An Analysis of the City of Waukesha Diversion Application

Focusing on Conservation and Efficiency Measures,
Demand Forecast, and Alternative Sources of Water Supply

Jim Nicholas
February 2013

Contents

Introduction

This paper presents an analysis of certain aspects of the City of Waukesha's Water Diversion Application (Application). The Application was submitted to Wisconsin DNR (WDNR) in May 2010. In addition to the Application, numerous other documents were submitted or referred to. Many of these are at WDNR's City of Waukesha Water Diversion Application web page. Documents reviewed in part or in whole are listed at the end of this paper.

The scope of this paper is limited to three aspects of the Application: conservation and efficiency measures, demand forecast, and sources of water supply. For sources the focus is on hydrologic and environmental aspects of withdrawals in the Application. Issues related to economic factors and return flows to Lake Michigan, for instance, are not addressed. The author assumes readers are familiar with the Application and related documents, so material from documents is not presented again in this paper; rather it is referred to and is described only to provide insight into analyses.

The goal of this paper is to provide an objective scientific analysis of particular aspects of the Application. The author is a scientist and an experienced hydrologist. He is neither an opponent nor a proponent of the Application. This paper contains no recommendations for actions by any parties.

The Application is for water to meet the needs of a service area that is not congruent with the City of Waukesha's current utility. Information in the Application regarding water sources, conservation measures, and demand is not presented separately for the parts of the service area outside of the City of Waukesha. Therefore, this paper assumes that facts and figures presented, in the Application and associated documents, are for the service area, unless documents specify otherwise. Where this paper refers to Waukesha water conservation measures, demand forecasts, and water sources, "Waukesha" refers to the service area for which the Application was made.

Water Conservation and Efficiency Measures

This section describes Waukesha's water conservation and efficiency measures (CEMs). It summarizes which CEMs have been implemented, which are still planned, and water savings for each, if available.

Regardless of the source of Waukesha's future water supply, water conservation is an essential part of the City's long-term strategy to meet future demands. Waukesha adopted a Water Conservation and Protection Plan in 2006 and updated it in 2012 as the Final Water Conservation Plan (FWCP). This plan describes water conservation and implementation strategies for all use sectors. The program will be evaluated annually and formally updated in 2016.

The FWCP sets a goal of 10 percent savings in water demand by 2050, based on the 2050 average day demand projection of 10.9 Mgd. Interim goals are savings of 0.2 Mgd by 2016 and 0.5 Mgd by 2030, with a final goal of 1.0 Mgd by 2050.

The principal CEMs are focused on 5 areas:

- Monitoring unaccounted for water and focusing on leak detection and repair;
- Promoting water conservation through public information and education campaigns;
- Replacing high-use fixtures by providing users with financial incentives;
- Reducing lawn sprinkling through ordinances; and
- Reducing average day and maximum day demand using inclining water rate block structures.

No specific water conservation targets are set for each CEM, except for fixture replacement. Rather they collectively are expected to meet the goals for 2016, 2030, and 2050.

Implemented CEMs

Unaccounted for water CEM—Waukesha has fairly low percentage of unaccounted for water, about 6 percent, with some variability from year to year. This is well below the average of 18 percent for large municipal systems in Wisconsin reported in Water Efficiency Potential Study (WEPS) for Wisconsin. It is also below AWWA's recommended 10 percent. Waukesha continues its leak detection and repair program, as well as auditing that can point to unaccounted for water. No specific amount of conserved water is associated with this CEM, because unaccounted for water continues to hover around 6 percent and is expected to do so in the future.

Public information and education CEM— According to WEPS, EPA estimates a 3 to 5 percent reduction in water use as a result of information and education programs. Waukesha has promoted conservation through a variety of media and methods. In 2011, Waukesha spent $16,545 on these efforts, according to their Report on Water Conservation Programs to the Public Service Commission of Wisconsin (PSC). Although no specific amount of conserved water is associated with this CEM, it is a critical part of ensuring success in rebate programs, outdoor watering, inclining water rate block structures, and reducing overall demand.

Fixture replacement rebate CEM—Waukesha launched a toilet rebate program in October 2008, with a goal stated in the Application of saving 0.5 Mgd by 2050. From inception through 2011, the program has resulted in replacements of 88 toilets at a cost of $25 per toilet. According to the Report on Water Conservation Programs the savings over this time period was 1,430,825 gallons or 0.001 Mgd. Waukesha estimates a savings of 15,000 gallons per year per toilet in the Application. Thus to reach the 2050 goal of 0.5 Mgd savings, the total number of toilets that would need to be replaced is a little over 12,000 or 300 per year between 2011 and 2050. Possibly the Application meant to refer to replacement of other fixtures besides toilets, because the FWCP sets a goal of 7,444,000 gallons saved over 5 years (2112-2016), which equates to about 99 toilets per year.

The PSC's Summary of 2010 Utility Water Conservation Reports is a summary of water conservation efforts for eight utilities required to report these to the PSC. The number of toilet rebates for these utilities ranged from 14 to 2504, the latter for a city three times bigger than Waukesha (table 1). Waukesha had 17 toilet rebates. The amount of water saved per rebate was quite variable, ranging from 2000 to 12,000 gallons per year. Waukesha's was 8000 gallons per year. This is significantly less than, nearly half, the amount Waukesha estimated to save in the Application, which was 15,000 gallons per year per toilet. Thus, there is some uncertainty with respect to projections of water savings from the toilet rebate program.

Reported Water Savings from Toilet Rebate Programs in Wisconsin (CY 2010)				
Utility	Number of Toilet Rebates	Estimated Water Savings (Gallons)	Estimated Water Savings per Rebate (Gallons)	Estimated Water Savings (Mgd)
Janesville Water Utility	104	335,809	3,229	0.0009
Kaukauna Water Utility	95	1,144,440	12,047	0.003
Madison Water Utility	2,504	18,345,151	7,326	0.05
Marshfield Utilities	54	108,000	2,000	0.0003
New Berlin Water Utility	77	820,000	10,649	0.002
Sun Prairie Utilities	14	34,829	2,488	0.0001
Waukesha Water Utility	**17**	**137,064**	**8,063**	**0.0004**
Total	2,865	20,925,293	7,304	0.0567

Source: Table 2 in 2010 PSC Conservation Summary.

Table 1. Reported water savings from toilet rebate programs in 2010 for eight water utilities in Wisconsin.

According to WEPS, toilets account for nearly 30 percent of indoor water consumption. Average residential single-family water use per household is 30 GPD for a toilet. Based on 2010 Census data on the year homes were built, 85 percent of residential customers in Wisconsin are estimated to have 3.5 gallons per flush (gpf) toilets, 13 percent have 1.6 gpf, and 2 percent have 1.28 gpf toilets. The distribution in Waukesha has not been estimated.

Outdoor watering ordinance CEM—Waukesha implemented outdoor sprinkling restrictions for all customer classes in 2006. According to Waukesha's 2010 Water Conservation report to the PSC, the restrictions are applicable from May 1 to October 1. The restrictions ban daytime sprinkling from 9:00 a.m. to 5:00 p.m. Customers are allowed to irrigate two days a week according to their address. According to WEPS, inefficient irrigation practices can cause observed water loss of 20 to 50 percent of outdoor water use.

In 2010, maximum day demand was 8.65 Mgd, which is 67 percent lower than the 2005 peak demand of 12.87. For the same time period, the difference in average day to maximum day demand decreased 61 percent. Although other factors affect maximum day demand, the sprinkling ordinance is likely a major factor in reducing it.

Inclining water rate block structures CEM—In 2007, Waukesha was the first city in Wisconsin to adopt an inclining water rate block structure. The structure is applicable to residential users. It sets different costs (or rates) for water according to the amount of use. Rate blocks are associated with different levels of quarterly use (for example, 0 to 10,000 gallons, 10,001 to 30,000 gallons, and over 30,001 gallons). Costs in the highest rate block are 40 percent higher than in the lowest rate block. The idea is to provide a price incentive for customers to use less water.

Since implementation of the inclining water rate block structure, residential water use has decreased. Over the same time period, water use has declined in the industrial, commercial, and public water use sectors also, so factors other than the inclining water rate block structure are likely causing a decline in water use in the residential sector. Still price incentives have been shown to significantly reduce water use, although adjustments in the number of rate blocks, the amounts of water associated with each, and the cost of water in each sometimes take several years to achieve desired results. Timely feedback (billing) to customers is also necessary so that decisions on use can be made. Monthly billing would likely influence water-use decisions more effectively than does quarterly billing. According to WEPS, EPA estimates that an inclining block rate structure can lead to a 5 percent overall reduction in water use.

Planned CEMs 2012 to 2016

Waukesha's current implementation strategy, outlined in the FWCP, is designed to develop a foundation for the programs in Year 1 (2012) through public education and incentives for residential customers, particularly the top 10 percent water users. Starting in Year 2 (2013), the program focus would expand to include incentives for commercial and industrial customers. As the program expands over the subsequent three years (2014 to 2016), additional measures would be emphasized to capture the greatest savings and the lowest costs. This plan is outlined in Table 8-5 in the FWCP.

Table 2, adapted from Table 8-1 in the FWCP, shows a projected 86 MG (0.24 Mgd) in water savings across all sectors in millions of gallons per year between 2007 and 2016. Waukesha's implementation schedule is outlined only until 2016, leaving some uncertainty about how the additional 0.26 Mgd in savings will be achieved by 2030. Furthermore, how Waukesha will achieve an additional 0.5 Mgd between 2030 and 2050 has not been described. That being said, plans need to remain flexible in order to be effectively budgeted and implemented. When the

Conservation Plan is reviewed again in 2016, Waukesha should know what its future water supplies will be and can better evaluate and adopt appropriate measures.

Total Projected Cumulative Water Savings										
User	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Residential	6.1	12	17.7	23	28.1	35.4	43.2	51	59.1	67
Commercial, Industrial, & Public	1.8	3.6	5.2	6.8	8.3	9.8	12.1	14.3	16.6	19.7
Total (Mgy)	7.9	15.5	22.9	29.8	36.4	45.2	55.3	65.4	75.8	86.8
Total (Mgd)	0.02	0.04	0.06	0.08	0.1	0.12	0.15	0.17	0.21	0.24

Table 2. Projected Waukesha water savings 2007-2016.

Unaccounted for Water CEM – As previously stated, unaccounted for water is relatively low in Waukesha. Waukesha will continue its leak detection and repair programs and water audits.

Public Information and Education CEM – Current measures already implemented will be further publicized and expanded in scope through 2016. Educational programs will expand into schools, from elementary to college campuses, such as Teach the Teacher workshops and course projects. Partnerships with coalitions throughout Waukesha County will strengthen and expand as well. Although this CEM is an essential part of any water conservation plan, no specific goal of water savings is associated with it.

Fixture Replacement Rebate CEM – Measures incentivizing fixture replacement will be expanded from 2012 to 2016 as well. For residential customers, the toilet rebate program will provide $100 rebates, rather than the current $25, with the objective of accelerating the number of replacements. Rebates or a distribution program will also begin for high-efficiency showerheads. Indoor water audits will also be available to residential customers. As shown in Table 3, the projected water savings from these measures are 8.34 MG (0.0046 Mgd).

For commercial, industrial, and institutional customers, rebates for high-efficiency toilets, showerheads, clothes washers, spray-rinse valves, and urinals will begin in order to provide incentives for these customers to make their facilities more efficient. Indoor water use audits will also begin for these use sectors between 2012 and 2016. According to WEPS, residential and nonresidential audits that include plumbing retrofits, evaluations of kitchen and irrigation systems, and leak reduction have the potential to reduce demand by 15 to 35 percent. Based on only the CII water demand from 2008-2010 in the FWCP, that would equate to 0.0009 to 0.0022 Mgd in water savings. As shown in Table 3, according to the FWCP an estimated 4.93 MG (0.0027 Mgd) in water savings is attributed to these programs.

Projected Water Savings 2012-2016			
User	Conservation Measure	Projected Water Savings (MG)	Projected Water Savings (Mgd)
Commercial, Industrial,	High-Efficiency Toilet Rebate	0.41	
and Public	Water-Efficient Showerhead	0.04	
	Indoor Water Use Survey	0.06	
	Outdoor Water Use Survey	-0.11	
	Urinal Rebate	0.28	
	Spray-Rinse Valves Rebate	4.24	
	High-Efficiency Clothes Washer Rebate	0.01	
		4.93	**0.0027**
Residential	High-Efficiency Toilet Rebate	7.44	
	Water-Efficient Showerhead	0.88	
	Indoor Water Use Survey	0.08	
		8.39	**0.0046**
Total		**13.32**	**0.007**

Source: Table 6-6 in FWCP

Table 3. Projected Waukesha water savings in millions of gallons for various fixtures, 2012-2016.

Outdoor Watering Ordinance CEM – The sprinkler ordinance will remain in effect through 2016 to continue to help reduce average and maximum day demand in summer months.

Inclining Water Rate Block Structure CEM - Water pricing is an important driver of a comprehensive conservation program. The current rate structure will continue to be evaluated annually.

Recommended Future CEMs in FWCP post-2016

A detailed outline of Waukesha's long-term implementation strategy is available in Appendix F of the FWCP. As many of these measures are continued or expanded versions of measures already implemented, proper tracking and evaluation over the next few years is essential in allowing stakeholders to better project water savings for the following measures.

Unaccounted for Water CEM –Leak detection and repair programs will continue post-2016. A new policy regarding the survey and repair of leaks upon the sale or lease of property may also come into affect.

Public Information and Education CEM – This CEM is planned to continue.

Fixture Replacement Rebate CEM - There are many areas within each use sector that Waukesha can, and in some cases already is, exploring for water savings through rebates. For example, one area that appears to have a high potential for water savings is addressing inefficiencies of cooling systems through audits and retrofits. According to WEPS, cooling systems account for 16.8 percent of indoor water use in nonresidential accounts. Irrigation technology or spinkler head replacement rebates are also being considered. A new policy requiring plumbing retrofits upon sale or lease of property may also come into effect. Furthermore, incentives or policies regarding water-efficiency standards for new buildings and low-impact development techniques are likely to begin.

Outdoor Watering Ordinance CEM – The sprinkler ordinance will continue to remain in effect. Irrigation control outreach, along with distribution of rain gauges or sensors to high water users with either large lots or high peak seasonal use will also be explored. New efficiency standards addressing outdoor decorative features and swimming pools may also be implemented.

Inclining Water Rate Block Structure CEM – The current rate structure will continue to be evaluated annually. Waukesha will also explore monthly billing which has been shown to increase customer awareness about water use and thus decrease demand.

Comparison to other cities

The EPA recently published a report that highlights the results of water conservation plans implemented by different cities around the country. As shown in Table 4, water savings from conservation plans that incorporate elements similar to Waukesha's ranged from 7.3 to 30 percent. Obviously, differences in climate, population, infrastructure, water savings potential, and user profiles exist between these cities and Waukesha. However, it does provide insight as to the level of water savings a city can hope to achieve following implementation of a comprehensive water conservation plan. The amount of water savings these cities achieved show that Waukesha's goal of a 10 percent reduction in average day demand is reasonable and may be conservative.

Water Conservation Case Studies		
City	**Approach**	**Results**
Houston, TX	Education Program, Plumbing Retrofits, Audits, Leak Detection and Repair, Increasing-Block Rate Structure, and Conservation Planning.	Estimated 7.3% reduction in water demand by 2006.
Goleta, CA	Plumbing Retrofits and Increased Rates.	30% decrease in district water use. 50% reduction in per-capita residential water use.
Irvine Ranch Water District, CA	Five-Tiered Rate Structure.	19% decrease in water use in the first year.
Cary, NC	Education Program, Toilet Rebates, Landscape and Irrigation Codes, and Rate Structure.	Water savings of 16% by 2028.
Santa Monica, CA	Education Program, Water Use Surveys, Toilet Retrofits, and Landscaping Measures.	14% reduction in water use.
Seattle, WA	Education Program, Plumbing Retrofits and Code, Seasonal Rate Structure, and Leak Detection and Repair.	20% drop in per capita water use in the 1990s.
Tampa, FL	Education Program, Plumbing Retrofits, Increasing-Block Rate Structure, and Irrigation and Landscape Codes.	Pilot retrofit program achieved 15% reduction in water use.

Source: USEPA Cases in Water Conservation.

Table 4. Results of water conservation case studies for eight North American cities.

Effect on average day demand and maximum day demand

Waukesha's plans for conservation and efficiency measures are to reduce average day demand by 10 percent. Maximum day demand, while important, is only the demand for a single day and can be affected by activities that are not impacted by conservation, such as firefighting. Maximum day demand is important mostly for design and infrastructure, and less so for environmental impacts of withdrawals. A better target might be reducing maximum week or month demand. Measures related to outdoor water and cooling will reduce maximum day demand, but more importantly, they will reduce maximum week or month demand.

FWCP 4.2.3 makes the argument that demand will increase due to improving economic conditions, especially growth in the commercial and industrial sectors. While it appears reasonable to argue that an increase in water utility customers will result in higher demand, the history of demand and per capita use by sector does not support this argument, as discussed in the next section on Demand Forecast.

If the FWCP is fully implemented and successful, then per capita demand and maximum day demand should continue to decrease. It is difficult, however, to directly measure progress towards the conservation goal for individual CEMs, other than fixture replacement, because there are many confounding factors that affect trends in demand. Demand and water use per capita were decreasing for a long time prior to implementation of CEMs, as shown in the next section. Estimates of savings for each CEM could be made, as they are, for example in WEPS.

Water Demand Forecasts

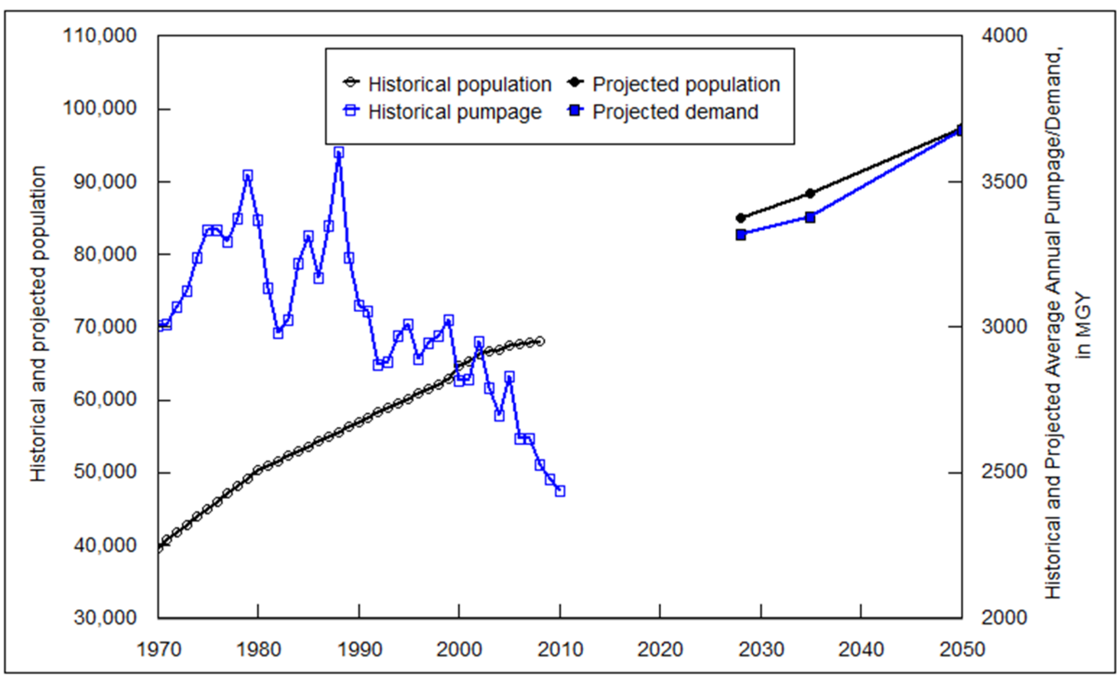
Future water needs are based upon projections of population growth, a future mix of water-use sectors (residential, commercial, industrial, and public), estimates of the amount each sector will use, and improvements and efficiencies in infrastructure and water use that conserve water. Estimates of future water needs are conservative in the sense that they must not under-predict future needs. Potential and largely unpredictable changes in infrastructure, demand, and climate must all be accounted for.

Waukesha forecasts water needs for 2050. The Application assumes that 2050 represents a timeframe in which the population and associated use sectors have reached their maximum based upon planning studies done by the City of Waukesha and SEWRPC. There are projections in various other documents for timeframes before 2050, such as SEWRPC's 2035 projections. However, the Application is conservative in the sense that it applies for water needs in "ultimate" buildout and water use for Waukesha.

Water demand forecasts, through the use of future population and water use estimates, project needs for water in the future. The Waukesha Diversion Application includes several documents that contain water demand forecasts or information relevant to forecasts. These were reviewed for this analysis and include: Appendix C—Future Water Supply (March 2002), Appendix K—Summary of Water Requirements, (May 2009), Appendix D—Water Supply Service Area Plan (April 2010), the Application (May 2010), and Final Water Conservation Plan (May 2012).

The most recent demand forecasts for 2050 are an average day demand of 10.9 million gallons per day (Mgd) and a maximum day demand of 18.5 Mgd (Appendix D, exhibit 13). The average day demand projected for 2050 assumes a constant gallons per capita per day (GPCD) from 2008 through 2050 for three use sectors (residential, commercial and public) that is near, but above, current GPCD (Appendix D, exhibit 13). GPCD is not given specifically for the industrial sector, but instead a total water use for 2050 is given (Appendix D, exhibit 13). Future average day demand is forecast simply by using a static GPCD of 112 and future population estimates, along with assumptions on unaccounted for water and a percent reduction in demand from implementing CEMs. Future maximum day demand is based on a ratio of maximum day demand to average day demand of 1.68 (Appendix D, p. 16), using analyses of historical ratios and precautionary assumptions regarding factors that may increase maximum day demand, such as extended drought (Appendix D, p. 16).

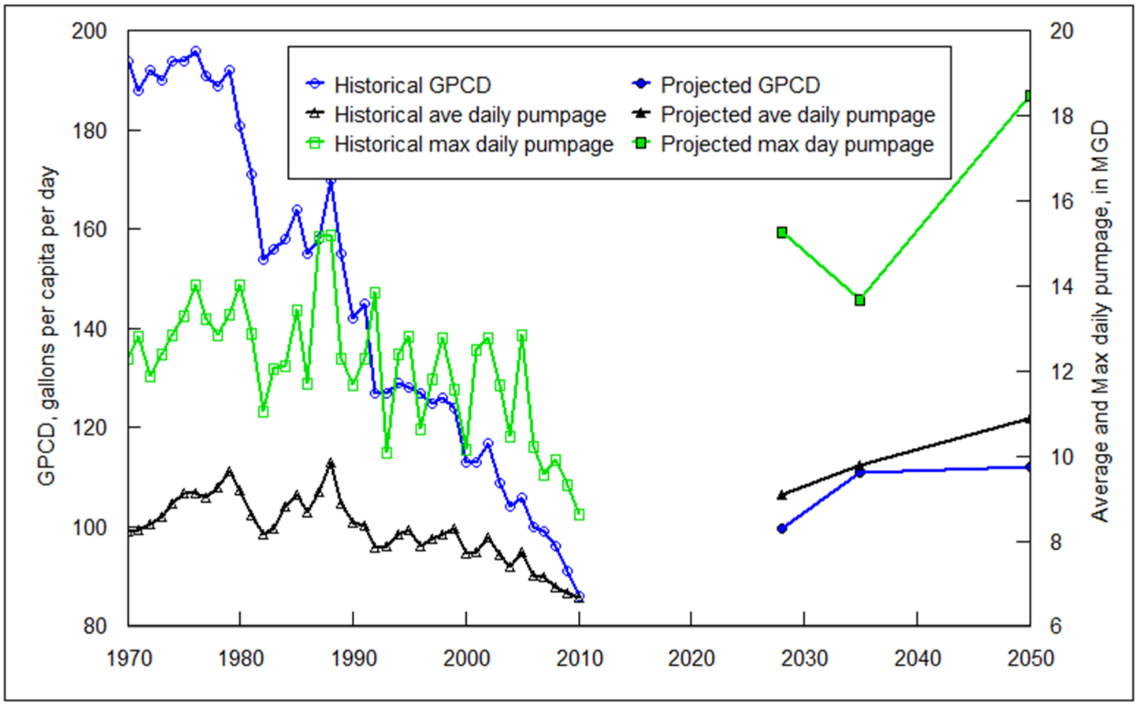
Figure 1 illustrates the historical trends in population and pumpage, along with projected population and demand. Note that both the historical and projected population have increasing trends. In contrast, Historical pumpage has a decreasing trend, and projected demand has an increasing trend.



Historical data through 2008 from App K, table 1, 2009-10 from Final Water Conservation Plan, figure 4-1. Projected 2028 data values from App K, table 5. Projected 2035 and 2050 values from App D, exhibits 11 and 13.

Figure 1—Historical and projected water demand and population for Waukesha.

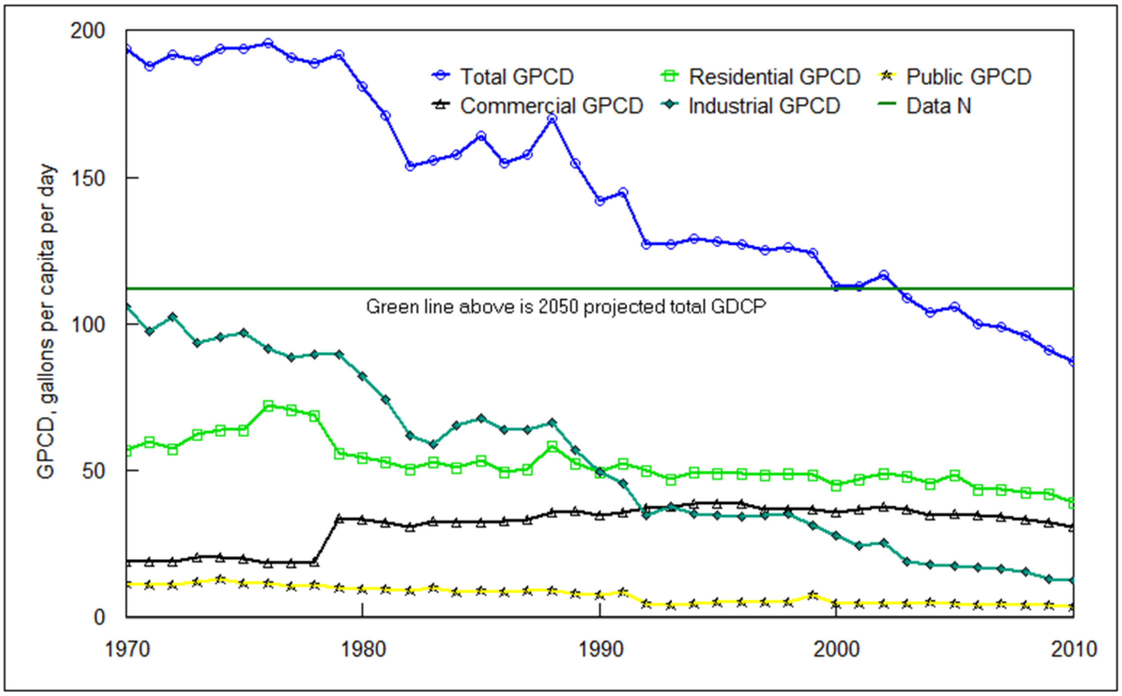
Illustrating similar trends to Figure 1, Figure 2 shows historical declines in GPCD, average day pumpage, and maximum day pumpage, while showing increases in projected values for all three of these.



Historical data through 2008 from App K, table 2 and 3, 2009-10 from Final Water Conservation Plan, figure 4-6. and 4-1. Projected 2028 data values from App K, table 5. Projected 2035 and 2050 values from App D, exhibits 11 and 13.

Figure 2—Historical and projected GPCD, average and maximum day demand for Waukesha.

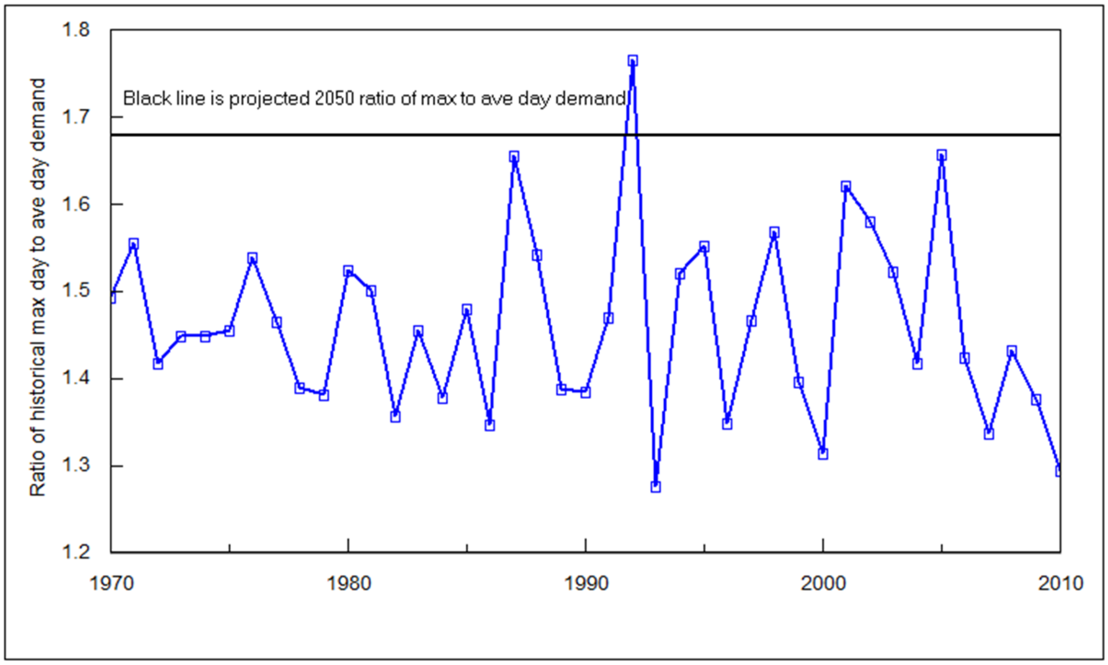
Figure 3 shows trends in GPCD for various use sectors and total GPCD. Aside from the commercial use sector, other use sector GPCDs and total GPCD show historical declines. The horizontal line indicates the total GPCD, 112, which is used to project 2050 average day demand (Appendix D, exhibit 13). In comparison, the total GPCD for 2010 was 86.



Historical GDCP through 2008 from App K, table 2, 2009-10 from Final Water Conservation Plan, figure 4-6. 2050 GDCP is from App D, exhibit 13.

Figure 3—Historical GPCD compared to projected GPCD for Waukesha.

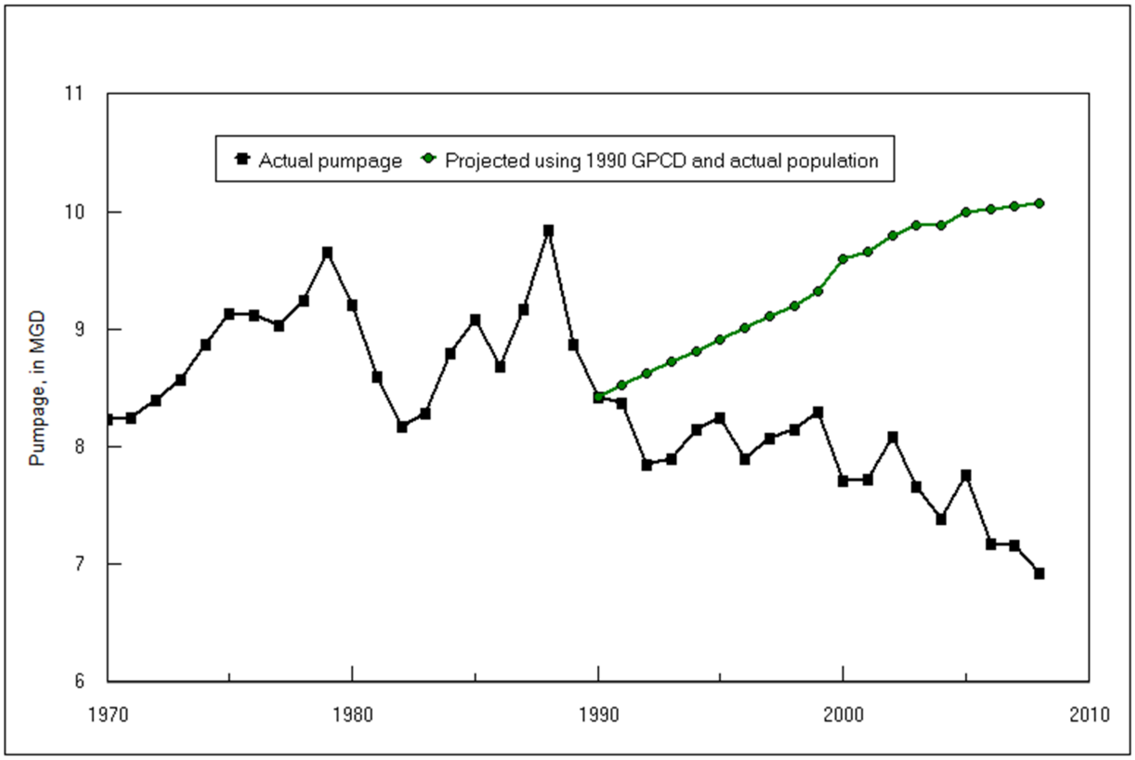
Future maximum day demand is projected by using a ratio of 1.68, based on historical ratios of maximum day demand to average day demand. Figure 4 shows the historical ratios. No trend is apparent. The average ratio is 1.46, and only thirteen years from 1970 to 2010 had ratios above 1.5. The most recent ratio for 2010 is 1.30. The horizontal line illustrates the ratio used for projection of 2050 maximum day demand. Only one year, 1992, has a value equal to or greater than 1.68.



Historical ratios through 2008 calculated from data in App K, table 3; 2009-10 calculated from data in Final Water Conservation Plan, figure 4-2.

Figure 4—Historical ratio of max imum to average day demand compared to projectedfor Waukesha.

Models of any kind that predict the future typically are calibrated to historical data. Doing so gives confidence that predictions are based on known historical relationships and functions. The demand forecast model used for Waukesha does not appear consistent with historical data; that is, it cannot predict historical data, as illustrated in this paragraph and Figure 5. The model used to forecast average day demand assumes a constant GPCD of 112, similar to that in 2000. Using a similar approach, one can test the predictive capabilities of the model by using the historical GPCD of 1990 (142), predict future demand, and compare it to historical average day pumpage from 1991 to 2008. The results of this test of the predictive model are shown below in Figure 5. Clearly, the further in time one moves from the base date of 1990, the more the model over-predicts demand.



Data from App K, table 2 and 3.

Figure 5—Actual pumpage compared to projected pumpage for Waukesha using 1990 GPCD and actual population as basis for projection

Another example of the difficulty in making demand projections can be illustrated using the projections for 2010 in Appendix C, which was written in 2002. Appendix C projects a 2010 average day demand of 9.32 Mgd and a maximum day demand of 15.37 Mgd, using a ratio of 1.65. In contrast, the actual figures for 2010 were an average day demand of 6.68 and a maximum day demand of 8.65, with a ratio of 1.30. The overprediction for this 8-year period is 40 percent for the average day demand and 78 percent for maximum day demand.

Demand projection is a difficult field, because it must account for possible future changes that are unknown. It must be precautionary in the sense of projecting the greatest possible demand and make appropriate assumptions in doing so. It should, however, be consistent with historical data and planned implementation of CEMs. These might at least hold GPCD stable at the recent level of 86. More likely, these measures would continue the historical decreasing trend. Measures directed at outdoor watering might decrease the ratio of maximum day pumpage to average day pumpage. Maximum day pumpage from 1970 to 2008 is almost always during the summer (Appendix K, table 3), a period during which most outdoor watering occurs. If demand projections are to be inconsistent with historical trends and with planned conservation and efficiency measures, then a clear explanation should be given of why changes in GPCD trends and ratios of maximum day to average day pumpage are anticipated.

A future demand scenario for 2050 could be made assuming that all downward historical trends in GPDC cease as of 2010, that proposed CEMs are successful in conserving water, and that the ratio of maximum to average day demand remains the same as the recent average from 2006-2010. The 2010 GPCD was 86 (Final Conservation Plan, figure 4-6), unaccounted for water from 2007-2010 averaged about 6 percent (Final Conservation table 4.1), and 2050 estimated population is 97,400. The average day demand for this scenario is 8.9 Mgd. With additional conservation savings of 10 percent (Appendix D, exhibit 11), the average day demand decreases to 8.0 Mgd. The ratio of average maximum to average day pumpage from 2006-2010 is 1.38 (Final Conservation Plan, table 4.2). Using this recent ratio, maximum day demand is 11.1. Again, note that this estimate does not assume that the clear and decreasing trend in GPCD continues. Rather it assumes, conservatively, that GPCD remains constant from 2010 to 2050.

Sources of Water Supply

This section discusses potential sources of water supply to meet Waukesha's future needs. These are evaluated with respect to the hydrological feasibility and environmental impact of the withdrawal. Costs related to infrastructure, treatment, and greenhouse gas emissions, for instance, are not considered.

Several documents listed at the end of this paper explore alternative sources of water for Waukesha's future needs. In these documents, sources were evaluated by several criteria and compared to each other. Additionally, possible combinations were explored, though not all possibilities, since all possible combinations is a very large number. This paper does not describe the alternative sources in detail, because such detail is given in many of the documents listed at the end of this paper.

Currently, Waukesha has two sources of water supply: (1) The Cambrian-Ordovician Aquifer, which is a relatively deep and confined aquifer, referred to as "deep confined aquifer" in this paper; and (2) sand and gravel deposits of glacial and recent origin, some unconfined and others semiconfined, referred to as "shallow aquifer" in this report". Waukesha has 10 wells in the deep confined aquifer. Two wells (#1 and #4) are no longer used due to contamination from human sources (#1) or the potential for contamination from human sources and low yield (#4). Well #2 was recently taken out of service due to decreasing yield. The remaining 7 wells have a combined capacity of 14.35 Mgd. Waukesha has 3 wells in the shallow aquifer near the Fox River. These 3 wells have combined capacity of 2.38 Mgd.

Natural sources of radium in the deep confined aquifer, and the costs associated with treatment to meet radium standards at all points of entry into the water supply system, were major factors that motivated Waukesha to explore alternative sources of water supply. In Waukesha's Future Water Supply study (Appendix C), fourteen alternative sources are considered. Nine are not discussed in detail, being removed from consideration using the evaluation criteria. Five are considered in more detail. The result of this analysis indicated that the best alternative source is a diversion from Lake Michigan (although Appendix C, written in 2002 before the Compact was completed, concluded this was only feasible if no return flow to Lake Michigan was required). The Application considers 6 alternative sources. Two are not discussed in detail, being removed from consideration using the evaluation criteria. Four are considered in more detail, and three of these are a combination of sources. The result of this analysis indicated that the best alternative source is a diversion from Lake Michigan. Additionally, WDNR requested that Waukesha reconsider the unconfined aquifer west of Waukesha (it was one of the two not considered in detail in the Application) and that they also consider a multiple source alternative. These latter two are reported in Response to Water Supply Questions WS7, WS7A, and WS10.

Evaluation Criteria and Issues

The Application used four main criteria for evaluating alternative sources and return flow: environmental impact, long-term sustainability, public health, and implementability. These criteria were chosen based on a Wisconsin Statute that defines a "reasonable water supply alternative" and which is applicable to a community in a straddling county in Wisconsin that wishes to apply for a diversion.

In the discussion of many of the alternative sources in the Application, five common concerns or issues are raised which this author views as problematic. These are discussed below.

The first is concern about contamination of source water supply. This results in lower ranking for sources in rivers or shallow aquifers, yet higher rankings for Lake Michigan. In fact, all sources are susceptible to contamination and need protection. Deep confined aquifers are typically viewed as those safest from contamination, yet 20 percent of Waukesha's wells in the deep confined aquifer are not used due to contamination, or the potential for contamination, from human sources. Lake Michigan, viewed as "high quality and safe" in the Application, was the source of a major water-borne disease outbreak in Wisconsin in the 1990s. These two examples illustrate that all water sources, even those deemed safe, can be contaminated. Rivers and groundwater are used throughout the Upper Midwest as sources of safe, potable water. Therefore concern about contamination of source water supply is not part of the evaluation in this paper.

The second are issues related to the effect of groundwater withdrawals on Waters of the Great Lakes Basin. By Compact definition, none of the groundwater sources considered by the Application are Waters of the Great Lakes Basin. Stopping deep confined aquifer pumping in Waukesha will not improve the Waters of the Great Lakes Basin; continued pumping in Waukesha will not impair Waters of the Great Lakes Basin. Regionally in southeast Wisconsin pumpage from the deep confined aquifer does result in a small amount of inducement of flow from Lake Michigan (1.33 Mgd in the SEWRPC model for 2000) and a small amount of capture of water that would have flowed to Lake Michigan (2.67 Mgd) and an unknown amount of streamflow capture and inducement within the Great Lakes Basin (not reported separately by watershed for SEWRPC model, though the total from inside and outside the Great Lakes Basin was 19.7 Mgd). Besides having small or unknown impacts on Waters of the Great Lakes Basin, there has been no study to indicate how changes in only Waukesha's pumping, using updated pumping in the area, will affect flow of groundwater to Lake Michigan or to streams tributary to Lake Michigan. Without knowing the impacts of continued or no pumpage from the deep confined aquifers, there is nothing to say about the environmental impacts on Waters of the Great Lakes Basin. Therefore the pros or cons of pumpage from the deep confined aquifer, with respect to impacts on Waters of the Great Lakes Basin, are not part of the evaluation in this paper.

The third issue is the Application's evaluation of how uses of various sources will or will not meet Compact requirements (Application exhibit 4-20). This exhibit treats the deep confined and shallow aquifer sources in Waukesha as Waters of the Basin, which they are not. The Compact sections referenced in the first column of exhibit 4-20 refer only to Source watershed and water sources that are parts of Waters of the Great Lakes Basin. They do not apply to other water sources in Wisconsin. Therefore the final two columns in exhibit 4-20 are not relevant to Compact requirements and should be filled in with "NA—not applicable". The Application's line of reasoning in this regard is illustrated by the following statement from Appendix D, p. 31 (and quoted in the Application):

> *One of the decision making standards of the Compact (4.11.1) states "All Water withdrawn shall be returned, either naturally or after use to the Source watershed less allowance for Consumptive Use." Since the deep aquifer and the waters of the Lake Michigan Basin are hydrologically connected, pumping the deep aquifer and discharging the water into the Fox River does not comply with this Compact decision-making standard.*

In fact, the Compact states that groundwater outside of the watershed boundary of the Great Lakes is not in any of the Source Watersheds of the Great Lakes Basin. Thus the Compact Decision-Making Standard is not relevant to Waukesha's return of wastewater from groundwater sources to the Fox River. Therefore the evaluation in this paper separately treats Waters of Wisconsin outside the Great Lakes Basin and Waters of the Great Lakes Basin and does so in a manner consistent with Compact language.

The fourth issue is related to statements about continued decline of water levels in the deep confined aquifer, such as "drastically declining water levels". The regional groundwater modeling done for SEWRPC clearly showed the historical and significant declines of groundwater levels in the deep confined aquifer. However, pumping patterns and amounts have changed. In particular, pumping in many areas has decreased (Waukesha, for example, has had decreasing pumpage since the late 1980's, as shown in Figure 1). There are only two long-term monitoring wells in the deep confined aquifer in southeast Wisconsin, in Kenosha and Walworth counties. Both of these wells show stable or increasing trends in recent years (Figure 6), although they are certainly also affected by decreases in pumpage in the Chicago area. Claims in the Application regarding continued groundwater level declines are without substantiation. That is, no observational data are presented that show continued groundwater level declines. A 2010 USGS report used regional pumpage around Lake Michigan through 2005 to evaluate changes in water levels, among other things. This model shows simulated heads in Waukesha increasing after 1986 (Figure 7).

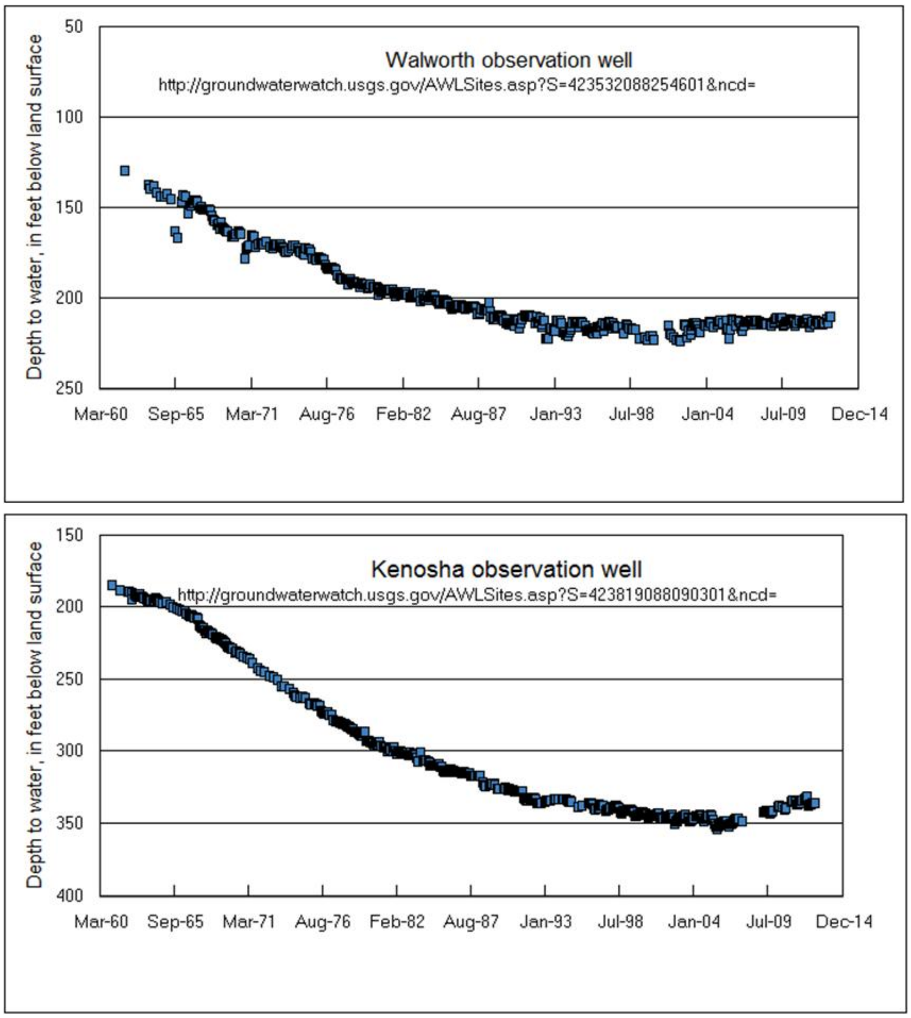
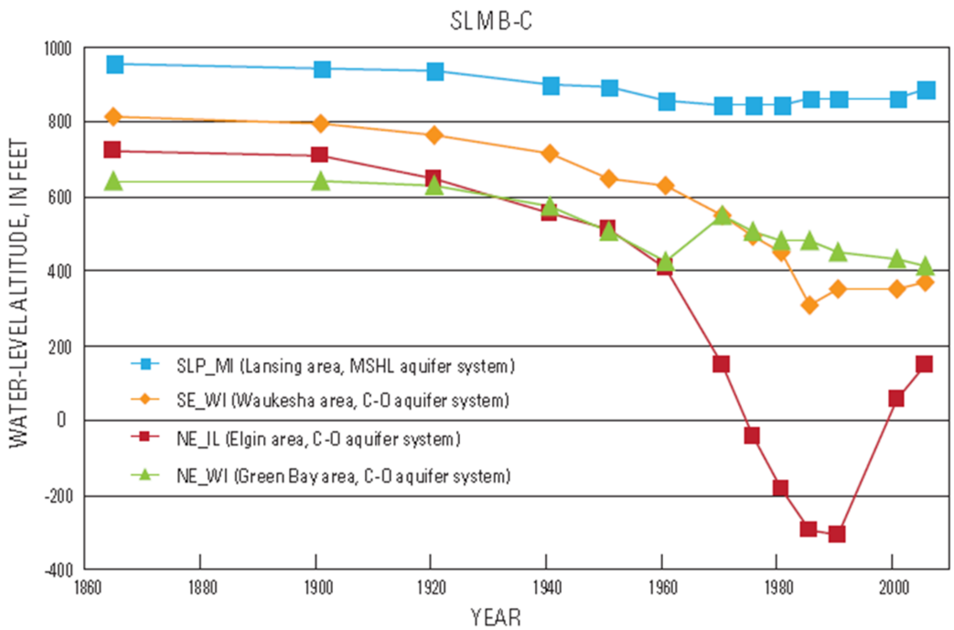


Figure 6—Historical groundwater levels for two observation wells in the deep confined aquifer in southeast Wisconsin.

Therefore, negative impacts linked to groundwater level declines in the Application may not occur. These include: increasing radium and TDS levels (with economic, public health, and environmental issues); decreasing well capacity (with economic and sustainability issues); and decreased flow to surface water (with environmental issues). Each of these potential impacts and issues are important, especially the issue of radium and TDS levels. Waukesha has several wells that would each have to be treated to comply with water quality standards. Future degradation in water quality or well capacity caused by future declining groundwater levels, however, will only occur if levels decline. Therefore these factors, as they relate to declining groundwater levels in the deep confined aquifer, are not part of the evaluation in this paper.



Michigan Basin, Scientific Investigations Report 2010-5109, p. 165, figure 55b

Figure 7—Simulated groundwater levels 1864 through 2005 in Lake Michigan area.

The fifth issue is related to treating water to meet drinking water standards and how this affects the merit of various sources. All of the types of water supply sources considered in the Application are used throughout the Upper Midwest. All are treated to meet drinking water regulatory standards or for aesthetics. The only real issue here is economic, that is, the costs of various treatments, which this paper does not consider. Therefore issues related to treating water to meet drinking water standards are not part of the evaluation in this paper.

Discussion of Alternative Sources

This section discusses the alternative sources considered in the Application and provides an evaluation of each. Combinations of sources are not evaluated. Evaluation includes the availability of information regarding capacity of the source, sustainability, and environmental impacts of the withdrawal. There is no evaluation of a return flow to Lake Michigan.

<u>Artificial Recharge</u>

Artificial recharge is not actually a source, but rather replenishes the shallow aquifer and mitigates some of the impacts of water withdrawals from that aquifer. Artificial recharge consists of inducing stormwater or treated wastewater to recharge aquifers. It is a common practice in some water-scarce areas of the U.S. A related concept is Aquifer Storage and Recovery, which is considered in some detail in Appendix C.

As noted in the Application, there are significant concerns related to using artificial recharge in shallow aquifers near Waukesha. These include access to substantial land areas for infiltration, potential contamination from stormwater, regulatory obstacles to using treated wastewater to recharge a potable drinking aquifer, the long-term viability of infiltration facilities (including those on land surface and in wells), and the potential to mobilize arsenic in the shallow aquifer using ASR. Furthermore, no estimates are available regarding how much capacity could be added to a shallow aquifer source near Waukesha using artificial recharge or how much artificial recharge would increase water levels in the shallow aquifer. Therefore, this potential supplement to water supply sources for Waukesha is not considered further in this paper.

Deep Unconfined Aquifer west of Waukesha

West of Waukesha, the Maquoketa Shale is absent, leaving the Cambrian-Ordovician Aquifer unconfined. Because it is unconfined, the deep aquifer west of Waukesha has much better hydraulic connection to the shallow aquifer than the confined portion, and is therefore more connected to surface water features, such as streams, lakes, and wetlands. This water supply source is dealt with briefly in the Application and more fully in *Response to Water Supply Questions, Attachment WS7 and WS7A*. Appendix C concluded this was a viable water supply source, except for legal considerations regarding access to land and potential negative impacts on surface water bodies. As noted in WS7, the aquifer produces water of good quality.

WS7 discussion of environmental impacts is based on findings from a groundwater flow model described in WS7A. These studies looked at the feasibility of meeting all of Waukesha's projected water needs in 2050 from the deep unconfined aquifer west of Waukesha, 10.9 Mgd average day demand and 18.5 Mgd maximum day demand, although those exact amounts of withdrawal were not simulated. WS7 states that at 15 Mgd the drawdown in the shallow aquifer would be less than 2 feet and that at 10 Mgd pumping would impact 480 acres of wetland and over 100 acres of surface waters within the 1-foot drawdown contour line in the shallow aquifer.

WS7 concludes that withdrawals from the unconfined deep aquifer would have a significant adverse environmental impact and a significant adverse impact on long-term sustainability, which this author assumes to mean these withdrawals are not sustainable. The arguments against sustainability, however, refer back mostly to those related to groundwater connection to Waters of the Great Lakes Basin and effect on groundwater levels in the deep confined system. These issues were discussed previously, and this paper concludes that no substantive issues regarding long-term sustainability are presented in WS7. The aquifer is largely protected from effects of drought, and the only issue of long-term sustainability would be increasing demand on the aquifer from new or increased withdrawals other than Waukesha's.

WS7A summarizes the use of the SEWRPC regional model to simulate pumping from the unconfined deep aquifer west of Waukesha. The modeling effort described in WS7A has technical issues. First, the SEWRPC model is not appropriately discretized for evaluation of local groundwater-surface water relationships, as noted in SEWRPC Memorandum Report 188 (MR 188). The telescoping mesh refinement should have been used, as it was in MR 188. Second, all of the pumpage was simulated from two wells in the proposed well field due to a misunderstanding that wells could not be simulated in layers 11 through 16 if layer 1 was represented as a surface-water feature. Thus the entire pumping amount was split among 2 simulated wells, rather than the 13 proposed for the well field in WS7. Concentrating unrealistically high amounts of pumpage into a single model cell exacerbates the local effects of drawdown. They are unrealistically high. Third, the MODFLOW module used to represent streams is not specified. If it is STR, then that is appropriate boundary condition (STR limits the amount of water than can flow from a stream into an aquifer according to flow estimates for that stream). However, WS7A does not state how streamflow was estimated for cells, nor how stream losses were compiled along a stream to calculate baseflow reduction. If RIV was used as a boundary condition, then unrealistically large amounts of water could be produced from these cells (RIV does not limit the amount of water that can flow from a stream into an aquifer). The effect of this could be to overestimate the amount of water induced from streams, but it also could be to underestimate drawdown in the uppermost layer, since the water level in so many cells is fixed by a surface water feature.

Therefore this paper concludes that there is insufficient information to determine if the unconfined deep aquifer west of Waukesha can provide for all or a significant part of Waukesha's future water supply needs without causing significant adverse environmental impacts to streams, lakes, and wetlands.

Silurian Dolomite Aquifer

The Silurian Dolomite aquifer, where not eroded through in bedrock valleys, directly underlies the glacial deposits in the Waukesha area. This aquifer can be very productive throughout eastern Wisconsin, and in fact, throughout much of the Great Lakes region. The aquifer is heterogeneous with respect to hydraulic conductivity, however, because it depends on subvertical fractures and subhorizontal bedding plane openings to transmit water. Therefore, productivity can vary greatly from place to place. The Silurian Dolomite aquifer provides water for municipal supplies in and near Waukesha, about 30 wells in eastern Waukesha County. Water from this aquifer can have objectionable levels of manganese and iron, which typically require treatment. Similar to the unconfined deep aquifer west of Waukesha, the Silurian Dolomite aquifer has good hydraulic connection to the overlying shallow aquifer, which means it has better connection to surface water features than does a confined aquifer. Where glacial deposits are thin, the Silurian Dolomite aquifer may be susceptible to drought; where glacial deposits are thick, they dampen the effect of drought on the Silurian Dolomite aquifer.

Attachment WS8 of the Response to Water Supply Questions evaluates The Silurian Dolomite aquifer as a potential water-supply source. WS8 notes that casing requirements of at least 60 feet and Silurian dolomite thickness requirements of at least 100 feet limit the geographic areas that could produce significant quantities of water. Well yields in the area are variable, but an average of 450 gpm from 3 to 5 possible wells may be realistic in the opinion of the WS8 author (the WS8 author is very experienced with developing municipal water supplies from the Silurian Dolomite Aquifer in this part of Wisconsin). If 3 to 5 wells were developed and produced 450 gpm each, then the well field would yield 1350 to 2250 gpm.

The Silurian Dolomite aquifer cannot meet all of Waukesha's projected 2050 water needs. However, this aquifer could provide 1.9 to 3.2 Mgd with 3 to 5 wells pumping 450 gpm each. Municipal wells in the Silurian Dolomite aquifer must have at least 60 feet of glacial deposits, which protects the aquifer in these areas from major withdrawal issues related to drought.

The Silurian Dolomite aquifer is not presented in the Application as an alternative source. It is presented as one of the 14 alternative sources in Appendix C, but is one of the 9 that are not considered in detail. It is eliminated because it cannot meet all of Waukesha's projected 2050 water needs. No discussion of any environmental impacts resulting from withdrawals from the Silurian Dolomite aquifer is presented in Appendix C or WS8. This author assumes there could be some local effect on surface water features because of the hydraulic connection to the overlying glacial deposits. However low porosity and highly transmissive solutional features tend to spread out effects of pumping and also make them unpredictable locally.

Deep Confined Aquifer

Using the deep confined aquifer as a source of water is described in detail in many of the documents listed at the end of this paper. Currently, this is the major source of water for Waukesha. The reasons to seek other sources have already been noted above.

The capacity of Waukesha's 7 remaining wells in the deep confined aquifer is 14.35 Mgd. The Application states these wells will be used at a rate of 7.6 Mgd, with treatment of 3 of the wells for TDS and radium. In the Application, use of the deep confined aquifer is only evaluated as an alternative in combination with use of the shallow aquifer. It is not evaluated as the sole source.

The issue of the long-term sustainability of this aquifer at historical regional rates is a regional concern. These concerns launched many regional and local studies related to future water use and supply. Results from the SEWRPC model led to the conclusion that ongoing regional increases in withdrawals from the deep confined aquifer do not appear to be sustainable.

There are ongoing changes in the region, however, that suggest that demand on this aquifer may not increase at rates similar to historical ones of the 20th century. Demand increase is slowing in some areas and declining in some areas. Some communities that historically relied on the deep confined aquifer have switched to shallow aquifers and to Lake Michigan. Groundwater levels may be stabilizing or increasing regionally (see figures 6 and 7). According to SEWRPC, groundwater pumpage in the 7-county SEWRPC region and in Waukesha County decreased from 2000 to 2005 (this includes all sources of groundwater). In the City of Waukesha, total pumpage has been decreasing since the late 1980's.

Locally, Waukesha's use of the deep confined aquifer may be sustainable in the long-term. Waukesha's total water use has declined from about 9 Mgd in the mid-80's to about 7 Mgd in recent years, a reduction of 20 percent. Use from the deep confined aquifer has declined a greater percentage, since the 3 wells in the shallow aquifer are relatively new (#11 and #12 began operation in 2006; #13 in 2009) and make up a part of the recent use of about 7 Mgd. As noted previously, there are no observational or model data presented to show that water levels in the deep confined aquifer are continuing to decline.

The Application presents only two types of negative environmental impacts from using the deep confined aquifer: (1) the effect of regional withdrawals from this aquifer on regional surface water supplies and (2) increasing chloride loading to streams from use of home water softeners. (Note, the Application presentation of other environmental impacts is discussed under *Evaluation Criteria and Issues* previously in this paper). Any waste stream discharged to the Fox River would have a permit requiring it meet water quality standards of Wisconsin, which are developed to protect against negative environmental impacts.

The SEWRPC regional groundwater flow model has not been used to specify only the impact of Waukesha's use of the deep confined aquifer on streams. It is not possible with a regional groundwater flow model to determine the local impact of Waukesha's use of the deep confined aquifer on specific small streams, such as Pebble Brook or Mill Brook. The amount and location(s) of impacts on streams remain unknown until appropriate local modeling is done. Similarly, the amount and location of any positive impact to streams from Waukesha stopping pumpage from this aquifer is unknown. If part of the effect is a flow reduction in the upper Fox River, then this reduction is mitigated by wastewater return. We do know how much of the source of water to Waukesha's deep confined aquifer wells is ultimately either release from storage (lower water levels) or from surface water (by inducement or capture). Though there is some negative impact on one or both, but less than there was in the 1980s. Thus it is not possible with information presented in various reports to quantify environmental impacts of Waukesha's use or nonuse of the deep confined aquifer.

<u>Shallow Aquifer</u>

The shallow aquifer consists of coarse unconsolidated sand and gravel of glacial or recent origin. Within the aquifer are deposits of fine material of the same origin, which act as confining units. As noted in many of the documents listed at the end of this paper, the distribution of coarse and fine material is very complex, difficult to map, and difficult to simplify for groundwater flow modeling.

The major negative environmental impact of withdrawals from the shallow aquifer is the reduction of groundwater flow to surface water bodies and the resulting ecological impacts.

Thus this analysis focuses on the effect of groundwater withdrawals on surface water. The shallow aquifer is directly connected to surface water bodies, such as the Fox River, Pebble Brook, and Vernon Marsh. All groundwater modeling studies that include the shallow aquifer recognize the complexity of understanding the local relationship between groundwater withdrawals from the shallow aquifer and effects on surface water bodies. Correct understanding of this relationship requires significant hydrogeological and monitoring data along with properly constructed groundwater flow models, with careful attention to the boundary conditions that represent the surface water bodies. A particular challenge is knowing the resistance to flow in the shallow materials that make up the surface of streambeds and wetlands. Even when known, it is difficult to represent that resistance appropriately in model cells that represent surface water features. Where transient data are available, a model can be calibrated to approximate this resistance appropriately. For some important surface water bodies, such as Vernon Marsh, no data are available to calibrate a groundwater flow model to a known system response of the marsh to a known system stress, such as a well.

The various local and subregional studies of groundwater withdrawal from the shallow aquifer describe or differentiate among three sources within the shallow aquifer. One is the Troy Bedrock Valley, another is the Fox River Alluvium, and the third is aquifer material not associated with the former two. The differentiation among these aquifers is, however, not clear in some of the reports. The alluvium in the Fox River Valley is fairly thin and discontinuous and no actual or simulated wells derive all of their water from these deposits. So, in this paper, wells in the Fox River Alluvium refer to wells that are in close proximity to the Fox River, are screened in glacial materials, and induce or capture a significant portion of their water from the Fox River. According to MR-188, Waukesha currently has no wells in the Troy Bedrock Valley. Waukesha wells #11 and #12 are in the Fox River Alluvium. Waukesha well #13 is in aquifer material other than the Troy Bedrock Valley or Fox River Alluvium.

Application Alternative 1 (deep and shallow aquifer) uses current shallow aquifer wells #11, #12, and #13 with a capacity of 2.38 Mgd (firm capacity of 1.2 Mgd), plus 14 new wells south of Waukesha near Vernon Marsh in the Troy Bedrock Valley with a firm capacity of 9.7 Mgd.

Application Alternative 2 (shallow aquifer and Fox River alluvium) uses current shallow aquifer wells #11, #12, and #13 with a capacity of 2.38 Mgd (firm capacity of 1.2 Mgd), 4 new Fox River Alluvium wells with a firm capacity of 4.5 Mgd), plus 14 new wells south of Waukesha near Vernon Marsh in the Troy Bedrock Valley with a firm capacity of 12.8 Mgd.

<u>Troy Bedrock Valley</u>

According to MR 188 (Troy Bedrock Aquifer model Waukesha and Walworth Counties), the Troy Bedrock Valley trends through three Wisconsin counties, including southern Waukesha County and includes tributary valleys that are not all fully mapped. The valley is filled with glacial deposits that range from fine confining material to coarse aquifer material. Several municipalities in southeast Wisconsin supply drinking water from the Troy Bedrock Valley aquifer.

MR 188 describes a groundwater flow model developed to assist in understanding groundwater flow in the Troy Bedrock Valley aquifer. The authors used existing data from wells, borings, geophysical surveys, aquifer tests, and water level measurements to develop a hydrogeological understanding of the valley for designing the groundwater flow model. The model was extracted from the SEWRPC model. Telescoping mesh refinement was used because the SEWRPC model horizontal discretization is too coarse to simulate the effects of groundwater withdrawals on surface water at a local scale.

Deeper aquifer materials in the Troy Bedrock Valley are typically confined by 200 feet or more of fine material. However, MR 188 points out that there are local gaps ("windows") in the confining material which allow better hydraulic connection between deeper aquifer material and shallow material. The location of these windows is known only where drilling or boring data have found them. There are certainly other windows than the known ones. Locally, the location of windows would be critical for understanding if a new well might impact a nearby surface water body. Additionally, if windows were in the area of a simulated well field, then any groundwater flow model would have to account for this by treating the lower sand unit as unconfined, rather than confined.

Appendix O describes the application of the model developed in MR 188 to four development scenarios. Scenario 1-1 simulates pumpage of 6.4 Mgd from 8 wells: existing wells #11, #12, and #13; and 5 wells in the area referred to as the Lathers property. Scenario 1-2 simulates pumpage of 6.4 Mgd from 17 wells: existing wells #11, #12, and #13; 5 wells in the area referred to as the Lathers property; and 9 wells in the Troy Bedrock Aquifer. Scenario 2-1 simulates pumpage of 10.9 Mgd from 12 wells: existing wells #11 and #13; 3 wells in the area referred to as the Lathers property; 4 wells in the Troy Bedrock Aquifer; and 3 wells near the Fox River. Scenario 2-2 simulates pumpage of 10.9 Mgd from 28 wells: existing wells #11, #12, and #13; 5 wells in the area referred to as the Lathers property; and 20 wells in the Troy Bedrock Aquifer. Appendix O describes the impact of these withdrawals on various nearby surface water bodies and on domestic wells in the area.

The text for Appendix O is brief; less than 3 pages. Therefore reviewing this modeling effort is difficult. However, several observations are possible. First, there is nothing said about impacts on domestic wells. The number in each section is plotted on maps of drawdown, but their location and screen depths are not given. So no conclusions can be drawn regarding impact on domestic wells. Second, the location of the simulated wells relative to the map of the Troy Bedrock Valley presented in MR 188 is not shown. Are they actually in the valley? Comparison of figure 1 in MR 188 to the maps in Appendix O suggests the simulated wells are outside or at the edge of the Troy Bedrock Valley. It is difficult to determine. Could wells be simulated further south, away from Pebble Brook and Mill Creek and closer to the center of the Troy Bedrock

Valley? Third, no information is given on the depth or layer of the Lather property or Fox River wells.

Fourth and most importantly, the concluding paragraph of MR 188 provides advice that is vital to doing model simulations such as those in Appendix O, but which appears to have been not been followed. That paragraph states:

> *It must be kept in mind that the geologic conditions in the Troy Bedrock Valley are only known in general terms. While the regional flow system is well described, the bedrock valley aquifer system is more complex than currently known. The model cannot, and does not, account for these unknown complexities, nor does it fully incorporate all of the geologic data available which can vary on scales smaller than the cell size of the model. Some of these variations between the model and the natural system may be significant, particularly on a local scale.* ***In applying the model to estimate the local impacts to a particular water body or specific area it will be essential to consider the degree of geologic complexity necessary to produce a simulation to the degree of desired detail. It may be necessary to revise portions of the model or construct inset models within the larger model to obtain the degree of detail required for specific applications. In many cases it may be necessary to conduct additional testing to obtain the data needed and the degree of local detail desired.***

Furthermore, D.S. Cherkauer's 2007 report to the Board of the Town of Waukesha regarding groundwater at the Lather's property presents a comprehensive set of questions that need to be answered to understand the impacts of withdrawals on domestic wells and surface water resources. The report also presents the information needed to answer these questions and whether or not that information is available. While many of these issues are addressed at a multi-county scale in MR 188, they are not addressed locally in Appendix O.

Fox River Alluvium

Municipal wells in the shallow aquifer in close proximity to the Fox River can derive a substantial amount of their water from induced flow from the river and captured groundwater that would otherwise flow to the river. This process is known as riverbank inducement (RBI). There are two principal effects from using RBI. First, there will be a significant reduction in Fox River baseflow. Second, there will be less drawdown, thus less impact on domestic wells and nearby surface water features, because release of water from storage becomes a smaller source of water to the municipal wells. The first effect can be mostly mitigated if wastewater return is upstream of a well field, since all of the water, less consumptive losses, would be returned to the portion of the Fox River affected by pumping. A probable consequence of having wastewater return upstream of a well field is an increasing concentration of chloride, and other constituents common to treated wastewater, in the well field water. Current wells #11 and #12 are RBI wells, whereas #13 is not. #13 derives its water from west of the well, not from the Fox River.

A recent USGS report (SIR 2012-5108) describes development and application of a groundwater flow model to hypothetical wells pumping from the Fox River Alluvium. The model is finely discretized horizontally and vertically. It uses a statistical approach to develop the hydrogeologic framework, resulting in two models (fine-favored and coarse-favored) that potentially bracket the system response to pumpage. The model uses boundary conditions that account for the amount of water in the Fox River. Flows in or out of the bottom of the model are set based on the SEWRPC model.

The model described in SIR 2012-5108 has 2 sets of wells: 12 wells downstream of the Waukesha WWTP and 15 wells upstream. Pumpage from each well is constrained to a maximum of 0.667 Mgd. For the simulation, the two sets of wells produce a little over 9 Mgd, about 3 Mgd from the upstream wells and about 6 Mgd from the downstream wells. Some downstream wells likely could have produced more than 0.667 Mgd had they not been constrained to that amount.

Two types of impacts of the hypothetical modeling are described. The fine-favored model derived about 65 percent of its water either by inducing flow from the Fox River or capturing water that would have flowed to the river; for the coarse favored model, the number is about 73 percent. For both models, maximum drawdown in the uppermost layer is 20 feet. Maximum drawdown in layer 3 is 30 feet (most wells pump from layers 3 and 4). Sensitivity analysis showed that without RBI drawdown in layer 1 drawdown would be as much as 90 feet, demonstrating the positive effect of RBI on issues related to drawdown.

The model described in SIR 2012-5108 is not a planning tool for a municipal well field. It does, however, suggest that a substantial part of Waukesha's water supply could come from a similar well field that uses RBI to reduce drawdown impacts and uses treated wastewater return flow to mitigate most of the effects of RBI on baseflow in the Fox River. A site-specific study for a well field similar to the one represented by the 12 downstream wells could also incorporate aquifer management modeling. Aquifer management models can maximize pumpage from each well, while using constraints to minimize impacts on drawdown and surface water bodies other than the Fox River.

Lake Michigan

Lake Michigan can provide sufficient water to meet all of Waukesha's future needs. Any impact of a withdrawal on Lake Michigan would be negligible. The loss of the current wastewater return to the Fox River would result in smaller baseflow in the river downstream from the current WWTP. Appendix N states that there would be a 25 percent reduction in the upper Fox River near Waukesha, assuming an average annual WWTP discharge of 10 Mgd. Appendix N concludes that the likely effect of this flow reduction would be a small adverse environmental impact on aquatic habitat. Effects on the Fox River may be mitigated to some degree by local increases in groundwater flow to surface water if Waukesha stops using groundwater.

Evaluation of Alternative Sources

This paper does not use the evaluative criteria from the Application for reasons stated previously. Alternative sources are evaluated by: (1) hydrological feasibility of the withdrawal; (2) the environmental impacts of the withdrawal on Waters of Wisconsin outside the Great Lakes Basin (that is, waters that are not defined as *Waters of the Basin* in the Compact); and (3) environmental impacts of the withdrawal on Waters of the Great Lakes Basin, defined as *Waters of the Basin* in the Compact. Hydrological feasibility includes capacity of the source, sustainability, and other issues; it is merely a summary of conclusions reached in the previous section. There is no evaluation of a return flow to Lake Michigan.

Deep Unconfined Aquifer west of Waukesha—This is a viable source of water supply with good water quality. The aquifer is largely protected from the effects of drought, and there are no substantive issues of long-term sustainability. The amount of water that can be pumped from this aquifer without causing significant adverse impacts to surface water bodies has not been determined. There would likely be adverse impacts on shallow domestic wells and surface water features, but the amount of impact is not known. The groundwater flow model used could not appropriately address these issues. Therefore the environmental impacts of withdrawals on Waters of Wisconsin are unknown. There are no environmental impacts of withdrawals on Waters of the Great Lakes Basin.

Silurian Dolomite Aquifer—This aquifer could provide a sustainable supply of 2 to 3 Mgd. The potential environmental impacts of withdrawals are not presented. Therefore the environmental impacts of withdrawals on Waters of Wisconsin are unknown. There are no environmental impacts of withdrawals on Waters of the Great Lakes Basin.

Deep Confined Aquifer—This aquifer could supply up to 14 Mgd from existing operational wells, although the Application only considers smaller withdrawals (7.6 Mgd) from this aquifer in combination with other sources. Withdrawals from this aquifer may be sustainable, however specific modeling to consider sustainability was not done. That is, no modeling scenario was run using updated regional pumping and ongoing pumpage of 7.6 Mgd from Waukesha. Specific impacts of Waukesha's pumpage on surface water are not known, because modeling done to consider this was done using a regional model, rather than a local model. Therefore the environmental impacts of withdrawals on Waters of Wisconsin are unknown. There are no environmental impacts of withdrawals on Waters of the Great Lakes Basin.

Shallow Aquifer (Troy Bedrock Valley Aquifer)—The amount of water that could be withdrawn from this aquifer without having significant adverse impacts on surface water or domestic wells has not been determined. There would likely be adverse impacts on shallow domestic wells and surface water features, but the amount of impact is not known. The groundwater flow model used could not appropriately address these issues. Therefore the environmental impacts of withdrawals on Waters of Wisconsin are unknown. There are no environmental impacts of withdrawals on Waters of the Great Lakes Basin.

Shallow Aquifer (Fox River Alluvium)—This aquifer may be able to provide a sustainable supply of 6 Mgd or more, provided there is wastewater return upstream to mitigate effects of reduced flow in the Fox River. The model of a hypothetical well field did not address any impacts on specific domestic wells. The Vernon Marsh was outside the local modeling area. There would likely be adverse impacts on shallow domestic wells and surface water features, other than the Fox River. Site-specific modeling of a planned well field would be needed to determine local effects on domestic wells and surface water. Therefore the environmental impacts of withdrawals on Waters of Wisconsin are unknown. There are no environmental impacts of withdrawals on Waters of the Great Lakes Basin.

Lake Michigan—This source can meet Waukesha's future needs. There would be some negative environmental impact on the Fox River due to smaller WWTP discharges. Therefore the environmental impacts of withdrawals on Waters of Wisconsin are small. There are no environmental impacts of withdrawals on Waters of the Great Lakes Basin.

Source	Hydrologic Feasibility and Issues	Environmental Impacts of Withdrawal on Waters of Wisconsin outside Great Lakes Basin	Environmental Impacts of Withdrawal on Waters of the Great Lakes Basin
Deep Unconfined Aquifer west of Waukesha	Sustainability and capacity to meet some or all of Waukesha's future demand cannot be determined from available studies.	Degree of impact of withdrawals on nearby surface water or domestic wells cannot be determined from available studies.	None
Silurian Dolomite Aquifer	Can provide a sustainable supply of 2-3 Mgd.	Not evaluated in available studies.	None
Deep Confined Aquifer	Available wells have a capacity of 14 Mgd. Sustainability of withdrawals to meet some or all of Waukesha's future demand cannot be determined from available studies.	Degree of impact of withdrawals on surface water cannot be determined from available studies.	None
Shallow Aquifer (Troy Bedrock Valley)	Sustainability and capacity to meet some or all of Waukesha's future demand cannot be determined from available studies.	Degree of impact of withdrawals on nearby surface water or domestic wells cannot be determined from available studies.	None
Shallow Aquifer (Fox River Alluvium)	Can provide a sustainable supply of at least 6 Mgd, provided wastewater return occurs upstream of well field.	Impacts on Fox River mitigated by wastewater return. Some negative impact on nearby surface water. Impact on domestic wells not studied.	None
Lake Michigan	Can meet all of Waukesha's future demand.	Baseflow reduction of about 25 percent downstream of current WWTP.	None

Table 5. Summary evaluation of Waukesha's alternative sources.

Summary and Conclusions

The goal of this paper is to provide an objective scientific analysis of particular aspects of the Application of the City of Waukesha's Water Diversion Application submitted to Wisconsin DNR (WDNR) in May 2010. Numerous other associated documents were also reviewed. The scope of this paper is limited to three aspects of the Application: conservation and efficiency measures, demand forecast, and sources of water supply. For sources the focus is on hydrologic and environmental aspects of withdrawals in the Application. Issues related to economic factors and return flow to Lake Michigan, for instance, are not addressed.

Conservation and Efficiency Measures

Waukesha developed a plan for water conservation in 2006 and updated it in 2012. The plan outlines Conservation and Efficiency Measures (CEMs) to meet a goal of 10 percent water savings by 2050 or 1.0 Mgd. The major CEMs are monitoring unaccounted for water, public education, replacing inefficient water fixtures, reducing outdoor watering, and pricing incentives. Specific water savings goals for each CEM are not given, other than for savings related to water fixtures.

Waukesha has relatively low unaccounted for water (about 6 percent) and plans to keep it low with ongoing response to issues shown from system audits. Public education is being carried out through various media and venues to ensure people are aware of the other CEMs. In the first three years of the fixture replacement program, only 88 toilets were replaced. Waukesha plans to increase the toilet rebate from $25 to $100, expand the types of inefficient fixtures in the rebate program, and expand the program to other use sectors other than just residential. Waukesha implemented outdoor watering restrictions in 2006, and these are part of the reason overall demand and maximum day demand have decreased since 2006. The pricing incentive is an inclining water rate block structure that was adopted by Waukesha in 2007 and is the first in Wisconsin. The structure has three rate blocks with a different cost of water in each. For instance, if a residential customer begins using more than 30,000 gallons in one quarter, then their cost of water is about 40 percent higher than when they were using 10,000 gallons or less. Waukesha is considering monthly, rather than quarterly, billing to provide better feedback to customers regarding their water use in each rate block, thus making the pricing incentive stronger.

Waukesha has set a specific conservation goal of 1.0 Mgd by 2050. It will be difficult to track progress toward meeting that goal for most of the CEMs, since there are many confounding factors that affect water use. However Waukesha's CEMs have been successful in conserving similar amounts of water at other municipal utilities in the U.S. If Waukesha's plan is fully implemented and successful, then the amount of water used per person each day (GPCD) should decrease.

Demand Forecast

Waukesha's demand for water has been decreasing since the late 1980's, although population has increased during that time. Thus, GPCD also has decreased since the late 1980s.

Waukesha's most recent demand forecasts for 2050 are an average day demand of 10.9 million gallons per day (Mgd) and a maximum day demand of 18.5 Mgd. Future average day demand is forecast by using a static GPCD of 112, future population estimates, assumptions on unaccounted for water, and a 10 percent reduction in demand from implementing CEMs. Future maximum day demand is based on a ratio of maximum day demand to average day demand of 1.68.

In contrast, Waukesha's 2010 GPCD was 86 and the ratio of maximum day demand to average day demand was 1.30. Only one year since 1970 had a ratio greater than 1.68; the average since 1970 is 1.46.

The demand forecast for 2050 does not account for historical trends in declining GPCD. There is no reason not to expect this decline to continue for some time. A conservative demand forecast could assume decreasing trends in GPCD cease at 86 and that CEMs will not decrease the ratio of maximum day to average day demand beyond the average from 2006-2010, which is 1.45. These assumptions would result in a demand forecast of an average day demand of 8.0 Mgd and a maximum day demand of 11.1 Mgd. To use these assumptions, however, one would have to provide convincing argument that declining trends in GPCD will cease and that CEMs will not further lower maximum day demand.

Alternative Sources

This paper evaluated six alternative sources of water supply: deep unconfined aquifer west of Waukesha, Silurian Dolomite aquifer, deep confined aquifer, shallow aquifer (Troy Bedrock Valley), shallow aquifer (Fox River Alluvium), and Lake Michigan. No combinations of sources were evaluated. These sources were evaluated according to (1) hydrological feasibility of the withdrawal; (2) the environmental impacts of the withdrawal on Waters of Wisconsin outside the Great Lakes Basin (that is, waters that are not defined as *Waters of the Basin* in the Compact); and (3) environmental impacts of the withdrawal on Waters of the Great Lakes Basin, defined as *Waters of the Basin* in the Compact. There is no evaluation of a return flow to Lake Michigan.

The Application raises some issues in evaluating the merits of alternative sources which this paper concludes are either a not an issue or not proven to be an issue. The first is concern about contamination of source waters. This paper points out that all sources can be contaminated, need to be protected, and that rankings related to this issue are not part of this paper's evaluation. The second are issues related to the effect of groundwater withdrawals on Waters of the Great Lakes Basin. This paper shows that none of the groundwater sources are Waters of the Great Lakes Basin and that no studies have been done to show how any changes in only

Waukesha's pumping would affect flow of groundwater to streams tributary to Lake Michigan. The third is the Application's evaluation of how uses of various sources will or will not meet Compact requirements. The Application treats the shallow and deep aquifers as Waters of the Great Lake Basin, which, by Compact definition, they are not. The fourth is related to statements of continuing decline of water levels in the deep confined aquifer. Available data and modeling show that water levels are stabilizing or rising due to recent regional changes, and there are no data presented in the Application to support the argument that significant declines are occurring nor modeling to show that they will occur. The fifth is related to treating source water to meet drinking water standards and how this affects the merit of different sources. All sources need to be treated, and since the issue is cost, it is not part of the scope of this paper.

Each of the alternative sources could provide some of Waukesha's future water needs. Some could meet all. There would be no adverse environmental impact from withdrawals on Waters of the Great Lakes Basin from any of the sources. For none of the groundwater sources, however, is there adequate information to determine the environmental impacts of withdrawals on the Waters of Wisconsin. For some sources, the information is inadequate because the groundwater model, as constructed, could not appropriately address the effect of groundwater withdrawals on surface water (unconfined aquifer west of Waukesha, deep confined aquifer and Troy Bedrock Valley). For others, the model or analysis were appropriately done, but effects of withdrawals on surface water features and domestic wells were not considered or within the scope of the modeling effort (Silurian Dolomite aquifer and Fox River Alluvium).

In conclusion, the Application's demand forecast and evaluation of alternative sources are problematic. The demand forecast does not provide justification for (1) using a GPCD that is higher than any of the last ten years; (2) assuming that the historical downward trends in demand will stop; and (3) why CEMs will not lower GPCD further and decrease the maximum day demand. The evaluation of alternative sources uses results of groundwater flow models that either (1) were inappropriately constructed to evaluate the effects of withdrawals on surface water and domestic wells or (2) did not specifically consider the effects of withdrawals on surface water and domestic wells.

Publications and Documents Reviewed

1998, March, 1997 Annual report of the Waukesha Water Utility to the Public Service Commission of Wisconsin, 71 p.

1999, P.W. Mayer and others, Residential End Uses of Water, 310 p.

2002, March, CH2MHILL, Appendix C, Waukesha Water Utility future water supply study, 135 p.

2002, July, United States Environmental Protection Agency, Cases in Water Conservation: How Efficiency Programs Help Water Utilities Save Water and Avoid Costs.

2004, April, 2003 Annual report of the Waukesha Water Utility to the Public Service Commission of Wisconsin, 80 p.

2005, June, D.T. Feinstein and others, A regional aquifer simulation model for southeastern Wisconsin, SEWRPC Technical Report 41, 63 p.

2005, December, Great Lakes – St Lawrence River Basin water resources compact, 27 p.

2006, March, Geosyntec Consultants, Appendix A, Waukesha Water Utility Water conservation and protection plan, 28 p. plus addendums and appendices, 176 p.

2007, September, D.S. Cherkauer, Ground water conditions around the Lather property, report to the Board of the Town of Waukesha, 24 p.

2009, March, 2008 Annual report of the Waukesha Water Utility to the Public Service Commission of Wisconsin, 91 p.

2009, May, AECOM, Appendix K, Final draft technical memorandum: summary of water requirements, 16 p.

2009, November, K.R. Bradbury and T.W. Rayne, Shallow groundwater quantity sustainability analysis demonstration for the southeastern Wisconsin region, SEWRPC Technical Report 48, 38 p.

2009, November, Ruekert & Mielke, Inc., Troy Bedrock Valley Aquifer model Waukesha and Walworth Counties, SEWRPC Memorandum Report 188, 56 p.

2010, February, D.S. Cherkauer, Groundwater budget indices and their use in assessing water supply plans for southeastern Wisconsin, SEWRPC Technical Report 46, 60 p.

2010, April, Appendix O, Results of groundwater modeling study: Shallow groundwater source Fox River & Vernon Marsh area Waukesha Water Utility, 13 p.

2010, April, CH2MHILL, Appendix D, Water supply service area plan for city of Waukesha, 53 p.

2010, May, Application for Lake Michigan water supply, 120 p.

2010, May, CH2MHILL , Environmental Impact Report City of Waukesha Water Supply, 326 p.

2010, December, SEWRPC, Regional water supply plan for southeastern Wisconsin, volume 1, PR-052, 831 p.

2010, December, SEWRPC, Regional water supply plan for southeastern Wisconsin, volume 2, PR-052, 329 p.

2010, D.T. Feinstein and others, Regional groundwater-flow model of the Lake Michigan Basin, USGS Scientific Investigations Report 2010-5109, 379 p.

2011, March, N. Quirk, Report on Water Conservation Programs to Public Service Commission of Wisconsin, 29 p.

2011, April, various authors, Responses regarding water supply, WS7, WS7A, WS9, WS10, WS11, 324 p.

2011, April, various authors, Responses regarding water conservation and water use efficiency, 367 p.

2011, September, A. Klusmeier and others, Summary of 2010 Utility Water Conservation Reports, Public Service Commission of Wisconsin, 16 p.

2011, November, C.A. Buchwald, Water use in Wisconsin, 2005, 74 p.

2011, December, CDM, Water Efficiency Potential Study for Wisconsin, 95 p.

2012, February, CH2MHILL, Environmental Report City of Waukesha Water Supply, 670 p.

2012, March, 2011 Annual report of the Waukesha Water Utility to the Public Service Commission of Wisconsin, 97 p.

2012, May, CH2MHILL, Final Water Conservation Plan, 168 p.

2012, D.T. Feinstein and others, Development and application of a groundwater/surface-water flow model using MODFLOW-NWT for the upper Fox River basin, southeastern Wisconsin, USGS Scientific Investigations Report 2012-5108, 124 p.

Commentary to UWM presentation to DNR on riverbank inducement, dated April 1, 2011.

Letter to Eric Ebersberger and others of the DNR from D.S. Cherkauer, dated June 17, 2011.

Letter to Eric Ebersberger of the DNR from Waukesha Utility Manager Dan Duchniak, dated July 29, 2011

Letter to Waukesha Utility Manager Dan Duchniak from Administrator Johnson, dated July 18, 2012

Letter to Secretary Cathy Stepp from Mayor Barrett and Alderman Hines dated July 18, 2012

Letter to Mayor Barrett and Alderman Hines from Secretary Cathy Stepp dated August 2, 2012

Web Site, USGS, Ground water in the and Great lakes: the case of southeast Wisconsin, http://wi.water.usgs.gov/glpf/

Acknowledgments—This analysis was funded by the National Wildlife Federation (NWF). Any opinions expressed are from the author and not from NWF. The author acknowledges the able assistance of Emily Posthumus in researching CEMs and providing draft materials for that section of the paper. Review of parts of the paper by several anonymous individuals was very helpful. Additionally, a team of Marc Smith (NWF), Peter McAvoy (UW Milwaukee), Karen Hobbs (Natural Resources Defense Council), and Jared Teutsch (Alliance for the Great Lakes) provided scoping advice during the analysis and reviews of the entire paper.

About the author—Jim Nicholas is owner of nicholas-h20, working at the water science and decision-making nexus and providing assistance to organizations in the Great Lakes region. Previously, as Director of the USGS Michigan Water Science Center he helped lead statewide and bi-national research efforts to better understand the relationship of groundwater and surface water in support of the Great Lakes-St Lawrence River Basin Compact and related Michigan legislation. During his 33-year career at USGS, he helped conduct, plan, or review scores of groundwater projects, including ones that examined flow in glacial deposits, Cambrian-Ordovician aquifer, and Silurian Dolomite aquifer. Jim has been a technical advisor to several state and regional groups that deal with the application of hydrology to policy, regulatory, and resource management issues. He holds a B.S. in Geology from Wheaton College, an M.S. in Geology from Northern Illinois University and an M.S. in Civil Engineering—Water Resources from Stanford University.