
5. Cudahy
6. South Milwaukee
7. Oak Creek
8. Racine
9. Kenosha

FIGURE 2-22 Location of Lake Michigan Water Plants

While each plant has its own unique methods for treating the lake water, treatment generally consists of coagulation, settling, filtration, and disinfection. The finished water provider is required, or it will soon will be required, to meet a variety of rules including:

- Surface Water Treatment Rule (SWTR) and Enhanced SWTR (Long-Term 1 & 2)
- Disinfection/Disinfection By-product Rules (Phase 1 and 2)
- Information Collection Rule
- Filter Backwash Rule

Some rules relate specifically to surface water plants, and are in addition to other rules all water utilities must meet.

One area of particular concern for surface water supplies since 1993 is *Cryptosporidium.* These concerns are—or have been— addressed by most treatment facilities using multiple barriers. For instance, the following discussion outlines the treatment practices and finished water quality of the Milwaukee Water Works.

The Milwaukee Water Works treats water by using various chemicals and processes to meet finished water product quality objectives. These include ozonation, alum coagulation, flocculation, settling, and filtration. Chlorine and ammonia are added for additional disinfection. Hydrofluosilicic acid is added at about 1 parts per million (ppm) for dental health, and phosphoric acid is added at about 2 ppm (as PO4) to reduce lead pipe corrosion.

Recently, the Milwaukee Water Works completed installation and placed into operation ozonation facilities at both treatment plants. Ozonation is now the primary method of disinfection. Ozone is an attractive water purification method for many reasons. It is a strong oxidant that reacts rapidly with most microrganisms and organic substances in water and does not impart tastes or odors. The effectiveness of ozone for inactivating viruses and killing bacteria is well known. It is the most powerful oxidant available for the chemical disinfection of a public drinking water supply, and is the most effective chemical disinfectant known for the inactivation of *Cryptosporidium*. Ozonation is typically installed at water treatment plants to achieve multiple water quality objectives. A common primary objective is to achieve enhanced disinfection without increasing chlorine dosage.

The water utility also practices chloramination, which is the combined application of ammonia and chlorine. Chloramination is performed at the end of the treatment process, prior to distribution. Chloramines are more stable than chlorine alone, providing a longer lasting residual disinfectant in the large distribution systems. Ammonia and chlorine are added at levels to achieve chloramine target concentrations of approximately 1 ppm in the distribution system.

The chemical, physical, and microbiological quality of finished water is constantly monitored at both treatment plants. The Linnwood treatment plant laboratory performs thousands of tests on the plant water treatment process, on water samples taken from the distribution system, and on water samples taken from new main construction. There are over 60 strategically located sites in the distribution system that are tested weekly. This physical, chemical, and microbiological testing goes on 24 hours per day, 7 days a week. The laboratory is certified by the State of Wisconsin to perform specified laboratory tests.

In late 1993, an outbreak of *Cryptosporidiosis* occurred in the Milwaukee area. This outbreak was associated with the public water supply and approximately 400,000 people were affected. Improvements implemented at both treatment plants since the outbreak include:

- Application of ozone as the primary method of disinfection
- Discontinuing the practice of recycling filter backwash water to avoid reintroduction of contaminants into the treatment process
- Improving the monitoring of filter effluent to better control the filtration process
- Improving control of chemical coagulant doses to improve particle removal
- Monitoring for *Cryptosporidium* in the raw, backwash, and treated water
- Developing new customer service systems to improve the response times to customer inquiries

In addition, the following completed work further enhances and protects the finished quality of Milwaukee water supplies:

- Relocation of a Lake Michigan intake pipe, which has reduced the influence of pollutants reaching the Howard Avenue plant
- Enhanced particle and turbidity removal at both treatment plants through improvements and upgrades to chemical feed systems and filters, including new dual media filters and underdrain systems

Water quality laboratory analysis results for plant finished water from the Milwaukee Water Works indicates that both plants are in compliance with all standards.

The following is an excerpt from the 2001 report on water quality issued by the Milwaukee Water Works, as required by the Safe Drinking Water Act:

"The Milwaukee Water Works (MWW) utilizes a multi-barrier approach to protecting the public health from waterborne diseases. In recent years, the utility has made improvements in source protection (A) by extending the south intake, in disinfection (B) by installing ozone facilities at both its treatment plants, and in filtration (C) by replacing underdrain systems and the filter media. The distribution system (D) is the final barrier in protecting against disease. Monitoring and testing in the distribution system is extensive…."

"MWW has never violated a contaminant level or any federal or state water quality standard. In this brochure, we have provided you with details about the source of water, what has been detected in it, and how it measures up against standards set by regulatory agencies. We continually strive to provide you with the highest quality drinking water available."

2.1.3.2 Lake Michigan Water Supply and Transmission

Providing Lake Michigan water to the City of Waukesha requires adequate treated water supply and transmission of the finished water to the city. Table 2-1 provides information regarding available treatment capacity at local plants.

Based upon these data, the only water system with the capacity to meet the current and projected Waukesha maximum water demands is the Milwaukee Water Works. Other water systems could provide adequate capacity with treatment plant expansion.

2.1.3.3 Milwaukee Water Facilities

The City of Milwaukee Water Works consists of two surface water filtration plants, three major pumping stations, 11 repumping stations, storage facilities, and about 1,900 miles of water mains serving approximately 160,000 residential, commercial, industrial, and public customers. The utility also provides wholesale service to the Cities of West Allis, Shorewood, Wauwatosa, Greendale, and Brown Deer; the Village of Menomonee Falls; and the Milwaukee County Institution Grounds. In 1999, the average day pumpage delivered by the Water Works was approximately 130 mgd. The peak day pumpage was about 190 mgd.

The total practical capacity of all of the Water Works facilities is approximately 380 mgd. Individually, the Linnwood purification plant, located in the north water production district, is capable of treating approximately 275 mgd. The Howard Avenue purification plant, located in the south water production district, is capable of treating approximately 105 mgd. Currently, the Milwaukee Water Works has a large surplus in treatment capacity.

Filtered water from the treatment plants is conveyed to three major pumping stations—the North Point Pumping Station, the Riverside Pumping Station, and the Howard Avenue Pumping Station. These major stations have pumping capacities which range from 165 to 240 mgd. From these facilities, water is further distributed to 11 booster stations throughout the city. These have total capacities which ranging from about 2.7 to 80 mgd. Most of the utility's pumping stations have two separate incoming power supply lines from the Wisconsin Electric Power Company system. In most cases, however, these separate feeds originate from the same substation. All pumping stations are equipped with independent sources of direct current electric power that operate pump control valves, supervisory control and data acquisition (SCADA) systems, and instrumentation devices. In the event of a power outage, the DC power sources continue to operate these systems and provide an indication to the main control center that a power outage has occurred.

The Milwaukee Water Works Control Center is located on the fourth floor at 841 North Broadway in Milwaukee, Wisconsin. The water systems operators monitor and control all of the pumping used to deliver water to the consumers after treatment. Operators have the responsibility of coordinating all of the activities of the Water Works pumping operations to maintain adequate pressure in the seven pressure districts of the service area. The load centers at the Linnwood and Howard treatment plants control and monitor the pumpage from Lake Michigan and the purification process.

The West Allis water system, which borders the northern portion of New Berlin at the Waukesha county border, is supplied by the Milwaukee Water Works through Milwaukee's high district service area. This district also serves much of the City of Milwaukee. This service area is primarily supplied by the Riverside Pumping Station, located at 1311 East Chambers Street. This station is the largest source of finished water in the Milwaukee Water Works distribution system, supplying water to about 60 percent of the Water Works customers. Pumping equipment at this station includes nine electric driven centrifugal units with individual capacities ranging from 15 to 30 mgd, a total capacity of 240 mgd, and a reliable capacity of 210 mgd. The average daily pumpage delivered by this station is approximately 50 mgd. The suction source for this station is finished water from the Linnwood treatment plant, which is conveyed by gravity through a 9-foot-diameter tunnel from the plant to the booster station.

The system-wide maximum day pumpage experienced by the Milwaukee Water Works, 322.25 million gallons, occurred on August 2, 1988. On that day, the Riverside station pumped 137 million gallons into the system.

The southern areas of Milwaukee County that border Waukesha County, Greenfield, and Hales Corners are provided service from the southwest service area. This area has a hydraulic grade of 966 feet, which is almost 100 feet higher than the Riverside district. Water is boosted to the Riverside side district from the Riverside station. The area of the Milwaukee system near Hales Corners can provide a hydraulic grade roughly 66 feet greater than the area around West Allis.

The Milwaukee system contains a network of water transmission mains ranging in size from 12 to 60 inches. The closest main with adequate capacity to meet a maximum day demand for Waukesha is located near the intersection of Howard Avenue and 92nd Street. From this point, it would take roughly 8 miles of large diameter water main to provide capacity for Waukesha.

2.1.4 Lake Michigan Wellfield

The compact between the Great Lakes governors strictly limits diversions of surface water out of the Great Lakes Basin. However, the compact did not recognize the connection between groundwater and surface water until recently. Research has shown that there are permeable sand and gravel and dolomite units that extend under Lake Michigan and connect Lake Michigan to the shallow aquifers in eastern Ozaukee County (Cherkauer, 1990). Under these conditions, it would be possible to construct a wellfield along the Lake Michigan shoreline and induce recharge from the lake. The produced water would have characteristics very similar to Lake Michigan water, but it would be considered groundwater for the purposes of the compact.

In past years, this legal distinction might have provided an avenue to pump groundwater that has been largely derived from Lake Michigan over the sub-continental divide without triggering the need to permit a diversion out of the Great Lakes Basin. However, in anticipation of just such an event, the WDNR enacted NR 142, which requires WDNR approval for any diversion of water greater than 2 mgd out of a surface water basin. The WDNR has indicated that they would consider such a wellfield as a diversion, and would require a permit from the Council of Great Lakes Governors. Further, the Council of Great Lakes Governors is revising the rules covering diversions under an instrument known as Annex 2001. A specific goal of Annex 2001 is to recognize the connection between surface water and groundwater. It is likely that such a wellfield would also be viewed as a diversion by the council under their future diversion rules.

In addition to the regulatory issues, developing a wellfield adjacent to Lake Michigan would require significant areas of lakefront property, and at least 15 to 20 miles of pipeline through potentially uncooperative municipalities. Given these obstacles, it does not appear that a wellfield along Lake Michigan would provide any advantages over a direct diversion of Lake Michigan water. As a result, this alternative will be eliminated from further consideration.

2.1.5 Fox or Rock River Dam

Both the Fox and Rock Rivers are unable to sustain adequate flow volumes to supply the needs of the Waukesha Water Utility during dry weather. Providing a dam on the Fox River was evaluated in the 1970 Fox River Watershed Plan as a method of bridging the summer dry periods by impounding wet weather flows. The concept was not carried forward in the 1979 Regional Water Quality Management Plan, as it would have required a significant areas of land purchase and would have posed significant regulatory and environmental challenges not likely to be resolved. Therefore, the concept of providing a dam on either the Fox or Rock Rivers will not be considered further.

2.1.6 Historic Springs in Waukesha

The City of Waukesha was once famous for its natural springs that were thought to have healing properties. These springs were fed by the confined water of the shallow sand and gravel aquifer. Many of these springs still exist, but deliver only small quantities of water relative to the demand of the current and future city (Figure 2-23). Therefore, the use of these historic springs as a source of water for the Waukesha Water Utility will not be considered further.

FIGURE 2-23
Hobo Springs: Waukesha, Wisconsin

2.1.7 Wastewater Reuse

Treated wastewater can be used for potable water supply either directly or indirectly. Direct potable reuse of wastewater involves treating wastewater plant effluent to drinking water quality, as shown on Figure 2-24. Although technically feasible, this method of wastewater reuse is discouraged because of the multiple barriers required, the higher health risks posed, the high costs involved, and the public perceptions of safety.
Several communities have demonstrated direct potable reuse, and tests have indicated that the water meets drinking water standards. However, none have successfully implemented direct potable reuse for public consumption, even in areas of limited water.

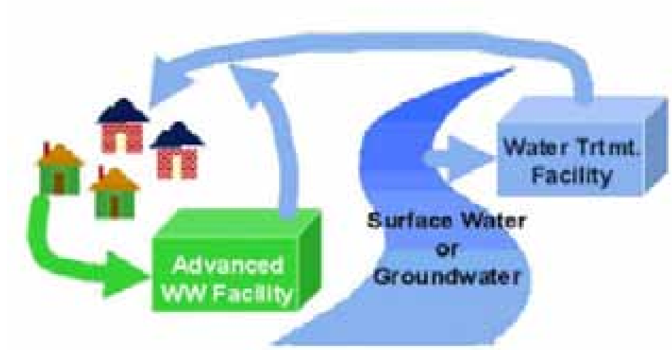

FIGURE 2-24
Direct Potable Reuse

Indirect potable reuse involves discharging treated wastewater to a receiving water body, then using that receiving water body as a source of drinking water supply (Figure 2-25).

Indirect potable reuse can be either planned or unplanned. Much of the Great Lakes Basin practices unplanned indirect potable reuse because wastewater plants discharge into the Great Lakes, which is a source of drinking water. There are no regulations for indirect potable reuse practices. However, the federal government enlisted the National Research Council to develop guidelines (*1998 Issues in Potable Reuse: The Viability of Augmenting Water Supplies with Reclaimed Water*). One of the major conclusions from that report asserts that indirect potable reuse is an option of last resort, after other high quality sources have been exhausted and conservation implemented. Since there are other sources of higher quality water for Waukesha, wastewater reuse will not be considered further as a source of potable water.

FIGURE 2-25
Indirect Potable Reuse

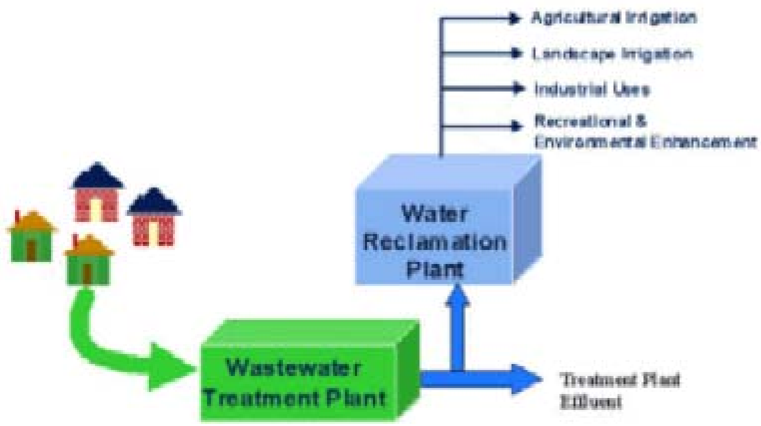

FIGURE 2-26
Non-Potable Reuse

Treated wastewater can also be considered for non-potable reuse, as shown on Figure 2-26. Golf courses and industries that require large volumes of non-potable water are candidates for non-potable reuse. The wastewater would require further treatment, and separate pumps and pipes would be required to deliver the water to potential customers. Non-potable reuse is used to supplement water demands, but is only part of the water supply equation. Non-potable reuse is most commonly practiced in arid regions with limited water supplies. In Waukesha, there would be limited and seasonal demand for non-potable water. Although non-potable water from treated wastewater may become a potential supplemental water source in the future, it is a small part of the entire water supply picture, it is costly, and it will not be considered further in this report as a main water supply source.

2.1.8 Milwaukee River

The Milwaukee River was also considered as a possible source of water for the Waukesha Water Utility. However, water quality is expected to be the lowest of the possible surface water sources. In addition, the river experiences summer low-flow periods, much like the Fox and Rock Rivers, which limit it as a reliable source during dry weather. The river water is also located a considerable distance from the City of Waukesha. It is slightly closer than the Rock River and significantly further than the other surface water sources. The conveyance route from the Milwaukee River would be significantly more complex than any of the other surface water options. Distances from various water sources to Waukesha are shown below:

- City of Milwaukee water from Lake Michigan: 8 miles
- Fox River: 0 miles
- Rock River: 17 miles
- Milwaukee River: 15 miles

The Milwaukee River is a tributary to the Lake Michigan Watershed. Therefore, diversion of Milwaukee River water requires the same consideration as the Lake Michigan/City of Milwaukee option. Given the lowest water quality, the limited low-flow volume, the transportation distance and complexity, and the Lake Michigan diversion situation, it does not appear reasonable to consider it as a viable source of water for the City of Waukesha. Therefore, the Milwaukee River will not be considered further as a potential source of water for the City of Waukesha.

2.1.9 Pewaukee Lake

Pewaukee Lake is located about 5 miles north of the center of the City of Waukesha. Its surface area of approximately 2,500 acres, and it contains about 12 billion gallons of water. The lake watershed is about 18,000 acres, or 28 square miles. The lake includes about 14 miles of shore land that is mostly high-value residential development. The lake is the source water for the Pewaukee River, which flows southeast to the Fox River upstream of the City of Waukesha. The source water for the lake is precipitation to the lake, runoff from the lake watershed, or infiltration/exfiltration to the shallow sand and gravel aquifer. The surface of the sand and gravel aquifer is reflected by the lake water surface.

Given that the annual Waukesha Water Utility water demand is 3 (2000) to 5 (2050) billion gallons per year, and the lake storage capacity is approximately 12 billion gallons, there are some serious questions about the use of the lake as a primary source of water. As a secondary source, there may be better potential. Secondary sources are required for the river sources to bridge the dry weather periods. Secondary sources may include such reservoirs as a quarry, lake, or aquifer that can serve to bridge the summer dry period.

Like the river water sources, Pewaukee Lake is also most vulnerable during the dry summer months. It must continue to provide base flow to the Pewaukee River and maintain its level to accommodate the high demand for summer recreational activities. One week of Water Utility demand is equal to about 1 inch of lake level. Dry periods can last up to 2 months, resulting in a significant potential draw down. Some replenishment from the sand and gravel aquifer is expected to offset the draw down, but significant impacts on Pewaukee River flows and lake levels during dry weather periods are likely.

2.1.10 Waukesha Quarry

The limestone quarry is located north of the City of Waukesha along the Fox River and just downstream of the confluence with the Pewaukee River (Figure 2-27). There are two quarry sites, one located on each side of STH-164. Both quarries are active and are expected to have many years of viable operation remaining. The combined quarry volume is approximately 5.75 billion gallons. Groundwater is drawn down to the bottom of each quarry. WDNR records indicate pumping in the range of 2 mgd, considerably less than the water demand of the Waukesha Water Utility. This water is pumped into the adjacent Fox River.

The quarry is not a good primary source of water because of the relatively low dewatering pumping rate, but it may hold the potential to be a secondary source of water as a reservoir used to supplement river flows during dry weather. The natural recovery rate of the groundwater in the quarries may not be enough to provide the water volume necessary to bridge dry periods. Supplemental water diverted from the Fox River during high river flows may be necessary to provide the required storage volume. Diversion of river water into the quarry may have some groundwater regulatory issues associated with it.

FIGURE 2-27
Waukesha Quarry

Given the anticipated long-term operation of the quarry, its use as a reservoir to supplement the Waukesha Water Utility water supply does not appear to be feasible. If there is a change in the plans to continue the quarry operation, the supplemental reservoir concept could be revisited.

2.1.11 Base Alternatives Summary

Fourteen separate water supply alternatives were evaluated for feasibility. A number of alternatives had fatal flaws (i.e., the inability to supply adequate water) and were screened out. A summary of the water sources that have been screened out are as follows:

Water Source	**Primary Reason for Screening**
Fox River	Inadequate year round supply
Rock River	Inadequate year round supply
Fox or Rock River Dam	Environmental and public concerns
Waukesha Quarry	Inadequate supply, other uses
Waukesha Springs	Inadequate supply
Pewaukee Lake	Limited supply, adverse environmental impacts
Milwaukee River	Poor quality, diversion issues
Wastewater Reuse	Public perception, water quality, limited supply
Milwaukee Wellfield	Political, legal, and infrastructure concerns
Dolomite Aquifer	Inadequate supply, limited sites

The base alternatives to be carried forward include:

- Sandstone aquifer
- Shallow aquifer (Fox River alluvium or sand/gravel)
- Lake Michigan

2.2 Combinations of Alternatives

The base alternatives can be combined to form additional water supply alternatives. There are many advantages to several sources of supply, including:

- Additional quantity
- More reliability/redundancy
- More flexibility for operations
- Ability to minimize environmental impacts
- Ability to phase implementation

If a Lake Michigan supply is obtained, there would not be any need for additional water supply quantity. For this reason, Lake Michigan was not combined with any other new water supply source. However, the sandstone wells may be desired as a backup supply for improved reliability.

Therefore, the following combinations of water supplies were carried forward for analysis:

- Sandstone/Shallow Aquifer
- Sandstone/Fox River Alluvium
- Shallow Aquifer/Fox River Alluvium

This creates a total of seven water supply alternatives to be carried forward for analysis. A general description of the combination alternatives is presented below.

2.2.1 Sandstone/Shallow Aquifer

In this alternative, shallow aquifer water would blended with existing sandstone water. The shallow aquifer would supply about 70 percent of the water. Shallow aquifer water would be blended with sandstone water at existing sandstone well sites so that the blended water would be below radionuclide regulations.

The shallow wellfield would consist of 11 wells. The water would be treated in a 15 mgd iron/manganese removal treatment plant and disinfected with chlorine. The treated water would be conveyed into Waukesha and sent to existing wells 6 through 9 for blending before being pumped into the distribution system. Existing wells 1 through 5 and 10 would be put on standby status.

2.2.2 Sandstone/Fox River Alluvium

In this alternative, Fox River alluvium water would be blended with existing sandstone water. The Fox River alluvium aquifer would supply about 70 percent of the water. Fox River alluvium aquifer water would be blended with sandstone water at existing sandstone well sites so the blended water quality would meet radionuclide regulations.

The Fox River alluvium wellfield would consist of five horizontal wells. The water would be treated in a 15 mgd direct filtration treatment plant and disinfected with chlorine and ultraviolet light. The treated water would be conveyed into Waukesha and sent to existing wells 6 through 9 for blending before being pumped into the distribution system. Existing wells 1 through 5 and 10 would be put on standby status.

2.2.3 Shallow Aquifer/Fox River Alluvium

In this alternative, Fox River alluvium water and shallow aquifer water to the South of Waukesha would be provided. About half the water would be provided from each source.

The Fox River alluvium wellfield would consist of four horizontal wells. The water would be treated in an 11 mgd direct filtration treatment plant and disinfected with chlorine and ultraviolet light.

The shallow aquifer wellfield would consist of eight vertical wells. The water would be treated in an 11 mgd iron/manganese removal treatment plant and disinfected with chlorine.

The treated water would be conveyed into Waukesha and tied into the existing distribution system. Existing sandstone wells would be put on standby status.

2.2.4 Aquifer Storage and Recovery

2.2.4.1 Description

Aquifer Storage and Recovery (ASR) was first used in the United States at Wildwood, New Jersey in 1968 as a method to help the area water utility meet summer peak demands, which could be as much as five times the ADD. ASR allows a utility to take excess capacity, available during low demand periods, and store it in aquifers through wells where it may be later recovered to meet seasonal peak demands (Figure 2-28). The treated water that is stored safely underground typically does not require treatment upon recovery and still meets all drinking water standards. Chlorine is typically added to maintain distribution system disinfectant residual when the water is recovered for use.

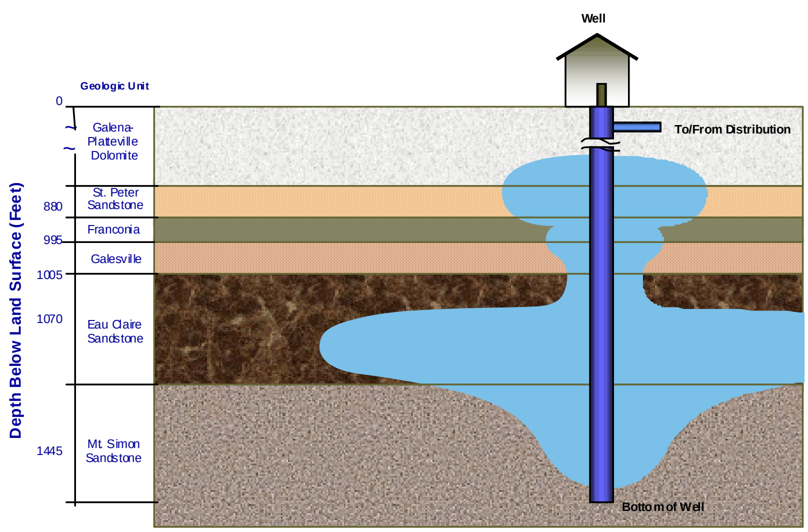

FIGURE 2-28
Aquifer Storage and Recovery

Since 1968, over 40 water utilities in 14 states have used operational ASR systems. Over 50 other pilot systems are being developed in these and seven other states. Wisconsin has an operating ASR well in Oak Creek, and another is being constructed in Green Bay. The Oak Creek ASR well proved that Lake Michigan water stored in the Sandstone aquifer maintains good quality, and it proved that Lake Michigan water stored in the sandstone aquifer does not pick up any radium.

ASR has been used for one or more of 23 different benefits. The most common benefit is deferment or elimination of the need to expand water treatment facilities to meet peak demand, which often results in a cost savings of 50 percent or more when compared to other methods. Other common primary and secondary benefits of ASR include:

- Restoration of declining water levels in deep aquifers caused by decades of over-pumping
- Recovery of previously stored water to avoid seasonal surface water quality variations in nitrate, turbidity, pesticides, taste and odor, or other parameters that increase the cost or complexity of water treatment
- Optimization of treatment plant sizing and reductions in the cost of water supply expansion programs
- Maintains capital investment in idle wells by returning them to beneficial use
- Provides large volume storage for emergency or drought supply
- Minimizes the transmission and distribution system sizing requirements needed to meet peak flow rates

Lastly, since the September 11, 2001, terrorist acts upon the United States have become a primary concern. The military has identified ASR as an acceptable method for storing potable water out of harm's way at military installations around the world.

2.2.4.2 Application to Waukesha

ASR could be used to economically augment any of the water supply alternatives being considered. One or more of the existing or new sandstone wells could be converted for ASR use with another source of suitable potable water.

Shallow Aquifer Alternative. ASR could be used by the Waukesha Water Utility to optimize facilities for a shallow aquifer source. Instead of being sized for maximum day demand, the treatment facility could be sized slightly larger than ADD. When water demand is below ADD, the excess treated water could be recharged into an ASR well. The treated water recharged into the ASR well would displace the radium-bearing native sandstone groundwater and create a zone of potable water stored around the well for recovery during the summer. This eliminates the need for radium treatment.

Potable water from the shallow aquifer would be stored in ASR wells. ASR would allow the Waukesha Water Utility flexibility for future expansion since both the shallow wellfield and ASR wells could be developed with actual rather than forecasted growth.

Lake Michigan Alternative. If the Waukesha Water Utility is successful in procuring a source of treated Lake Michigan water, the water could be recharged into the existing sandstone wells within the city to provide a redundant water supply for emergencies or seasonal peaking. Furthermore, depending on the Lake Michigan water purchase contract terms, ASR could allow the Waukesha Water Utility more flexibility in negotiating off-peak water prices by using their own ASR wells to minimize or eliminate the variability in seasonal flow rates. This near-constant flow rate scenario may also allow the Waukesha Water Utility to reduce the transmission main and pump station sizing needed to meet peak season flows.

Sandstone Aquifer Alternative. If existing sandstone wells are used, ASR could be used by the Waukesha Water Utility to optimize the size of radium removal water treatment facilities.

Water from several sandstone wells could be routed to a treatment facility sized slightly larger than ADD. When water demand is below ADD, the excess treated water could be recharged into an ASR well. The treated water recharged into the ASR well would displace the radium-bearing native groundwater and create a zone of potable water stored around the well for recovery during the summer.

If new sandstone wells are developed that produce radium-free water from areas near the aquifer's recharge area, this water could be used in a similar manner to restore the existing wells to beneficial use without the need for providing radium removal treatment.

2.2.4.3 ASR Regulatory Status

The Oak Creek Water and Sewer Utility began developing the first ASR system in Wisconsin in 1996. They have since proven that ASR can be used successfully for seasonal peaking using treated Lake Michigan water and the deep sandstone aquifer in Southeastern Wisconsin. During the summer of 2001, they recovered their third full-scale cycle (42 million gallons each) into their distribution system with conditional approval from WDNR.

Green Bay is currently constructing ASR facilities and will begin testing them in 2002, also using Lake Michigan water and existing sandstone aquifer wells. ASR may allow Green Bay to supply water to nine neighboring communities and save $150 million in capital costs.

Prior to 1996, potable water injection was not even considered by WDNR. In fact, there is a prohibition against injection wells– assuming any injection well would be disposing of waste. The 1986 Safe Drinking Water Act (SDWA) amendments included Underground Injection Control (UIC) provisions. Many states, including Wisconsin, have primacy to oversee the UIC program. ASR wells are currently included under Class V "non-hazardous other" wells, which include septic tanks and a variety of other miscellaneous underground injection practices. Due to the breadth of Class V, the United States Environmental Protection Agency (USEPA) allows Class V practices to be permitted on a case-by-case basis or "by rule."

ASR is practiced in 14 states. Wisconsin is in the process of passing ASR legislation, along with at least five other states. WDNR has drafted rules for ASR that will be taken to the WDNR board for comment in 2002. The draft rules allow potable water to be stored underground and discuss meeting the groundwater regulations.

SECTION 3

Evaluation Criteria

A workshop meeting was conducted on October 2, 2001 to determine evaluation criteria for the water supply alternatives. The following six criteria groups were agreed to during the meeting:

- **Reliability**
  - Adequate quantity
  - Source water quality, vulnerability, and consistency
  - Redundancy
  - Sustainability over 50 years
- **Infrastructure**
  - Treatment requirements
  - Intake, wells, pumping, and transmission
  - Integration with distribution system
- **Operations and Maintenance**
  - Staffing levels
  - Residuals handling and wastewater plant impacts
  - Distribution system operation (pumping and compatibility of water quality)
  - Treatment plant operations
  - Ease of overall operation
  - Safety
- **Regulations/Legal**
  - SDWA compliance
  - WDNR compliance and permits
  - Impacts on other natural resources
  - Liability
  - Impact on permit conditions for stormwater and wastewater dischargers
  - Land requirements, zoning, and land use
  - Other regulations or agreements
- **Political and Public Acceptance**
  - Neighborhood aesthetics
  - Home softening impacts
  - Public perception (quality, reliability)
  - Political issues (Great Lakes governors; state; county and township; and local)
  - Potential for a regional solution
- **Schedule**
  - Time to implement
  - Ability to phase

3.1 Rank Evaluation Criteria

Each of the six criteria groups were ranked in hierarchical order of importance, from the most to the least important. For ranking purposes, each criteria group was compared to the other criteria groups to develop a "forced ranking." The results are shown below. For example, Reliability (criterion A) was more important than Infrastructure (criterion B), so an "A" was placed in the Reliability row.

Forced Criteria Ranking							Points	Rank
Reliability	A	a	a	a	a	a	6	1
Infrastructure		B	c	d	e	f	1	6
Operations and Maintenance			C	d	e	c	3	4
Regulations/Legal				D	d	d	5	2
Political and Public					E	e	4	3
Schedule						F	2	5

In descending order of importance, this process resulted in a ranking as follows:

- Reliability
- Regulations/Legal
- Political and Public Acceptance
- Operations and Maintenance
- Schedule
- Infrastructure

The criteria were weighted according to the given ranking. The top-ranking criterion (Reliability) was given a weight of 100. The other criteria were weighted relative to this score, with the weight of a criterion of lower rank never being higher than the one above it. Three scores from the Waukesha Water Utility and one average score from the consultants were used. The results are summarized below.

Criteria					Average
Reliability	100	100	100	100	100
Regulations/Legal	95	99	95	90	95
Political/Public	75	80	80	81	79
Operations and Maintenance	60	40	60	70	58
Schedule	50	20	50	55	44
Infrastructure	40	10	40	50	35

Based on the data, the weight of each criterion will be the average weight, expressed as a percentage, as shown on Figure 3-1.

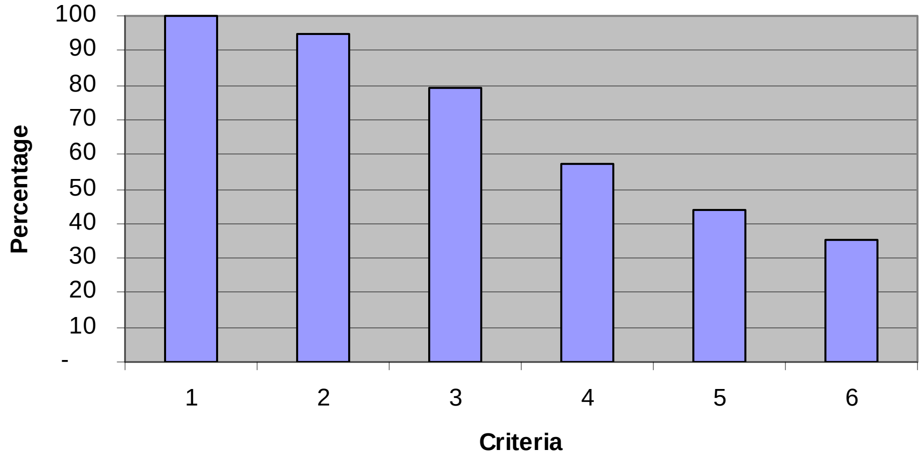

FIGURE 3-1
Evaluation Criteria Weighting

3.2 Evaluation Methodology

Water supply alternatives are evaluated based on the criteria (Section 3), then scored by a team of evaluators on a scale of 1 (worst) to 10 (best) in each of the six categories (Section 5). The scores from each of the evaluators are averaged and weighed accordingly. For example, if the average score for the criterion Political and Public Acceptance for Alternative A is 4, the weighted score would be 3.16 (4 × 79 percent). Weighted scores from all criteria are added for each alternative.

The weighted scores are compared to life cycle costs to develop Benefit/Cost relationships. Based on this information, the alternatives determined to provide the most value for the cost are selected (Section 6).

SECTION 4

Evaluation of Alternatives

4.1 Alternative 1 – Sandstone Aquifer

Water from the sandstone aquifer may be able to meet current and future needs using several approaches. Though multiple variations could be discussed, the options can be separated into two distinct pathways:

- Expand the existing wellfield
- Develop a new wellfield in a more favorable location

The relative merits and limitation of each option are presented in this section. These options are not mutually exclusive, and hybrid solutions that combine portions of each option are possible. The alternatives are described below.

4.1.1 Alternative 1a – Expand Existing Wellfield

This alternative consists of adding nine new sandstone wells southwest of the City of Waukesha. Existing wells 6 through 10 would be maintained, but wells 1 through 5 would be abandoned due to lower capacity and old age. Three treatment plants for radium and TDS removal would be added; one for well 9, one for well 10, and one for wells 6 through 8 and the new wells. The major facilities are shown on Figure 4-1.

4.1.1.1 Reliability

The Waukesha Water Utility currently operates a field of ten wells in the sandstone aquifer. This wellfield has been a reliable source of water since well 1 was drilled in 1935. The aquifer is protected from surface contamination by the Maquoketa shale, which makes the risk of well contamination relatively low. The existing wellfield and related distribution system represent a significant capital asset for the Waukesha Water Utility, and there are numerous advantages to maintaining the existing system. These include maximizing the use of existing capital investments and minimizing the technical and political problems associated with developing a new source of supply. New wells could be drilled adjacent to the existing wellfield to meet future demands. However, over the last few years several factors have emerged that call into question the long-term viability of the expanding the existing wellfield.

Many of the existing wells are old and are not constructed to current municipal well code requirements. The oldest well is 66 years old, while the youngest is 22 years old. Five of the active wells are over 50 years old. Based on the age and construction of many of the existing wells, it is reasonable to assume that additional wells may experience physical failures such as casing leaks or bore hole collapse, which will require extensive rehabilitation or replacement of affected wells.

The concentration of high-capacity wells in southeastern Wisconsin is causing the head in the sandstone aquifer to drop. This problem is most pronounced in eastern Waukesha County, where head in the aquifer has declined by over 500 feet from predevelopment

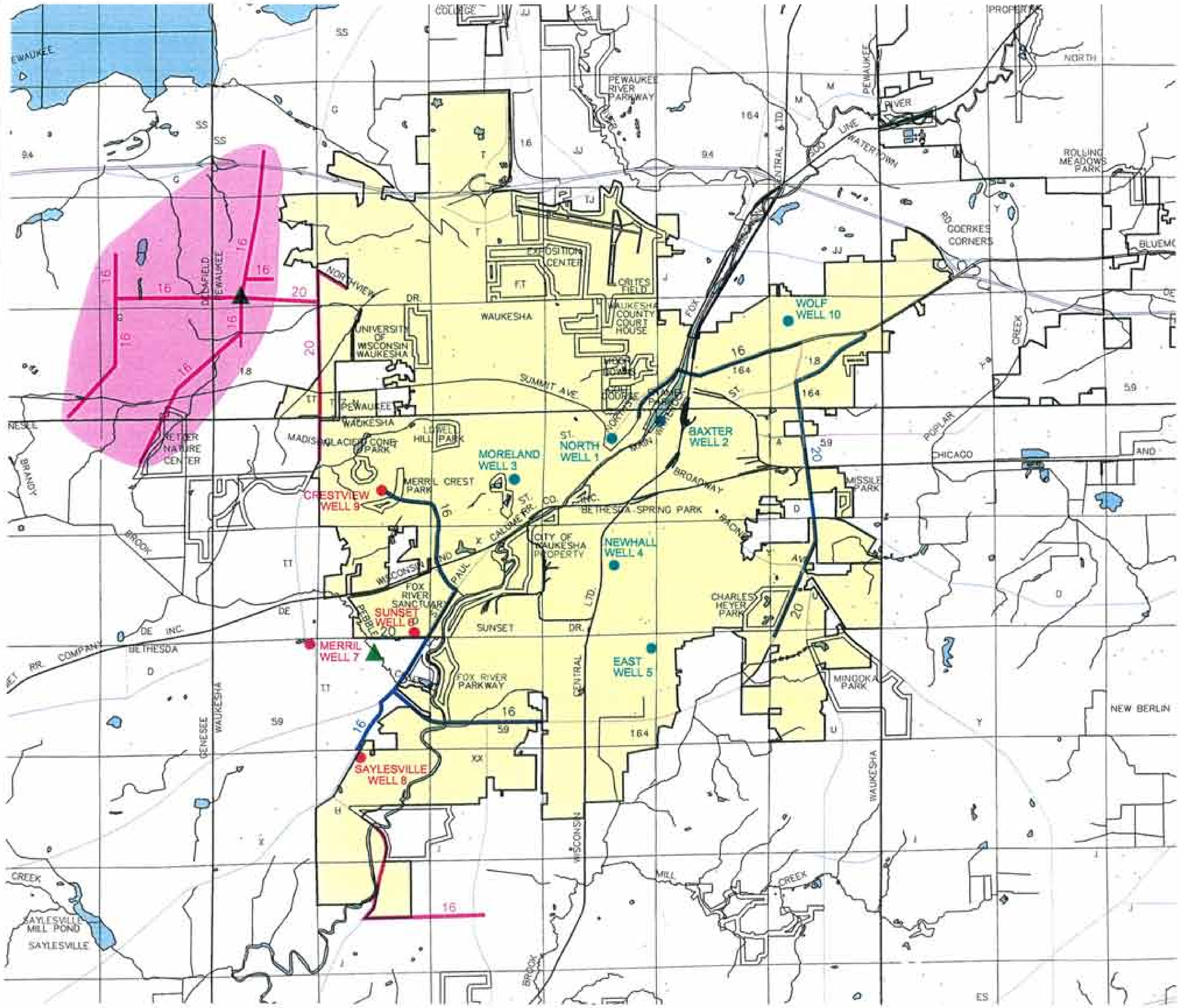

FIGURE 4-1

SANDSTONE WATER SYSTEM NEAR WAUKESHA

N
W E
S

0 1 2 3 4 5 10,000

SCALE IN FEET

LEGEND

- EXISTING WELL TO BE ABANDONED
- EXISTING WELL TO BE RETAINED
- PROPOSED NEW WELL FIELD (CONCEPTUAL LOCATION)
- PROPOSED NEW TRANSMISSION MAIN
- PROPOSED WATER MAIN ADDITION
- PROPOSED TREATMENT FACILITY

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conditions. Figure 2-3 shows the rate of decline in head between 1975 and 1995 in southeastern Wisconsin (Jansen and Rau, 1998). During this period, the Waukesha Water Utility wellfield experienced an average rate of decline of about 5 feet/year. The rate of decline was approximately twice this rate in municipal wellfields located immediately to the north of the Waukesha Water Utility. Reliable estimates of future rates of decline will not be available for about one to two years, until the SEWRPC regional groundwater model has been completed. However, a screening model completed in 1996 (Jansen and Rau, 1998) indicated that pumping levels in several wells in eastern Waukesha County could exceed 1,000 feet within 20 to 50 years, depending on the rate of increase in demand from the aquifer. Unless some level of regional management of pumpage can be accomplished, further water level declines may make long-term reliance on the sandstone aquifer economically non-viable.

The large cone of depression in the sandstone aquifer has created a strong vertical gradient between the upper portion of the aquifer and the sandstone units in the aquifer below the depth of the municipal wells. The resulting upward gradient heads is causing migration of saline water from the deepest portion of the aquifer into the producing interval. This has resulted in a significant rise in the TDS levels in several of the deepest and largest producing wells in eastern Waukesha County.

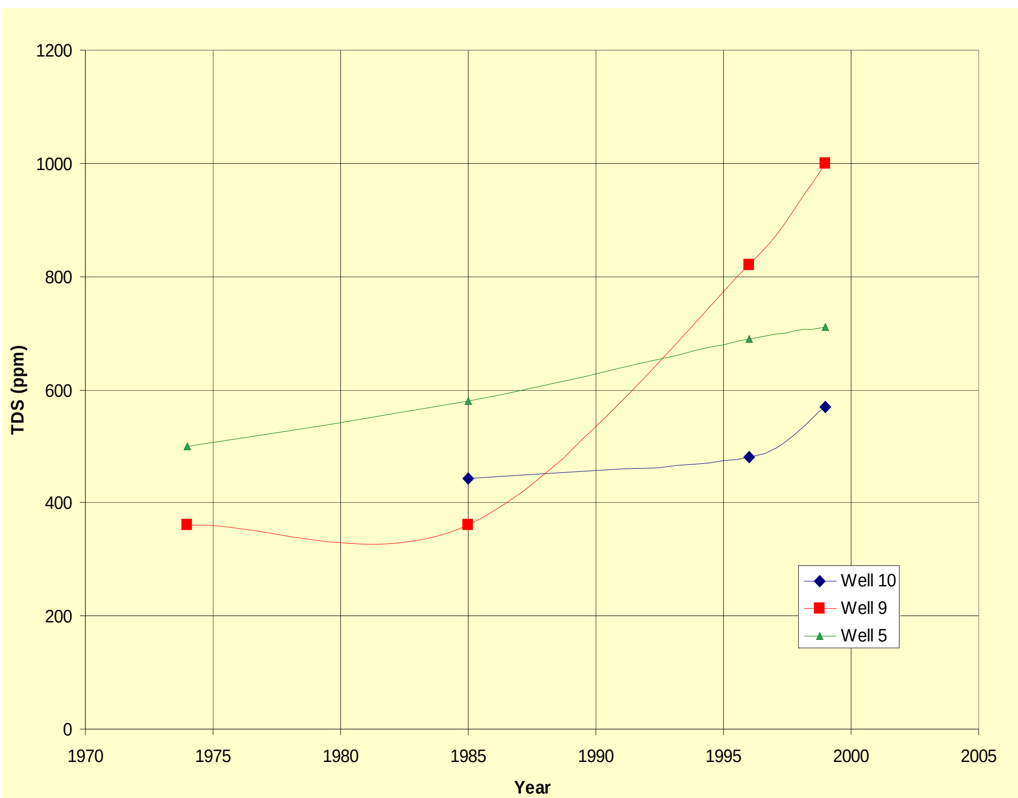


FIGURE 4-2
Trends in Total Dissolved Solids–Sandstone Aquifer

Figure 4-2 shows the trend in TDS levels in Waukesha Water Utility wells 5, 9, and 10 between 1974 and 1999. These are the three deepest wells and are generally the heaviest pumped wells. TDS levels have risen between 28 and 142 percent in the these wells over a 25-year period, with the largest changes occurring over the last 15 years. Well 9 reached TDS levels of 1,000 ppm before a recent well rehabilitation project reduced the concentration by about 50 percent at the expense of over 50 percent of the specific capacity of the well. Similar increases in TDS are likely in other wells as they are pumped harder to meet future demand. These increases could be potentially reversed by rehabilitating the wells. Unfortunately, the reduction in TDS will come at a significant loss in capacity, and the long-term effectiveness of the rehabilitation process has not been demonstrated.

The rise in TDS levels may place practical limits on the production capacity of the existing wellfield before declining pumping levels force a reduction in pumpage. The reduction in capacity will have to be offset with water from a new source or from additional sandstone aquifer wells. Recent geophysical investigations to map the distribution of saline water in the sandstone (AST, 2000a; AST, 2000b) have indicated that the zone of saline water is pervasive in the deeper portion of the aquifer on the down-thrown side of the Waukesha fault where all of the existing Waukesha Water Utility wells are located. A recent geophysical survey (AST, 2001) to screen two potential sandstone well sites on the up-thrown side of the Waukesha fault in the northwest portion of the city of Waukesha indicated that a previously unknown zone of saline water may be present in a stagnation zone behind a mound of impermeable Precambrian rock that projects into the aquifer to the northwest of the sites. The presence of the Precambrian mound has been confirmed by logs of a municipal well in Delafield, as well as from high resolution aeromagnetic data (Mudrey, 2001).

The data suggests that any new sandstone wells drilled in the northwest side of the city run the risk of encountering high TDS groundwater, and any sandstone wells drilled on the down-thrown side of the Waukesha fault run the risk of accelerating the upward migration of saline water from deeper within the aquifer. Based on this information, any new sandstone wells should be drilled no deeper than about 1,500 to 1,800 feet and pumped at typical rates of about 1,000 gpm. The wells could be pumped at rates of up to about 1,500 gpm for short periods by using a variable speed pumps. These problems could be largely avoided by drilling wells closer to the recharge zone for the aquifer where better water quality is expected, as described in Alternative 1b.

The water produced by all ten of the Waukesha Water Utility wells exceeds the MCL for radium and gross alpha. At present, all of the Waukesha Water Utility wells would need treatment or well rehabilitation to comply with the radionuclide standards. Several treatment processes are available to reduce radium and gross alpha levels. Some wells can be reconstructed to reduce radionuclide levels.

While these technologies will probably be sufficient to bring the water into compliance, some recently discovered trends in radionuclide levels may complicate compliance strategies. Distribution system samples indicate that gross alpha levels have more than doubled from about 1982 to present (Figure 4-3), while radium levels have not risen. Similar trends have been observed in most water utilities using sandstone wells in Waukesha County. Studies are under way by the Wisconsin State Laboratory of Hygiene to identify the specific elements responsible for the increase in gross alpha levels.

The cause of rising gross alpha is presently unknown. This trend is significant because it raises questions about the long-term effectiveness of any treatment process or well reconstruction designed to treat gross alpha. Some of the alpha emitting elements in the decay series of radium 226 and radium 228 can not be effectively removed by ion exchange or lime softening treatment. Depending upon the particular elements responsible for the rising gross alpha levels, it may be necessary to install membrane treatment, which would substantially increase the cost of compliance.

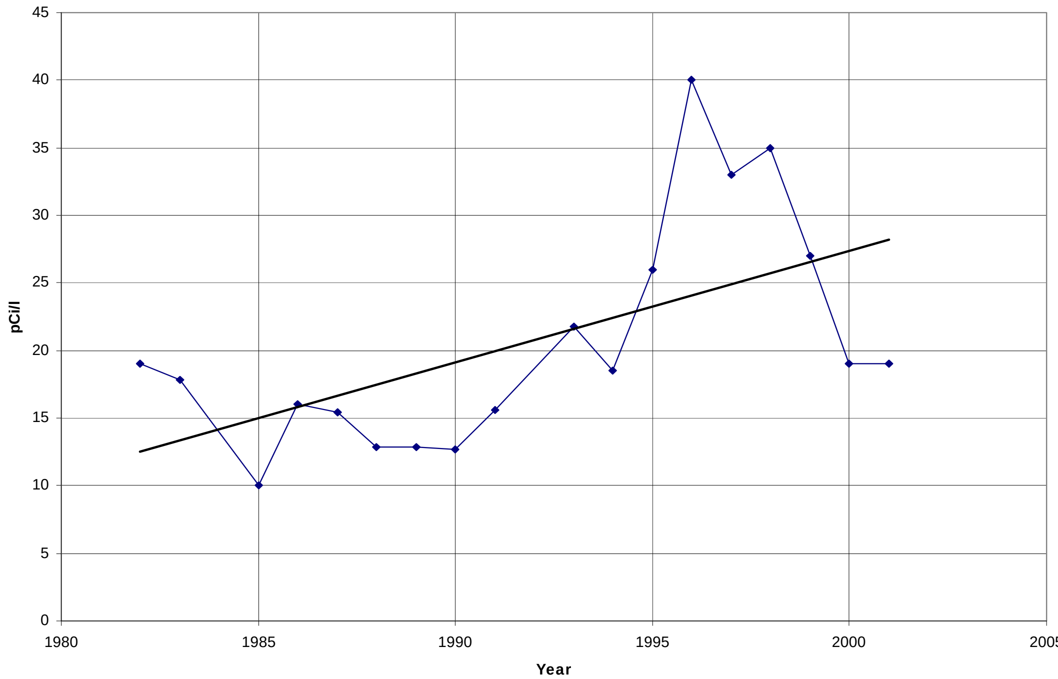


FIGURE 4-3
Trends in Gross Alpha–Sandstone Aquifer

In addition to the TDS and radionuclide issues, several other water quality problems could affect the long-term reliability of the existing sandstone aquifer wellfield. The arsenic standard has been reduced from 50 ppb to 10 ppb. Seven of the Waukesha Water Utility wells were sampled by the WDNR in 1999 for arsenic. The data indicated that all of the seven Waukesha Water Utility wells sampled were well below the new standard. However, review of the sample description logs that have been completed by the Wisconsin Geological and Natural History Survey (WGNHS) for several of the Waukesha Water Utility wells indicated that sulfide minerals are present in the aquifer. Arsenic levels may increase in the wells if these minerals are exposed to oxygen due to dropping pumping levels caused by declining heads in the aquifer.

In addition, the dropping pumping levels are starting to expose the upper portion of the aquifer to both air and the vegetable grade food oil used as a pump lubricant. The oil provides oxygen and a carbon source for natural bacteria in the aquifer. One of the Waukesha Water Utility wells has experienced positive coliform tests (negative for fecal coliform) due to this process. Similar problems have been experienced in other sandstone wells in Waukesha County in recent years.

4.1.1.2 Infrastructure

Wells. Assuming that the capacity of the existing wellfield can be maintained, a minimum of 6 mgd of new capacity will be needed to meet projected future demands. However, it is likely that the capacity of the existing wellfield can not be maintained due to declining heads, the probable need for additional well reconstruction to reduce TDS levels, and the potential need to abandon older wells as they reach the end of their service life.

Existing sandstone wells that are preserved would have to be brought into compliance with the radionuclides MCLs. This could be accomplished through a combination of treatment, well reconstruction, or blending with water from shallow aquifers. Given the layout of the wellfield, wells 6, 7, and 8 are attractive candidates for treatment at a single plant. Wells 1 through 5 do not produce enough water to justify the cost of treatment. Wells 9 and 10 could be treated with separate plants at or near the well sites. However, the capacity of both of these wells is likely to be reduced to deal with rising TDS levels. For the purpose of this analysis, it was assumed that wells 1 through 5 would be abandoned and the capacity of wells 9 and 10 would be reduced to about 2 mgd each. Given these assumptions, the capacity of the existing wellfield would be about 11 mgd.

To meet the forecasted maximum day pumpage of 22 mgd, a minimum of 11 mgd of new capacity would be needed. If the average capacity of each new sandstone well is limited to 1,000 gpm, approximately nine new sandstone wells will be needed to meet the reliable capacity requirements. Most of these wells will probably be drilled to the south and the west of the existing wellfield due to minimum spacing requirements, the presence of other municipal wellfields to the east and north, and the potential presence of a zone of elevated TDS water in the aquifer to the northwest. Assuming a minimum separation of approximately 1-mile between wells, approximately 5 to 10 miles of transmission main will be needed to accommodate the new wells.

Treatment for Sandstone Aquifer Water. All of the existing wells and most or all of the new wells will need some sort of rehabilitation or treatment to comply with the radionuclide MCL. Treatment may also be required for TDS or aesthetic water quality parameters such as hardness or iron. Construction of one or more treatment plant with modifications of the existing distribution system would also be required.

Water from the sandstone aquifer is hard with low levels of iron and manganese (Table 4-1). The sandstone groundwater is not treated (beyond chlorination and silicate sequestration) in Waukesha or many other communities using this aquifer. The only parameters not meeting primary drinking water regulations are radium and gross alpha.

If the sandstone aquifer continues to be used as the sole source of drinking water, and current radionuclide regulations are enforced, radium and gross alpha will have to be reduced below the MCL (5 pCi/L combined radium 226 and radium 228, 15 pCi/L gross alpha).

TABLE 4-1
Sandstone Aquifer Water Quality Data
Future Water Supply

	Typical Value	MCL Primary Standard	Secondary Standard
Total Hardness (mg/L as $CaCO_3$)	250-480		
Calcium (mg/L)	61-130		
Magnesium (mg/L)	20-26		
Total Alkalinity (mg/L as $CaCO_3$)	220-230		
pH	7.5		
Sulfate (mg/L)	36-140		250
Chloride (mg/L)	4.1-30		250
Total Dissolved Solids (mg/L)	300-710		500
Iron (mg/L)	0.2-0.4		0.3
Manganese (mg/L)	0.03		0.05
Sodium (mg/L)	40		20
Radium 226+228 (pCi/L)	5.8-13	5	
Gross Alpha (pCi/L)	13-38	15	

Source: City of Waukesha Wells 1, 2, 4, 5, 6, 7, 8, 9 and 10

There are many treatment processes for radium reduction, including:

- Lime softening
- Ion exchange (zeolite softening resin or radium specific resins)
- Membrane softening (nanofiltration or reverse osmosis)
- Adsorption onto iron and manganese oxide coated filter media (or hydrous manganese oxides)

All of these processes are capable of reducing radium, and all have their respective advantages and disadvantages. Lime softening removes hardness along with radium, but it produces a solid waste that requires disposal. Ion exchange softening also removes hardness and radium, but it increases sodium levels in drinking water and produces a liquid brine waste (sodium, calcium, and magnesium chlorides). Membranes remove hardness and radium along with many other cations and anions (sulfates, arsenic, and chlorides). However, membranes also produce a liquid brine waste, but the brine is concentrated groundwater so no additional salts are added to the environment. Iron and manganese filtration is less effective at radium removal, but the process is less complex and costly. Iron and manganese filtration does not soften the water or remove other cations or anions.

Determining the optimum radium removal treatment process is beyond the scope of this study. Of the treatment processes described above, membrane softening provides the best overall water quality. Given the trend toward higher dissolved solids and gross alpha in the sandstone wells, a treatment process that removes these elements is prudent for a long-term solution. Although the exact constituents contributing to the higher gross alpha levels are not yet known, membrane softening (nanofiltration or low-pressure reverse osmosis) has the best potential for removal when compared to the other treatment alternatives mentioned.

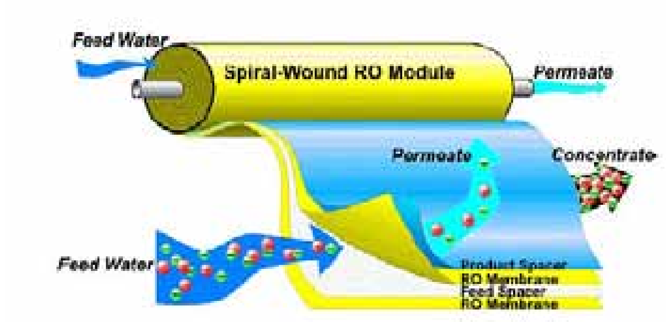


FIGURE 4-4
Spiral Wound Membrane Cartridge

Nanofiltration removes radium, calcium, magnesium and other divalent ions. It is lower pressure (around 100 psi) than reverse osmosis, and thus is lower in cost. Nanofiltration involves passing water through a semi-permeable membrane that rejects many dissolved solids and allows water and some monovalent ions to pass. The membranes are typically spiral wound in a cartridge as shown on Figure 4-4. A number of cartridges are assembled into a skid as shown on Figure 4-5. Anti-scalants are added to the membrane feed water to reduce the chance of membrane fouling by precipitants. If these anti-scalants include acid, carbon dioxide is produced and can be removed by aeration. A portion of the water can be bypassed around the nanofiltration process. For example, if the radium concentration of a well was 20 pCi/L, about 20 percent of the water could be bypassed while still meeting the radium limits. This also reduces the cost of treatment.

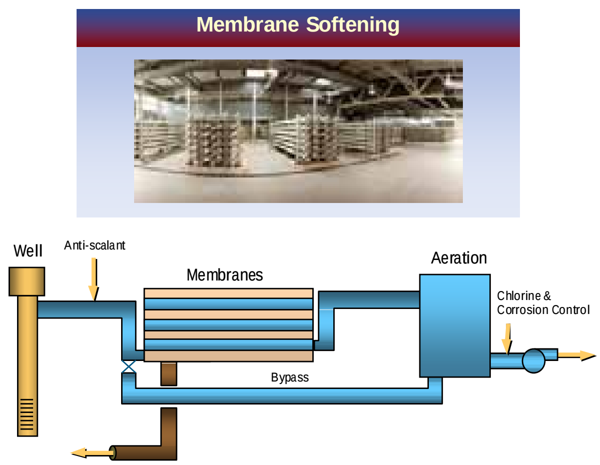


FIGURE 4-5
Membrane Treatment Process

A typical nanofiltration treatment process is shown on Figure 4-5. Treatment for iron/manganese reduction may be required before membranes, depending on the concentrations in the groundwater. If aeration is required for carbon dioxide removal, the water would be collected after aeration and pumped into the distribution system.

A minimum number of treatment plants is desirable to minimize O&M costs. In this alternative, it was assumed that wells 6 through 8 and nine new wells would be directed to a central treatment plant in the southwest portion of the city. Wells 9 and 10 would have their own separate treatment plants, while wells 1 through 5 would be placed on standby or abandoned.

Transmission. Transmission lines would be needed to bring water from wells 6 through 8 together to a central treatment plant, then back into the distribution system. In addition, transmission lines from the nine new wells would be needed to convey water to and from a new treatment plant. Approximately 12 miles of transmission main are required.

4.1.1.3 Regulations/Legal

Expanding the existing wellfield will only be viable if the water is brought into compliance with the radionuclide MCL. It is also likely that most of the new sandstone wells will be located in the surrounding townships. The townships may attempt to prevent this by refusing to rezone land or to grant rights-of-way for transmission lines. If the head in the aquifer continues to decline, future pumpage may be restricted by some regulatory body that may require the Waukesha Water Utility to find alternate sources in the future.

The treatment plant will require WDNR approval based on NR 811 and 809 requirements. Pilot testing of treatment processes will likely be required.

4.1.1.4 Political and Public Acceptance

Expanding the existing wellfield will not be acceptable to the public unless the water complies with the MCL for radionuclides and aesthetic water quality parameters improve. While using an existing investment may seem attractive, the cost of treating the existing wells more than offsets any savings achieved. In addition, most regulatory bodies will not perceive expansion of the wellfield as a permanent solution unless the issues of declining head and deteriorating water quality can be addressed. Continued use of the confined portion of the sandstone aquifer minimizes environmental impacts on surface water and avoids conflicts with shallow domestic wells in surrounding rural areas.

The treatment plants will require aesthetic features to make them acceptable to nearby citizens and comply with zoning requirements. Truck traffic and noise should be minimized where possible.

The transmission pipes would require easements, and distribution pipes would be located largely within the city limits, resulting in potential traffic slow-downs during construction.

4.1.1.5 Operations and Maintenance

Wells. Many of the O&M procedures that would be required for this alternative are similar to the current practices of the Waukesha Water Utility. However, the level of these activities would be increased significantly due to the additional wells that would be needed and the higher levels of maintenance that will be required to service the existing wells. As the head in the aquifer continues to drop, deeper pump settings and higher pumping costs will be necessary. Eventually, the remaining line shaft pumps will need to be replaced by submersible pumps. Larger pumps with higher horsepower motors will be needed over time with greater capital costs and higher O&M requirements. If the pump settings approach shot holes in the well bores, sand pumping and bore hole collapse problems could occur. As the pump setting get deeper, some wells may have to be straightened or re-drilled to accommodate the pumps.

The continued decline in head may also accelerate the increase in TDS in the aquifer, which will require additional well rehabilitation or treatment. Periodic nuisance bacteria problems are likely in wells that used food grade vegetable oil in the past. These wells may require periodic cleaning and disinfection.

Water Treatment. New treatment plants will require additional maintenance for the building and equipment. Maintenance activities for the following equipment would be required: instrumentation and controls, valve and piping, membrane skids, HVAC, chemical systems, and general building facilities. The membranes do not last indefinitely, and need to be replaced every 5 to 10 years depending on water quality and operating procedures.

Membrane plants can be automated so that full-time attendance is not required. The treatment plants should be checked several times a day for proper operation and chemical feed. The anti-scalant chemical and chlorine would be added to the treated water. If one of the plants will be out of operation for a long time (i.e., winter), procedures to protect the membranes would be recommended.

The water quality resulting from nanofiltration will be much softer with lower dissolved solids, which is different from what has been in the distribution system piping since the beginning of the water system. Therefore, there is potential for pipe scale to dissolve and enter the water supply. In addition, lead corrosion conditions may change. A distribution system water quality study should be conducted to determine any adverse impacts and methods to minimize effects. In many cases, adverse effects are short-term and related to aesthetics (i.e., red water).

Water Plant Residuals. Residuals from a nanofiltration plant consist of a liquid brine concentrate. Approximately 10 percent of the water treated by nanofiltration is wasted. If it is assumed that 25 percent of the water is bypassed, about 7.5 percent of the total well flow would be wasted to the sanitary sewer. At the current ADD of 8 mgd, the waste volume would be about 0.6 mgd. At a maximum day demand of 15 mgd, the waste volume would be about 1.1 mgd. It should be noted that this volume of waste would require additional groundwater supply to meet water demands.

The waste brine from nanofiltration is just concentrated groundwater. The concentration of various constituents is roughly 10 times the concentration in the groundwater (Table 4-1). Monovalent ions such as sodium and chloride are not removed by nanofiltration and would not be concentrated in the waste brine.

Radium levels in the waste brine would range from 50 to around 200 pCi/L depending on the level in the well. These levels are below those required by WDNR for special handling as radioactive, so discharge to the sanitary sewer should be acceptable.

Besides the additional volume of water, the wastewater plant should not receive additional solids (dissolved or particulate). Although the brine has concentrated dissolved solids, the total amount of dissolved solids entering the wastewater plant will not be increased because it will be blended with the membrane softened water in the sewer system. Actually, the dissolved solids entering the wastewater plant will decrease significantly if home softening is reduced, especially sodium and chloride.

Transmission. The additional pipe and valves will require maintenance, similar to existing pipe and valves in the Waukesha Water System.

4.1.1.6 Schedule

Expanding the existing wellfield offers some flexibility in schedule since wells can be added as needed. However, all wells will probably be required to be compliant with the radionuclide standard, which will require major capital investment and changes in the infrastructure. Design and construction of water treatment plants could take about

2 to 3 years to complete. If a pilot-plant study is required, another year would be needed. Transmission main improvements may be constructed in this time frame as well.

4.1.2 Alternative 1b – Develop a New Wellfield in a More Favorable Area

This alternative consists of adding 11 new sandstone wells about 11 miles west of the City of Waukesha. Existing wells would be abandoned or kept as standby. A treatment plant for removal or iron/manganese would be provided. The major facilities are shown on Figure 4-6.

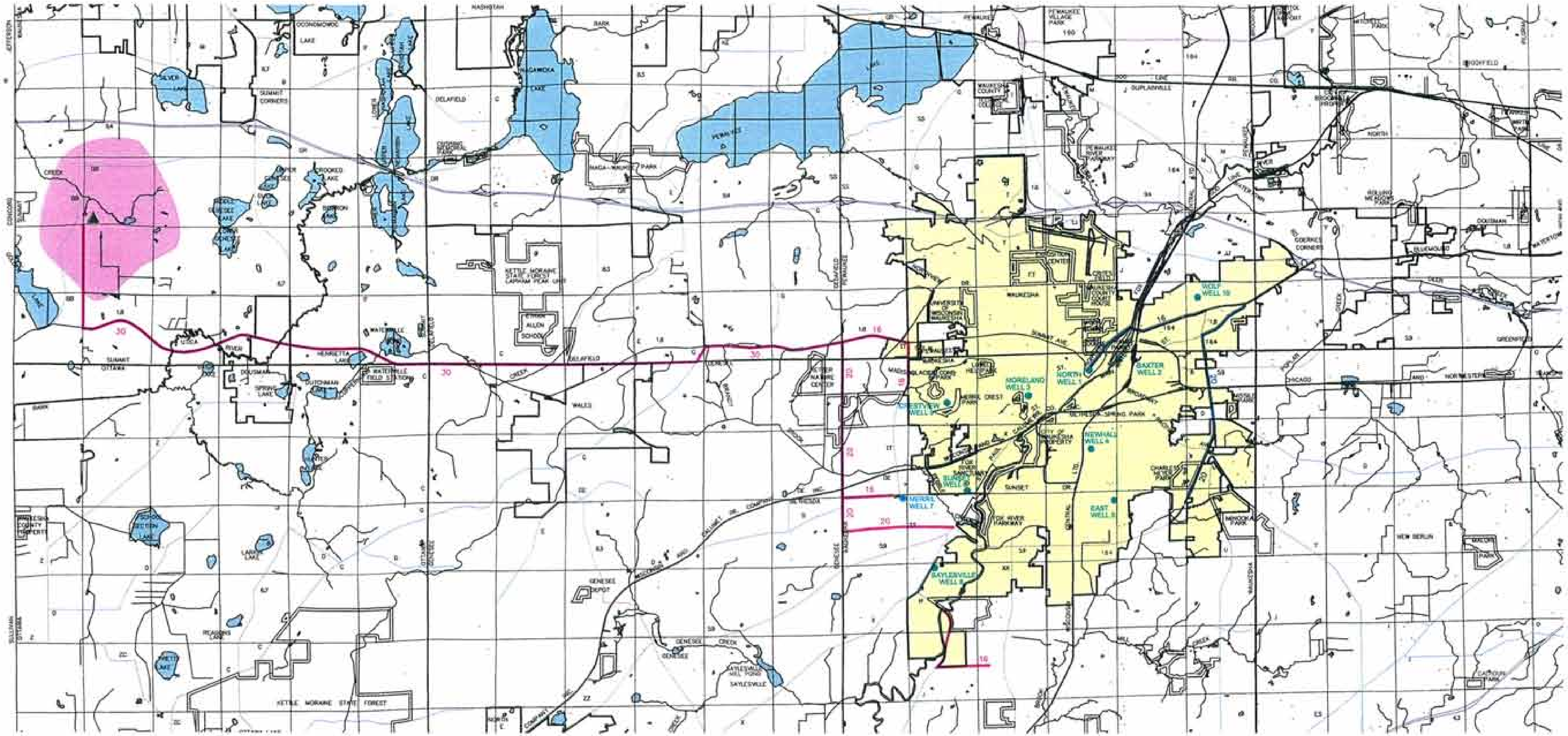
4.1.2.1 Reliability

The problems currently experienced by the existing Waukesha Water Utility wellfield are related to the fact that the wells are all located in the confined portion of the aquifer near the center of the regional cone of depression. If the wellfield were located in the recharge area west of the Maquoketa shale subcrop, it would not be experiencing the same problems.

A large bedrock valley is present west of the Maquoketa subcrop. This valley is an extension of the Rock bedrock valley that extends into Illinois. This area is indicated on Figure 4-7, and covers portions of the Townships of Oconomowoc, Summit, and Ottawa. The valley is filled with glacial deposits that are predominantly sand and gravel. The valley extends through the upper confining unit of the sandstone and places saturated sand and gravel units directly in contact with the sandstone aquifer. The sandstone aquifer tends to be more permeable in this area. Most of the confining units within the sandstone are thin or absent, allowing faster vertical recharge throughout the full thickness of the sandstone aquifer. This valley is the major recharge source for the sandstone aquifer in Waukesha County.

Figure 4-7 shows the portion of the sandstone aquifer recommended for unconfined sandstone aquifer wells and the location of a potential unconfined sandstone wellfield. The location of the wellfield on Figure 4-7 is only conceptual. The actual position of any wellfield or individual well would be determined based on local geologic conditions and land availability.

Two municipal water systems with sandstone wells, Oconomowoc and Dousman, are located in this area. The data from these wells can be used to draw conclusions as to the properties of the aquifer in the recharge area. Because the valley is a major recharge feature that receives recharge from the surface, the water entering the sandstone is younger and generally of much better quality. TDS levels and radionuclides are lower than under the confined portion of the aquifer. TDS levels are generally below 500 ppm and most wells are well below the radionuclide standards. Water levels in the aquifer are not declining significantly in this area in spite of the large draw down occurring in the confined portion of the aquifer. Static water levels in municipal wells in this area have been essentially stable and typically are within 100 feet of the surface. The aquifer is thinner in this area, generally less than 1,000 feet, but capacity of wells in the area is relatively high, generally over 1,000 gpm, due to the ample recharge and high permeability of the sandstone.



LEGEND

- EXISTING WELL TO BE ABANDONED
- PROPOSED NEW WELL FIELD (CONCEPTUAL LOCATION)
- PROPOSED NEW TRANSMISSION MAIN
- PROPOSED WATER MAIN ADDITION
- PROPOSED TREATMENT FACILITY

0 1 2 3 4000 8000
SCALE IN FEET

Waukesha Water Utility
SERVING WAUKESHA SINCE 1886

FIGURE 4-6

SANDSTONE WATER SYSTEM
WEST OF WAUKESHA

N
W E
S

CH2MHILL

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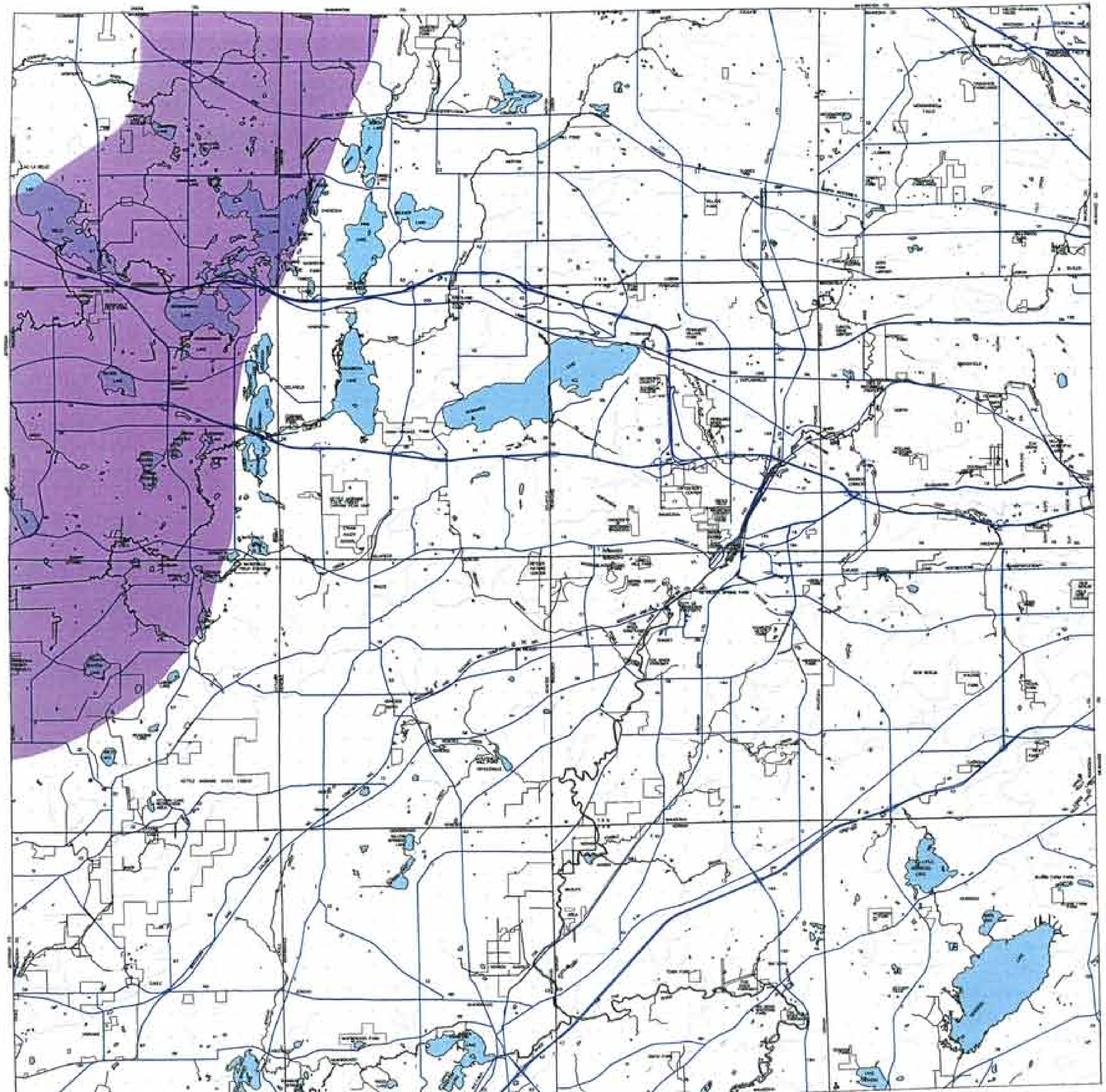

Waukesha Water Utility
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FIGURE 4-7

RECOMMENDED EXPLORATION AREA FOR UNCONFINED SANDSTONE AQUIFER WELL FIELD

N
W E
S

0 1 2 3 4 5
SCALE IN MILES

LEGEND

RECOMMENDED EXPLORATION AREA

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Moving the Waukesha Water Utility wellfield or portions of it to the recharge area would have two major benefits. First, the water quality would be substantially improved. It is likely that the TDS of the water would be below 500 ppm and remain relatively constant over time. Secondly, the sustainable capacity of the wellfield would be increased. By pumping from the recharge area, the wellfield would be intercepting the same water that it currently produces, just at a point where the water is younger and of higher quality. The cone of depression would be much shallower due to the unconfined nature of the aquifer in this area and the availability of ample recharge. The draw down created by the wellfield would induce more recharge into the system, increasing the sustainable capacity of the aquifer. In addition, by moving a major pumping center out of eastern Waukesha County, static water levels in the confined portion of the aquifer would recover, reducing the pumping costs for the remaining wells in the confined portion of the aquifer and extending its useful life.

Inducing more recharge into the sandstone aquifer has some potentially undesirable effects. Most significant is the potential to impact surface water bodies. The pumpage is likely to reduce base flows to some streams and may have measurable affects on some springs and wetlands. However, it is unlikely that the induced recharge would have measurable impacts on the lakes in the area.

The proposed wellfield is directly analogous to the wellfield in Dane County, Wisconsin. The municipal water utilities for Madison and the surrounding communities, along with several large industrial users, pump approximately 50 mgd from the sandstone aquifer in the county. This pumpage has dropped water levels in the sandstone aquifer approximately 60 feet below predevelopment conditions in the area of highest pumpage. The area of highest pumpage is within the City of Madison where the shallow confining unit is absent and the Madison-area lakes are in direct connection with the permeable portion of the aquifer. The extensive pumpage has induced recharge from the shallow aquifer, which has affected several springs and decreased base flows in several streams. Portions of the lake beds are now recharging the aquifer where groundwater was previously discharging to the lakes under predevelopment conditions. While this is certainly not a desirable condition, the induced recharge to the aquifer occurs over such a large area that the actual vertical flux through any given area is relatively small, so that the actual loss of water through the lake bed is negligible compared to the natural flux through the lakes. As a result, the affect on the lakes after decades of heavy pumpage is not measurable.

While the new wellfield would be more susceptible to surface contamination than the existing wellfield, the travel time through the unconsolidated units into the sandstone aquifer is likely to be decades to perhaps a few hundred years. Given the travel time from a surface spill area to the intake of a sandstone well, and given the large amount of dilution within the unconsolidated material and the sandstone aquifer that would occur, the risk of contamination of the wells would be low.

4.1.2.2 Infrastructure

Wells. Assuming the new wells will have a typical capacity of 1,500 gpm, 11 new wells will be needed to provide the ultimate reliable capacity of the Waukesha Water Utility. Assuming that some of the existing wells could be retained, the total number of wells needed could be somewhat lower. Assuming a wellfield designed with a minimum spacing of 0.5 mile between wells, approximately 10 to 12 miles of transmission main with approximately 5 miles of smaller diameter feeder lines would be needed.

Treatment. An objective of this study is to provide water that meets all primary (enforceable) and secondary (non-enforceable) drinking water standards. Available water quality data indicate that the sandstone aquifer in this area meets primary drinking water standards. However, secondary standards for iron and manganese may be exceeded, depending on local conditions. Secondary standards are aesthetic and do not represent a health concern.

For the purposes of this study, the conservative assumption of treatment for iron and manganese removal was made. Iron and manganese removal may not be required depending on the concentrations in the actual wells and public acceptance. However, iron/manganese treatment can also remove some radium if levels approach the MCL.

Sequestering is an alternative to treatment for removal of iron and manganese. Sequestering involves adding a chemical, such as a polyphosphate or a silicate, that binds the iron and manganese in a soluble form without removing it from the water. A careful review of impacts of a sequestering chemical on the distribution system pipe scale would be required before implementation. Sequestering can be considered further during implementation if the sandstone aquifer becomes a preferred alternative and if radium levels are well below the MCL.

Iron and manganese can be removed by a number of processes, including:

- Aeration or chemical oxidation, detention, filtration
- Greensand filtration
- Lime softening
- Biological filtration

Although all the treatment processes mentioned above will remove iron and manganese, greensand filtration was chosen because:

- Simplicity of operation and lower costs than some other alternatives
- Adequate removal efficiency for the levels likely to be encountered

A typical iron/manganese removal treatment process is shown on Figure 4-8. Greensand is a mineral (glauconite, a clay composed of hydrous aluminosilicate) that is treated so that its surface is coated with manganese dioxide. The greensand is typically placed below a layer of anthracite coal, which filters out the larger particles and makes the greensand filter more effective. Potassium permanganate can be continuously added to the water for

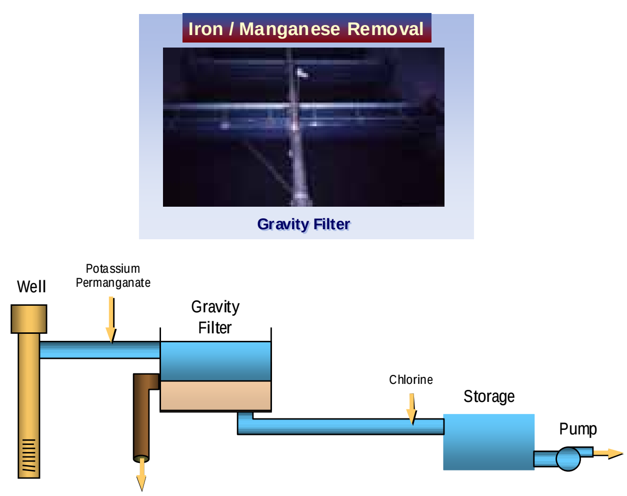

FIGURE 4-8
Treatment for Iron/Manganese Removal

oxidation of soluble iron and manganese and regeneration of the filter media. The water can pass through a pressurized vessel or concrete gravity box containing the greensand and anthracite where iron and manganese are removed by filtration, ion exchange, and adsorption. Based on the large size of this treatment plant, gravity filtration will likely be more economical than pressure filters.

The filters are backwashed periodically to remove the captured iron and manganese; this water is sent to waste. Sanitary sewer may not be available to discharge this waste, so a lagoon would be provided for solids accumulation and eventual disposal. Chlorine is added to the filtered water. Chlorine can also be added before filtration to reduce the potassium permanganate dose.

A single water treatment plant would be desirable to minimize O&M and costs. The wellfield water could be conveyed to the plant, treated, then pumped to the distribution system.

With this alternative, the existing wells would be abandoned or placed on standby. Existing storage tanks and pump stations would be used to convey water through the distribution system.

Transmission. Transmission from a western wellfield to Waukesha would be accomplished with dual 30-inch-diameter transmission lines. The second line would provide a degree of reliability and redundancy. About 11 miles of large transmission main would be required.

Another 14 miles of 20- and 16-inch water main are required to distribute the treated groundwater throughout the City of Waukesha.

4.1.2.3 Regulations/Legal

Under current high-capacity well law, the Waukesha Water Utility cannot be prevented from developing a wellfield in the recharge area. Future regulations may seek to quantify and limit the impact of municipal wells on surface water. It is possible that pumpage restrictions may be placed on the wellfield if negative impacts to the environment can be documented.

Local townships are likely to be very concerned about the perceived threats to their local water supplies and loss of autonomy. They may elect to resist zoning changes or grant rights-of-way that may be required to develop a wellfield. These issues may be largely resolved through the formation of a water authority that grants itself greater extraterritorial rights.

The treatment plant will require WDNR approval based on NR 811 and 809 requirements. Pilot testing of treatment processes is not likely to be required.

4.1.2.4 Political and Public Acceptance

The customers of the Waukesha Water Utility would probably perceive a great benefit in improved water quality and a more sustainable source of supply. The development of a large wellfield outside of the City corporate limits is likely to draw strong opposition from a number of surrounding townships and municipalities. The number of objecting parties could be reduced if the wellfield was seen as part of a regional water authority providing water to several communities.

A number of environmental and citizen groups may object to the wellfield based on perceived risk to surface water resources. These concerns could be addressed to some extent by the use of comprehensive groundwater models to predict the effect on the aquifer and optimize the wellfield design to minimize impacts to surface water. However, even if the wellfield can be demonstrated to have no significant impacts to the environment, some groups may remain opposed.

The treatment plants will require aesthetic features to make them acceptable to nearby citizens and comply with zoning requirements. Truck traffic and noise should be minimized where possible.

The long transmission main would require easements and could result in some public opposition. Some transmission lines would be run in the city limits, resulting in traffic slow-downs during construction.

4.1.2.5 Operations and Maintenance

Wells. The proposed wellfield will have lower O&M costs because the wells will be newer, pumping levels will be on the order of 200 to 300 feet, and the water will be of higher quality.

The wellfield will require one or more long transmission lines, which will require additional maintenance.

Treatment. A greensand filtration facility would consist of several filters and chemical systems (potassium permanganate and chlorine) housed in a building. A storage tank and pump station would also be included. The filtration system can be automated for backwash based on volume of water treated, time, effluent iron concentration, headloss, or other parameters.

Potassium permanganate is added to the well water before greensand filtration. This chemical is delivered as a granular solid in drums. The dry chemical is transferred to a hopper, dissolved into solution, and added to the water through metering pumps or other measuring devices. Typical doses of potassium permanganate are 0.6 mg per mg of iron and 2 mg per mg of manganese. The chemical feedrate can be automatically adjusted based on flowrate. More sophisticated controls can adjust chemical doses based on iron concentrations and flowrate.

Chlorine can be in liquid (sodium hypochlorite) or gas form. Sodium hypochlorite is more expensive, but safer to handle. For the purposes of this report, the use of sodium hypochlorite is assumed. Sodium hypochlorite is delivered by bulk truck and unloaded into storage tanks. The chemical is transferred to a day tank and can be fed through metering pumps. Provisions to feed chlorine before and after filtration should be made.

A greensand filter plant can be automated so continuous attention by operators is not required. The treatment system should be checked several times a day for proper filtration and backwashing, pressures and flowrates, chemical storage levels and feed rates, and general water quality.

A new treatment plant will require additional maintenance for the building and equipment. Activities may include instrument calibration, valve and piping maintenance, HVAC maintenance, filter media replacement, and chemical system and general building maintenance.

Water Plant Residuals. When a greensand filter accumulates iron and manganese, the filter media becomes clogged and the required head to drive water through the media increases. At some point, the filter must be backwashed to remove the accumulated iron and manganese by reversing the flow through the media and washing the solids to waste. Assuming a sanitary sewer is not available nearby, the backwash waste can be discharged to a lagoon. The lagoon can be constructed with a sand bottom so water filters into the ground and the iron and manganese particles remain. Periodically, the particles are removed and disposed of in a landfill or land applied.

For a groundwater with 1 mg/L iron and 0.1 mg/L manganese, the estimated amount of dry solids in the backwash water is about 32 lb./million gallons of water treated. This amounts to about 256 pounds per day with the current average day water demand (8 mgd) and about 480 pounds per day with the current maximum day demand (15 mgd). The solids are mainly inorganic with very low biological oxygen demand.

The volume of backwash wastewater can vary significantly depending on operational procedures, filter design, and water quality characteristics. An AWWARF study of nine iron and manganese removal plants indicated that the average backwash volume was 1.4 percent of the treated water flow. Therefore, the volume of wastewater would be about 112,000 gallons per day (gpd) on an average day, and about 210,000 gpd on a maximum day. The backwash flow is intermittent and instantaneous flowrates would be higher than the daily averages stated above. An equalization tank for backwash waste may or may not be required, depending on the location of the lagoon in relation to the treatment plant.

Transmission. The additional pipe and valves will require maintenance, similar to existing pipe and valves in the Waukesha Water System.

4.1.2.6 Schedule

The wells can be built as needed to provide the necessary capacity, while the existing sandstone wells are phased out. The treatment plant can be constructed in conjunction with the wells. Design and construction time frames are roughly 2 to 3 years. It may also be possible to use the water as a blending source for one or more of the existing wells on the west side of the wellfield (wells 6, 7, and 8), which may extend the useful life of these wells and postpone the need for some new wells.

The transmission line will be needed before any water can be delivered into the system. Obtaining zoning approval and easements may slow the process. Once these hurdles are cleared, a 3- to 4-year design and construction schedule is typical.

4.1.3 Alternative 2 – Fox River Alluvium

This alternative consists of adding six new horizontal wells just south of the City of Waukesha along the Fox River. Existing sandstone wells would be abandoned or retained on standby. A treatment plant for disinfection and removal of iron/manganese would be provided. The major facilities are shown on Figure 4-9.

4.1.3.1 Reliability

Properly developing an alluvial wellfield involves a balance between the characteristics of the aquifer and river system. In the Waukesha area, there are at least two potential areas for developing and alluvial wellfield. The two most promising areas are the shallow sand and gravel deposits along the Fox River immediately south of the city and potential shallow alluvial deposits along the Fox River.

To the south of Waukesha, the Fox River runs above a bedrock valley that is a tributary of the much larger Troy bedrock valley. Boring logs from the area indicate that the bedrock valley is filled with a series of interlayered sand and gravel rich outwash deposits and clay rich till sheets. The upper 50 feet of the unconsolidated material consists primarily of permeable sand and gravel deposits. In 1999, a dewatering system was operated for construction of a subdivision along River Road immediately west of the Fox River. According to a representative of the dewatering contractor, a total of 23 wells were installed and operated as needed during construction. The wells were generally 50 feet deep and each well was reported to have a capacity of about 1,000 gpm. The system typically produced about 5,000 gpm during the construction project. This information suggests that the shallow unconsolidated units in the area consist of a generally uniform permeable sand and gravel deposit that may be in direct hydraulic connection with the Fox River. The upper sand and gravel unit is isolated from deeper sand and gravel units by at least one clay till sheet. The depth to bedrock in the area is 150 feet or greater.

Figure 4-10 shows the extent of the alluvial deposits that would be suitable for siting an alluvial wellfield. The figure also shows the position of a potential alluvial wellfield. The location of the wellfield as shown on Figure 4-10 is only conceptual. The actual position of any wellfield or individual well would be determined on the basis of local geologic conditions and land availability.

The large storage volume provided by the sand and gravel deposits would offset seasonal periods of low flow in the Fox River. Given the extent of the shallow sand and gravel unit along the Fox River, the potential for developing a sufficient source capacity to satisfy the Waukesha Water Utility demands is good. The water is hard, naturally low in radionuclides, but may contain some constituents above secondary MCLs such as iron or manganese. The transit time and mixing of ground and surface water that would occur in the aquifer would buffer any changes in water quality or temperature that occur in the river. Due to the shallow well depths, the water will need adequate disinfection as a minimum. If subsequent testing indicates that the water is classified as groundwater under the direct influence of surface water, additional treatment would be required.

The wellfield is likely to produce a significant portion of its water from groundwater flowing toward the river. Given the high permeability of the soils and the relatively shallow depth of the aquifer, the groundwater portion of the wellfield will be vulnerable to contamination. As a result, it will be important to select wellfield locations that minimize the potential for contamination from upgradient sources. Well head protection will be a critical element for maintaining the wellfield.

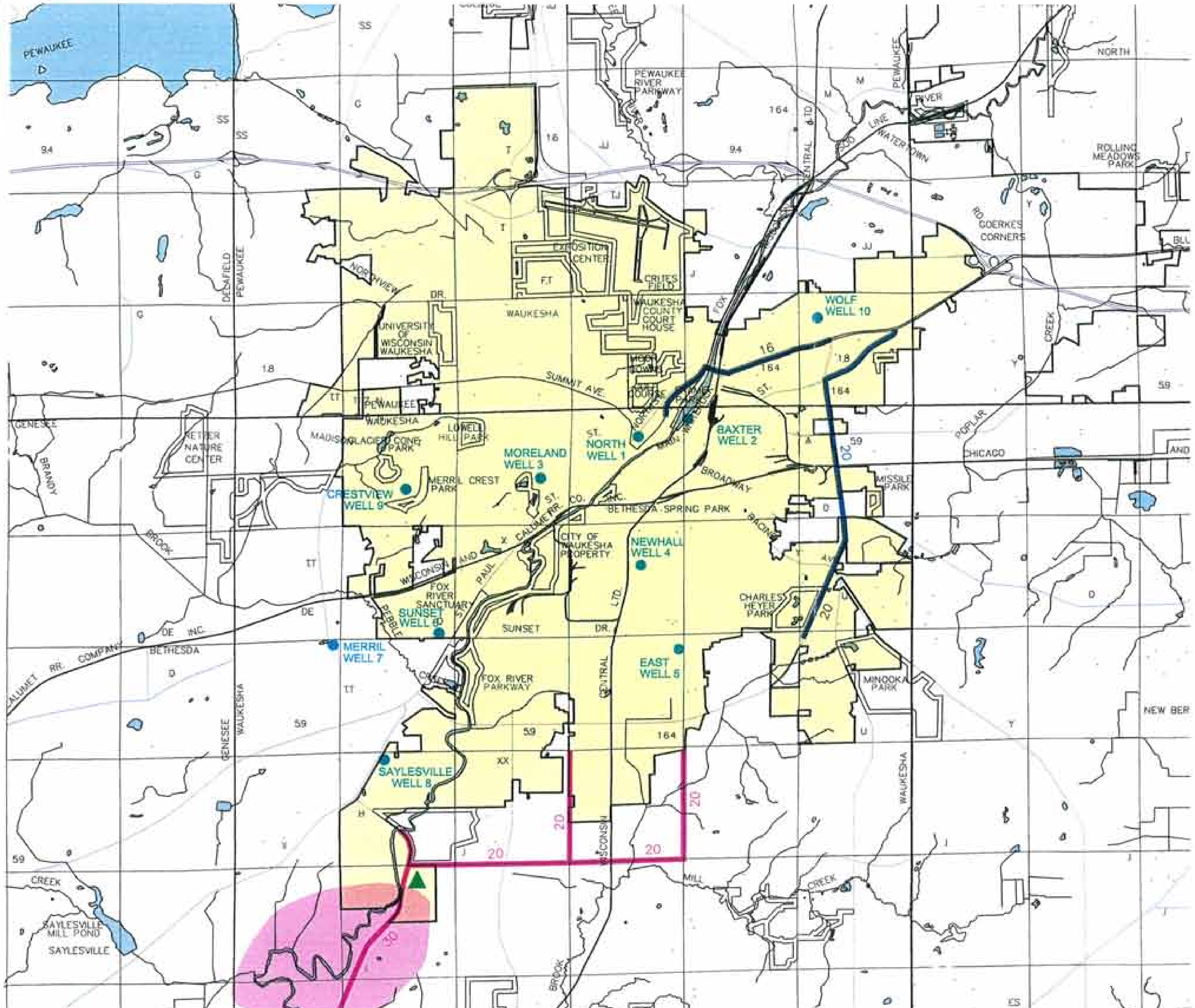

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FIGURE 4-9

FOX RIVER ALLUVIAL WELL FIELD

N

W E

S

0 1 2 3 4 5 10,000

SCALE IN FEET

LEGEND

- EXISTING WELL TO BE ABANDONED
- PROPOSED NEW WELL FIELD (CONCEPTUAL LOCATION)
- PROPOSED NEW TRANSMISSION MAIN
- PROPOSED WATER MAIN ADDITION
- PROPOSED TREATMENT FACILITY

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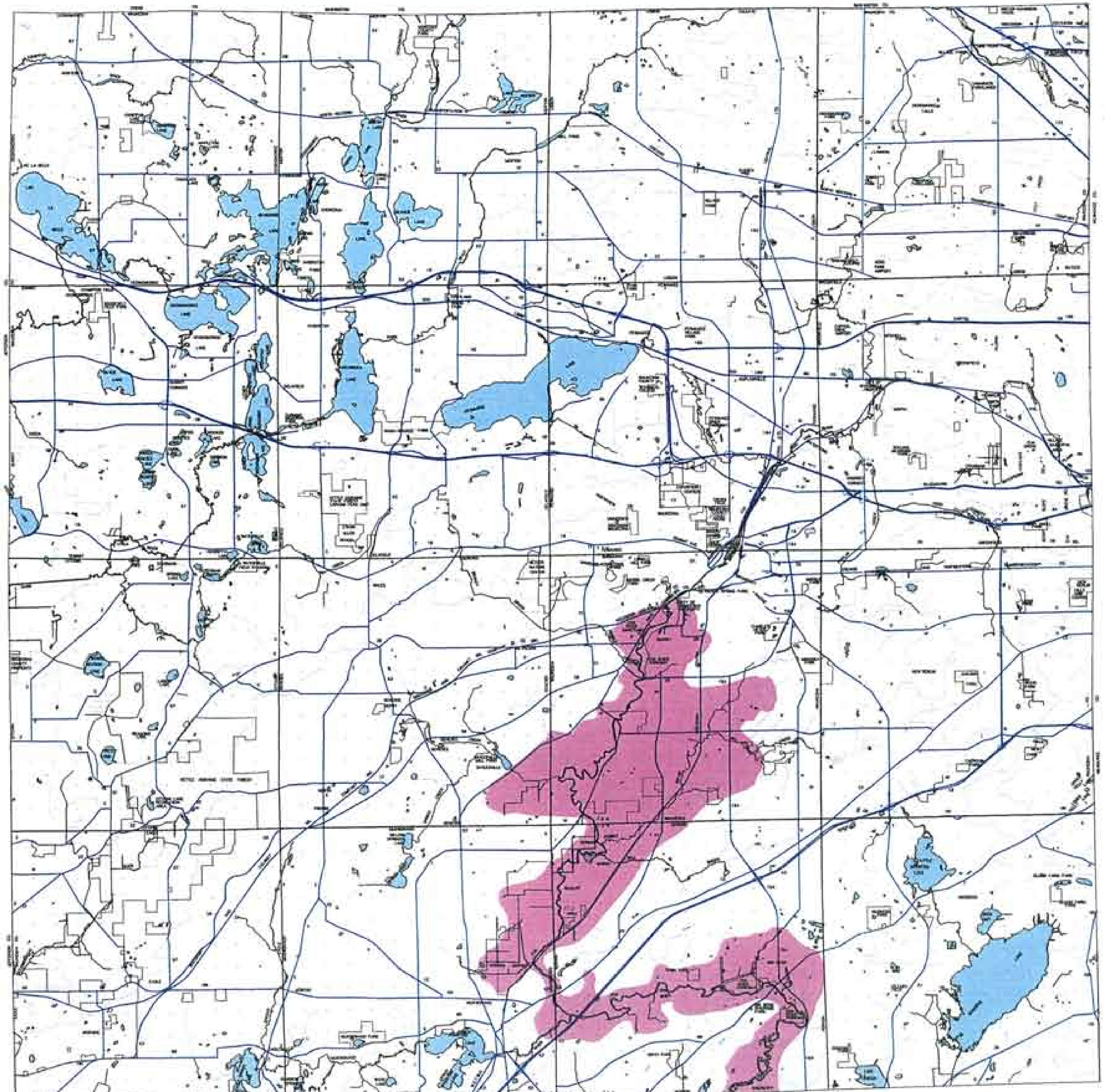

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FIGURE 4-10

RECOMMENDED ALLUVIAL WELL FIELD EXPLORATION AREA

N
W E
S

0 1 2 3 4 5
SCALE IN MILES

LEGEND

RECOMMENDED EXPLORATION AREA

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4.1.3.2 Infrastructure

Wells. Given the reported performance of the dewatering system near River Road, a properly designed vertical well should probably be able to produce approximately 1,000 gpm. A minimum of 16 vertical wells would be required to produce the 22 mgd needed for maximum ultimate demands (reliable capacity with one well out of service). Assuming the wellfield is designed to induce recharge from the river, well spacings of 500 feet or less may be possible. If the wells are constructed on one side of the river, the wellfield would extend a minimum of 6,500 feet along the river. If wells are constructed on both sides of the river, the wellfield would extend approximately 3,000 feet along the river. It appears that sufficient undeveloped land is available to accommodate either design.

Horizontal wells could be used instead of vertical wells. Given the permeable nature of the sand and gravel deposits, a horizontal well should be able to produce at least 3,000 gpm. A minimum of six horizontal wells would be needed to meet ultimate demand (reliable capacity with one well out of service). Depending on the aquifer properties, the spacing between the horizontal wells will probably need to be larger than for the vertical wells. For the sake of comparison, a spacing of between 1,000 feet to 0.5 mile between the wells would require between 1 to 2 miles to accommodate the wellfield if the wells are placed on one side of the river. It is unlikely that horizontal wells could be placed directly opposite each other on both sides of the river.

About 1 to 4 miles transmission line would be required for a vertical wellfield, with an additional mile of feeder lines. Additional modifications to the distribution system are required to accommodate the water entering the system.

Treatment for Fox River Alluvium Water. The Fox River alluvium water quality is assumed to be similar to that of the sand/gravel aquifer (Table 4-2). However, there is a possibility that this water may be influenced by the Fox River depending on well construction, location, and seasonal water variations. The WDNR regulations (NR 811 and 809) state that groundwater under the direct influence of surface water must be treated according to surface water regulations. The presence of *Cryptosporidium*, *Giardia*, or Coliform bacteria at any time would designate a groundwater as under the direct influence of surface water. As a conservative assumption, the Fox River alluvium water will be treated as groundwater under the direct influence of surface water.

The major treatment impacts include requirements for particle removal and additional disinfection. There are many treatment processes that can be used to meet the regulations. It is beyond this scope of work to determine the optimum treatment method. For the purposes of this study, it is assumed that the Fox River alluvium will be treated by direct filtration (coagulation, flocculation, gravity filtration) followed by ultraviolet light and chlorine disinfection. The filtered water will be collected in a clearwell and pumped to the distribution system. A schematic of the treatment process is shown on Figure 4-11.

TABLE 4-2
Shallow (Sand & Gravel) Aquifer Water Quality Data
Future Water Supply

	Typical Value	MCL Primary Standard	Secondary Standard
Total Hardness (mg/L as $CaCO_3$)	420		
Calcium (mg/L)	90		
Magnesium (mg/L)	45		
Total Alkalinity (mg/L as $CaCO_3$)	320		
pH	7.3		
Sulfate (mg/L)	60		250
Chloride (mg/L)	60-170		250
Total Dissolved Solids (mg/L)	470-540		500
Iron (mg/L)	0.1-0.9		0.3
Manganese (mg/L)	0.02-0.05		0.05
Sodium (mg/L)	23-60		20
Radium 226+228 (pCi/L)	BD	5	
Gross Alpha (pCi/L)	BD	15	
Radon (pCi/L)	BD		

BD = Below Detection
Data Source: WDNR Mukwonago Wells 5 & 6; Oconomowoc Well 4; Hartland Wells 2, 4 & 5

Currently, there are no municipal water systems in Wisconsin designated as groundwater under the direct influence of surface water. However, discussions with WDNR indicate that this treatment process should be acceptable, but would likely require pilot testing depending on actual conditions. Ultraviolet light is very effective in inactivating protozoan pathogens such as *Cryptosporidium* and *Giardia*, along with many bacteria and viruses. Chlorine is not effective against *Cryptosporidium*. Ultraviolet light disinfection may not be required if adequate disinfection is achieved with chlorine and *Cryptosporidium* is absent. However, the conservative assumption to include ultraviolet light disinfection was made.

A shallow unconfined aquifer like the Fox River alluvium is susceptible to contamination. Potential contaminants include volatile organic compounds, herbicides, and nitrates. Although treatment for these contaminants is not required unless they are detected, flexibility to add processes to the treatment plant should be designed.

A single water treatment plant would be desirable to minimize O&M and costs. The wellfield water could be conveyed to the plant, treated, then pumped to the distribution system.

Transmission. Transmission from a Fox River alluvium wellfield to Waukesha would be accomplished with dual 30-inch-diameter transmission lines. The second line would provide a degree of reliability and redundancy. About 3 miles of large transmission main would be required.

Another 11 miles of 20- and 16-inch water main are required to distribute the treated groundwater throughout the City of Waukesha.

4.1.3.3 Regulations/Legal

The alluvial wellfield will probably be scrutinized carefully to determine the level of treatment required. If the wellfield is classified as groundwater under the direct influence of surface water, some surface water treatment will be required. The well sites will need to comply with NR 811, which specifies a minimum lot size and minimum setbacks from a variety of potential groundwater contamination sources. Currently, NR 811 does not recognize any connection between surface and groundwater. Therefore, it appears that the wellfield would not need to gain approval for any surface water diversion from the Fox River, though the WDNR may want to review this point.

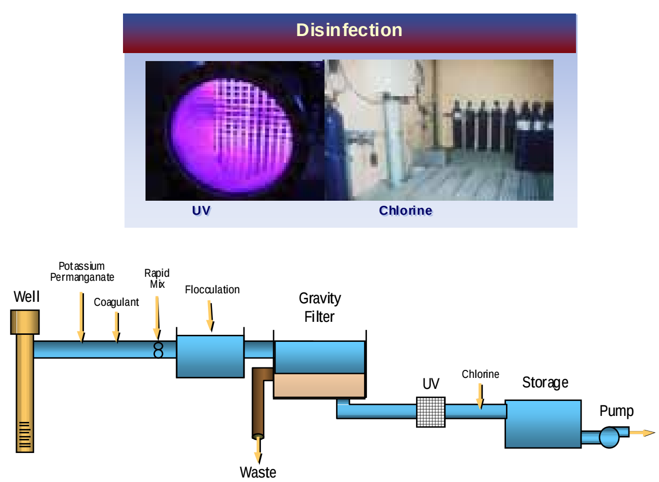

FIGURE 4-11
Treatment for Fox River Alluvium Water

The treatment plant will require WDNR approval based on NR 811 and 809 requirements. Pilot testing of treatment processes is likely to be required.

This alternative will require the least amount of transmission piping, and thus issues such as easements would be minimized.

4.1.3.4 Political and Public Acceptance

The public may have some initial resistance about drinking water that comes in part from the Fox River. However, with appropriate treatment and public education, most of these concerns should be addressed. Environmental groups may be concerned about the potential impact on the Fox River, particularly during low flows. However, most of the water will be returned to the river through the Waukesha wastewater treatment plant a few miles upstream of the likely wellfield location. The water derived from aquifer storage during low-flow periods of the Fox River will augment the base flow conditions by replacing more water than is infiltrated.

The treatment plants will require aesthetic features to make them acceptable to nearby citizens and comply with zoning requirements. Truck traffic and noise be minimized where possible.

The transmission main would require easements and could result in some public opposition. Some transmission lines would be run in the city limits, resulting in traffic slow-downs.

4.1.3.5 Operations and Maintenance

Wells. Alluvial wellfields are more prone to plugging and biofouling than traditional wells due to the higher dissolved oxygen and total organic carbon content of the induced river water. These problems can be controlled through close monitoring of the hydraulic performance of the wells and proactive well rehabilitation practices. Vertical wells could also be used in the alluvial aquifer if desired.

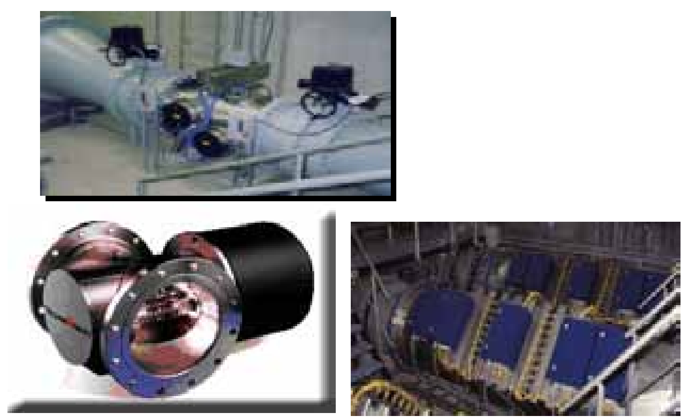

FIGURE 4-12
UV Disinfection Equipment

Water Treatment Plant. A surface water treatment plant will have mixing equipment (rapid mix, flocculation), chemical storage, and feed systems as well as filters. The filter media will be in concrete boxes with associated pipes and valves. The controls can also be automated so that operators do not have to be onsite 24 hours a day. Chemical systems (potassium permanganate, coagulant, and chlorine) will be will be stored and fed onsite. Typical monitoring includes flowrate, chemical feed rates and residuals, filter headloss, turbidity, and iron/manganese. All these parameters can be monitored on-line and sent to a computer data collection system.

The ultraviolet light disinfection system consists of lamps in an enclosed pipe. Typical equipment configurations are shown on Figure 4-12. This disinfection system can be automated for day to day operations. Monitoring will include recording light intensity, flowrate, UV 254 absorbance, and IT (irradiance multiplied by time) as a measure of disinfecting power. All these parameters can be measured on-line and sent to a computer data collection system. Typical maintenance items include replacing lamps (1 to 2 times per year), sensors (every 1 to 3 years), quartz sleeves and lamp ballasts (5 to 10 years), and occasionally (1 to 2 times per year) manually cleaning the lamps and sleeves. Most ultraviolet systems are equipped with automatic wipers for routine quartz sleeve cleaning. Iron can reduce ultraviolet disinfection effectiveness and should be minimized for optimum ultraviolet performance.

A pump station will have O&M procedures for the pumps, pipes, and valves.

The treatment system should be checked several times a day for proper filtration and backwashing, pressures and flowrates, chemical storage levels and feed rates, and general water quality. Additional distribution system water quality parameters will have to be measured, including chlorine residual, heterotrophic plate counts, and coliforms.

A new treatment plant will require additional maintenance for the building and equipment. Activities may include instrument calibration, valve and piping maintenance, HVAC maintenance, filter media replacement, chemical system maintenance, and general building maintenance.

Water Plant Residuals. Filters will accumulate precipitated iron and manganese, along with coagulant chemical. When the filter media becomes clogged, the required head to drive water through the media increases. At some point, the filter must be backwashed to remove the accumulated coagulant, iron, and manganese. This is accomplished by reversing the flow through the media and washing the solids to waste. In this alternative, it is assumed that a sanitary sewer will be available roughly 1 mile from the water plant. Backwash waste can be discharged to the sewer and treated at the wastewater plant.

For water with 1 mg/L iron and 0.1 mg/L manganese, the estimated amount of dry solids in the backwash water is about 32 lb./million gallons of water treated. At coagulant doses for direct filtration, typical solids production would be about the same as that from the iron/manganese. This amounts to about 500 pounds per day of dry solids with the current average day water demand (8 mgd) and about 960 pounds per day with the current maximum day demand (15 mgd). The solids are mainly inorganic with very low biological oxygen demand. The above numbers assume the suspended solids in the water are very low, which is expected from an alluvial wellfield.

The volume of backwash wastewater can vary significantly depending on operational procedures, filter design, and water quality characteristics. Typical backwash volumes are about 1 to 3 percent of the treatment plant flow. Therefore, the volume of wastewater would be about 160,000 gpd on a current average day and 300,000 gpd on a maximum day. The backwash flow is intermittent and instantaneous flowrates would be higher than the daily averages stated above. An equalization tank for backwash waste may be required to minimize pipe size.

Transmission. The additional transmission pipe and valves will require maintenance, similar to existing pipe and valves in the Waukesha Water System.

4.1.3.6 Schedule

Developing an alluvial wellfield will require some initial site investigations and pumping tests. Other studies that may take a year include a pilot-plant study to evaluate treatment requirements and an environmental impact evaluation of the groundwater and surface water resources.

The design and construction of the wellfield will require about 2 to 3 years. The treatment facilities and pipelines could be completed within this time frame.

4.2 Alternative 3 – Shallow Aquifers (Sand/Gravel, Dolomite)

The shallow aquifers of Waukesha County consist of the sand and gravel aquifer and the dolomite aquifer. Both aquifers are hydraulically connected and are recharged by local precipitation. The distribution and characteristics of the two aquifers are different and described separately.

A shallow aquifer alternative consists of 16 new vertical wells located 2 to 3 miles south of the City of Waukesha. Existing sandstone wells would be abandoned or kept as standby. A treatment plant for removal of iron/manganese would be provided. The major facilities are shown on Figure 4-13.

4.2.1 Alternative 3a – Sand and Gravel Aquifer

4.2.1.1 Reliability

The unconsolidated soils above bedrock in the Waukesha area predominantly consist of a series of glacial deposited during the Wisconsin Ice Age. Pre-Wisconsin glacial deposits may be present at the base of some bedrock valleys. Modern alluvial sediments cover the glacial deposits along the floodways of several rivers. When the glacial deposits are thick and permeable enough, they form an aquifer commonly called the sand and gravel aquifer. The occurrence of the sand and gravel is generally sporadic in the eastern half of Waukesha County, but produces a significant portion of the water supply for several surrounding communities.

Figure 4-14 shows the thickness of unconsolidated material in Waukesha County. The glacial deposits within the city are typically too thin or impermeable to act as aquifers for high-capacity wells. However, thick, permeable sand and gravel deposits are present in several areas near Waukesha. Figure 4-14 shows the elevation of the bedrock surface. The areas of thick unconsolidated materials generally correspond to buried river valleys incised into the bedrock prior to the last glacial advance. These bedrock valleys have been filled with glacial sediments that serve as aquifers for several municipal systems in the county.

These aquifers consist of permeable sand and gravel deposits from outwash deposits of sand and gravel deposited by water flowing off the receding ice mass during periods of glacial retreat. Some older channel deposits from rivers flowing in the bedrock valleys prior to the deposition of the glacial deposits may be present at the very base of some bedrock valleys. Following deposition of a sand and gravel deposit units during a glacial retreat, the outwash units were usually buried by clay rich till deposits from a readvance of the ice sheet. This pattern is repeated several times in most valleys. This results in a layer cake type pattern of permeable sand and gravel deposits under low permeability clay till or glacial lake clay deposits. Most bedrock valley aquifers contain two to three permeable sand and gravel units between low permeability clay confining units. The sand and gravel units are generally not uniform and the capacity of an individual well will vary depending on the relative permeability of the sand and gravel units at that location.

There are three significant bedrock valley features in Waukesha County. The closest bedrock valley to the city is the Troy bedrock valley. The Troy bedrock valley generally runs west to east about 1 mile south of the city. A smaller tributary valley extends into the city along the Fox River. The Troy bedrock valley trends to the southwest into Illinois where it merges into a larger system of buried bedrock valleys. The Troy bedrock valley actually consists of two segments: one segment is part of an old drainage that flowed to the southwest, and the other segment flowed to the east toward Lake Michigan. The divide between these two segments is located roughly due south of the city.

Figure 4-15 is a geologic cross section through the Troy bedrock valley about 2 miles south of the city. The bedrock elevation in the center of the Troy bedrock is about 500 feet with over 400 feet of glacial deposits filling the valley. Past well site exploration work in the valley determined that the glacial deposits contain at least two permeable sand bodies suitable for high-capacity wells. Well capacities of between 500 to 1,500 gpm are possible from properly sited wells. The water is naturally low in radionuclides, but may exceed some secondary MCLs, especially for iron.

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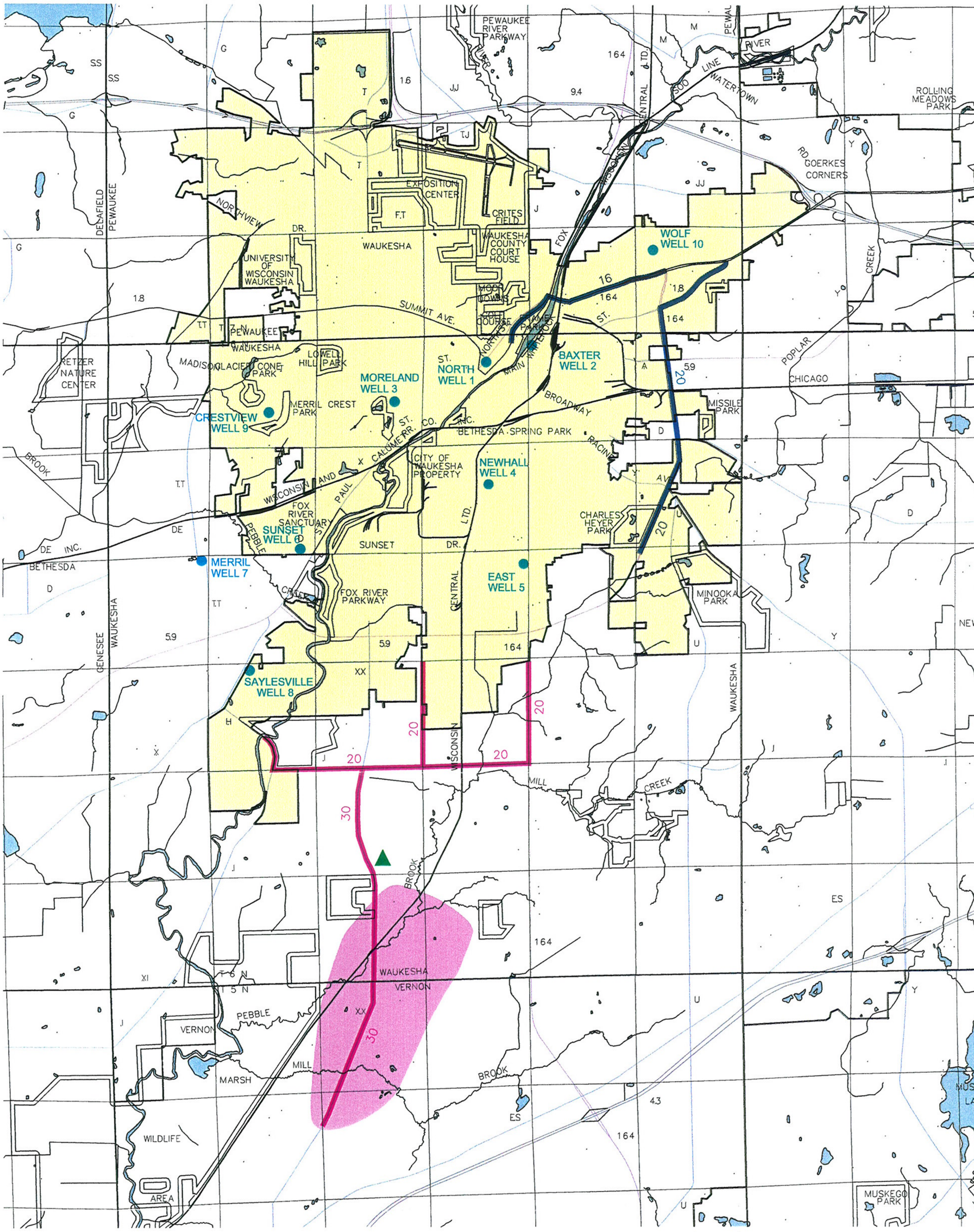

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FIGURE 4-13

SHALLOW AQUIFER WATER SUPPLY

N
W E
S

LEGEND

- EXISTING WELL TO BE ABANDONED
- PROPOSED NEW WELL FIELD (CONCEPTUAL LOCATION)
- PROPOSED NEW TRANSMISSION MAIN
- PROPOSED WATER MAIN ADDITION
- PROPOSED TREATMENT FACILITY

0 1 2 3 4 5 10,000
SCALE IN FEET

CH2MHILL

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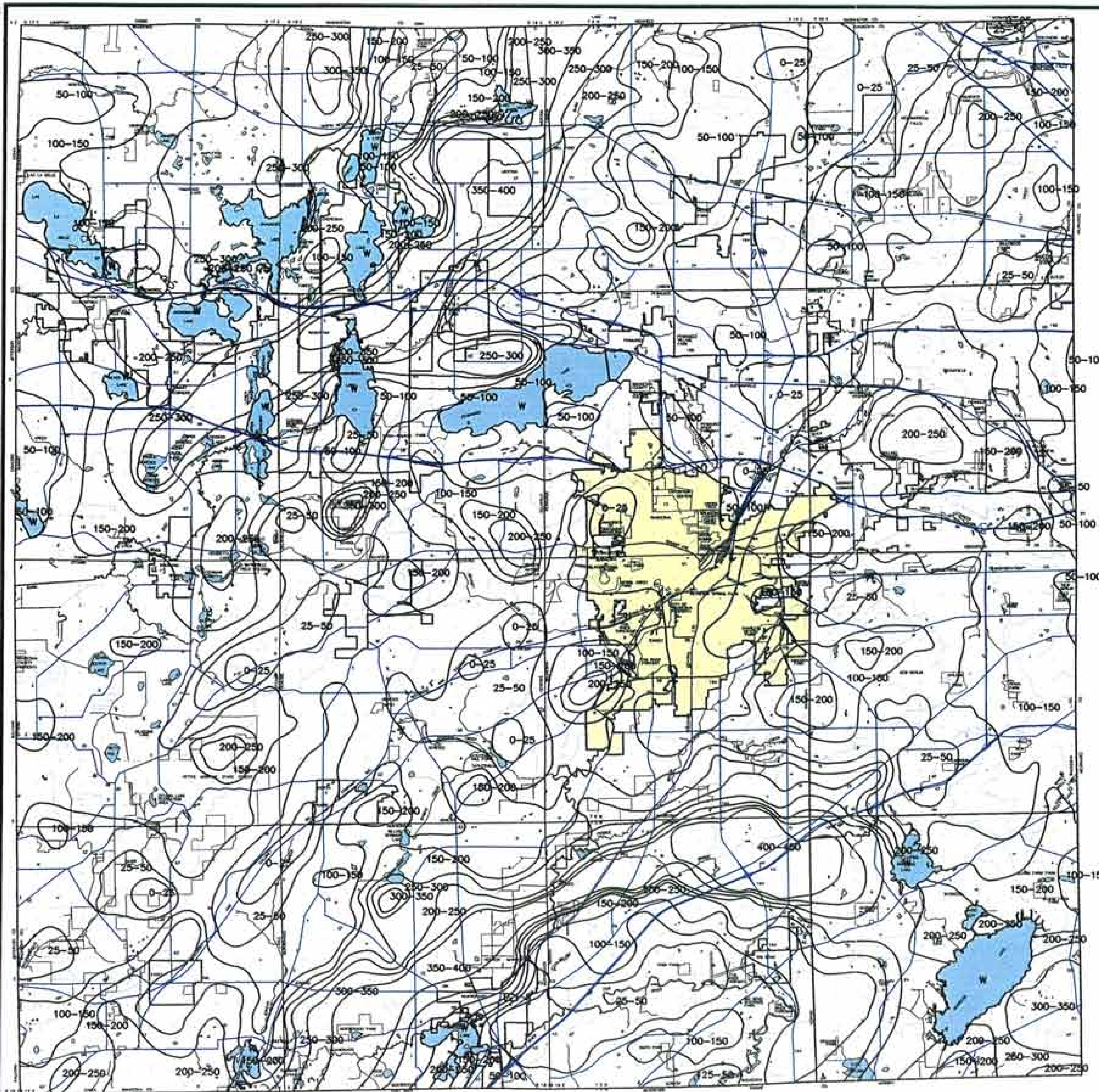
FIGURE 4-14

DEPTH TO BEDROCK IN WAUKESHA COUNTY



N
W E
S

0 1 2 3 4 5
SCALE IN MILES

LEGEND

75 DEPTH TO BEDROCK

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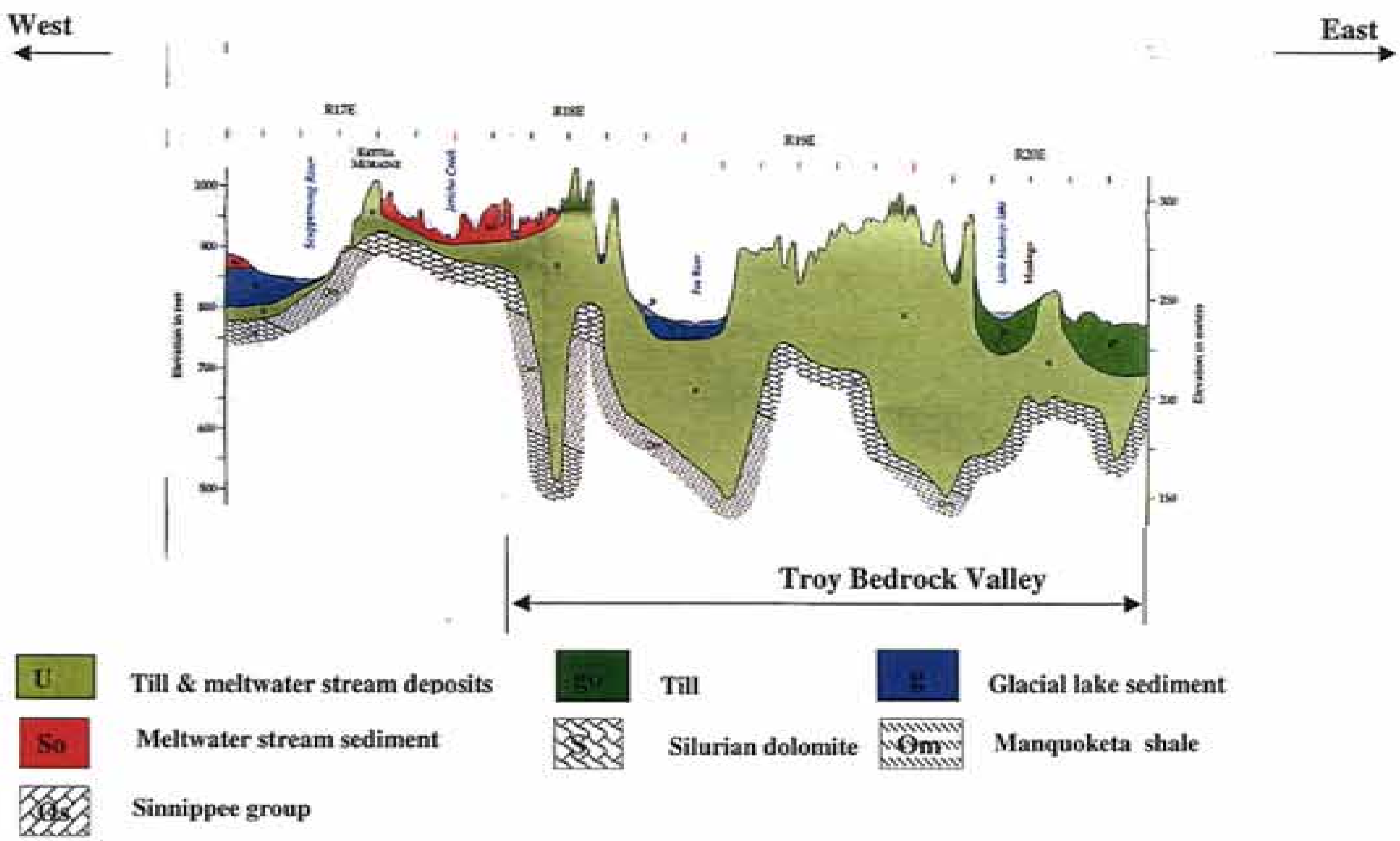
Figure 4-15
Geologic Cross-Section Through Northern Waukesha County Showing the Troy Bedrock Valley



Modified from Clayton, 2001

The Rock bedrock valley lies about 7 miles west of the city. This valley trends southwest to northeast through the northwest part of the county, and extends into Illinois where it merges with a larger bedrock valley system. The Rock River lies several miles west of the Rock bedrock valley in Waukesha and eastern Jefferson Counties. The Rock River joins the Rock bedrock valley near Fort Atkinson and the two features follow similar paths into Illinois.

Figure 4-16 is a geologic cross section through the Rock bedrock valley immediately north of the city. The elevation of the bedrock surface is approximately 550 feet in the center of the Rock bedrock valley. Glacial material is over 350 feet thick in parts of the valley. Several municipal water systems operate wells in the aquifer. A properly sited well should produce roughly 1,000 to 2,000 gpm, with higher yields possible in some circumstances. The water quality is very similar to the groundwater in the Troy bedrock valley.

The Menomonee bedrock valley is a smaller valley that starts about 1 mile northeast of the city and trends nearly due east toward Lake Michigan. The elevation of the bedrock at the base of the valley is about 700 feet with a maximum of about 250 feet of glacial fill. Exploration work conducted for the City of Brookfield indicated that the sand and gravel deposits are generally not as thick or permeable as the Troy or Rock bedrock valley aquifers. The expected yield of wells in this valley is about 500 gpm. The valley runs under heavily developed land with numerous potential sources of contamination. Based on limited potential wells capacity and the limited land availability, the Menomonee bedrock valley is probably not a potential water source for the Waukesha Water Utility.

Figure 4-17 shows the location of two potential sand and gravel wellfields. The wellfields are located in the Troy and Rock bedrock valleys. The location of the wellfields as shown on the map is only conceptual. The actual position of any wellfield or individual well would be determined on the basis of local geologic conditions and land availability.

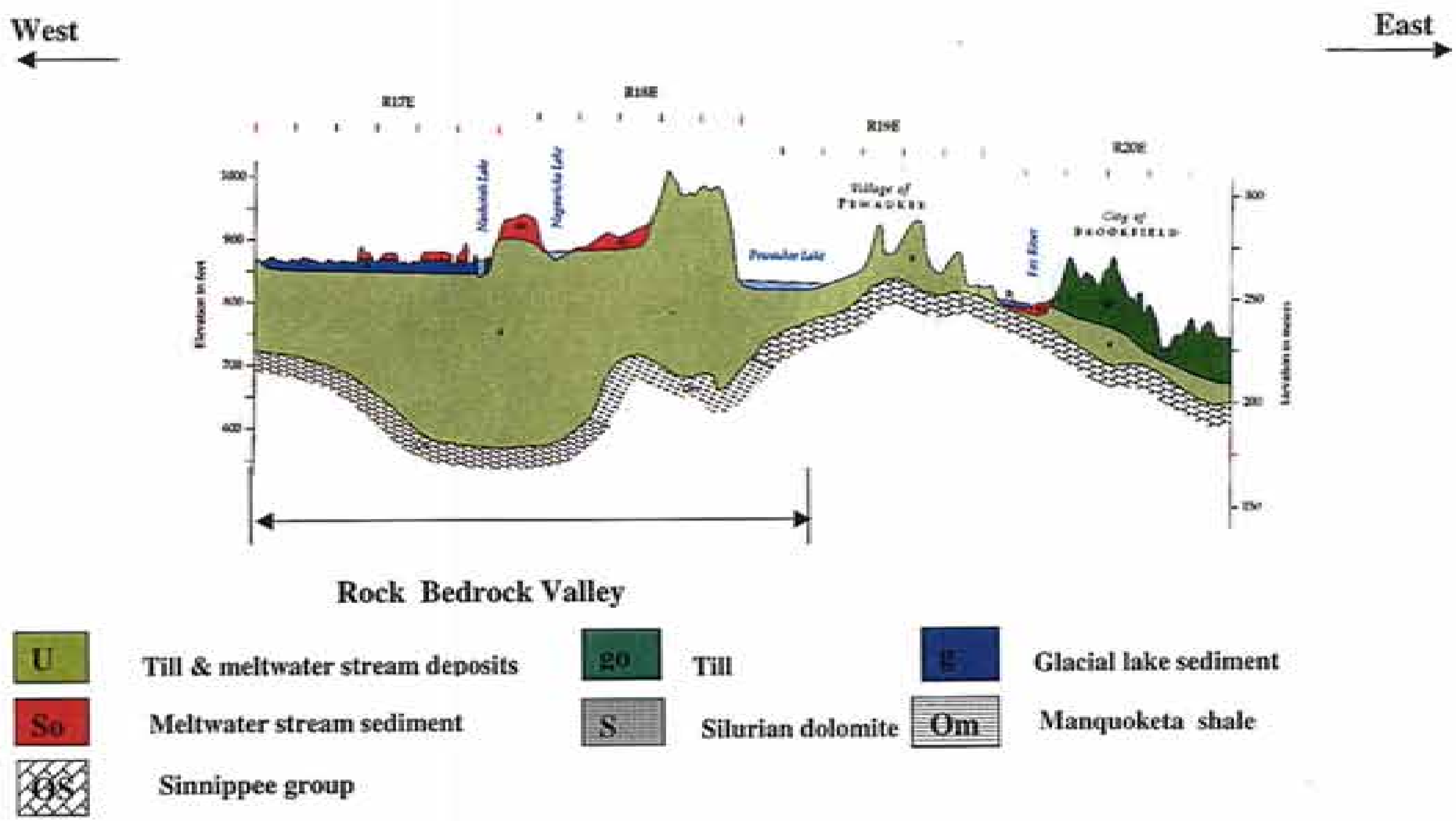
4.2.1.2 Infrastructure

Wells. Assuming the new wells will have a typical capacity of 1,000 gpm, 16 new wells will be needed to provide the ultimate capacity of the Waukesha Water Utility (reliable capacity with one well out of service). The length of water main required will depend on which bedrock valley aquifer is developed. If the Troy bedrock valley is used, about 3 to 5 miles of transmission main will be needed. Assuming a wellfield designed with a minimum spacing of 0.25 mile between wells, about 2 to 3 miles of smaller diameter feeder lines would also be needed. Treatment facilities for iron or manganese will be assumed for the purposes of this study.

Treatment for Shallow Aquifer Water. The shallow aquifer (sand gravel or dolomite) water quality is summarized in Table 4-2. This water is characterized as hard with moderate iron and manganese levels.

Treatment for shallow aquifer water will include iron/manganese removal and chlorination. The treatment process will be similar to that described for the Western sandstone wells (Alternative 1b).

Figure 4-16
Geologic Cross-Section Through Northern Waukesha County
Showing the Troy Bedrock Valley



Modified from Clayton, 2001

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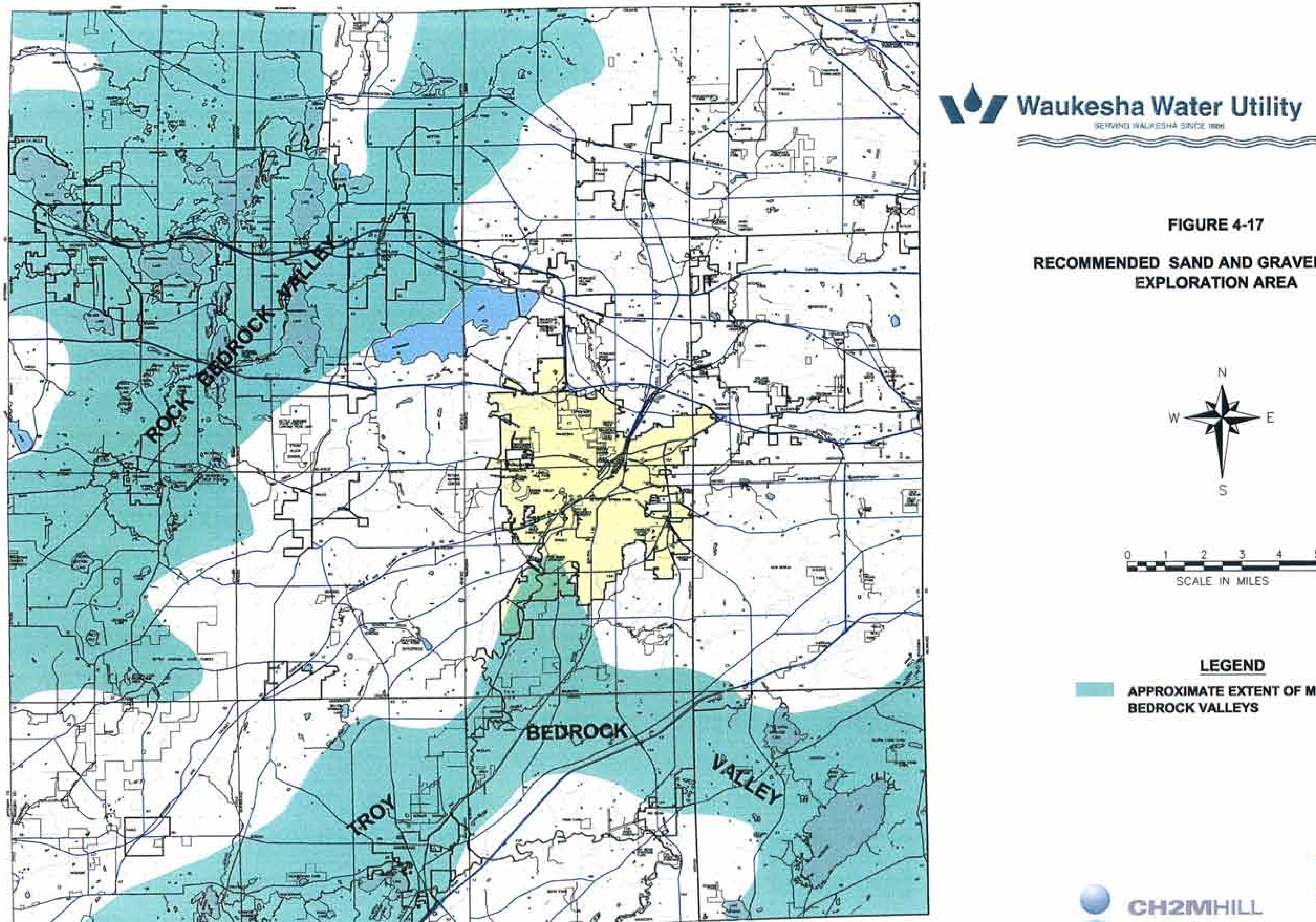
FIGURE 4-17

RECOMMENDED SAND AND GRAVEL AQUIFER EXPLORATION AREA



LEGEND

APPROXIMATE EXTENT OF MAJOR BEDROCK VALLEYS

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Transmission. Transmission from a Troy bedrock valley wellfield to Waukesha would be accomplished with dual 30-inch-diameter transmission lines. The second line would provide a degree of reliability and redundancy. About 5 miles of large transmission main would be required.

Another 11 miles of 20- and 16-inch water main are required to distribute the treated groundwater throughout the City of Waukesha.

4.2.1.3 Regulations/Legal

Current well siting requirements will allow the Waukesha Water Utility to pursue a wellfield in either bedrock valley. Local townships and municipalities are likely to resist granting any needed zoning changes or granting rights-of-way for transmission lines. Extensive development of the shallow sand and gravel units in either bedrock valley aquifer could affect local stream flows or surface water bodies. The WDNR does not currently have a mechanism for denying well permits based on surface water impacts but rule changes to that affect are likely in the next few years. Developing wells in deeper sand and gravel units below confining layers will reduce the impact on surface water.

The wellfield will require a well head protection plan to satisfy NR 811 requirements and protect the wells from contamination from agricultural sources. The Waukesha Water Utility will have no zoning control to enforce the well head protection ordinance because the wellfield will be beyond Waukesha corporate limits. As mentioned previously, formation of a water authority may eliminate some of the local ordinances and zoning requirements.

The vulnerability of the sand and gravel aquifer will vary depending on the degree of impermeable cover over the aquifer and the surrounding land use. If deeper sand bodies below clay confining units are developed, the wells may have relatively low susceptibility to contamination. If shallower sand units with no clay confining units are developed, the wells will be much more vulnerable to contamination and local land use will be more important. If this is not possible, it may be necessary to acquire larger tracts of land or find mechanisms to influence land use on surrounding properties. This might be accomplished by providing incentives to surrounding landowners to grow crops that require lower inputs of fertilizers and chemicals and prevent high density developments with septic tanks. As a result, the most effective protection for these wells would probably come from finding aquifers with low susceptibility or by controlling large areas of land, such as in a park.

The treatment plant will require WDNR approval based on NR 811 and 809 requirements. Pilot testing of treatment processes is not likely to be required.

4.2.1.4 Political and Public Acceptance

The customers of the Waukesha Water Utility should perceive a net benefit from obtaining water that complies with radionuclide standards. There may be some perception that the water is better because it comes from more a rural area. Local townships, citizen groups, and other municipalities may oppose the wellfield.

The treatment plant will require aesthetic features to make it acceptable to nearby citizens and comply with zoning requirements. Truck traffic and noise should be minimized where possible.

The transmission main would require easements and could result in some public opposition. Some transmission lines would be run in the city limits, resulting in traffic slow-downs.

4.2.1.5 Operations and Maintenance

Wells. The O&M of a shallow aquifer wellfield should be similar to the current level of effort. More sampling and maintenance may be required due to a greater number of wells. However, pumping and repair costs will probably be lower due to shallower well depths and pumping levels. Treatment facilities built to meet secondary MCLs would require additional maintenance.

Water Treatment. O&M requirements for an iron/manganese plant would be similar to the Western sandstone wellfield, described under Alternative 1b.

Water Plant Residuals. Water plant residuals for an iron/manganese removal plant would be similar to the Western sandstone wellfield, described under Alternative 1b.

Transmission. The additional transmission pipe and valves will require maintenance, similar to existing pipe and valves in the Waukesha Water System.

4.2.1.6 Schedule

The wellfield can be developed in stages as the water is needed. The water main and initial wellfield could be on-line within 3 to 5 years. Treatment and transmission facilities could be built concurrently.

4.2.2 Alternative 3b – The Dolomite Aquifer

4.2.2.1 Reliability

Below the glacial deposits lies the regional bedrock, the Silurian dolomite commonly called the Niagaran dolomite. The Silurian dolomite extends from the base of the unconsolidated deposits to a maximum depth of about 350 feet in eastern Waukesha County. The dolomite aquifer is near the surface in portions of Waukesha County and is mined for aggregate in several quarries. The dolomite is over 300 feet thick in portions of northeastern Waukesha County but has been removed by erosion in much of the western half of the county (Figure 4-18). The Waukesha Water Utility wellfield lies near the western edge of the dolomite.

The Silurian dolomite serves as an aquifer for much of eastern Wisconsin that is called the dolomite aquifer. The dolomite itself is relatively dense and incapable of storing or transmitting significant quantities of water. The dolomite aquifer usually produces small quantities of water sufficient for private homes only. However, numerous zones of fractured rock exist within the dolomite, which can produce several hundred gallons per minute from the void spaces created by the fractures and related solution cavities. It is only where the dolomite aquifer is fractured that it produces enough water for municipal needs. The fractures tend to concentrate in regional fracture zones. The fracture zones are nearly vertical and are typically several miles long, but only a few tens of feet wide. The difficulty in locating the fracture zones with sufficient accuracy has limited the use of the aquifer for high-capacity wells.

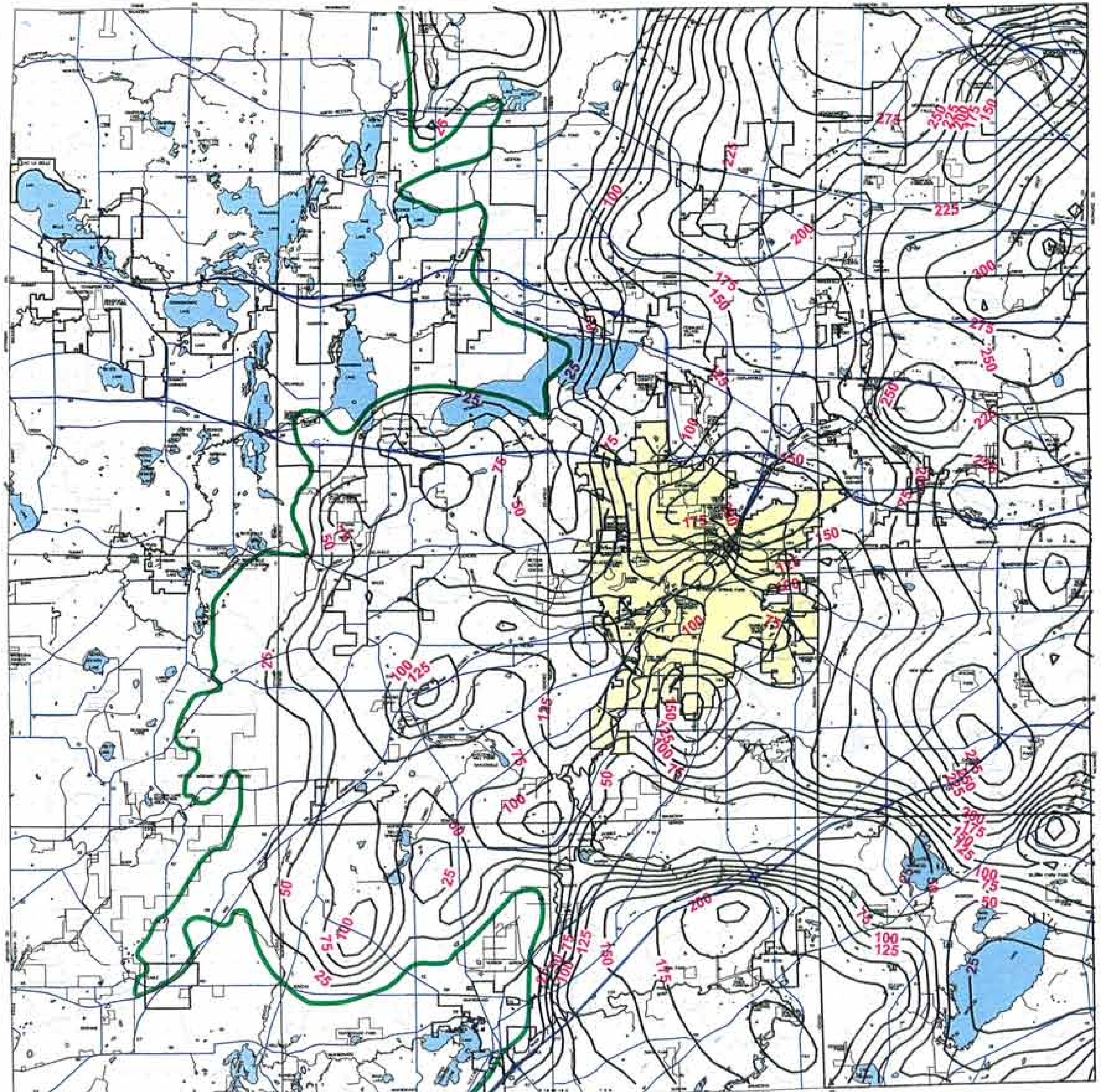

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FIGURE 4-18

THICKNESS OF SILURIAN DOLOMITE IN WAUKESHA COUNTY

N
W E
S

0 1 2 3 4 5
SCALE IN MILES

LEGEND

75 THICKNESS OF DOLOMITE

APPROXIMATE WESTERN EXTENT OF SILURIAN DOLOMITE

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Within the last 15 years, new geophysical techniques have been used in southeastern Wisconsin to locate regional fracture zones. This technology has made it possible to explore for high-capacity municipal wells in the dolomite aquifer. The dolomite aquifer has become an important water source for municipal wells for much of eastern Wisconsin, including the Cities of New Berlin and Brookfield, the Towns of Brookfield and Pewaukee, and the Villages of Germantown and Menomonee Falls.

Properly sited dolomite wells can yield up to 1,400 gpm, though capacities of 500 to 700 gpm are more common. The dolomite aquifer receives its recharge through the overlying glacial deposits. The dolomite aquifer can be locally confined where the glacial deposits are composed of dense clay. Where the glacial deposits are thin, the dolomite is susceptible to contamination from surface sources. The cone of depression of a dolomite aquifer well is typically elliptical with the long axis along the fracture zone. The shape and orientation of the cone of depression can be hard to define, which makes effective well head protection more difficult. As a result, it is usually prudent to site new dolomite aquifer wells in areas where the glacial materials offer some degree of natural protection from surface contamination rather than to rely on land use controls within a well head protection area defined on limited data.

The water quality of the dolomite aquifer is generally hard but otherwise acceptable. Radionuclides are typically low, but a few dolomite wells with gross alpha levels of up to 7 pCi/L have been found in Waukesha County. Though these levels are well below the MCL, they can have a significant impact if the water is to be used as a blending source. Some aesthetic water quality parameters above secondary MCLs, such as iron, sulfate, and TDS, are common. Several private dolomite wells with arsenic levels above the new MCL have been found in the county. Several municipal dolomite wells have measurable arsenic levels below the MCL. A few municipal dolomite wells appear to have experienced rising arsenic levels over the last 5 to 10 years.

The probability of finding a reasonable well yield from the dolomite aquifer is greater when the aquifer is greater than about 150 to 200 feet thick. Figure 4-18 shows the portion of Waukesha County is generally thick enough to warrant exploration for a high-capacity well. The City of Waukesha is located near the western edge of the dolomite aquifer. The dolomite aquifer is too thin in most of the city to make finding an adequate yield likely. This fact, in conjunction with the minimum required setback from a variety of potential contaminant sources mandated by the municipal well code (NR 811), makes serious exploration efforts for high-capacity dolomite wells within most of the City of Waukesha impractical. The dolomite is thin or absent to the west of the city. However, the dolomite is thick enough in the northeastern portion of the city, as well as in portions of the Towns of Brookfield and Vernon, and the Cities of Pewaukee and New Berlin, to potentially serve as a high-capacity aquifer.

Siting a dolomite aquifer well is an extensive process requiring significant exploration and testing. Large areas are usually screened to arrive at few potential well sites. The minimum setbacks from contaminant sources mandated by NR 811 typically limit the number of potential sites that can be developed. The elongated cone of depression created by dolomite wells typically limits the number of wells that can be drilled into a single fracture zone. As a result, suitable sites on multiple fracture zones will be needed to develop more than one or two dolomite wells. Given the limited area suitable for exploration, and a typical capacity of 500 to 700 gpm, it is unlikely that anything more than a small fraction of the Waukesha

Water Utility's water need can be met from the dolomite aquifer. However, one or two dolomite wells could be developed to augment the system's capacity or serve as a blending source to reduce radionuclides in existing sandstone aquifer wells, particularly well 10, which is located in an area with favorable dolomite thickness.

One of the major limitations of siting a dolomite well is the difficulty in encountering a narrow vertical fracture zone with a vertical well. Large pieces of land may be available, but surface developments may make it impossible to put the well house directly over the fracture. Horizontal drilling techniques can be used to intercept the fracture zones under surface obstruction and place the well house where it is more convenient. While to our knowledge no horizontal dolomite wells have been drilled in the state, we have discussed the concept with the WDNR and several drilling contractors. We believe that this technology is technically feasible and can be permitted under existing well code. This technology may make development of dolomite wells for the Waukesha Water Utility more feasible.

4.2.2.2 Infrastructure

The level of infrastructure needed to accommodate new dolomite wells would be minimal. Assuming that the wells are drilled within or immediately adjacent to the existing wellfield, the amount of new transmission line required will be minimal. Longer runs of dedicated raw water mains may be needed if the water is used for blending with specific Sandstone aquifer wells.

Treatment facilities for iron and manganese may be needed to meet secondary MCLs.

Water treatment and transmission requirements would be similar to those described above for sand/gravel aquifer alternatives.

4.2.2.3 Regulations/Legal

Dolomite aquifer well siting requirements are well established in NR 811. In addition to the minimum setbacks from potential contaminant sources, deeper casing can be required in areas with thin unconsolidated cover over bedrock or near quarries.

The wellfield will require a well head protection plan to satisfy NR 811 requirements and protect the wells from contamination from agricultural sources. The Waukesha Water Utility will have no zoning control to enforce the well head protection ordinance if the wellfield will be beyond the Waukesha corporate limits. The irregular shape of the cone of depression around the dolomite wells will make it difficult to define an accurate well head protection area. These factors will make it difficult to enact effective well head protection efforts to minimize the risk of contamination. However, if the wells are located in areas with thick deposits of clay above the dolomite, the risk of contamination to the aquifer will be significantly reduced making enforcement of a well head protection plan less important.

The treatment plant will require WDNR approval based on NR 811 and 809 requirements. Pilot testing of treatment processes is not likely to be required.

4.2.2.4 Political and Public Acceptance

The Waukesha Water Utility's customers should perceive a net benefit from getting water that complies with radionuclide standards. Local townships and other municipalities may oppose the wellfield if it is located in or near their corporate limits.

The treatment plant will require aesthetic features to make it acceptable to nearby citizens and comply with zoning requirements. Truck traffic and noise should be minimized where possible.

The transmission main would require easements and could result in some public opposition. Some transmission lines would be run in the city limits, resulting in traffic slow-downs.

4.2.2.5 Operations and Maintenance

Wells. The O&M of dolomite wells should be similar to the current level of effort. More sampling and maintenance may be required due to the greater number of wells to produce an equivalent amount of water. However, the pumping and repair costs will probably be lower due to the shallower well depths and pumping levels.

Water Treatment. Any treatment facilities built to meet secondary MCLs would require additional maintenance, as described under the shallow aquifer alternative.

Transmission. Water transmission main requirements would be similar to those described above for sand/gravel aquifer.

4.2.2.6 Schedule

The wellfield can be developed in stages as the water is needed. The wells could be on-line within 2 to 3 years. Any treatment or transmission facilities could be built concurrently.

4.3 Alternative 4 – Lake Michigan

As previously discussed, Lake Michigan water could best be provided from the Milwaukee Water Works. While other options exist, the current infrastructure in the Milwaukee system best lends itself to the provision of water to Waukesha. In this section, the relative merits and limitations of providing Lake Michigan water will be presented. Generally, the evaluation of Lake Michigan as a source is not dependent on the water provider. In instances where the evaluation dictates that the provider be identified, it is assumed Milwaukee is the source.

This alternative consists of a transmission line from Milwaukee to Waukesha, and a storage tank and pump station near the Hillcrest reservoir site. The major facilities are shown on Figure 4-19.

4.3.1 Reliability

The long-term reliability of Lake Michigan as a source of supply is excellent. The quantity of water contained in the lake is roughly 160 thousand times the annual projected water use for the city. Annual recharge to the lake is about 13 trillion gallons. Water quality is considered very good and the chance of major contamination is low.

To transmit the water to the city, a long, large diameter water main would be required. A dual water transmission main will be assumed in this alternative to provide more reliability than a single main.

Since the Milwaukee water treatment plant improvements, Milwaukee water is considered to be some of the safest around. The WDNR has indicated that “The Department believes the City of Milwaukee drinking water quality is among the best in the nation. …”

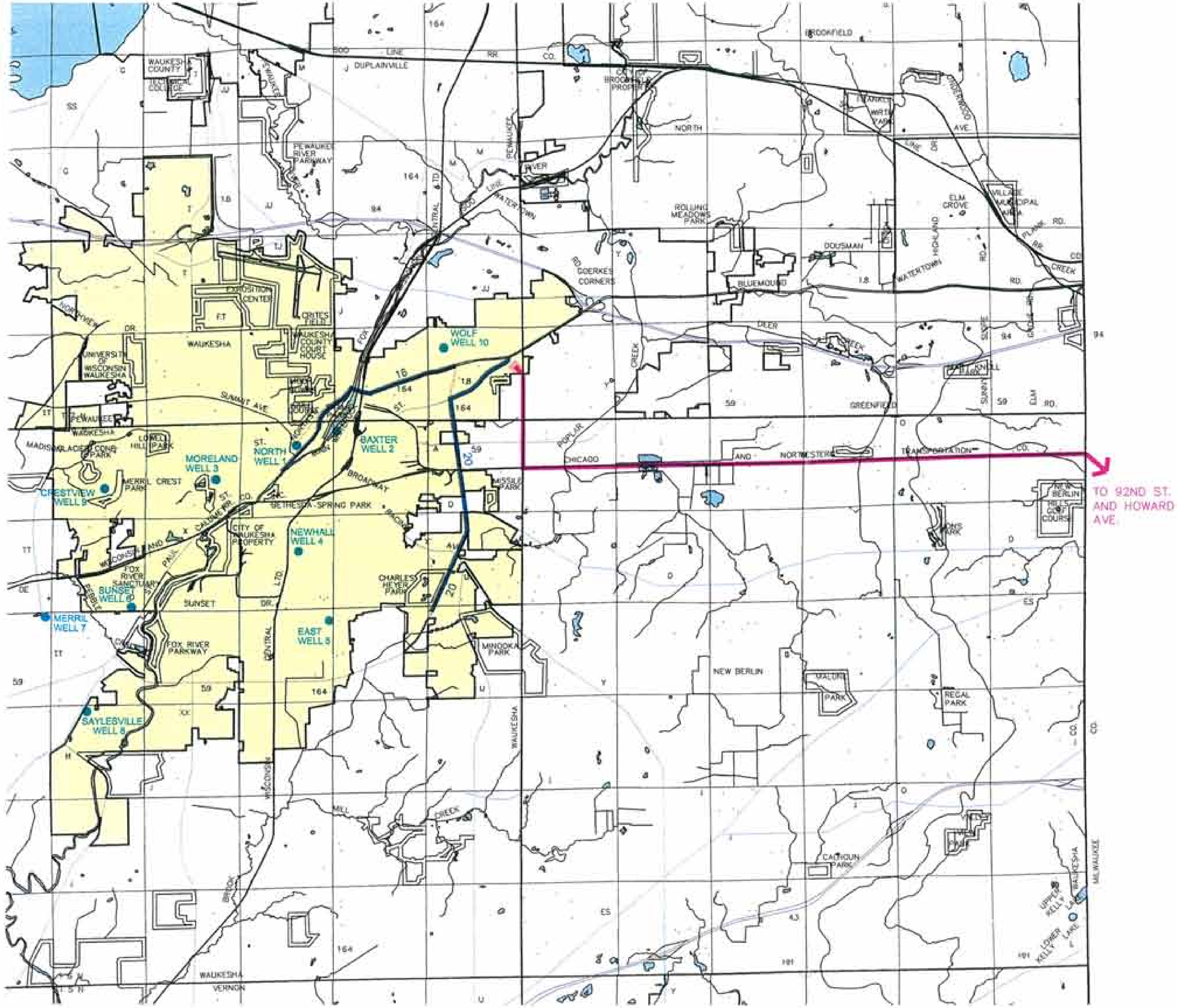

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FIGURE 4-19

LAKE MICHIGAN SUPPLY

N
W E
S

LEGEND

- EXISTING WELL TO BE ABANDONED
- PROPOSED NEW TRANSMISSION MAIN
- PROPOSED WATER MAIN ADDITION
- PROPOSED STORAGE ADDITION

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Infrastructure

In order to make reasonable projections of the infrastructure required for Lake Michigan water, assumptions regarding a supplier must be made. As previously state, the logical and most cost-effective supplier is Milwaukee. To bring water to the Waukesha system, the following assumptions have been made.

- The 60-inch main on west Howard Avenue at South 92nd Street would be the start of a transmission main to provide service to Waukesha.
- About 9 miles of dual 30-inch water main would be required to transmit water.
- Water would be delivered to the Hillcrest reservoir and distributed from that location.
- A pumping station will be required to boost pressure along the pipeline.
- A new 5-million-gallon storage reservoir is assumed.
- Distribution system improvements will be required to transmit water throughout the system due to the changes in supply location.

4.3.3 Regulations/Legal

There are many issues that govern the transfer of water from Lake Michigan to the City of Waukesha. International agreements, as well as agreements among the Great Lakes states, inhibit the diversion of Great Lakes surface water to other drainage basins. No net loss diversions, such as diversions over the subcontinental divide where equal or greater amounts of water are returned, have been allowed in the past. There are questions, however, regarding the future of such diversions. The following is a discussion of the water law related to water diversions.

4.3.3.1 Boundary Water Treaty

On January 11, 1909, a Boundary Water Treaty between the United States of America and "His Majesty the King of the United Kingdom of Great Britain and Ireland and of the British Domains beyond the Seas, Emperor of India..." was signed. The treaty was designed to prevent and provide a means to resolve disputes over the use of shared water and establish the International Joint Commission (IJC). The IJC also was established to provide independent advice on a variety of transboundary environmental issues. The IJC has been diligent in their attention to issues under their purview. One particular element of the treaty requires the IJC to approve all diversions of water that affect the level and flow of the Great Lakes. While this is an important component, it falls short of addressing small scale diversions.

4.3.3.2 Great Lakes Charter

In the early 1980s, it became apparent to the Great Lakes governors that additional measures were required to better manage the Great Lakes water. In particular, it was determined that the smaller water uses and diversions not covered by the Boundary Water Treaty needed to be addressed. As a result, the governors created the Council of Great Lakes Governors to meet these goals.

In 1985, the council oversaw the development and implementation of the Great Lakes Charter. The charter was a voluntary agreement between the governors of the Great Lakes and premiers of Ontario and Quebec. The charter put forth a number of principles to be used in governing Great Lakes water management decisions. The charter first provided that proposed diversions and consumptive uses of greater than 5 mgd would trigger a process by which a governor or premier could object to a particular use. Furthermore, the states and provinces agreed to more closely define a plan to collectively manage the water resources. That management would be achieved by establishing a Water Resources Management Committee.

4.3.3.3 Water Resources Development Act

The third, and most important component for Waukesha, is a binding federal law requiring the Great Lakes governors to review and approve *any* diversion of Great Lakes water within the United States. This law is called the Water Resources Development Act (WRDA) of 1986. Since implementation of the charter and WRDA, all of the proposals that have gone through the formal review process have been for small-scale diversions to communities just outside the Great Lakes Basin. One proposal to increase the Chicago River diversion to raise Mississippi water levels was withdrawn. As time has progressed, the detail involved in evaluating diversion proposals has increased.

In 1989, the Village of Pleasant Prairie, Wisconsin, requested a temporary diversion of a small volume of water. One governor failed to approve the diversion but also did not object when the project moved forward. Many believe this is an unsanctioned diversion.

Later, Michigan's governor did withhold approval of a diversion proposed by Lowell, Indiana. He cited a number of reasons for not approving the diversion, including lack of imminent danger to health, safety, and welfare and lack of conservation measures on the city's behalf.

The most recent case is the Akron, Ohio, proposal. It is the only formal approval of a diversion since the WRDA of 1986. Basically, after a number of years of review and submittals, all governors approved the diversion. The last state to approve was Michigan and that approval was qualified "... only to the extent that it results in no net loss of water to the Great Lakes watershed and does not diminish, degrade or lower the water quality of Lake Erie or its tributaries, or result in a new or increased loading of pollutants to the water of Lake Erie or its tributaries." After all these conditions were met, the project still had many critics, mostly from environmental groups.

4.3.3.4 Annex 2001

On February 22, 2000, the IJC submitted the final report to the United States and Canada regarding protection of the waters of the Great Lakes. That report was the culmination of efforts by the Study Team on Consumption, Diversion & Export of Water, a task force of the IJC. The recommendations contained in the document are by far the most restrictive to date. The first recommendation, Removal, reads as follows:

> "Without prejudice to the authority of the federal governments of the United States and Canada, the governments of the Great Lakes states and Ontario and Quebec should not permit any proposal for removal of water from the Great Lakes Basin to proceed unless the proponent can demonstrate that the

> removal would not endanger the integrity of the ecosystem of the Great Lakes Basin and that:
>
> a) there are no practical alternatives for obtaining the water,
>
> b) full consideration has been given to the potential cumulative impacts of the proposed removal, taking into account the possibility of similar proposals in the foreseeable future,
>
> c) effective conservation practices will be implemented in the place to which the water would be sent,
>
> d) sound planning practices will be applied with respect to the proposed removal, and,
>
> e) there is no net loss to the area from which the water is taken and, in any event, there is no greater than a 5 percent loss (the average loss of all consumptive uses within the Great Lakes Basin); and the water is returned in a condition that, using the best available technology, protects the quality of and prevents the introduction of alien invasive species into the waters of the Great Lakes.
>
> In reviewing proposals for removals of water from the Great Lakes to near-Basin communities, consideration should be given to the possible interrelationships between aquifers and ecosystems in the requesting communities and aquifers and ecosystems in the Great Lakes Basin."

Subsequent recommendations are contained in a proposed annex to the charter called "Annex 2001," which applies to all new water uses and diversions. Annex 2001 calls for conservation, reinforcement of the Great Lakes charter and existing institutions, and research into the relationship between groundwater and the Great Lakes Basin.

Annex 2001 recognizes the critical connection between surface and groundwater. For most shallow aquifers, the groundwater divides will be fairly close to the surface water divides, so the areas where conflicts might arise will be fairly limited. However, for some deeper aquifers, the area of the aquifer that discharges into the Great Lakes is much larger than the surface water basin.

For example, the groundwater divide for the deep sandstone aquifer of eastern Wisconsin lies as much as 30 miles west of the surface water divide. This area includes several communities such as Waukesha that produce most or all of their water from the sandstone aquifer. Conceivably, it could be argued that these communities are intercepting groundwater that would have normally flowed into the Great Lakes and are now diverting it into the Mississippi River Basin via their wastewater plants. It would be unreasonable to attempt to limit the future use of the sandstone aquifer in these communities or to require these communities to return their effluent to the Great Lakes Basin.

Returning effluent to the Great Lakes Basin from water systems using sandstone aquifer water would greatly diminish base flow conditions on several rivers such as the Fox River in southeastern Wisconsin and northeastern Illinois. This would cause deterioration in surface water quality and riparian habitat during dry years. Similar problems are likely in other portions of the Great Lakes Basin.

The Great Lakes Basin is already being affected by the removal of water from the sandstone aquifer. By pumping and intercepting groundwater that flowed west to east and eventually flowed into the Great Lakes in predevelopment times, a subsurface diversion has been created. Not only is water being intercepted that eventually would have reached the basin, the hydraulic gradient in the sandstone has been reversed and flow has been induced away from Lake Michigan. If the use of the sandstone aquifer is diminished or even stopped in southeastern Wisconsin, conceivably the hydraulic gradient would return to predevelopment conditions. We believe this could be a valuable argument to use to request a Great Lakes water supply.

Basically, the theory is that Waukesha and other local communities are already diverting water and therefore should be grandfathered under diversion law. Furthermore, changing from an underground diversion to a lake water diversion could result in complying with the Annex 2001 by providing an improvement to the waters and water-dependent resources of the Great Lakes Basin. Specifically, stopping the pumpage of sandstone aquifer groundwater could:

- Contribute to recharging the aquifer and restoration of groundwater levels
- Contribute to more groundwater entering the Great Lakes Basin
- Reduce groundwater chemistry changes (i.e., reverse the current trend toward higher TDSs and radium)
- Reduce the huge amounts of salt discharged into the environment by home water softening devices

To make any proposal for Lake Michigan water withdrawal more attractive to the governing bodies, there are potential credits that can be explored to replace the withdrawn surface water and/or improve the waters and water-dependent resources of the Great Lakes Basin. Credits may come in one of the following ways:

- Directly returning treatment plant effluent to the Great Lakes Basin
- Restoring historic diversion from the Mississippi Basin to the Great Lakes Basin
- Receiving credit for biological and environmental projects resulting in improvements to the environment
- Reducing lake shore erosion by withdrawing and storage during high lake levels and withdrawing from storage during low lake levels

Such actions may be necessary to ensure that any ecological consequences of a Lake Michigan diversion are more than offset to result in an improvement. Annex 2001 is scheduled to be completed in late 2003 or early 2004. Annex 2001 will:

- Forge a new binding agreement to manage the Great Lakes waters
- Create a new standard requiring an improvement to the water and water-dependent natural resources of the Great Lakes before allowing new water uses
- Implement the new standard for interim decisions under the WRDA

- Obtain better information so that the water is managed rationally
- Include the premiers in reviewing and consulting on all new proposed diversion subject to the WRDA
- Lower the "trigger level" for reviewing proposed diversions to include any proposed diversions that are subject to the governors' authority under the WRDA

Improvements to the waters of the Great Lakes required by Annex 2001 will require the mitigation of adverse effects of a new water use by improving the resources of the Great Lakes in some way, and will also include strong provisions for water conservation. Diversions which result in a net loss of water of over 1 mgd and meet Annex criteria will have to be reviewed. The proposals will be judged for conservation and impacts on natural resources. Pre-existing uses are exempted.

4.3.3.5 Wisconsin Diversion Codes

Two specific sections of the Wisconsin Administrative Code, NR 142 and NR 811, refer to diversion of water from the Great Lakes Basin. NR 811.13(1)(c) states:

> "A supplier of water shall obtain approval from the department prior to creating a water loss or interbasin diversion as defined in S.NR 142.01, in accordance with the requirements of Ch. NR 142."
>
> "Interbasin diversion" is described in NR 142 as "… a transfer of waters of the state from either the Great Lakes basin or the upper Mississippi River basin to any other basin."

Chapter NR 142 goes on to present the means by which the department may approve withdrawals of over 100,000 gpd (about 70 gpm); interbasin diversions; and Great Lakes Basin water loss. The provisions of this chapter require the notification of Great Lakes governors and premiers only if the department receives an application for a withdrawal greater than 5,000,000 gpd.

Discussions with WDNR water supply representatives indicate that the WDNR may have differing views regarding required approvals from the Council of Great Lakes Governors. The resolution of this issue is well beyond the authority of this study. We do recommend that Waukesha receive a legal opinion on the issue prior to proceeding with any action on the permanent Lake Water Supply Plan.

4.3.4 Political and Public Acceptance

Obtaining water from Lake Michigan has issues related to political and public acceptance. This section will discuss the following issues:

- *Cryptosporidium*
- Milwaukee and other supplier service agreements
- Wastewater disposal issues
- Water quality

4.3.4.1 *Cryptosporidium*

Following the *Cryptosporidium* outbreak in Milwaukee in 1993, much public attention was focused on lake water as a source of drinking water. While the Milwaukee Treatment Facilities have been upgraded and other local plants are also monitoring and improving their processes, the perception that another outbreak could happen is still present. The more recent communities to receive lake water, Menomonee Falls and Butler, both initially had to deal with similar concerns. For the most part, the concerns in these areas were dealt with and customers have complemented the quality of the lake water.

4.3.4.2 Milwaukee Service Agreements

If the City of Milwaukee is the source of supply, there is potential that the city may try and control “urban sprawl” by linking allowable water sales to new construction. There are factions in Milwaukee’s local government who believe this is the best way politically to handle water sales. Other communities with surface water treatment plants have generally not been as restrictive as Milwaukee.

4.3.4.3 Wastewater Disposal Issues

Should Waukesha receive lake water and also be required to return an equal amount of water to the Great Lakes Basin, a number of other issues arise. First, SEWRPC has indicated that it would be highly unlikely that they would agree to discharging treatment plant effluent to any of the streams or rivers in the Great Lakes Basin. Areas in and around Underwood Creek, the Root River, and other streams are already at or near capacity and additional flow would exacerbate the problem.

Another option is discharge of Waukesha sewage plant effluent into the Milwaukee metro sewer collection system, or directly to the lake. In either case, pipes would be constructed through communities Waukesha does not have political control over. A user fee would be charged for discharging even treated wastewater into the sewer system.

Untreated sewage could be pumped into the Milwaukee metro sewer system. This would eliminate the cost of operating the Waukesha wastewater plant, but additional user fees would be charged by Milwaukee Metro Sewerage District. Capacity problems in Milwaukee and other facilities could make this a political issue.

In all cases above, there are serious legal, political, and cost issues if wastewater has to be returned to the Great Lakes Basin. An alternative approach is use of constructed wetlands for treated sewage effluent. The effluent would have to infiltrate shallow aquifers in the Great Lakes Basin. Other environmental improvements may also be implemented in lieu of returning wastewater to the Great Lakes basin.

4.3.4.4 Water Quality

Water quality from Lake Michigan is generally viewed in an positive manner. Lower hardness and iron in Lake Michigan water compared to the current groundwater should be viewed positively. Typical water quality parameters are listed in Table 4-3.

TABLE 4-3
Lake Michigan Treated Water Quality
Future Water Supply

	Typical Value	MCL Primary Standard	Secondary Standard
Total Hardness (mg/L as $CaCO_3$)	120		
Calcium (mg/L)	35		
Magnesium (mg/L)	10		
Total Alkalinity (mg/L as $CaCO_3$)	95		
pH	7.5		
Sulfate (mg/L)	10		250
Chloride (mg/L)	10		250
Total Dissolved Solids (mg/L)	170		500
Iron (mg/L)	BD		0.3
Manganese (mg/L)	BD		0.05
Sodium (mg/L)	10		20
Radium 226+228 (pCi/L)	BD	5	
Gross Alpha (pCi/L)	BD	15	
Radon (pCi/L)	BD		

BD=Below Detection
Data Source: Milwaukee Waterworks

4.3.5 Operations and Maintenance

Many of the O&M procedures will be eliminated if Lake Michigan water is the sole source of supply. The existing wells will not be needed or used only on standby. If they are not used on standby, the electrical cost to pump water will be reduced because of the difference in lift required to pump from Milwaukee to the central zone versus lifting from the sandstone aquifer. If the wells are used on standby, monthly visits to remaining stations are recommended to run the pumps and verify operations. Maintenance for the distribution system will increase slightly due to the construction of new mains.

It is likely that the addition of chlorine will be required to boost levels provided by Milwaukee or another provider. The levels required should be less than currently provided because the delivered water will already have background levels. All other routine maintenance should remain relatively the same.

One final area of concern is the potential impacts to the water distribution piping and plumbing resulting from changing water chemistry. It is possible that increased flushing, digging, pH adjustment, or combinations may be required after lake water has been used for a period of time. Without pilot testing on a representative section of the system, it is difficult to predict impacts. Indications are from Menomonee Falls and Franklin, which have similar conditions to Waukesha, that impacts are minimal.

4.3.6 Schedule

The schedule to provide lake water depends largely on the ability of the City of Waukesha to obtain a diversion and arrive at an agreement with a surface water provider. As previously mentioned, Milwaukee is the only existing surface water treatment plant with sufficient capacity to serve Waukesha. If a new or expanded plant needs to be constructed, the schedule will be extended. However, if an agreement can be made with Milwaukee water and a diversion granted in a timely manner, a connection could be in service within about 3 to 4 years.

4.4 Alternative 5 – Sandstone/Shallow Aquifer

This alternative consists of 11 new vertical wells 2 to 3 miles south of the City of Waukesha, along with an iron/manganese removal plant. Existing sandstone wells 6 through 9 would be used for blending. The remaining wells would be abandoned or kept as standby. Additional piping to bring treated shallow aquifer water to sandstone wells 6 through 9 would be required. The major facilities are shown on Figure 4-20.

4.4.1 Reliability

While it appears feasible to develop a new source of supply from a single groundwater source, there are advantages to be derived from using multiple sources. The shallow sand and gravel or dolomite aquifer could be used in conjunction with the sandstone aquifer to develop a reliable source of supply for the Waukesha Water Utility. By developing a new source, the demand from the existing wellfield can be reduced, thereby reversing or reducing the decline in head and negative changes in water quality. Ideally, the existing sandstone wells would be reserved for peak demands, thereby substantially reducing annual pumpage from the aquifer while avoiding heavy pumpage from the shallow aquifers during dry periods.

The existing sandstone wells that are retained would have to be brought into compliance with the radionuclides MCLs through some combination of traditional treatment, well reconstruction, or blending with water from shallow aquifers. Given the layout of the wellfield, wells 6, 7, and 8 are attractive candidates for blending with water from the shallow aquifers. Given the radium and gross alpha levels in these wells, the ratio shallow aquifer water to sandstone aquifer water needed to meet the MCLs would be at least 2:1 or greater. Given this mixing ratio, a minimum of 15 mgd of water will be needed from the shallow aquifer to meet the projected peak day of 22 mgd. This will also provide enough water from the shallow aquifers to meet projected ADDs, making it possible to only pump the sandstone wells to meet MDDs.

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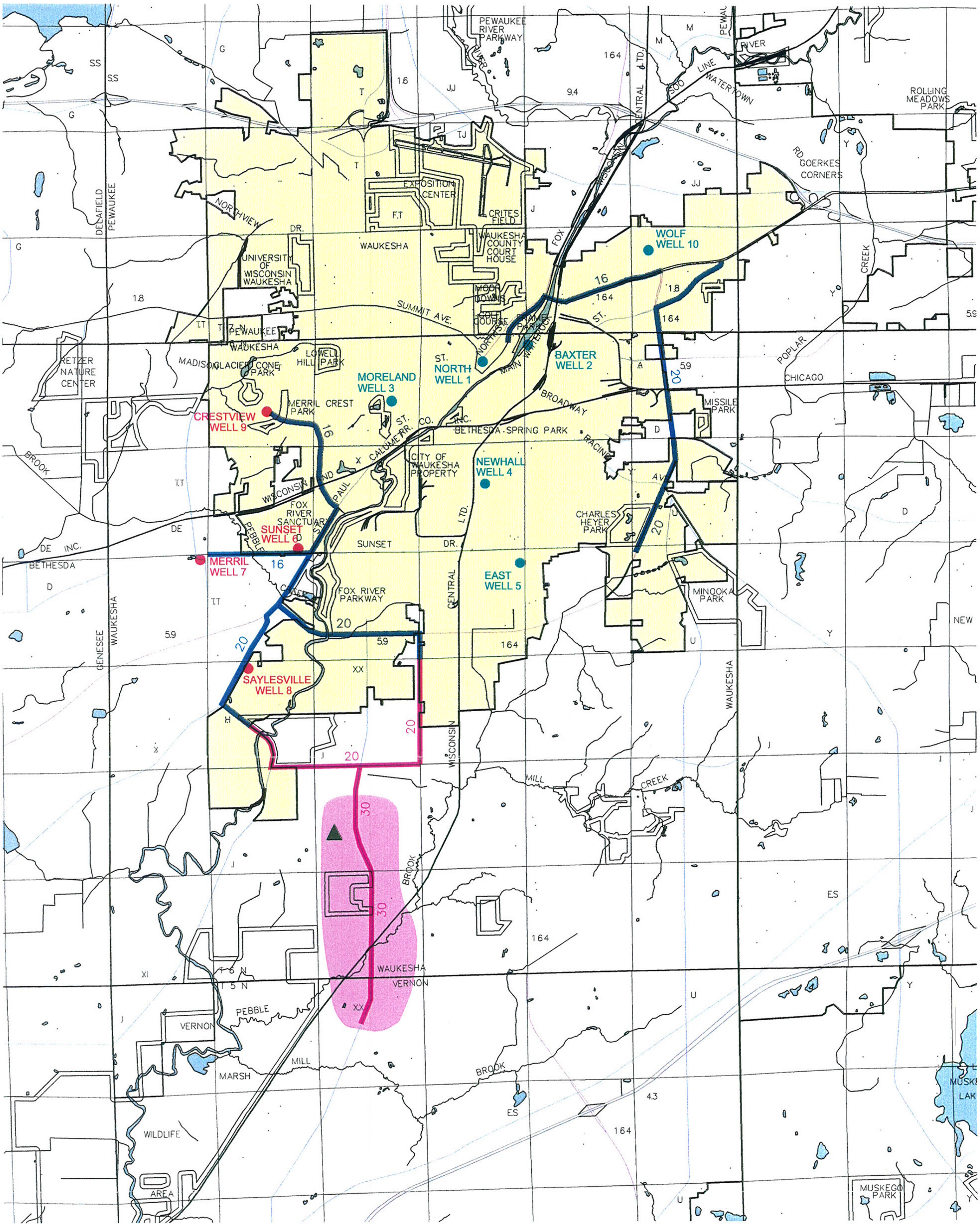

FIGURE 4-20

COMBINED SANDSTONE AND SHALLOW AQUIFER WATER SUPPLY

Waukesha Water Utility
SERVING WAUKESHA SINCE 1886

LEGEND

- **EXISTING WELL TO BE ABANDONED**
- **PROPOSED NEW WELL FIELD (CONCEPTUAL LOCATION)**
- **PROPOSED NEW TRANSMISSION MAIN**
- **PROPOSED WATER MAIN ADDITION**
- **PROPOSED TREATMENT FACILITY**

0 1 2 3 4 5 10,000
SCALE IN FEET

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Wells 1 through 5 do not produce enough water to justify the cost to treat or blend the water. Wells 9 and 10 could potentially be blended with low radium water or treated at or near the well sites. However, due to the location of these wells, both of these options are probably cost prohibitive. For the purpose of this analysis, it was assumed that wells 1 through 5 and 9 and 10 would be abandoned. This would leave approximately 8.8 mgd of capacity from the sandstone aquifer, which is sufficient to make up the difference between the projected capacity from the shallow aquifer and the peak day demand. If some low cost means of controlling radium levels at the well head were to become available, the cost of saving additional sandstone wells would be reduced dramatically and the volume of shallow water that would be needed would be reduced significantly.

The Troy bedrock valley aquifer is the most logical choice for the shallow aquifer water due to its close proximity to the city. Depending on the depth of the aquifer and the degree of protection from clay confining units, the wellfield could be vulnerable to surface contamination. Proper well siting and well head protection will be critical elements of maintaining a viable source of supply. Given that the wellfield is likely to be out of the corporate limits of the city, siting wells that have natural protection from contamination may prove to be the most effective strategy to avoid contamination problems.

It would also be possible to develop new sandstone wells in the recharge area in western Waukesha County that are coupled with sand and gravel wells in the Rock or Troy bedrock valley aquifers. This would have the advantage of reducing the demand from any one source and providing a blending option to offset potential water quality issues from any individual aquifer. However, the cost of the transmission main required to bring this water back to the city makes these options less attractive.

Given the multiple potential sources of groundwater available to the Waukesha Water Utility, it will be possible to find an optimal blend of supply sources that minimizes overall costs and provides more options to adjust to unknown changes in future conditions. Developing more than one supply source limits the impact on any one resource and provides operational flexibility to adapt to changes in regulation, seasonable variability in the availability of water, and changes in source water characteristics such as rising arsenic levels. However, if the sandstone aquifer is not managed more effectively on a regional basis, the continued decline in head may require more shallow aquifer water to offset a reduction in the sustained yield in the sandstone aquifer over time.

4.4.2 Infrastructure

Assuming that the shallow aquifer wells can produce an average of approximately 1,000 gpm, 11 wells will be needed to provide a reliable capacity of about 15 mgd. Roughly 3 to 4 miles of transmission main and 3 miles of feeder main will be needed to collect the water from the wellfield and move it into the city. Additional piping and controls will be needed to blend the water with wells 6, 7, and 8. Modifications to the distribution system will be needed to get the water to the city and accommodate a single entry point.

4.4.2.1 Treatment for Shallow Aquifer Water

Treatment for shallow aquifer water will include iron/manganese removal and chlorination. The treatment process will be the same as that described above for the sand/gravel aquifer, except the treatment plant will be 15 mgd instead of 22 mgd.

4.4.2.2 Transmission

Transmission from a Troy bedrock valley wellfield to Waukesha would be accomplished with dual 24-inch-diameter transmission lines. The second line would provide a degree of reliability and redundancy. About 5 miles of large transmission main would be required. Another 11 miles of 20- and 16-inch water main would be required to distribute the treated groundwater throughout the City of Waukesha.

Additional piping for bringing shallow aquifer water to the sandstone wells will be required. Approximately 6 miles of blending water main would be required.

4.4.3 Regulations/Legal

Producing water from multiple aquifers is consistent with the long standing practices of several surrounding communities. It is generally considered to be a wise supply strategy and should not be opposed by any regulatory body. The concept of blending water to meet radionuclides rules is also being practiced by several neighboring communities. Modifications to the distribution system and controls will be required to ensure that all points of entry into the distribution system meet radionuclide standards. This can be accomplished by blending in reservoir or using in-line mixers in the piping from a sandstone well prior to the point of entry.

The wellfield will require a well head protection plan to satisfy NR 811 requirements and protect the wells from contamination from agricultural sources. The Waukesha Water Utility will have no zoning control to enforce the well head protection ordinance because the wellfield will be beyond the Waukesha corporate limits. As a result, finding an aquifer with natural protection, such as a clay confining layer, may be the most effective form of well head protection than can be achieved. If this is not possible, it may be necessary to acquire larger tracts of land or find mechanisms to influence land use on surrounding properties. This might be accomplished through providing incentives to surrounding landowners to grow crops that require lower inputs of fertilizers and chemicals and prevent high density developments with septic tanks.

The treatment plant will require WDNR approval based on NR 811 and 809 requirements. The blending scheme and controls will also be evaluated by WDNR for radionuclide compliance. Pilot testing of iron/manganese treatment processes are not likely to be required.

4.4.4 Political and Public Acceptance

The public should perceive a benefit from obtaining radionuclide-compliant water. However, the water will not be radium free as in other alternatives. If the water from the shallow sources is treated to meet secondary standards, the public should perceive a net improvement in aesthetic properties of the water. Some change in iron concentrations may be experienced when the sandstone wells are in use. Assuming that the TDS levels of the sandstone wells can be controlled at present levels, the hardness of the blended water will not be noticeably different than the shallow water.

The treatment plant will require aesthetic features to make it acceptable to nearby citizens and comply with zoning requirements. Truck traffic and noise should be minimized where possible.

The transmission main would require easements and could result in some public opposition. Some transmission lines would be run in the city limits, resulting in traffic slow-downs. The blending alternatives have the most water transmission main run through Waukesha streets because of the additional blending pipe required.

4.4.5 Operations and Maintenance

4.4.5.1 Wells

Retiring most of the sandstone wells will reduce the O&M costs of the system. The shallow wells will have significantly lower costs to operate and maintain due to the shallower pump settings and lower pumping costs.

Blending at the sandstone wells to meet radionuclide standards will increase the operational complexity and monitoring of the water system. Radium levels in the sandstone wells and flowrates from both sources must be balanced to ensure radium standards are not exceeded. The requirements for adequate water volume and pressure must be balanced with radium concentration requirements.

Assuming regional demand from the sandstone aquifer does not rise significantly, the local reduction in pumping from the sandstone aquifer is expected to provide some degree of rebound in water levels. This should reduce pumping costs and stabilize maintenance costs to some degree.

4.4.5.2 Water Treatment

O&M requirements for an iron/manganese plant would be similar to the shallow aquifer alternative discussed previously. However, the size of the plant would be smaller.

4.4.5.3 Water Plant Residuals

Water plant residuals for an iron/manganese removal plant would be similar to the shallow aquifer alternative discussed previously. However the quantity of residuals would be about 30 percent less.

4.4.5.4 Transmission

The additional transmission pipe and valves would require maintenance, similar to existing pipe and valves in the Waukesha Water System. This alternative has more distribution system mains than others because of the blending pipes required.

4.4.6 Schedule

From the perspective of meeting demand, the shallow water source can be added as needed to meet increasing demands. However, to comply with the radionuclide rule, at least 10 mgd of shallow water would be needed at implementation, and at least an additional 5 mgd of shallow capacity added as demand dictates. Time frames for implementation will be similar to the shallow aquifer alternative, but an additional year or so might be required due to the blending water main passing through the city.

4.5 Alternative 6 – Sandstone/Fox River Alluvium

This alternative consists of five new horizontal wells south of the City of Waukesha along the Fox River. A treatment plant for disinfection and iron/manganese removal is provided.

Existing sandstone wells 6 through 9 would be used for blending. The remaining wells would be abandoned or kept as standby. Additional piping to bring treated Fox River alluvium water to sandstone wells 6 through 9 would be required. The major facilities are shown on Figure 4-21.

4.5.1 Reliability

The option of using the alluvial aquifer water in combination with the sandstone aquifer is very similar to the option of using the shallow aquifer described above. The probable location of an alluvial wellfield is in the same general vicinity of the proposed Troy bedrock valley aquifer wellfield. Given the location and condition of the existing sandstone wells, wells 6, 7, and 8 could be retained to meet peak demands. These wells could be brought into compliance with radionuclide standards by blending with the alluvial water. By retaining several sandstone wells, the capacity of the alluvial wellfield can be reduced and heavy pumpage during period of low flow in the Fox River can be avoided. If necessary, the capacity of the shallow alluvial deposits can be increased through enhanced recharge of stormwater or peak flows from the river.

The alluvial wellfield is likely to produce a significant portion of its water from groundwater flowing toward the river. Given the high permeability of the soils and the relatively shallow depth of the aquifer, the groundwater portion of the wellfield will be vulnerable to contamination. As a result, it will be important to select wellfield locations that minimize the potential for contamination from upgradient sources. Well head protection will be a critical element for maintaining the wellfield.

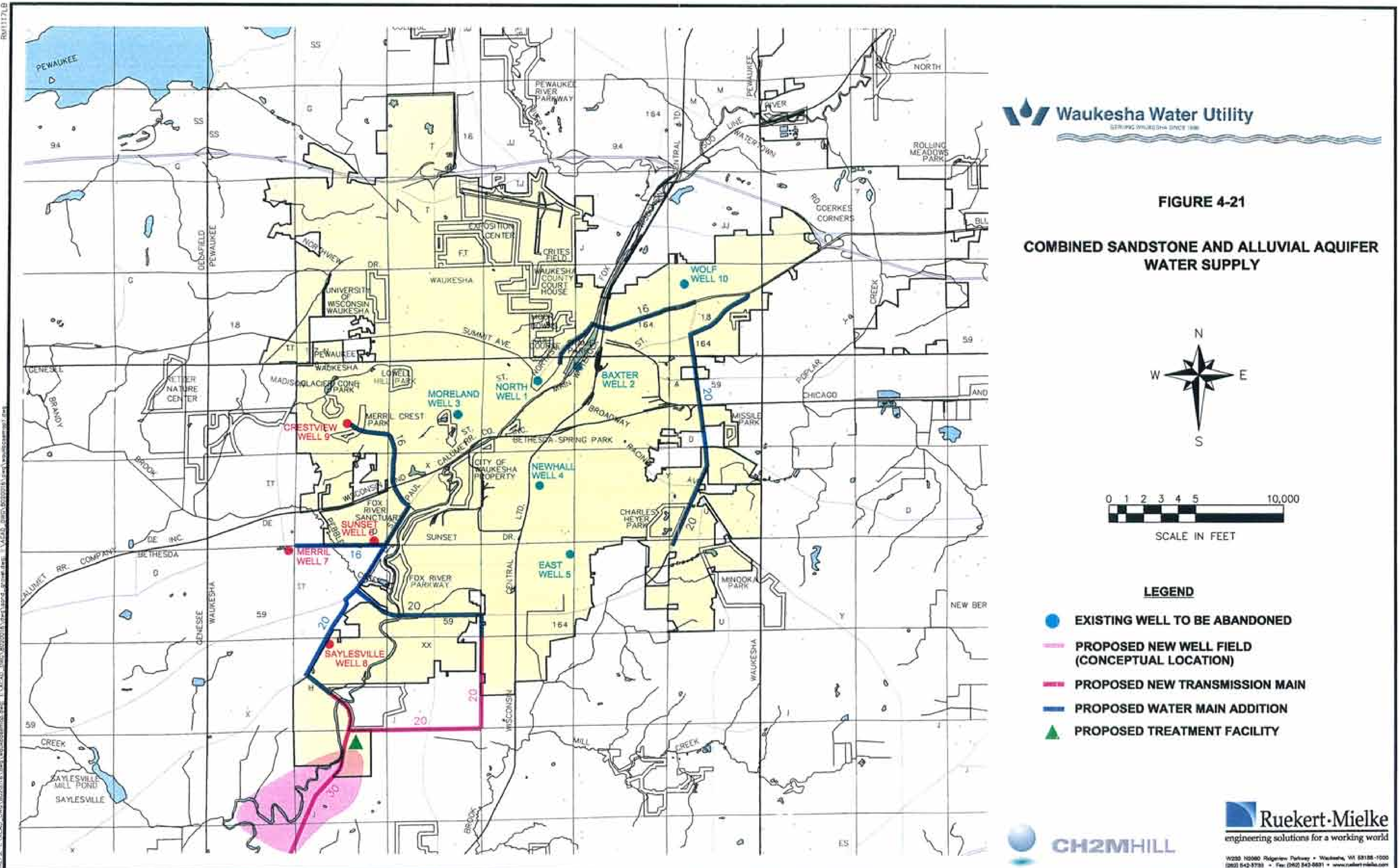
4.5.2 Infrastructure

4.5.2.1 Wells

Assuming that the vertical wells in the alluvial aquifer can produce an average of approximately 1,000 gpm, 11 wells will be needed to provide a reliable capacity of approximately 15 mgd. Horizontal wells can generally produce five to ten times as much water as a vertical well. Assuming that a horizontal well could produce at least 3,000 gpm, then five horizontal wells would be required to provide a reliable capacity of 15 mgd. Existing sandstone wells 6, 7, and 8 would be capable of providing enough capacity for peak days. Piping modifications to accommodate blending will be required.

4.5.2.2 Treatment

Treatment for Fox alluvium aquifer water will include direct filtration, ultraviolet light disinfection, and chlorination. The treatment process will be the same as for the Fox River alluvium aquifer, except the treatment plant will be 15 mgd instead of 22 mgd.


Waukesha Water Utility
FIGURE 4-21
COMBINED SANDSTONE AND ALLUVIAL AQUIFER WATER SUPPLY
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W
E
S
0 1 2 3 4 5 10,000
SCALE IN FEET
LEGEND
EXISTING WELL TO BE ABANDONED
PROPOSED NEW WELL FIELD (CONCEPTUAL LOCATION)
PROPOSED NEW TRANSMISSION MAIN
PROPOSED WATER MAIN ADDITION
PROPOSED TREATMENT FACILITY
CH2MHILL
Ruekert·Mielke
engineering solutions for a working world
PEWAUKEE
WOLF WELL 10
BAXTER WELL 2
NORTH WELL 1
MORELAND WELL 3
CRESTVIEW WELL 9
NEWHALL WELL 4
SUNSET WELL 6
MERRIL WELL 7
EAST WELL 5
SAYLESVILLE WELL 8
SAYLESVILLE MILL POND
SAYLESVILLE
WAUKESHA
EXPOSITION CENTER
UNIVERSITY OF WISCONSIN WAUKESHA
RETZER NATURE CENTER
FOX RIVER SANCTUARY
FOX RIVER PARKWAY
BETHESDA SPRING PARK
CITY OF WAUKESHA PROPERTY
CHARLES HEYER PARK
MINOOKA PARK
MISSILE PARK
GOERKES CORNERS
ROLLING MEADOWS PARK
MERRIL CREST PARK
LOWELL HILL PARK
GLACIER CONG PARK

4.5.2.3 Transmission

Transmission from a Fox River alluvium wellfield to Waukesha would be accomplished with dual 24-inch-diameter transmission lines. The second line would provide a degree of reliability and redundancy. About 3 miles of large transmission main would be required. Another 11 miles of 20- and 16-inch water main would be required to distribute the treated groundwater throughout the City of Waukesha.

Additional piping for bringing alluvium aquifer water to the sandstone wells will be required. Approximately 6 miles of blending water main would be required.

4.5.3 Regulations/Legal

Producing water from multiple aquifers is consistent with the long standing practices of several surrounding communities. It is generally considered to be a wise supply strategy and should not be opposed by any regulatory body. The concept of blending water to meet radionuclides rules is also being practiced by several neighboring communities. It will require modifications to the distribution system and controls to ensure that all points of entry into the distribution system meet radionuclide standards. This can be accomplished by blending in a reservoir or using in-line mixers in the piping from a sandstone well prior to the point of entry.

The use of an alluvial wellfield may be subjected to higher treatment requirements due to the potential for the influence of surface water. Though not specifically addressed by current regulations, the WDNR may require that the impacts of the alluvial wellfield on the Fox River be documented. However, since the water is returned to the river upstream from the wellfield, the impacts are expected to be minimal.

It may be possible to develop an alluvial wellfield that is largely within the city or land owned by Waukesha County. This should provide the city with significant advantages in terms of obtaining land for well sites and pipelines. It will also simplify the well head protection process.

The treatment plant will require WDNR approval based on NR 811 and 809 requirements. The blending scheme and controls will also be evaluated by WDNR for radionuclide compliance. Pilot testing of the treatment processes is likely to be required.

4.5.4 Political and Public Acceptance

The public should perceive a benefit from obtaining radionuclide compliant water. If the water from the alluvial wellfield is treated to meet secondary standards, the public should perceive a net improvement in aesthetic properties of the water. Some change in iron concentrations may be experienced when the sandstone wells are in use. Assuming that the TDS levels of the sandstone wells can be controlled at present levels, the hardness of the blended water will not be noticeably different than the shallow water.

The treatment plant will require aesthetic features to make it acceptable to nearby citizens and comply with zoning requirements. Truck traffic and noise should be minimized where possible.

The transmission main would require easements and could result in some public opposition. Some transmission lines would be run in the city limits, resulting in traffic slow-downs. The blending alternatives have the most water transmission main run through Waukesha streets because of the additional blending pipe required.

4.5.5 Operations and Maintenance

4.5.5.1 Wells

Alluvial wellfields are more prone to plugging and biofouling than traditional wells due to the higher dissolved oxygen and total organic carbon content of the induced river water. These problems can be controlled through close monitoring of the hydraulic performance of the wells and proactive well rehabilitation practices.

Blending at the sandstone wells to meet radionuclide standards will increase the operational complexity and monitoring of the water system. Radium levels in the sandstone wells and flowrates from both sources must be balanced to ensure radium standards are not exceeded. The requirements for adequate water volume and pressure must be balanced with radium concentration requirements.

Assuming the regional demand from the sandstone aquifer does not rise significantly, the local reduction in pumping from the sandstone aquifer is expected to provide some degree of rebound in water levels. This should reduce pumping costs and stabilize maintenance costs to some degree.

4.5.5.2 Water Treatment

O&M requirements for a direct filtration plant with ultraviolet would be similar to the Fox River alluvium alternative discussed previously. However, the size of the plant would be smaller (15 versus 22 mgd).

4.5.5.3 Water Plant Residuals

Water plant residuals for a direct filtration plant would be similar to the Fox River alluvium alternative discussed previously. However the quantity of residuals would be about 30 percent less.

4.5.5.4 Transmission

The additional transmission pipe and valves would require maintenance, similar to existing pipe and valves in the Waukesha Water System. The blending alternatives have more distribution system mains than others because of the blending pipes required.

4.5.6 Schedule

From the perspective of meeting demand, the Fox River alluvium water source can be added as needed to meet increasing demands. However, to comply with the radionuclide rule, at least 10 mgd of Fox River alluvium water would be needed at implementation, and at least an additional 5 mgd of Fox River alluvium capacity added as demand dictates. Time frames for implementation will be similar to the Fox River alluvium alternative, but an additional year or so might be required due to the blending water main passing through the city.

4.6 Alternative 7 – Shallow Aquifer/Fox River Alluvium

This alternative consists of four new horizontal wells south of the City of Waukesha along the Fox River and eight vertical shallow aquifer wells. A treatment plant for disinfection and iron/manganese removal is provided for the Fox River alluvium water. An iron/manganese removal plant is provided for the shallow aquifer water. Existing sandstone wells would be abandoned or kept as standby. The major facilities are shown on Figure 4-22.

4.6.1 Reliability

Obtaining water from both the shallow aquifer and the alluvial aquifer provides the most flexibility in developing and operating the shallow wellfield. If the Troy bedrock valley aquifer is used in conjunction with the Fox River alluvial aquifer, many of the facilities, such as the transmission main and possibly the treatment plant, can be used jointly. In addition to sharing facilities, conjunctive use of the two aquifers will allow the Waukesha Water Utility to shift demand as environmental conditions dictate. In the event of a spill in the Fox River, pumpage could be shifted to the Troy bedrock valley until the spill had passed. In the event of extremely dry years, pumpage could be shifted to the Troy bedrock valley to minimize any impacts on stream flow from induced recharge and to augment stream flow by adding water from the Troy bedrock valley aquifer to the river through the wastewater treatment plant. Having the alluvial wellfield available during normal flow conditions reduces the water that must be drawn from the Troy bedrock valley aquifer on a sustained basis, thereby reducing any negative impacts to the aquifer or surface water features.

This alternative assumes that two water plants will be built, one for each water source. This provides more reliability than all the water being treated by one plant.

4.6.2 Infrastructure

4.6.2.1 Wells

For the purposes of this study, we have assumed that the capacity is split evenly between the two wellfields (11 mgd each). Assuming that the Troy bedrock valley aquifer produces and average of 1,000 gpm per well, eight wells would be needed. The alluvial wellfield could consist of either four horizontal wells or eight vertical wells.

4.6.2.2 Treatment

Treatment for Fox alluvium aquifer water (direct filtration, ultraviolet light disinfection, and chlorination) will be accomplished in a new 11-mgd water plant. The treatment process will be the same as that described above for the Fox River alluvium aquifer, except the treatment plant will be 11 mgd instead of 22 mgd.

Treatment for shallow aquifer water (iron/manganese removal and chlorination) will be accomplished in a new 11-mgd water plant. The treatment process will be the same as that described above for the shallow aquifer, except the treatment plant will be 11 mgd instead of 22 mgd.

Treatment could be done in one 22-mgd water plant as well. However, having the ability to produce potable water from two plants provides more reliability and is beneficial for future growth and ability to serve customers (i.e., less future distribution and transmission mains).

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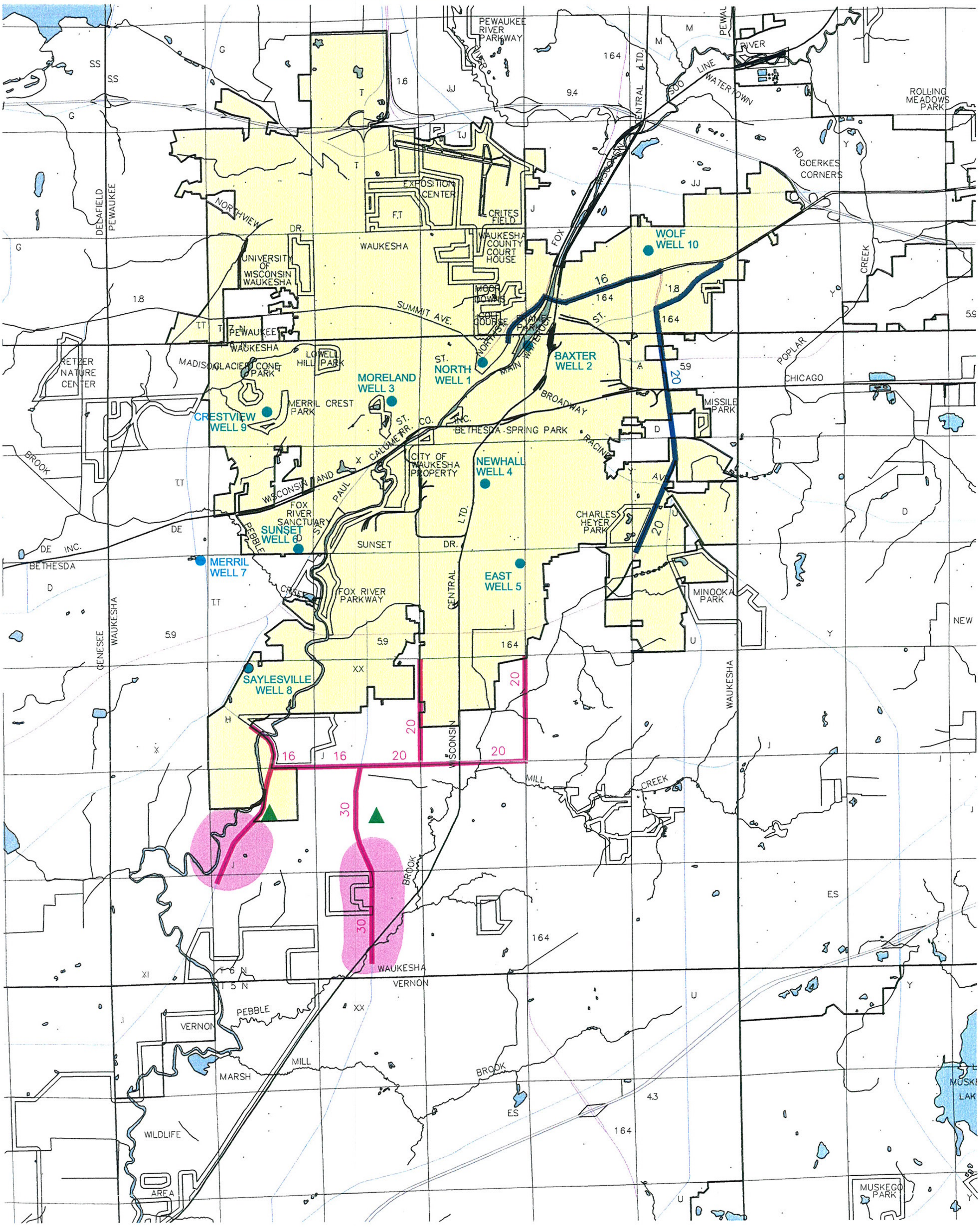

Waukesha Water Utility
SERVING WAUKESHA SINCE 1886

FIGURE 4-22

COMBINED SHALLOW AND ALLUVIAL AQUIFER WATER SUPPLY

N
W E
S

0 1 2 3 4 5 10,000
SCALE IN FEET

LEGEND

- EXISTING WELL TO BE ABANDONED
- PROPOSED NEW WELL FIELDS (CONCEPTUAL LOCATION)
- PROPOSED NEW TRANSMISSION MAIN
- PROPOSED WATER MAIN ADDITION
- PROPOSED TREATMENT FACILITY

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4.6.2.3 Transmission

Transmission from the two wellfields to Waukesha could be accomplished with dual 30-inch-diameter transmission lines. About 3 miles of large transmission main would be required. Smaller transmission lines would be needed from the shallow aquifer treatment plant. Another 11 miles of 20- and 16-inch water main would be required to distribute the treated groundwater throughout the City of Waukesha.

4.6.3 Regulations/Legal

Producing water from multiple aquifers is consistent with the long standing practices of several surrounding communities. It is generally considered to be a wise source of supply strategy and should not be opposed by any regulatory body. Both wellfields will require a well head protection plan to satisfy NR 811 requirements and protect the wells from contamination. The Waukesha Water Utility will have no zoning control to enforce the well head protection ordinance for the Troy bedrock valley wellfield because the wellfield will be beyond the Waukesha corporate limits. As a result, finding an aquifer with natural protection, such as a clay confining layer, may be the most effective form of well head protection that can be achieved. If this is not possible, it may be necessary to acquire larger tracts of land or find mechanisms to influence land use on surrounding properties. This might be accomplished through providing incentives to surrounding landowners to grow crops that require lower inputs of fertilizers and chemicals and prevent high density developments with septic tanks.

The alluvial wellfield is likely to produce a significant portion of its water from groundwater flowing toward the river. Given the high permeability of the soils and the relatively shallow depth of the aquifer, the groundwater portion of the wellfield will be vulnerable to contamination. As a result, it will be important to select wellfield locations that minimize the potential for contamination from upgradient sources. Well head protection will be a critical element for maintaining the wellfield.

Portions of the alluvial aquifer wellfield will also be beyond the corporate limits. Given the limited ability enforce well head ordinances beyond their corporate limits, it may be necessary to find means of controlling surrounding land use either through incentives to landowners or by siting wells in favorable locations, such as park land.

The treatment plant will require WDNR approval based on NR 811 and 809 requirements. Pilot testing for the Fox River alluvium source is likely to be required.

4.6.4 Political and Public Acceptance

The public should perceive a benefit from obtaining radionuclide compliant water. If the water is treated to meet secondary standards, the public should perceive a net improvement in aesthetic properties of the water.

The public may have some initial resistance about drinking water that comes in part from the Fox River. However, with appropriate treatment and public education, most of these concerns should be addressed. Environmental groups may be concerned about the potential impact on the Fox River, particularly during low flows. However, most of the water will be returned to the river through the Waukesha wastewater treatment plant a few miles upstream of the likely wellfield location. The water derived from aquifer storage during low-flow periods of the Fox River will augment the base flow conditions by replacing more water than is infiltrated.

Surrounding townships may be concerned about impacts to private wells and wetlands around the Troy bedrock valley wellfield. With proper testing and well siting, it should be possible to minimize these impacts.

The treatment plants will require aesthetic features to make them acceptable to nearby citizens and comply with zoning requirements. Since there are two plants, the issues may be more numerous than alternatives with only one treatment plant. Truck traffic and noise should be minimized where possible. Again, two plants will increase the traffic and noise over one plant.

The transmission main would require easements and could result in some public opposition. Some transmission lines would be run in the city limits, resulting in traffic slow-downs.

4.6.5 Operations and Maintenance

4.6.5.1 Wells

Retiring the sandstone wells will reduce the O&M costs of the system. The shallow wells will have significantly lower costs to operate and maintain due to the shallower pump settings and lower pumping costs.

4.6.5.2 Water Treatment

O&M requirements for the treatment plants would be similar to those described previously. However, O&M will be greater for two 11-mgd water plants compared to one 22-mgd water plant.

4.6.5.3 Water Plant Residuals

Water plant residuals handling will be similar to that described previously for these sources. However, residuals from two smaller treatment plants will increase O&M over that of one larger treatment plant.

4.6.5.4 Transmission

The additional transmission pipe and valves will require maintenance, similar to existing pipe and valves in the Waukesha Water System.

4.6.6 Schedule

The wellfields could be constructed to meet current demands and expanded as necessary to meet future demands as needed. Given the time needed for exploration, testing, and construction, sufficient capacity could be on-line within a 3- to 5-year period.

Construction of two smaller water plants will take more time than one large plant, mainly due to siting, land purchase, zoning, and other site-specific issues.

4.7 Aquifer Storage and Recovery

As mentioned previously, ASR can be used with any of the alternatives to enhance reliability, provide more water management flexibility, and reduce costs. Application of ASR would involve storing drinking water in existing sandstone wells during periods of lower demand (i.e., winter) and pumping it out during periods of higher demand (i.e., summer). ASR would have the following impacts on the alternatives:

- Increased reliability because drinking water would be stored at various well locations for use when needed.
- Increased operational flexibility because another source of water would be provided in the event of emergencies (i.e., failure of pipes or treatment plants). In addition, ASR could be used if one or more sources of water are stressed from drought conditions.
- Reduced costs because wells, treatment plants, and pipes could be sized closer to ADD instead of maximum day demand. Typical operations would be to produce water more consistently at slightly above ADD and store it on the sandstone aquifer during low demand and pump it out of the aquifer during high demand.
- Use of existing facilities and resources (sandstone wells, storage tanks, and pump stations) would save some of Waukesha's infrastructure investment and assist with water distribution.

To illustrate these points, the use of ASR with shallow aquifer alternatives (Troy bedrock valley, Fox River alluvium, or a combination of the two) on each evaluation criteria will be discussed.

4.7.1 Reliability

ASR provides more reliability by providing another drinking water source. The most reliable alternative is to have both Fox River alluvium water and shallow aquifer water with ASR. Even if both sources are unavailable due to contamination or infrastructure failure, or drought, ASR could be used to provide at least the ADD.

4.7.2 Infrastructure

4.7.2.1 Wells

ASR would reduce the number of shallow aquifer wells from 16 to 10, and the Fox River alluvium horizontal wells from six to five.

Four or five of the existing sandstone wells would be modified for ASR. This involves additional piping and valves in existing pump stations.

4.7.2.2 Treatment

ASR would reduce the size of treatment plants from 22 to 14 mgd.

4.7.2.3 Transmission

Transmission mains from the wellfields to Waukesha could be smaller because they would have to deliver 14 mgd instead of 22 mgd. In addition, less distribution system pipeline would be required because use of existing wells would help distribute water around the system.

4.7.3 Regulations/Legal

As mentioned previously, ASR regulations are being finalized by WDNR. The requirements of these regulations may include a monitoring well and additional testing to determine the fate of some chlorine by-products in the aquifer.

4.7.4 Political and Public Acceptance

Additional information may be required to educate the public on ASR. Use of the existing sandstone aquifer may be appealing to some since this is the historical source of drinking water.

4.7.5 Operations and Maintenance

4.7.5.1 Wells

Sandstone wells retained for ASR use will need to be maintained in a similar manner as now. With much less sandstone water being used, pumping levels should increase and maintenance requirements decrease. Only four or five of the existing 10 wells would be used. The other wells could be used as standby or abandoned.

4.7.5.2 Water Treatment

O&M requirements for the treatment plant would decrease because the size would be reduced from 22 to 14 mgd.

4.7.5.3 Water Plant Residuals

Water plant residuals handling would decrease because the size would be reduced from 22 to 14 mgd.

4.7.5.4 Transmission

The quantity and size of transmission and distribution system pipes would decrease, potentially decreasing O&M requirements.

4.7.6 Schedule

ASR would add another component to the construction of facilities. Conversion of existing wells to ASR wells could be done in the same time frame as new wells and treatment plants. The conversion would have to be phased to maintain water supply capacity during construction.

SECTION 5

Benefit Ranking of Alternatives

5.1 Methods

The method of determining evaluation criteria and assigning relative weights was discussed in Section 3. The criteria were used by a team of evaluators to rank each alternative for its ability to provide benefits. Initially, a large group of evaluators was used to get a broad perspective on the benefits of major water supply alternatives. Groups represented included:

- Waukesha Water Utility staff
- Waukesha Water Commission
- WDNR
- SEWRPC
- City Legal Counsel
- US Geologic Survey
- University of Wisconsin
- Wisconsin Geologic Survey
- CH2M HILL
- Ruekert & Mielke

When the alternatives were evaluated and developed further, a smaller group of evaluators (consultants and water utility) repeated the benefit ranking of alternatives. Overall, the results were similar with both groups.

5.2 Results

Figure 5-1 shows the results of the benefit ranking. The height of the bar is proportional to the benefit the alternative provides. Therefore, the higher the bar the more benefits. The alternatives were grouped into three major categories:

- Sandstone aquifer
- Shallow aquifer
- Lake Michigan

The general conclusions that follow can be made from the benefit analysis.

5.2.1 Sandstone Aquifer

The sandstone alternatives provided the lowest benefit as a group. Reliability of the sandstone aquifer near Waukesha was low because of declining water quality and groundwater levels. In addition, more extensive treatment was required to deal with radium and increasing TDSs. This created infrastructure and O&M concerns.

Placing sandstone wells west of Waukesha in the recharge area of the sandstone aquifer improved reliability significantly. However, this alternative was located farthest from Waukesha with significantly more pipeline infrastructure and concerns for political and public acceptance issues.

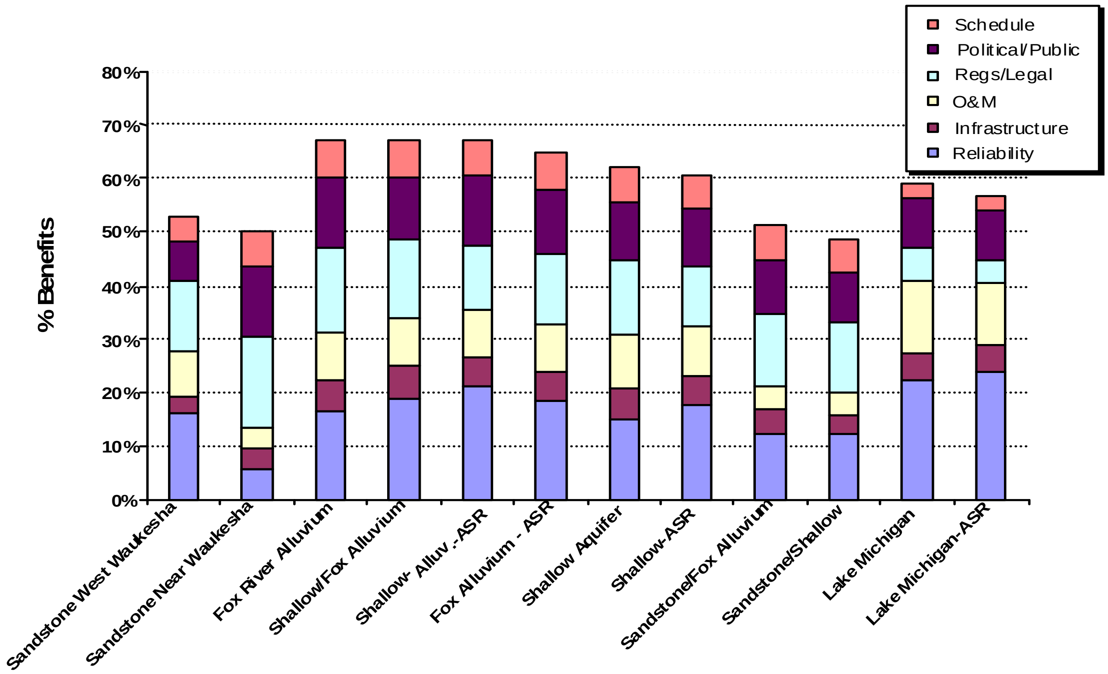

FIGURE 5-1
Benefit Ranking Results

5.2.2 Shallow Aquifer

Eight shallow aquifer alternatives and combinations of alternatives were evaluated. ASR was included with three alternatives. Blending sandstone water with shallow aquifer water was included in two alternatives. Overall, the shallow aquifer alternatives provided the highest benefit.

The alternatives with the highest benefits were the shallow aquifer/Fox River alluvium combination and Fox River alluvium alone. These were followed very closely (0.1 percentage point) by the shallow aquifer/Fox River alluvium/ASR combination. Although the Fox River alluvium alternative was rated lower on reliability, it is located closest to Waukesha and scored higher on legal, political, and public acceptance issues. The combination of shallow aquifer and Fox River alluvium was rated higher in reliability because there are two sources of water, and the shallow aquifer has more protection (clay confining layer) from contaminants. The shallow aquifer/Fox River alluvium/ASR alternative was rated highest in this group for reliability because it has three sources of water.

The lowest ranked shallow aquifer alternatives involved blending with sandstone water. O&M concerns with balancing water demand requirements and radium levels were a factor. Significantly more piping in the city limits was also required.

5.2.3 Lake Michigan

The Lake Michigan alternatives were evaluated with and without ASR. Lake Michigan was slightly lower in benefits than the shallow aquifer alternatives, but higher than the sandstone aquifer. Lake Michigan was rated the most reliable and best O&M of all alternatives. However, concerns for getting permission for a diversion without sending wastewater back to the Great Lakes Basin caused this alternative to be ranked lowest in regulatory/legal, political and public acceptance, and schedule.

SECTION 6

Costs

Capital and O&M costs were estimated for each alternative. A summary of these costs is presented in Table 6-1. Capital costs include new facilities needed for an operational system with a 22-mgd capacity. Capital costs also include land purchase, allowances for additional studies, permits, and easements. A 20-percent contingency and 15 percent for engineering, legal, and administrative costs was included in each alternative capital cost estimate. Costs are in 2002 dollars.

Annual O&M costs for each alternative are also presented in Table 6-1. Costs were based on a 10-mgd ADD. These costs include source of supply, treatment, residuals disposal, transmission, and water purchase where applicable (Lake Michigan). A 5-percent contingency was added to O&M costs. The increase in each alternative's O&M costs over current water system costs is also presented in Table 6-1 to estimate impacts on the water utility budget.

Total cost is the capital cost plus present worth O&M cost (20 years at 6 percent). This number can be used to compare the various alternatives. As shown in Table 6-1, the sandstone alternatives have the highest total cost. Costs for the sandstone wells near Waukesha are driven by the capital and high O&M cost of treatment. Costs for the sandstone wells west of Waukesha are driven by the high cost of long transmission pipes from the wellfield to Waukesha.

The shallow aquifer alternatives have some of the lowest total costs. There is a range of costs depending on location of the wellfield, treatment required, and use of ASR. The lowest cost alternative is a shallow aquifer wellfield south of Waukesha and the use of ASR to store drinking water for use during high demand periods ($62 million total cost). ASR reduces capital costs significantly because it reduces the number of wells, size of pipes, and size of treatment plants. These facilities are sized closer to ADD (about 14 mgd) instead of maximum day demand (22 mgd). The highest shallow aquifer alternative cost is the combination of the Fox River alluvium and shallow aquifer south of Waukesha ($83 million total cost). These costs are driven by more pipe for multiple sources, two treatment plants, and a higher degree of treatment for the Fox River alluvium. If ASR is combined with this alternative, the total cost is reduced from $83 million to $69 million total cost because of smaller pipes, smaller plants, and less wells.

Lake Michigan water has a total cost of $90 million. This alternative has the lowest capital cost ($42 million), but the O&M costs are high, mainly from the cost of purchasing treated wholesale water from a Lake Michigan supplier. This alternative assumes that a permit will be issued that allows the use of Lake Michigan water without returning it to the Great Lakes Basin. If return of water to the Great Lakes Basin is required, the cost of this alternative will be double or more.

TABLE 6-1
Summary Cost Estimate (in $ millions)
Future Water Supply

	Capital Cost[a]	O&M$/yr[b]	Increase Over Current O&M$/yr [c]	Total Cost [d]	Total Cost w/Home Softening Credit [e]
Sandstone Alternatives					
Sandstone Near Waukesha	$ 67	$ 5.9	$ 4.7	$ 135	$ 108
Sandstone West of Waukesha	$ 77	$ 1.8	$ 0.6	$ 98	
Shallow Aquifer Alternatives					
Shallow Aquifer	$ 56	$ 1.3	$ 0.1	$ 71	
Shallow Aquifer with ASR	$ 45	$ 1.5	$ 0.3	$ 62	
Fox River Alluvium	$ 62	$ 1.6	$ 0.4	$ 80	
Fox River Alluvium with ASR	$ 50	$ 1.7	$ 0.5	$ 69	
Shallow Aquifer/Sandstone	$ 51	$ 1.2	$ (0.01)	$ 65	
Fox River Alluvium/Sandstone	$ 57	$ 1.4	$ 0.2	$ 73	
Fox Alluvium/Shallow Aquifer	$ 66	$ 1.5	$ 0.3	$ 83	
Fox Alluv/Shallow Aquifer with ASR	$ 52	$ 1.5	$ 0.3	$ 69	
Lake Michigan Alternatives					
Lake Michigan	$ 42	$ 4.2	$ 3.0	$ 90	$ 63
Lake Michigan with ASR	$ 36	$ 4.3	$ 3.1	$ 85	$ 58

[a] 2002 dollars, facilities for 22 mgd.
[b] 10 mgd average day demand. Source of supply, treatment, and new transmission only.
[c] Alternative O&M (column 2) minus existing O&M (10 mgd for source of supply & treatment only).
[d] Capital plus O&M present worth, 20 years, 6%.
[e] Subtracts capital and O&M cost of home softening, 20 years, 6%.

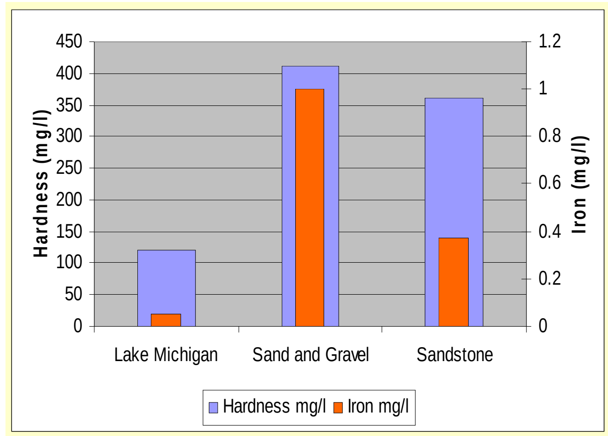

FIGURE 6-1
Hardness and Iron in Source Waters

Lake Michigan water is naturally soft. Water from the shallow and sandstone aquifer is hard. A comparison of hardness and iron between the water sources is on Figure 6-1. The shallow aquifer is a bit harder than the sandstone. It also has higher iron, but the iron removal plant would reduce the iron levels to low levels similar to Lake Michigan water. Currently, many Waukesha residents have home water softeners. If soft water from Lake Michigan was obtained, the home softeners would not be needed and the associated cost of operating them would be eliminated. There is a cost advantage to providing soft water estimated at a 20-year present worth of about $27 million, mostly from the cost of salt purchase. If this home softening cost is subtracted from the cost of providing Lake Michigan water, the alternative total cost is $63 million, which is close to the lowest shallow aquifer alternative ($62 million).

These cost estimates were prepared without detailed engineering design. The purpose of the cost estimate is for guidance in project evaluation and implementation based on information available at the time of the estimate. The final cost of the project will depend on market conditions, actual site conditions, final project scope, schedule, and other variable factors. As a result, the final project costs will vary from the estimates presented here.

6.1 Benefits and Costs

The best alternatives provide high benefits at reasonable costs. The alternative benefits from Section 5 and present worth costs from Section 6 are combined on Figure 6-2. The alternatives with the highest benefits and lowest costs are:

- Lake Michigan
- Shallow Aquifer

The Lake Michigan alternative cost includes the softening cost credit. It also assumes a diversion permit will be granted and will not require returning water to the Great Lakes Basin or other environmental improvements. If a diversion permit is not granted or return of water to the Great Lakes Basin is required, the Lake Michigan alternative is not cost effective. If a diversion permit is granted without a return flow requirement, Lake Michigan provides the most reliable and highest quality source of water for Waukesha and potentially other communities.

Of the eight shallow aquifer alternatives evaluated, the ones with the highest benefit and lowest cost are:

- Shallow aquifer with ASR
- Fox River alluvium/shallow aquifer with ASR

The combination of Fox River alluvium, shallow aquifer, and ASR provides the most reliability and flexibility for delivering water and managing water resources. It is the preferred shallow aquifer alternative. However, future conditions and issues may change the best water supply alternative for Waukesha.

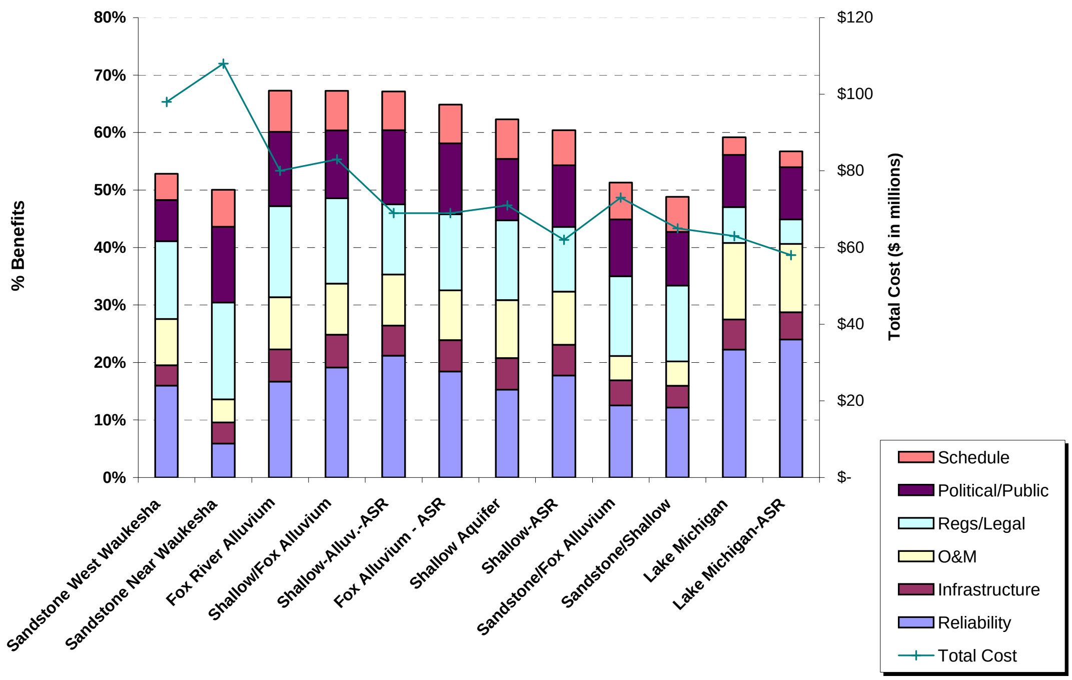

FIGURE 6-2
Benefits and Costs

SECTION 7
Summary and Implementation Plan

7.1 Summary

Over 20 water supply alternatives were evaluated for the Waukesha Water Utility. The alternatives were screened down to seven, then evaluated in detail. The three major categories of water supply sources are the sandstone aquifer; shallow aquifer; and Lake Michigan.

These alternatives were evaluated based on the following criteria:

- Reliability
- Infrastructure
- Regulations/Legal
- Political and Public Acceptance
- Operations and Maintenance
- Schedule

Capital and operating costs were developed for the alternatives. The alternatives with the highest benefits and lowest costs are:

- Lake Michigan
- Shallow aquifer

7.2 Implementation Plan

Implementation of a new water supply for Waukesha should proceed on a parallel path as shown on Figure 7-1.

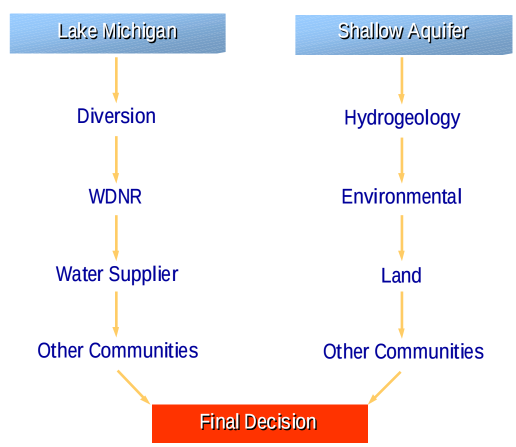

FIGURE 7-1
Implementation Plan

The feasibility of the Lake Michigan supply will depend on obtaining a diversion permit where return of water to the Great Lakes Basin is not required. Feasibility will also depend on negotiating a water contract with a Lake Michigan Water supplier. The criteria and process for evaluating the merits of a diversion are planned to be finalized in 2004 by the Council of Great Lakes Governors. However, investigations into the environmental impacts and requirements of a diversion can begin at any time. Other activities that can proceed toward a Lake Michigan water supply include:

- Discussions with WDNR on regulatory requirements
- Discussions with potential Lake Michigan water suppliers
- Discussions with other communities facing similar water supply issues

Further steps toward a shallow aquifer supply include:

- Hydrogeologic investigations and test wells in the shallow aquifer to determine optimum well locations, sustainable capacities, and environmental impacts
- Land issues including purchase, lease, and zoning
- Discussions with other communities regarding use of the shallow aquifer and potential partners in a water supply system

When information on the critical issues for the water supply sources becomes available, a final decision on the best water supply source can be made. Engineering design activities can then commence, followed by construction, start-up, and operation of the new water supply system.

SECTION 8

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