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GROUNDWATER SUSTAINABILITY IN A HUMID CLIMATE: GROUNDWATER PUMPING, GROUNDWATER CONSUMPTION, AND LAND-USE CHANGE

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ABSTRACT

Recent concerns in Wisconsin over groundwater quality and water supply have drawn attention to water use and groundwater withdrawals. We compiled groundwater pumping data for two Wisconsin counties to assess its reliability for use in numerical simulations of regional groundwater flow and to evaluate relations between development and population growth on demand for groundwater resources.

We estimated that in 2003, municipal wells supplied 60% (28.3 Mgal/d, or million gallons/day) of the total groundwater pumped (47.2 Mgal/d) in Waukesha County. In Sauk County, municipal systems supplied 25% (7.4 Mgal/day) of the groundwater used (29.6 Mgal/day). Sauk County has a much higher per capita water use rate than Waukesha County (500 and 107 gallons/person/day, respectively). Pumping for agricultural irrigation has a disproportionate effect on Sauk County water-use statistics, approximately 12,470 acres in Sauk County were in irrigated agricultural production in 2002 compared to 769 acres in Waukesha County. The population of Waukesha County is about six times greater than Sauk County, but total water use is only 60% higher.

Sauk County has a relatively low population density and water-intensive industrial, agricultural, and commercial activities. In Waukesha County, rapid population growth resulted in high residential water use, but this has been offset by decreases in water used by industry and agricultural irrigation. In Waukesha County, 45% of all groundwater pumped is for residential use; 39% for commercial and industrial use; 2% for irrigated agriculture and 2% for golf course irrigation. In Sauk County, about 12% of groundwater pumped is for residential use; 45% for commercial and industrial use; 39% for irrigated agriculture and less than 1% for golf course irrigation. Residential use averages about 74 gallons/person/day in Waukesha County and 61 gallons/person/day in Sauk County.

Impacts of water use on the hydrologic system are quite apparent in Waukesha County, where there are several hundred feet of drawdown in the potentiometric surface of the confined aquifer. Regional-scale impacts of groundwater pumping are not apparent in Sauk County. These conditions illustrate a counter-intuitive consequence of land use change: increasing residential development and population growth accompanied by a reduction in irrigated agriculture results in a significantly lower per capita water use rate in Waukesha County, but groundwater withdrawals are concentrated within the geographic region of water utility service areas. In contrast, effects of a much higher per capita water use rate in Sauk County are spread out over a large area; agricultural land overlies an unconfined sand and gravel aquifer and cumulative impacts of pumping are not readily apparent at a regional scale.

Use of the southeast Wisconsin regional flow model demonstrated that selected measures of hydrologic impact in the deep groundwater flow system were not sensitive to increases in pumping forecast for 2035. Both the extent of the 150-ft drawdown cone and the location of the regional groundwater divide were relatively insensitive to the tested rates of pumping. In this hydrogeologic setting, these measures are controlled by the geometry of the regional aquitard rather than the magnitude of pumping. Identifying areas appropriate for groundwater

INTRODUCTION

The status and trends in water use in the United States are critical to planning for economic development and environmental resource preservation. In regions that rely heavily on groundwater resources, information about pumping rates and volumes is needed to assess the impact of withdrawals on groundwater levels, base flow to streams and lakes, and the capacity to meet future demand for water. In arid and semi-arid climates, tracking and regulating water use is well accepted. This has not traditionally been the case in "water–rich" states, such as Wisconsin, where humid conditions, many lakes and streams, and an average annual precipitation rate over 32 inches create an impression of water abundance. Recent conflicts over groundwater quality and water supply have raised awareness of groundwater quantity and a need in some areas of the state to improve tracking of groundwater withdrawals.

This project involved assessment of groundwater pumping data in Wisconsin and whether these data are sufficiently reliable for use in numerical simulations of regional groundwater flow. A fundamental problem to groundwater management in Wisconsin is that pumping from non-municipal supply wells is neither metered nor reported. This lack of pumping data may increase the uncertainty of simulations from groundwater flow models developed for regions of the state, and it may impair the accuracy of water-use statistics compiled at the State and county level.

The Wisconsin Department of Natural Resources (DNR) recently sought authority to require water-use reporting (Tim Asplund, DNR, oral communication, 2004). The DNR has several intended purposes for the water-use information, including documenting the existing demands on groundwater resources, evaluating hydrologic impacts of new proposed groundwater withdrawals, monitoring permitted conditions, tracking trends in groundwater use, and identification of areas in which groundwater use may be regulated ("groundwater-management areas").

This report includes a detailed inventory of water use in Sauk and Waukesha Counties in Wisconsin and recommendations about methods to track or estimate these values statewide. The project was also designed to investigate consequences of development and land use change on demand for groundwater resources in Wisconsin. This subject is an outgrowth of the groundwater pumping data compiled for a regional aquifer model of southeastern Wisconsin (Feinstein et al. 2005). The pumping data compiled during model development suggested that water use in southeast Wisconsin doubled between 1965 and 2000 (Figure 1). Southeast Wisconsin is densely populated; in these areas land use has transitioned from agricultural and industrial development to commercial and residential uses. In contrast, other areas of the State remain primarily rural, with much of the land in agricultural production.

Intuitively, significant changes in water use result from changes in land use. We investigated changes in groundwater pumping related to land use change in two regions of the state that have experienced contrasting patterns of development and growth. The pumping data were used to address the following questions: What changes in groundwater use may be expected as population increases, or as a region changes from primarily agricultural and rural land use to urban and suburban developments? What impacts on groundwater resources result from water use patterns in suburban versus rural regions of the state? Information on groundwater pumping resulting from various land uses should inform current debate in Wisconsin about groundwater management and water conservation.

We selected two counties for this study with contrasting water use, land use, and population characteristics – Sauk and Waukesha Counties. Our first task was to construct a record of groundwater pumping by various users (residential, commercial, agricultural, etc.) and evaluate this record for a predictive relation to population growth or change in land use. We evaluated the methods currently applied in Wisconsin to track pumping and to apportion the groundwater use between different sectors. Finally, we used an existing groundwater flow model to evaluate sensitivity to improved estimates of groundwater pumping and to demonstrate effects of land use change on groundwater resources. Through this work, we identified some potential pitfalls associated with current methods to estimate water use in the State.

METHODS AND SOURCES OF INFORMATION

Information compiled for this project included data on population, climate, land use, wells and pumping rates. Data sources are described below. Much of the data are presented in appendices to this report.

Population

Data on population and household size in Sauk and Waukesha Counties were obtained from the U.S. Bureau of the Census through a web-based interface provided by the Applied Population Laboratory, Department of Rural Sociology, University of Wisconsin (http://www.apl.wisc.edu/). Additional information was obtained from the City of Brookfield in Waukesha County, and from SEWRPC. Data and sources are reported in Appendix A.

Climate

Precipitation records for the months of June through September for the study areas were obtained from the Midwestern Regional Climate Center. Data used in this report are compiled in Appendix B. The data were compared to pumping records to evaluate the effects of summer precipitation patterns on annual water use.

Wells and pumping rates

A variety of sources were used to identify wells and their pumping rates. For the purposes of this report, wells are categorized as municipal wells, self-supplied (non-municipal) high capacity wells, and self-supplied domestic wells.

Municipal wells

The DNR requires municipal water-supply systems to report total groundwater pumped on a monthly basis, however the DNR has not regularly entered this information into a computer database. The Public Service Commission of Wisconsin (PSC) requires each municipal water utility in Wisconsin to file an annual report of groundwater pumped and sold. Reports from 1904 through 1983 are archived on microfilm at the Wisconsin State Historical Society. Paper copies of reports from 1984 to 1996 are available from the PSC. Reports from 1997 to the present are available on-line at http://psc.wi.gov/apps/annlreport/ .

The annual reports from each water utility contain total water sales by volume, water sales within each of six water use categories, and the number of customers in each category. Customers are counted according to the number of water meters. If one facility has two meters, it is counted as two customers. If one apartment building has one meter, the building is counted as one customer.

The six primary water use categories include residential, commercial, industrial, resale, loss/unaccounted for, and public use (such as parks and schools). Sales to apartment buildings with four or more residential units are reported in the commercial category, which complicates accurate accounting of residential water use. Utilities occasionally report volumes sold for minor categories such as irrigation, fire protection, or resale. In general, volumes reported for these categories were small compared to the six primary categories listed above.

These annual reports do not provide the monthly or annual withdrawal from individual wells. The total volume pumped on a monthly basis from each *system* is reported, along with a list of wells in operation for the year. Utilities report a "yield per day (in gallons)" for each well, but this is not reported consistently by all utilities. Some utilities apparently report the pump capacity while others report a value that varies from year to year.

Appendix C contains the municipal pumping data compiled from these annual reports for the 17 water utilities in Waukesha County and the 15 utilities in Sauk County. The Wisconsin Dells Water Utility is included in this analysis although some of its wells are located in Columbia County; its service area is in both Sauk and Columbia Counties. Data from these annual reports are also used to estimate residential water use in the study areas (Appendix D).

Self-supplied domestic wells

In areas not served by public water supply, homes are typically supplied by a privately-owned well located on the property. We used various sources of information to estimate the number of homes in the study areas with self-supplied water, the number of those homes that have on-site septic systems, and the number of homes that are connected to a sanitary sewer system (Appendix E). Using estimates of residential water use generated from municipal water utility reports (Appendix D), we calculated groundwater pumping from self-supplied domestic wells.

Self-supplied high capacity wells

The DNR maintains a database of high capacity well systems in Wisconsin. NR 812.07(53) defines a high capacity well system as: *"one or more wells, drillholes or mine shafts used or to be used to withdraw water for any purpose on one property, if the total pumping or flowing capacity of all wells, drillholes or mine shafts on one property is 70 or more gallons per minute based on the pump curve at the lowest system pressure setting, or based on the flow rate."* Operators of "other than municipal" public supply wells (wells serving 25 or more year-round residents) and other high capacity wells are not required to measure or report the quantity of groundwater pumped.

The high capacity well database contains applications for high capacity wells, including information on the well owner and category of use (e.g. irrigation, commercial, industrial, etc), and normal and maximum permitted pumping rates. If a property has one high capacity well, all of the wells on that property are recorded in the database regardless of their capacity. Therefore, the total number of wells in the database is higher than the number of wells expected to pump at or above 70 gpm. Database fields are available to record the well status (active, inactive or abandoned), date approved, date constructed, and the expected number of days per year of operation. Not all of these fields are completed for each well record. In some cases, the database is updated with notification that the well has been abandoned. Wells that come into disuse or undergo a change in typical pumping rate (for example, if a significant change in process occurs at a facility) are not routinely reported to the DNR.

We used this database to inventory high capacity self-supplied wells in Sauk and Waukesha Counties. The intended use of the database is to maintain records of applications for high capacity wells and the reliability of it to account for water use was unknown (personal communication, Bill Furbish DNR, Oct. 6, 2005). We surveyed non-municipal well owner/operators in Sauk and Waukesha counties to asses the relation between pumping estimated from information in the database and pumping reported by well owners. A letter mailed to each well owner/operator requested information about the number of wells in use, if well and water use is metered or estimated, and if so, a report of the rate and volume pumped. Appendix F contains the survey, a summary of responses and a comparison to the database.

A subset of wells in the high capacity database are used for agricultural or golf course irrigation. The owners of these wells were included in our survey, and we compared their responses to alternative methods to estimating pumping for agricultural and golf course irrigation. We compiled information about the number of golf courses in each county and attempted to determine how irrigation water was obtained on each course (Appendix G). We estimated groundwater use for agricultural irrigation from data on the number of acres in irrigated agriculture in each county and compared this to an estimate based on the number of irrigation wells reported in the high capacity database (Appendix H).

Land use

Land use change in the study areas was evaluated by tracking increases in developed land. The Digital Historic Urban Growth Inventory (SEWRPC, 2004a) contains approximate urban boundaries in Waukesha County for 1850 through 1920, based on historical maps and records. Urban boundaries for the years 1940 through 2000 are identified using aerial photography acquired in those years. These were cross-checked with the Digital Land Use Inventory (SEWRPC, 2004b), which applies a consistent and detailed land use classification to maps based on aerial photography. The Digital Land Use Inventory is available for 1963, 1970, 1975, 1980, 1985, 1990, 1995, and 2000. Ultimately, we used the Digital Historic Urban Growth Inventory because it provided a consistent method applied over a longer period of time.

There are no similar historic land use inventories available for Sauk County. An alternative method using county tax assessment records proved unreliable because of inconsistent reporting from year to year. Ultimately, we accounted for land use change using

County Platt book records. For 11 selected years from 1924 through 2005, we calculated the number of acres within municipal and village boundaries, and the acres that had been subdivided into parcels under 20 acres. For the purposes of this project, the total acres in these categories are considered developed land.

Return flow

Information on the return flow of pumped groundwater to surface water bodies is of interest to assess water transfers within the hydrologic cycle and to quantify inter-basin transfers. We attempted to quantify return flows in the study areas by obtaining readily available discharge data from the DNR for Sauk and Waukesha Counties (presented in Appendix I). In Wisconsin, municipal, industrial, and animal waste operations discharging water to surface or groundwater are regulated through the DNR's Wisconsin Pollutant Discharge Elimination System (WPDES) permit program. We used the WPDES discharge data for 2005 for all permit-holders in the two study areas, along with calculations of recharge to the water table from irrigation and domestic septic systems, to evaluate return of pumped water to surface water and groundwater in each county.

STUDY SETTING

Sauk and Waukesha are both relatively large counties, but they have very different population and land-use characteristics (Figure 2). Sauk County remains predominantly rural in nature with about 15% of the population of Waukesha County (Table 1). Population growth in Waukesha County has far out-paced that of Sauk County, as has growth in developed acres (Figure 3). More than 99% of the total water used in both regions is from groundwater, and there are no power plants in either county (Ellefson et al. 2002). The lack of power plants is significant because of the overwhelming effect power plant water use typically has on water use statistics of a given region.

Table 1. Characteristics of study areas.

Characteristics	Sauk County	Waukesha County
Area (mile^2)	838	556
Population density (people/mile^2)	65.9	649.4
Multi-family housing units (% of all housing)	18.6	23.2
2004 median household income	$46,566	$69,154
Data from: US Census http://quickfacts.census.gov/qfd/states/		

Hydrogeology of Waukesha County

Two regional aquifers underlie southeast Wisconsin. As illustrated in Figure 4, the shallow aquifer consists of unlithified sand and gravel deposits within fine-grained till and the underlying Silurian dolomite. To the west, the Silurian dolomite is absent and the shallow system consists solely of unlithified materials. The deep aquifer system consists of a series of Cambrian and Ordovician sandstone and dolomite units. In the eastern two-thirds of the region, the shallow and deep flow systems are separated by the low-permeability Maquoketa Formation.

Intensive groundwater use has altered the flow system throughout this region. Feinstein et al. (2005) developed a groundwater flow model developed for the area and quantified impacts of pumping, including drawdown, reduced base flow to surface water, shifting groundwater divides, and increasing inter-aquifer recharge from the shallow to the deep parts of the flow system. The model demonstrates that the cone of depression in the potentiometric surface of the confined aquifer is up to 500 feet deep. Water intercepted prior to discharge to surface water accounts for 71% of groundwater pumped from the shallow and deep aquifers in this region. Other sources of water to wells are release of groundwater from storage (11%) and net groundwater flow into the region (10%). Groundwater flow into the region is primarily water flowing toward deep wells that would otherwise discharge to surface water to the west of this region.

Hydrogeology of Sauk County

In Sauk County, there are also two aquifers. The uppermost unlithified aquifer is over 200 feet thick in the Wisconsin River valley, but it is absent in much of the western portion of the county (Figure 5). A sandstone aquifer underlies the unlithified aquifer where the unlithified aquifer is present. The sandstone aquifer is the uppermost aquifer in the western portion of the county, where the surficial deposits are generally thin and unsaturated. A shale facies of the Eau Claire Formation is present over a limited part of the county. Where present, it constitutes an aquitard that restricts flow between the unlithified and sandstone aquifers. A groundwater model constructed for Sauk County shows that almost all groundwater pumped from wells originates as recharge within the county. Simulated drawdowns at municipal wells are not significant in relation to regional water levels.

RESULTS

The results of this study include a compilation of municipal pumping rates and estimates of self-supplied pumping and total groundwater use in Sauk and Waukesha Counties. This is compared to estimates of water use made by the USGS. Finally, the southeast Wisconsin groundwater flow model is used to investigate the sensitivity of model simulations to changes in pumping.

Municipal water use

Pumping from municipal wells has increased more rapidly in Waukesha County than in Sauk County (Figure 6). In both regions, the volume pumped is positively correlated to population growth (Figure 7) and the proportion of developed land (Figure 8).

Municipal pumping in Sauk County has increased more rapidly in relation to population growth than in Waukesha County (as demonstrated by the greater slope of the Sauk County line in Figure 7), although the volume of municipal withdrawals is much greater in Waukesha County (Figure 6). As indicated by the higher rate of growth shown in Figure 7, Sauk County municipal pumping on a per capita basis currently exceeds that of Waukesha County (Figure 9). (The step increase in Sauk County per capita municipal water use apparent in the late 1980s is attributed to the Lake Delton and Wisconsin Dells Water Utilities, both of which began service in 1988.)

The increasing reliance on municipally supplied water in Sauk County is attributed to significant growth in water use by industrial, commercial and residential customers in the county. This is illustrated in Figure 10, which shows municipal water sales by sector from 1970 through 2003. In contrast, Waukesha water utilities have experienced a decrease in industrial water use offset by growth in residential and commercial water use (Figure 11).

Residential Water Use

We used data compiled for this project to compare residential water use on a per capita basis in the study areas. This analysis is based on records of sales to one- and two-family residences served by municipal water utilities and on estimates of household size presented in Appendix A. Per capita residential use is about 10 gallons per person per day more in Waukesha County than in Sauk County (Figure 12). This may be related to higher household incomes in Waukesha County (Table 1); affluent homes typically use more water for both indoor and outdoor uses (Vickers 2001). Year-to-year differences in residential water use apparent in Figure 12 correlate to variation in summer precipitation (see Appendix D).

In general, data presented in Figure 12 suggest that per capita residential water use has remained steady or slightly decreasing since the early 1980s in Waukesha County and since the mid-1980s in Sauk County. These county-wide data do not reflect the trends in residential water use seen in individual water utilities (Figures 13 and 14). For example, the Spring Green and Reedsburg (Sauk County) water utilities show continued increasing trends in per capita residential water use. In Waukesha County, per capita residential use is decreasing in Brookfield and Menomonee Falls but appears steady to slightly declining amongst households served by the Waukesha Water Utility. Factors that contribute to decreasing per capita residential use might include modernization of plumbing and appliances or local water conservation efforts; evaluation of these factors is beyond the scope of this project.

Two limitations to this analysis of per capita residential water use should be noted. First, water use is metered and reported by household, and the per capita use data are based on available estimates of household size in each county (Appendix A). The estimates of household size may vary in accuracy within each county. A second limitation is that water utility sales to multi-family residences are reported within the commercial water use category and not within residential water use. We have not corrected for this in the figures presented above. Residential water use is generally lower in multi-family buildings than in one- or two- family residences due to less outdoor water use and fewer appliances (Vickers 2001). By neglecting per capita use in multi-family dwellings, we have likely inflated the per capita residential use rates in each county. Neglecting multi-family use probably results in a larger error in overall per capita residential use for Waukesha County than Sauk County because there is higher percentage of multi-family dwellings in Waukesha County (Table 1).

The City of Brookfield Water Utility provided data that allowed comparison of household and per capita residential water use in one- and two-family dwellings and in multi-family buildings (Appendix D). These data suggest that water use is about 100 gallons per day per unit greater in one- and two-family homes than in multi-family buildings.

Self-supplied groundwater pumping

Domestic self-supplied wells

About 9 million gallons per day (Mgal/day) of groundwater was pumped for self-supplied residential use in Waukesha County in 2000 compared to about 1.6 Mgal/day in Sauk County (Table 2). However, the number of homes with self-supplied groundwater is declining in Waukesha County and increasing in Sauk County. We attribute the decrease in Waukesha County to the growing numbers and service areas of water utilities in the County. In contrast, the increasing number of homes with domestic wells in Sauk County is likely caused by residential development in rural areas remote from municipal service areas. Data sources and calculations used to prepare these estimates are provided in Appendix E.

A significant aspect of self-supplied domestic water concerns the transfer of waste-water off the property. If homes with self-supplied water have on-site septic systems, it may be valid to assume little net loss of groundwater from the local hydrogeologic system because of recharge from septic systems. Our accounting of homes with self-supplied water shows that in 2000, most of those in Sauk County have on-site waste disposal (Table 3). Less than 10% of the self-supplied domestic water in Sauk County is discharged off-site, presumably to waste water treatment plants that discharge to surface waters. In Waukesha County, about 3 Mgal/day of self-supplied domestic groundwater is discharged off-site.

Table 2. Total self-supplied domestic pumping.

Year	Waukesha (Mgal/d)	Sauk (Mgal/d)
1980	11.90	1.05
1990	10.76	1.36
2000	8.93	1.58

Table 3. Self supplied domestic pumping at residences with off-site waste disposal.

Year	Waukesha (Mgal/d)	Sauk (Mgal/d)
1980	2.88	0.00
1990	3.65	0.09
2000	3.19	0.10

High capacity wells

We relied on the WDNR database of high capacity well permit applications (referred to here as the "database") to estimate groundwater withdrawals from self-supplied high capacity wells. However, our survey of owners and operators of these wells revealed two significant concerns with respect to using information from the database to estimate pumping. As described in Appendix F, the database does not accurately reflect the number of wells in use. Forty-three percent of 65 survey responses reported <u>more wells</u> in use on their property than were recorded in the database. Twenty-eight percent of 65 survey responses reported fewer wells in use than recorded in the database. A second concern identified through the survey is that the permitted pumping rates recorded in the database generally overestimate survey-reported pumping by many of the largest permitted users, commonly by more than an order of magnitude. Results of the survey did not suggest any consistent relation between permitted pumping rates and survey-reported pumping rates (see Appendix F).

In light of these findings, we used survey responses to estimate pumping rates at wells for which we obtained a survey response. We estimated withdrawals at all other wells recorded in the database using the following procedure:

1. Groundwater pumping for irrigation was estimated using the number of golf courses and the number of acres in irrigated agriculture in each county (Appendices G and H).

2. For all other wells, we used the normal permitted pumping rate recorded in the database as an estimate of actual pumping. We assigned the maximum permitted pumping rate as an upper bound, based on the logic that a well cannot be pumped at a rate exceeding the pump capacity. For a lower bound, we assigned a rate equal to the normal permitted pumping rate times the ratio of the normal to the maximum permitted rate. On average, this results in a lower bound of about ½ the normal permitted rate.

3. Many wells in the database have an owner name or description suggesting seasonal water use but do not have a database record of seasonal adjustment. For these wells, we estimated a number of days of normal operation. Wells adjusted in this fashion include those at schools, campgrounds, ski resorts and outdoor water parks.

This method of estimating pumping rates and reasonable upper and lower bounds is somewhat arbitrary. Impediments to improving this estimate of pumping from self-supplied high capacity wells include:

1. The number of high capacity wells in operation is not known. There is a large discrepancy between survey-reported number of wells in use and database records of wells in use; survey results indicate that the database incorrectly describes the number of wells in use in 43% of the test cases (28 of 65).

2. Based on the survey results, there does not appear to be a relation between survey-reported pumping and database records of pumping; survey results cannot be used in any systematic fashion to improve interpretation of database records

Excluding agricultural irrigation, current rates of self-supplied high capacity pumping are about 8 Mgal/d in both Sauk and Waukesha Counties (Figure 15). (The large step increase apparent in the Sauk County record in 1988 is the result of applications for several large wells, including a snow-making facility, an outdoor waterpark, a food processing plant, and several groundwater remediation wells at the Badger Army Ammunition Plant.)

The relation between population growth and non-irrigation self-supplied high capacity pumping in each county is illustrated in Figure 16. The high correlation coefficients suggest that population growth may provide a reasonable predictor of growth in self-supplied high capacity water use, if past patterns continue. However, due to the uncertainty associated with this estimate of pumping (Figure 15), this relation should be applied with caution.

Since the late 1970s, land in irrigated agricultural production is decreasing in Waukesha County and increasing in Sauk County. Groundwater pumped for irrigation over the last few decades reflects this difference (Figure 17). The estimates shown in Figure 17 are based the number of acres in irrigated agricultural production and a range of estimates of water applied per acre. This method yields higher water use rates than those derived by multiplying the number of irrigation wells (recorded in the high capacity well database) by an average pumping rate for irrigation wells in Wisconsin (Krohelski 1986). The method used here is preferred because of potential inaccuracies in the number of irrigation wells in use each year (Appendix H).

Groundwater withdrawals in Sauk and Waukesha Counties

The distinction between municipally supplied and self-supplied groundwater is significant with respect to tracking water use in the two study areas. Pumping from municipal systems is metered and reported, and these records are readily obtained. Self-supplied pumping must be estimated, and it is not possible to calculate a statistically robust confidence interval on the estimates because the number of wells is unknown. Our survey-derived estimate of self-supplied pumping indicates about 75% of all pumping in Sauk County is self-supplied (Figure 18). Water pumped for agricultural irrigation accounts for more than half of this. This suggests that in areas of Wisconsin with significant irrigated agricultural production, efforts to improve water use tracking should focus on this sector of self-supplied pumping.

In Waukesha County, a higher percentage of pumping (60%) is from municipal wells and is known with much greater accuracy. In Waukesha County, about 47% of self-supplied pumping is for domestic use and about 43% of self supplied pumping is from commercial and industrial facilities. Groundwater pumped for agricultural irrigation contributes very little to the amount of self-supplied water use.

Sauk and Waukesha Counties have very different characteristics of water use (Figure 19). Agricultural irrigation has a dominant role in Sauk County. In Waukesha County, where the population density is ten times greater than in Sauk County, water use is dominated by residential demand.

When including groundwater pumped for agricultural irrigation and considering the upper and lower bounds on these our estimates, total withdrawal in Sauk County approaches that in Waukesha County (Figure 20). The bounds on this estimate include uncertainty in non-irrigation self-supplied pumping (Figure 15) and agricultural irrigation (Figure 17). Self-supplied domestic pumping at homes with on-site septic systems is not included in Figure 20 because this pumping is not typically simulated in regional groundwater flow models.

Although total groundwater pumping is greater in Waukesha County, Sauk County has a much higher per capita water use rate (Figure 21). This trend is due in large part to the increase in pumping for agricultural irrigation. With agricultural irrigation pumping excluded, pumping correlates strongly to population in each county (Figures 22 and 23).

Evaluation of current methods for tracking water use and return flow in Wisconsin

The USGS compiles a summary of water use in Wisconsin, by county and category, every five years [for example, Ellefson et al. (2002)]. The primary sources of information used to compile the report are the DNR and the Wisconsin Public Service Commission. In some parts of the USGS report, water use is estimated by applying a factor that was developed in previous years. For example, the total volume pumped by municipalities in each county is multiplied by

25% to obtain an estimate for water use in that county by the manufacturing sector, by 25% to obtain a value for public use and loss, by 19% to account for commercial use, and by 31% to account for residential use (Cheryl Buchwald, USGS, written communication, 2004). These reports are widely used by resource managers and planners (for example, Sinykin et al. 2005; Southeast Wisconsin Regional Planning Commission's Water Supply Study at http://www.sewrpc.org/watersupplystudy/), and hydrogeologists (Feinstein et al. 2005; Gotkowitz et al. 2005).

We compared water use estimates presented in this report to those compiled by the USGS. In general, we used similar sources, and the estimates compare favorably overall. However, our estimates of agricultural irrigation are higher than those in USGS reports (Figure 24). This difference may be caused by basing our estimate on the number of acres in irrigated agriculture, while the USGS estimate is based on the number of irrigation wells. We surmise that many irrigation wells may not be registered as high capacity wells, and it may be difficult to count for these wells. As a result of internal review, the USGS has recently revised some of the estimates shown in Figure 24 (Cheryl Buchwald, USGS, written communication, 2008).

Currently, there is no effort in Wisconsin to integrate information on points of discharge with information on points of groundwater withdrawal. Estimates of consumptive use and the location of wastewater discharge associated with proposed pumping are not required on well-permit applications or well construction records. To roughly evaluate available information, we compared our estimates of pumping to WPDES-reported discharge and recharge from irrigation and septic systems. As shown in Table 4, 51% and 60% of groundwater pumping is accounted for in Sauk and Waukesha Counties, respectively. It seems unlikely that consumptive use is on the order of 40 to 50 % in this humid region, suggesting that more might be done to improve tracking of return flows in Wisconsin.

Table 4. Pumping, waste-water discharge and return flow.

	Sauk County (Mgal/d)	Waukesha County (Mgal/d)
municipal pumping	7.46	28.27
private high capacity pumping, including irrigation	20.7	8.18
domestic self-supplied pumping	1.58	8.93
total pumping[1]	29.74	45.38
WPDES-reported discharge (to surface water or groundwater)[2]	12.62	22.67
irrigation return[3]	1.29	0.15
domestic septic system return[4]	1.2	4.6
total return	15.11	27.42
percent of pumping returned	51%	60%

Notes: Mgal/d = million gallons per day

[1]Values reported or estimated for 2005

[2]See Appendix I

[3]Estimated at 10% of pumping based on Ellefson et al. (2002)

[4]Estimated at 80% of pumping from residences with on-site systems (see Vickers 2001)

The lack of discharge data linked to the location and volume of groundwater withdrawal would hamper efforts to track inter-basin water transfers, which are critical to communities impacted by the Great Lakes Charter. Although groundwater pumping leads to decreases in baseflow, locations of return flow also impact the quality and quantity of stream flows critical to maintaining freshwater ecosystems. Additionally, the relatively high percentage of agricultural irrigation pumping in Sauk County suggests the importance of estimating evapotranspiration in irrigated fields.

Southeast Wisconsin groundwater flow model: sensitivity to pumping rates

The southeastern Wisconsin regional groundwater flow model (Feinstein et al. 2005) uses a variety of inputs, including estimates of pumping over the last 120 years for nearly 1,000 high capacity wells. Compilation of pumping history at those wells was challenging; this project gave us an opportunity to revisit those estimates and evaluate the effect of uncertainty in pumping on model calibration and predictive simulations.

We tested the effect of uncertainty in historical pumping rates on the model calibration by recalibrating the model with new estimates of pumping in Waukesha County. Figure 25 shows the base, upper, and lower estimates. The base estimate is that originally used in model construction (Feinstein et al. 2005), which is similar to the sum of municipal and self-supplied high capacity pumping (excluding agricultural irrigation) estimated for this project (Figures 6 and 15). The upper estimate includes municipal pumping and the upper bound of pumping from all non-irrigation high capacity wells. The lower estimate includes municipal pumping and the lower bound of pumping from all non-irrigation high capacity wells. The pumping rates estimated for each year were averaged over each model stress period; the average rate is applied over the entire model stress period.

Pumping for self-supplied domestic use and for agricultural irrigation was not simulated in the model. In Waukesha County, wells constructed for these purposes are generally completed in the shallow aquifer, and the well locations are poorly known. Although these withdrawals represent a net use in terms of water balance, the regional model is not well-suited to simulate these stresses on the shallow system.

The pumping rates were applied to the model by multiplying the pumping rate at each well by the percentage of increase or decrease in total pumping. We did not differentiate between possible changes in the ratio of shallow system to deep system pumping; we assumed the shallow to deep ratio from the year 2000 was preserved.

For recalibration, we varied pumping in Waukesha County only and did not change simulated pumping rates in other counties within the model domain. As shown in Figure 26, these counties have different water-use histories and applying the change in pumping determined for Waukesha County would not be realistic. For example, Milwaukee County switched to a surface water source in about 1950, which significantly reduced groundwater withdrawals. Waukesha County water use accounts for nearly half of all pumping in southeastern Wisconsin, and therefore has the largest impact on the model results.

Model Recalibration

Many of the input parameters in the regional model are highly correlated. An increase in the pumping rate can be offset by an increase in the horizontal hydraulic conductivity (Kh) of the deep sandstone aquifer or by an increase in the vertical hydraulic conductivity of the regional confining unit, the Maquoketa shale. To simplify the modeling effort we recalibrated the models by changing the value of the deep sandstone aquifer horizontal hydraulic conductivity alone. A slightly better calibration might have been achieved by varying other parameters as well but that effort was beyond the scope needed to evaluate changes to model results under various estimates of pumping.

We used the absolute residual mean as a measure of the spread of the residuals (how well the model fit the data), and the residual mean to measure the bias (whether the model over- or under-estimated the heads in the deep sandstone aquifer). Figure 27 shows the calibration statistics as a function of changing the deep sandstone Kh for the three pumping estimates. The recalibrations are a compromise between these two measures of fit, slightly favoring the absolute residual mean. The base and lower pumping estimates required no change in the Kh of the sandstone for recalibration. The mean residuals are close to zero and the absolute mean residuals are close to the minimum of the curve at a Kh multiplier of one. Using the upper estimate of pumping, calibration that minimized the absolute residual mean and maintained a residual mean near zero required adjusting the Kh of the deep sandstone aquifer by a factor of only 1.25. These results indicate that potential errors in accounts of historical groundwater pumping did not have a significant effect on model development; model calibration would not have changed substantially with realistic bounds on estimates of historical pumping.

Model Results and Comparisons

To evaluate the effect of various pumping estimates on model results, we extrapolated the pumping rates to the year 2035 and used those rates to predict drawdown in the deep aquifer and the deep sandstone aquifer groundwater divide between the Lake Michigan Basin and the Mississippi River Basin. In contrast to the calibration runs, we applied these projected increases in pumping across all wells in the model domain, assuming that population growth and associated groundwater use will impact the entire region similarly. We extrapolated pumping rates using two different methods. The first method merely applies a second-order polynomial fit to the historical pumping data from Waukesha County and extrapolates that rate to 2035. The second method assumes that future pumping rates will be related to population growth and that per capita water use will remain relatively constant. Although per capita water use increased during the last century in Waukesha County, it has leveled off over the last decade (Figures 9 and 21). Estimates of future pumping based on estimates of population growth are much lower than that realized by fitting the second-order curve to the historical pumping rates. Figure 28 shows three predicted pumping rates using the two methods.

We compared drawdown simulated for the three pumping rates in 2035 and the base model run in the year 2000 (Figure 29). Where it is present, the Maquoketa shale limits recharge to the deep sandstone aquifer. This results in significant and extensive drawdown of water levels in the deep system, beneath the aquitard. Higher simulated pumping rates result in larger areas of drawdown, but little change in the location of the 150 ft. drawdown line. The pumping rate in the second order polynomial extrapolation to 2035 is approximately twice that of the base model, but the location of the 150-foot drawdown contour changes less than 3 miles along the western edge and no more than 15 miles at the northern edge. The contour extends into Illinois in all four simulations. The 150-ft contour is in a sense geologically fixed; drawdown is not exacerbated at the edge of the Maquoketa because increased pumping is off-set by induced infiltration from the unconfined system to the west. The recent groundwater quantity legislation, Wisconsin 2003 Act 310, uses the 150 ft drawdown line to designate groundwater management areas. If this line is insensitive to pumping, as indicated by these simulations, there may be better criteria for determining the management area.

The simulated 400-ft drawdown contours suggest that the area of extreme drawdown will continue to expand as pumping increases. The increase with the second order increase in pumping is large, but the upper and lower estimates of 2035 pumping produce very similar 400-ft drawdown areas. This result can be used to examine potential impacts at the regional scale of water conservation. Given an increase in population, conservation might reasonably reduce water use from the upper bound (49 Mgal/d) to the lower bound (39 Mgal/d). However, this results in little to no change in the simulated drawdown.

Another measure of the effect of pumping on groundwater resources is a shift in the location of the regional groundwater divide in the deep sandstone aquifer. The groundwater divide has been cited in discussions concerning diversions from Lake Michigan; its location has changed over time in response to pumping (Feinstein et al. 2004). Under pre-development conditions, the groundwater divide separated flow to the Mississippi River Basin from that to the Lake Michigan Basin. Under current conditions, the divide separates flow to the Mississippi River Basin from that directed to the regional pumping center underneath Waukesha and Milwaukee Counties (Feinstein et al. 2005).

We compared the model-simulated location of the divide under pre-development (1864) conditions, current (year 2000) conditions, and the three estimates of 2035 pumping (Figure 30). These results indicate that the divide has shifted up to 10 miles to the west since pumping began in the late 1800s. The simulations suggest that the divide will not shift significantly from its current location over the next several decades, even under a scenario of exponential growth in withdrawals. The location of the divide is not sensitive to the increase in pumping because of increasing induced recharge from the shallow to the deep system in the western region, where the shale is absent. The model simulations show that where vertical groundwater flow is relatively unimpeded, drawdown is limited by induced recharge and the location of the divide is relatively fixed. This suggests that increased pumping could impact groundwater discharge to springs, streams and lakes west of the subcrop of the Maquoketa shale.

In summary, the model simulations suggest that drawdown in the potentiometric surface and shifts in the groundwater divide are imperfect measures of sustainable groundwater use in this hydrogeologic setting. A measure that reflects impacts of induced infiltration from the west should be employed to evaluate the impact of potential increases in groundwater withdrawals.

CONCLUSIONS AND RECOMMENDATIONS

Data compiled for this study show that in both densely (Waukesha) and sparsely (Sauk) populated counties, growth in municipal water use over the last 75 years is proportional to population growth and increases in developed land. While overall water use is much greater in Waukesha County, the rate of growth and the per capita water use rate are higher in Sauk County.

We estimate that municipal wells supply 60% of the groundwater pumped in Waukesha County, where about 30% of the land is in suburban and urban development. In Sauk County, where 8% of the land is similarly developed, municipal systems supply 25% of the groundwater used in the County. The volume pumped from non-municipal wells in both counties is dominated by trends in agricultural irrigation, and this volume is increasing in Sauk County and decreasing in Waukesha County. Although the population of Waukesha County is about six times greater than Sauk County, total groundwater use in Waukesha County is only about 60% greater than in Sauk County.

These findings illustrate a subtle but significant difference in the water use in these two settings: In Waukesha County, high total withdrawals concentrated in a small geographic region (the water utility service areas) cause significant drawdown in the confined aquifer. In Sauk County, a small population density with a large amount of agricultural irrigation results in a high per capita use rate. However, regional-scale degradation of groundwater resources is not apparent because a large proportion of pumping is spread across the Wisconsin River valley, drawing water from an unconfined sand and gravel aquifer.

One interpretation of this finding is quite positive: given that the population density is relatively very high in Waukesha County, it is important that overall groundwater use is lower on a per capita basis. Sauk County, with a relatively low population density, is a better area for water-intensive industrial, agricultural, and commercial businesses. In Waukesha County, increasing residential water use resulting from population growth has been offset by decreases in industrial water use and agricultural irrigation.

This account of pumping in rural and developed counties demonstrates the impact of socioeconomic factors on water use, but it does not illustrate the impact of pumping on water resources. For example, pumping from a single high capacity well may have a small impact on the water use statistics of a county but it might have a large environmental impact by reducing base-flow to a near-by stream. By using the southeast Wisconsin regional flow model to demonstrate regional hydrologic impacts from increases in pumping, we found that our selected measures of hydrologic impact in the deep flow system (lowering of the potentiometric surface and change in the location of the groundwater divide) are not sensitive to the forecasted range in pumping rates. In this confined aquifer setting, both measures of hydrologic impact are strongly controlled by the geometry of the regional aquitard. Identifying and delimiting areas appropriate for groundwater management might be better based on some other measure of groundwater sustainability, such as impact on baseflow to surface water.

Project findings have several practical implications for current efforts to track water use in Wisconsin. Areas with more land in urban and suburban development have a higher proportion of residences and businesses served by public water supply. In these areas, water use information is of a much higher quality because pumping from municipal systems is metered and reported, and these records are readily obtained. We found that relatively simple improvements in tracking water use will reduce uncertainty in current pumping rates and improve our understanding of the impacts of groundwater withdrawals. For example, estimates of groundwater pumped for agricultural irrigation can be based on existing surveys of acres in irrigated agricultural production, rather than on estimates of the number of wells drilled for irrigation.

As it now exists, the DNR high-capacity well database is not accurate with respect to the number of wells in use, incorrectly describing the number of wells in use in 43% of the test cases (28 of 65). Therefore, use of a random sampling method (Cochran 1977) to estimate pumping (see for example, National Research Council 2002) is not currently feasible in Wisconsin because the total number of wells is largely unknown. Focusing additional surveys and data collection efforts on the location and pumping rates of wells in use at each high capacity property could substantially improve the database as a resource for tracking groundwater pumping. The Bureau of Dinking Water and Groundwater at the DNR has begun this task of identifying which wells are in use, and surveying owners for pumping rates. Great strides could be made by concentrating this effort on the largest-volume permit holders. Similarly, linking well records, pumping records, or high capacity well permits to a location or facility of waste water discharge and/or to an estimate of consumptive use would represent a great improvement to the current system.

The DNR should consider alternative methods for estimating groundwater use, rather than requiring reporting, from certain high capacity well owners. Two obvious categories for which this may be appropriate are golf courses and agricultural irrigation. Organizations such as the Wisconsin Agricultural Statistics Service and the Applied Population Lab at the University of Wisconsin – Madison offer expertise and the potential for collaboration. Estimating groundwater use in the agricultural and irrigation sectors may be preferable to overcoming potential resistance to, and inherent inaccuracies in, self-reporting for these categories.

Pumping is typically much lower at some types of private high capacity wells than at those wells for municipal, industrial and irrigation use. For example, many high capacity wells in rural areas supply small hotels and resorts, nursing homes, mobile home parks, and schools. The DNR should determine if metering and reporting of water use at these systems is of interest. For the purpose of hydrogeologic modeling, groundwater pumping by these smaller uses may be adequately estimated from information about the number of residences served, or the number of camp sites or students served, rather than on the permitted volume reported in the high capacity database.

Water utility annual reports to the PSC are an excellent source of municipal pumping records and they are readily available. The DNR should work with the PSC to add a report of the total volume pumped from each well; this would improve the quality of the information for use in hydrogeologic models.

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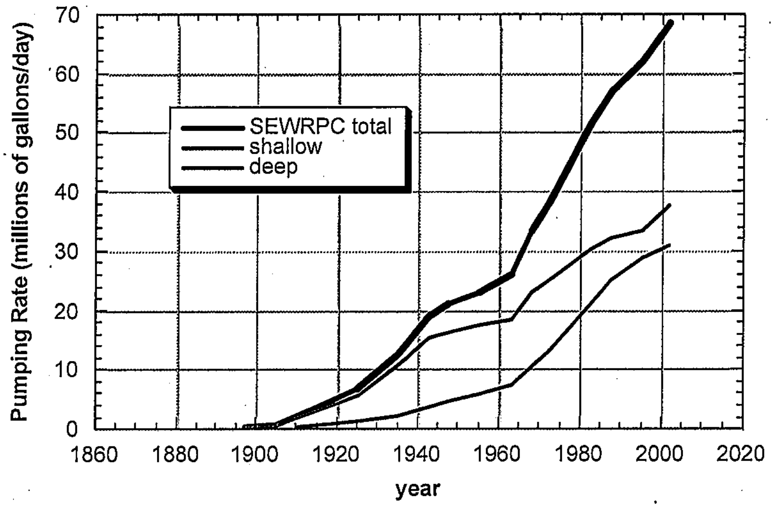


Figure 1. Total groundwater pumping in southeast Wisconsin compiled for the SEWRPC regional groundwater flow model (Feinstein et al. 2005)

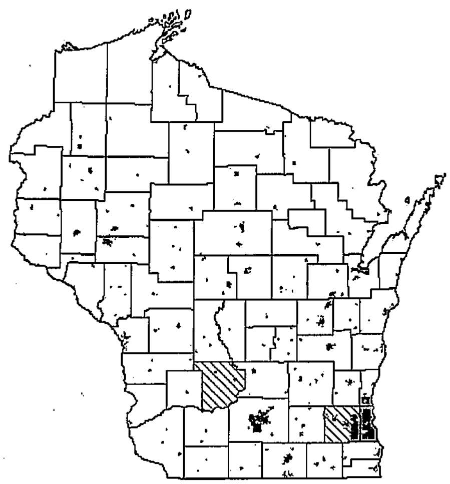


Figure 2. Location of study areas. *Population centers shown in gray.*

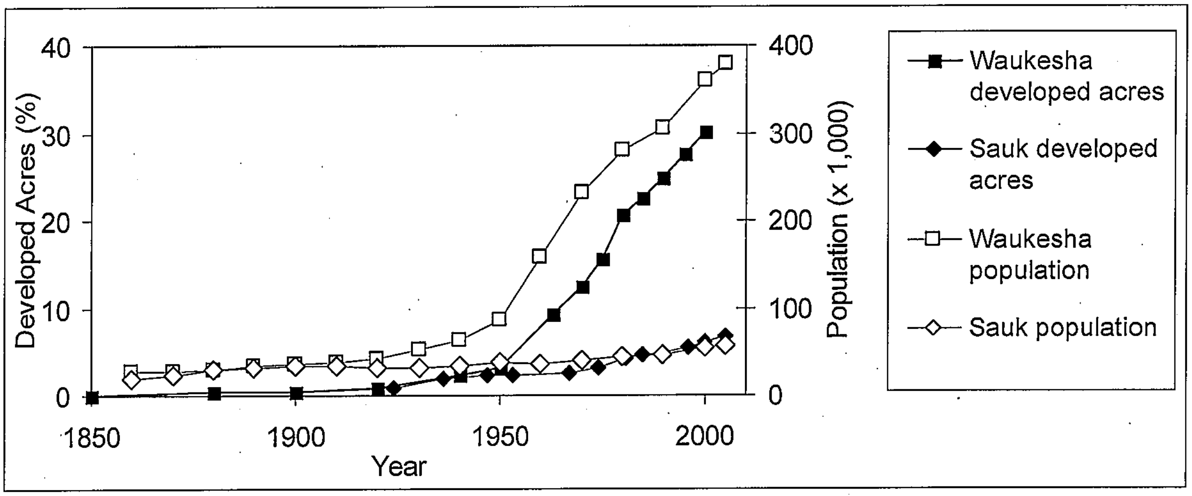


Figure 3. Population growth and development in study areas.

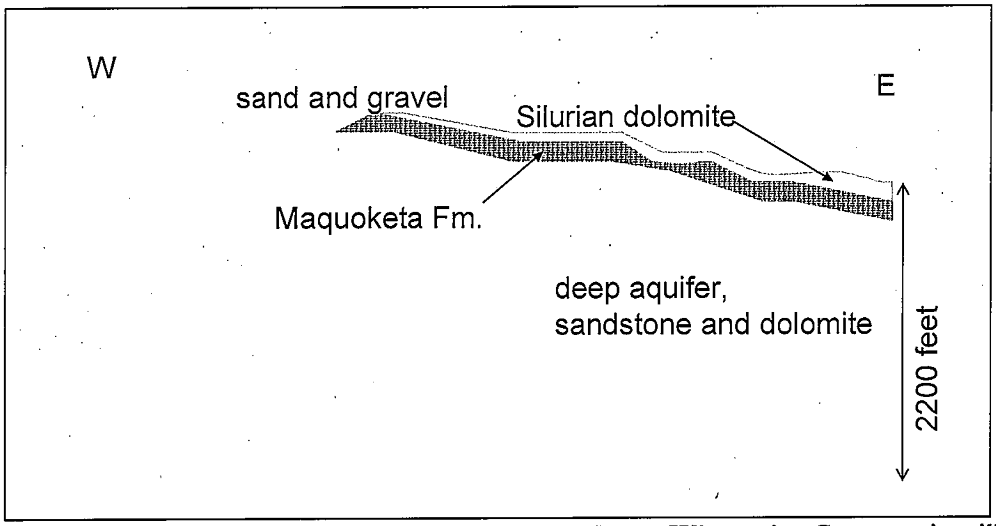


Figure 4. Hydrostratigraphic cross-section, southeast Wisconsin. Cross-section illustrates about 25 miles west to east. Not to scale.

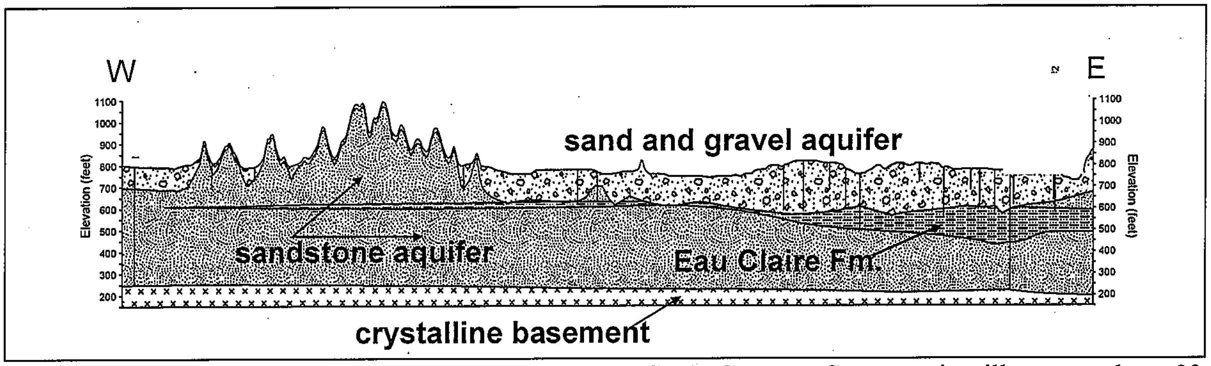


Figure 5. Hydrostratigraphic cross-section, southern Sauk County. Cross-section illustrates about 33 miles west to east. Not to scale. Adapted from Gotkowitz et al. 2005.

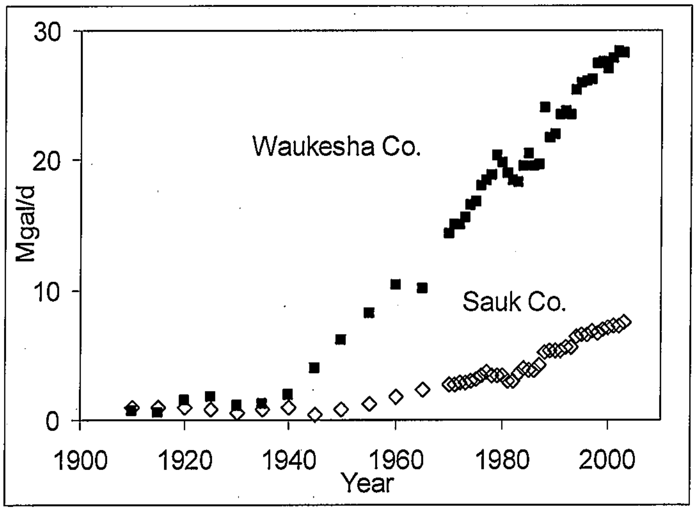


Figure 6. Municipal pumping in Sauk and Waukesha Counties, 1910-2003.

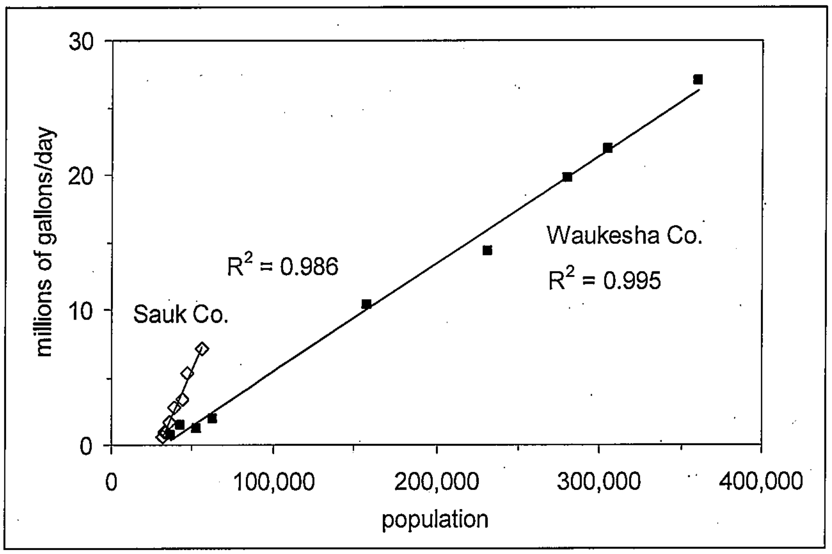


Figure 7. Municipal pumping as a function of population growth. *Figure shows data from 1910 to 2000 at ten year intervals. Correlation coefficient is shown for each data set.*

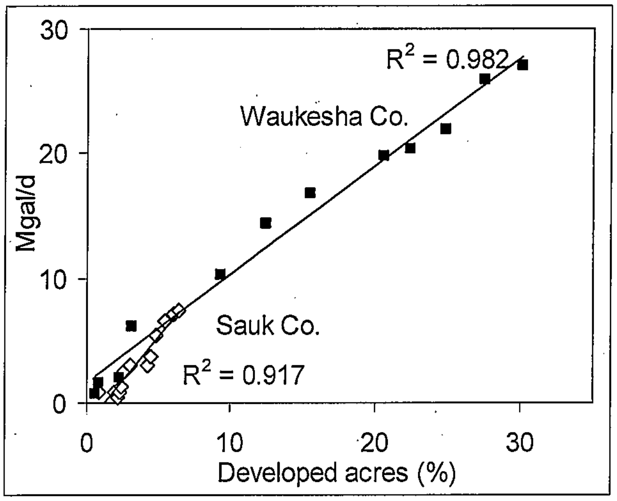


Figure 8. Municipal pumping as a function of developed acres. *Data are from selected years during 1910 to 2003. Correlation coefficients are shown for each county.*

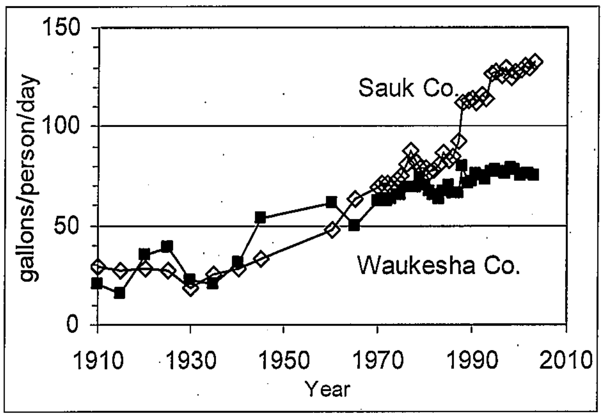


Figure 9. Per capita municipal pumping. *Per capita calculation is based on the county population.*

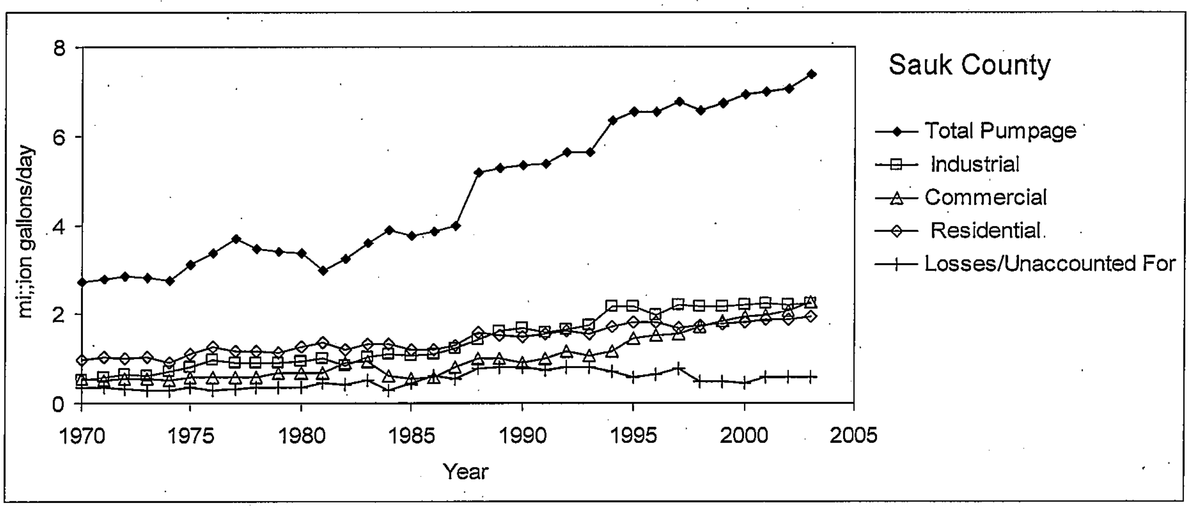


Figure 10. Sauk County municipal water sales by category.

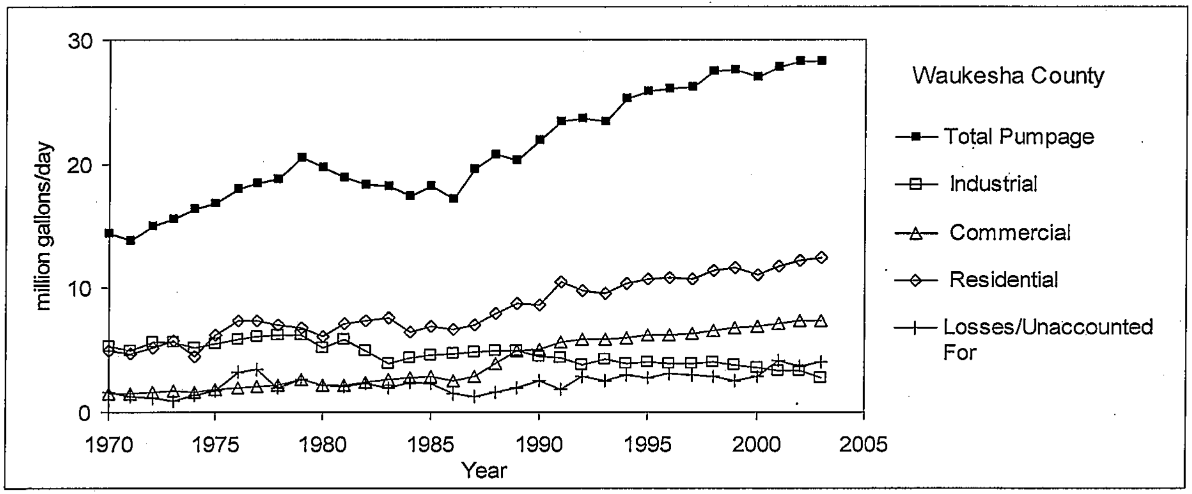


Figure 11. Waukesha County municipal water sales by category.

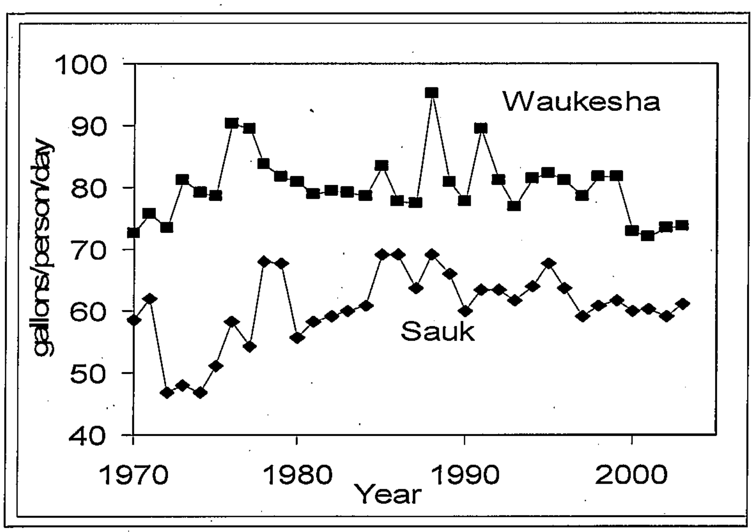


Figure 12. Per capita residential water use. *Based on water utility sales to one- and two-family residences and average household size.*

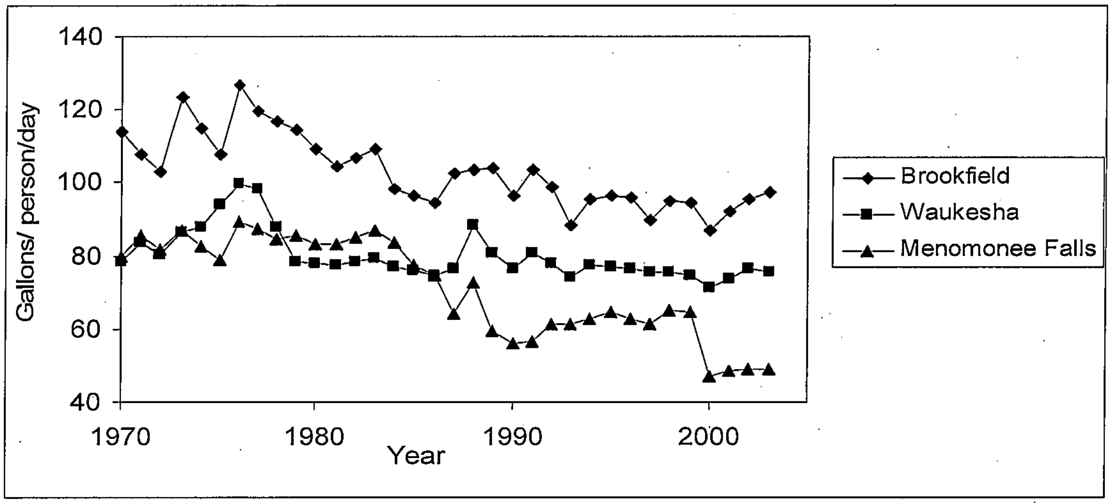


Figure 13. Per capita residential water use from selected municipal systems in Waukesha County.

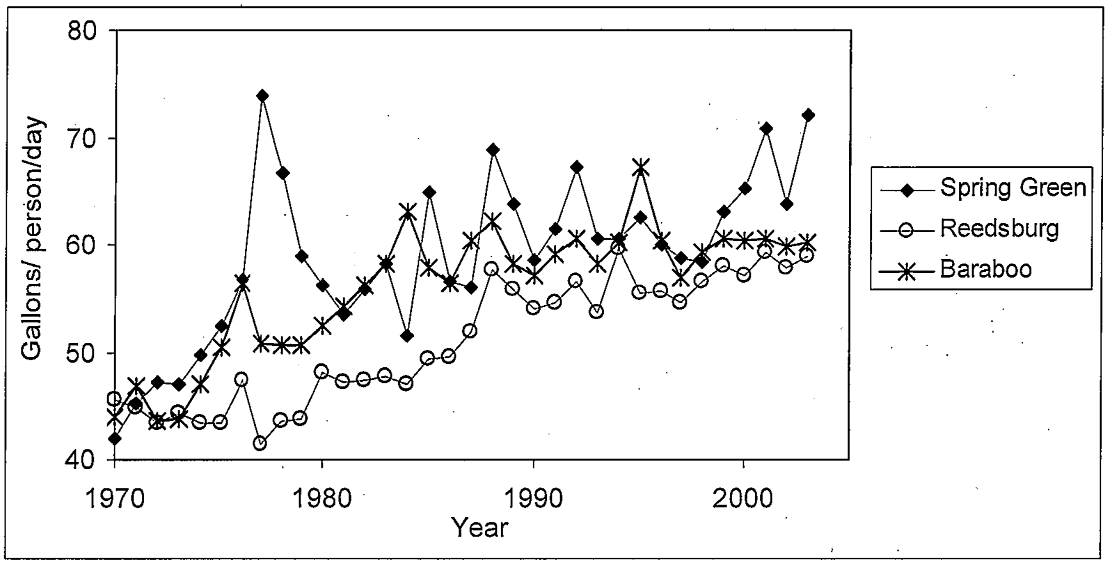


Figure 14. Per capita residential water use from selected municipal systems in Sauk County

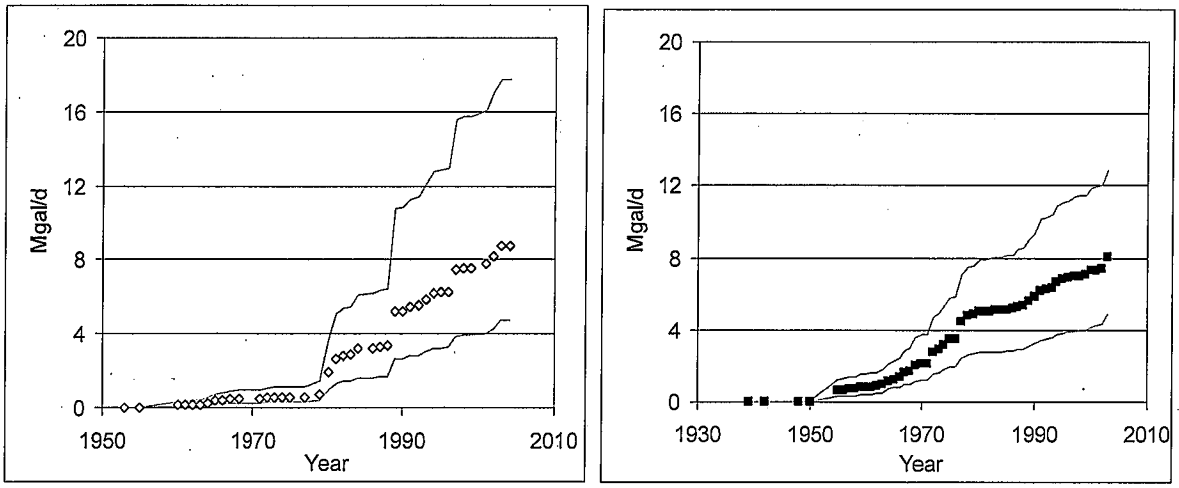


Figure 15. Self-supplied high capacity pumping in Sauk County (left) and Waukesha County (right). *Figures do not include pumping for irrigation. Lines indicate upper and lower bounds on the estimates.*

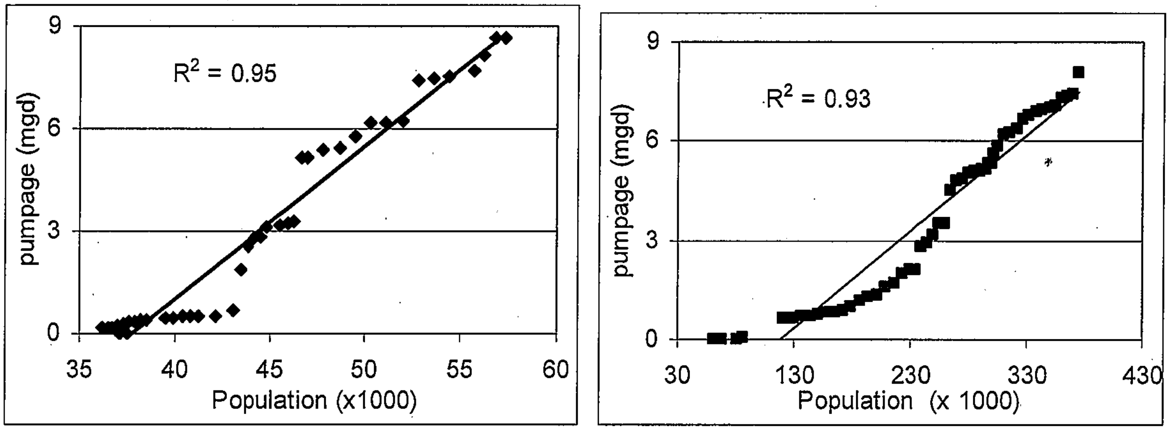


Figure 16. Population growth and self-supplied high capacity pumping in Sauk County (left) and Waukesha County (right).

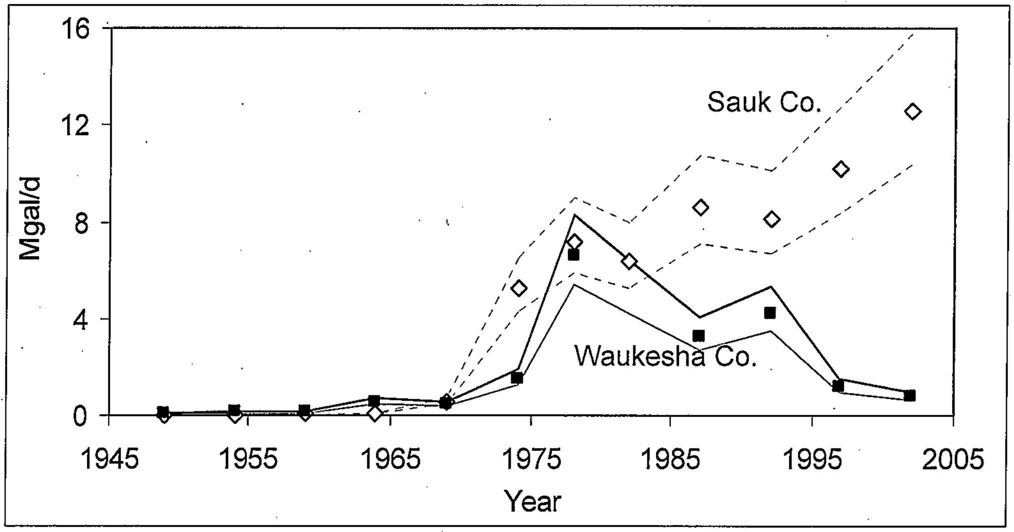


Figure 17. Self-supplied pumping for agricultural irrigation. *The lines show the range of estimates resulting from multipliers developed in Appendix H.*

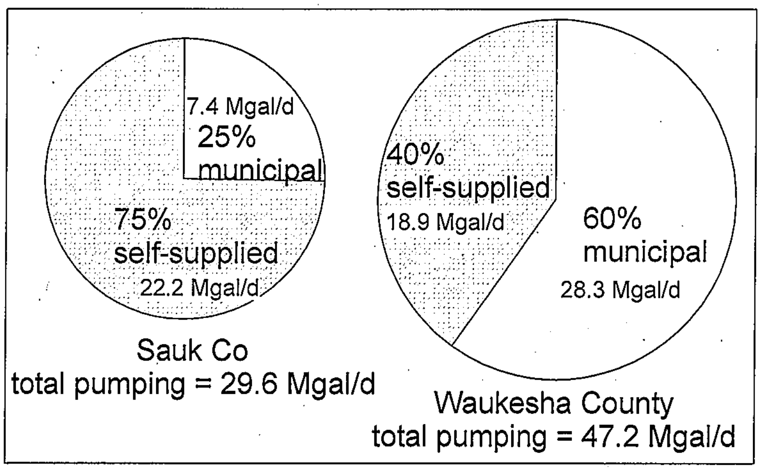


Figure 18. Proportion of self- and municipally-supplied groundwater in Sauk and Waukesha Counties in 2003. *Includes domestic self-supplied groundwater.*

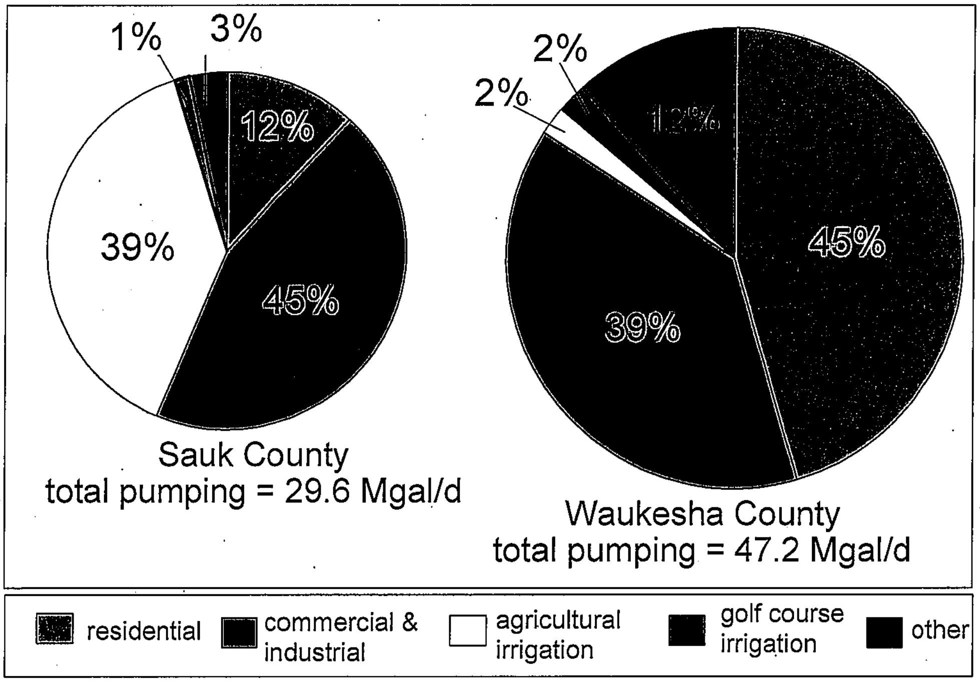


Figure 19. Water use in Sauk and Waukesha Counties, 2003. *All non-irrigation self-supplied high capacity pumping is included in the industrial and commercial category, whereas some similar uses are likely categorized as "other" in municipal water use records. Residential category includes all self-supplied domestic pumping and municipal sales to one- and two-family residences. Multi-family residential use is included in the commercial category.*

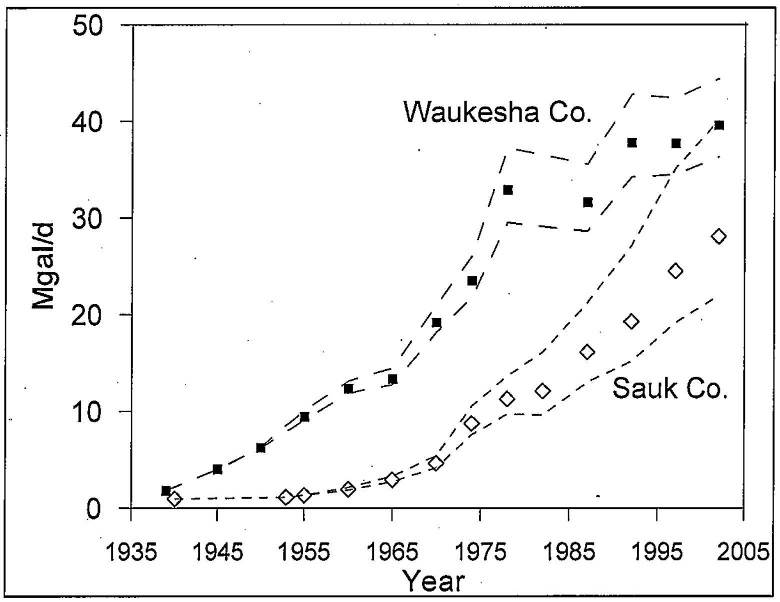


Figure 20. Groundwater pumping in Waukesha and Sauk Counties from municipal and self-supplied sources. *Figure does not include self-supplied domestic pumping at residences with on-site septic systems. Upper and lower bounds include uncertainty in non-irrigation self-supplied pumping (Figure 12) and the range of estimates in agricultural irrigation water use (Figure 14).*

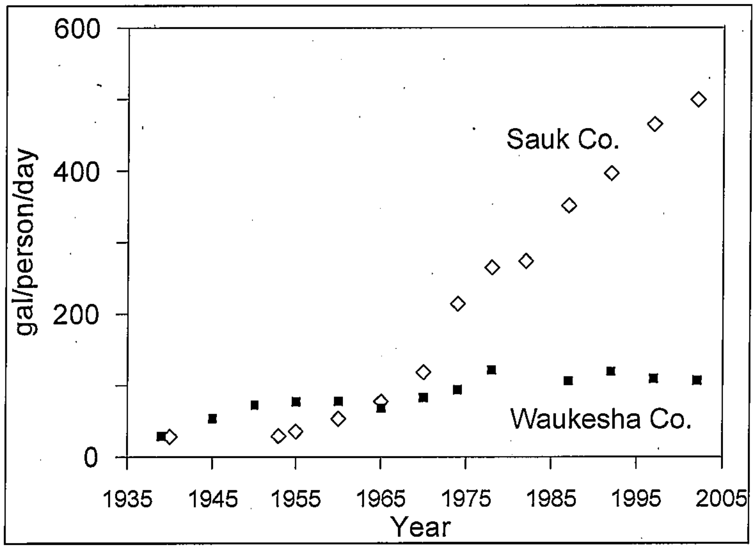


Figure 21. Per capita water use in Waukesha and Sauk Counties. *Includes all self-supplied and municipal pumping except self-supplied domestic pumping at residences with on-site septic systems.*

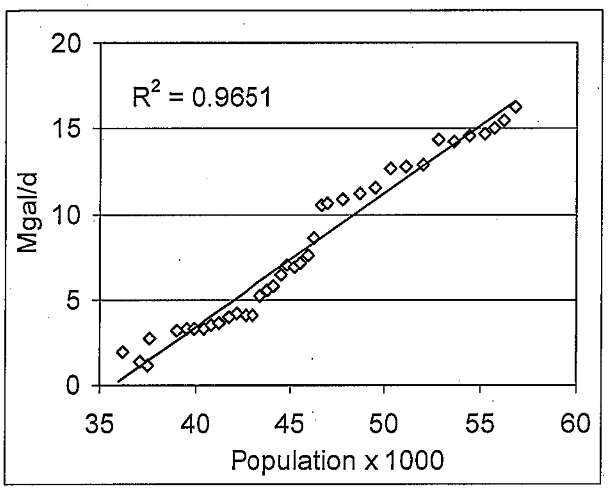


Figure 22. Groundwater pumped as a function of population Sauk County, 1953 – 2003. *Does not include pumping for agricultural irrigation or self-supplied domestic pumping at residences with on-site waste disposal.*

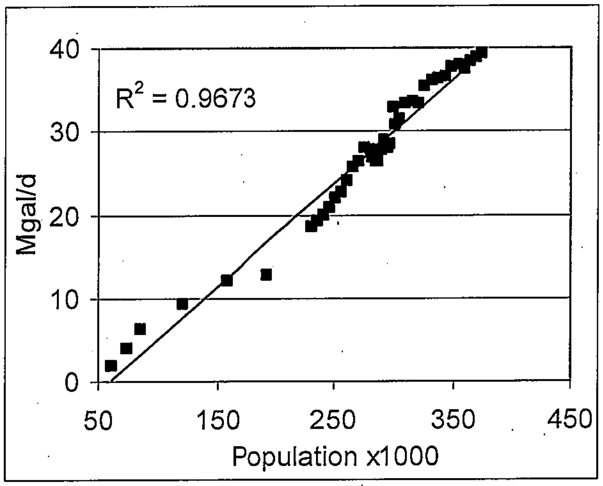


Figure 23. Groundwater pumped as a function of population Waukesha County, 1939 – 2003. *Does not include pumping for agricultural irrigation or self-supplied domestic pumping at residences with on-site waste disposal.*

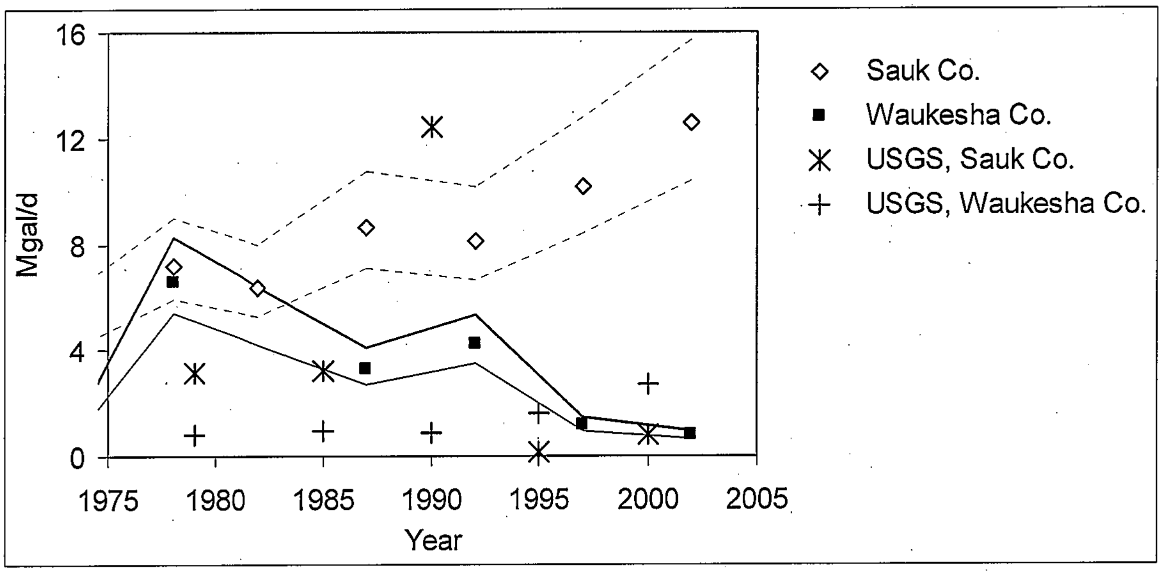


Figure 24. Estimates of pumping for agricultural irrigation compared to USGS estimates.

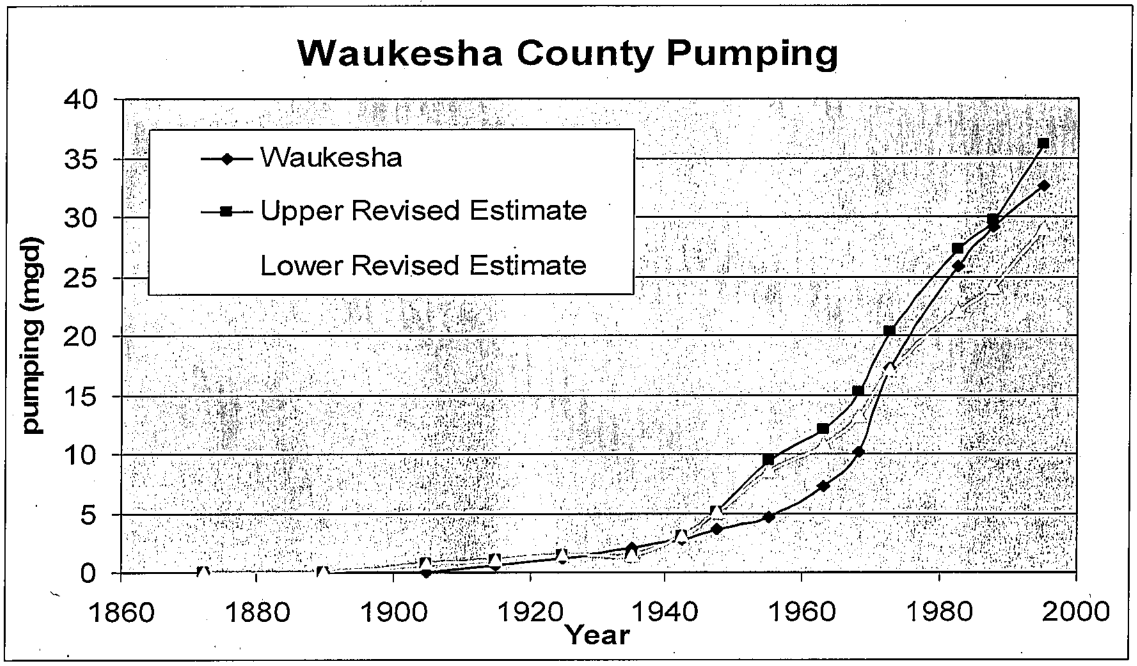


Figure 25. Pumping estimates for the model calibrations over time.

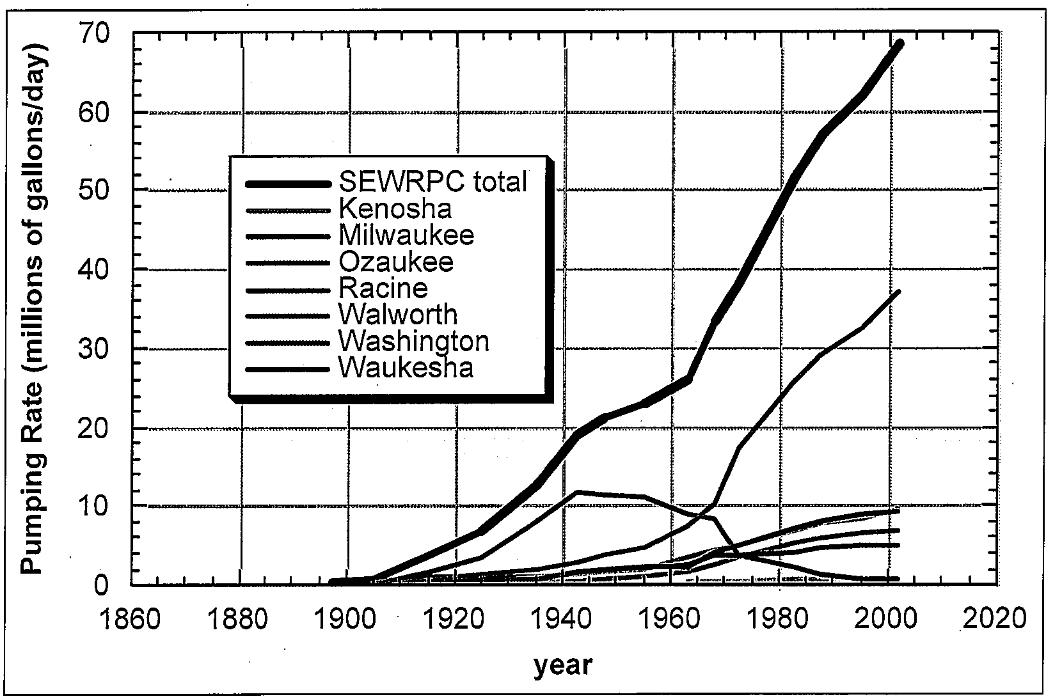


Figure 26. Pumping rates by county in southeastern Wisconsin.

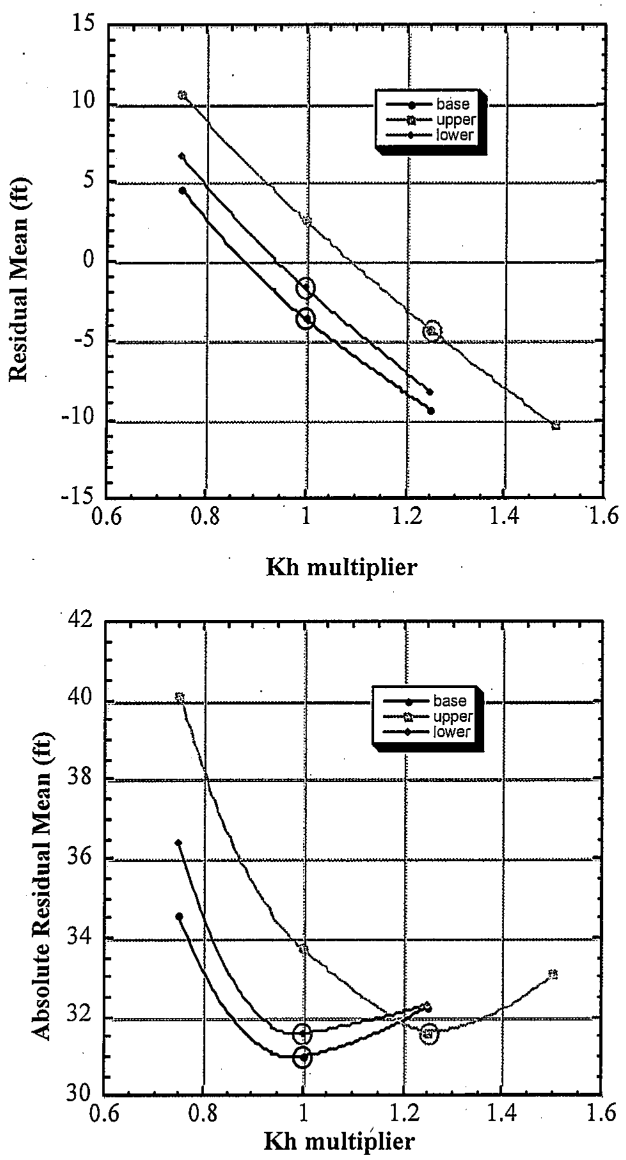


Figure 27. Calibration statistics for the different pumping estimates. *The sandstone multipliers for the final calibrated models are circled (no change, a value of 1, for the base and lower estimates, a value of 1.25 for the upper estimate).*

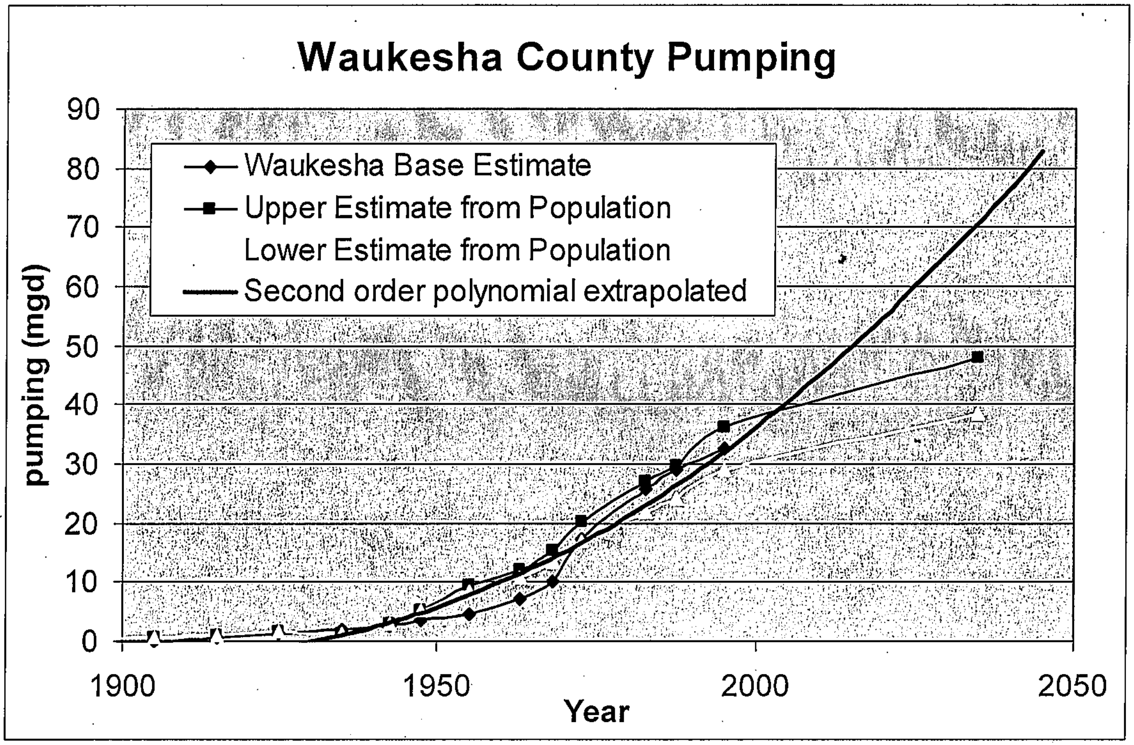


Figure 28. Extrapolated pumping rates. *The base estimate is the historical pumping record used to calibrate the model.*

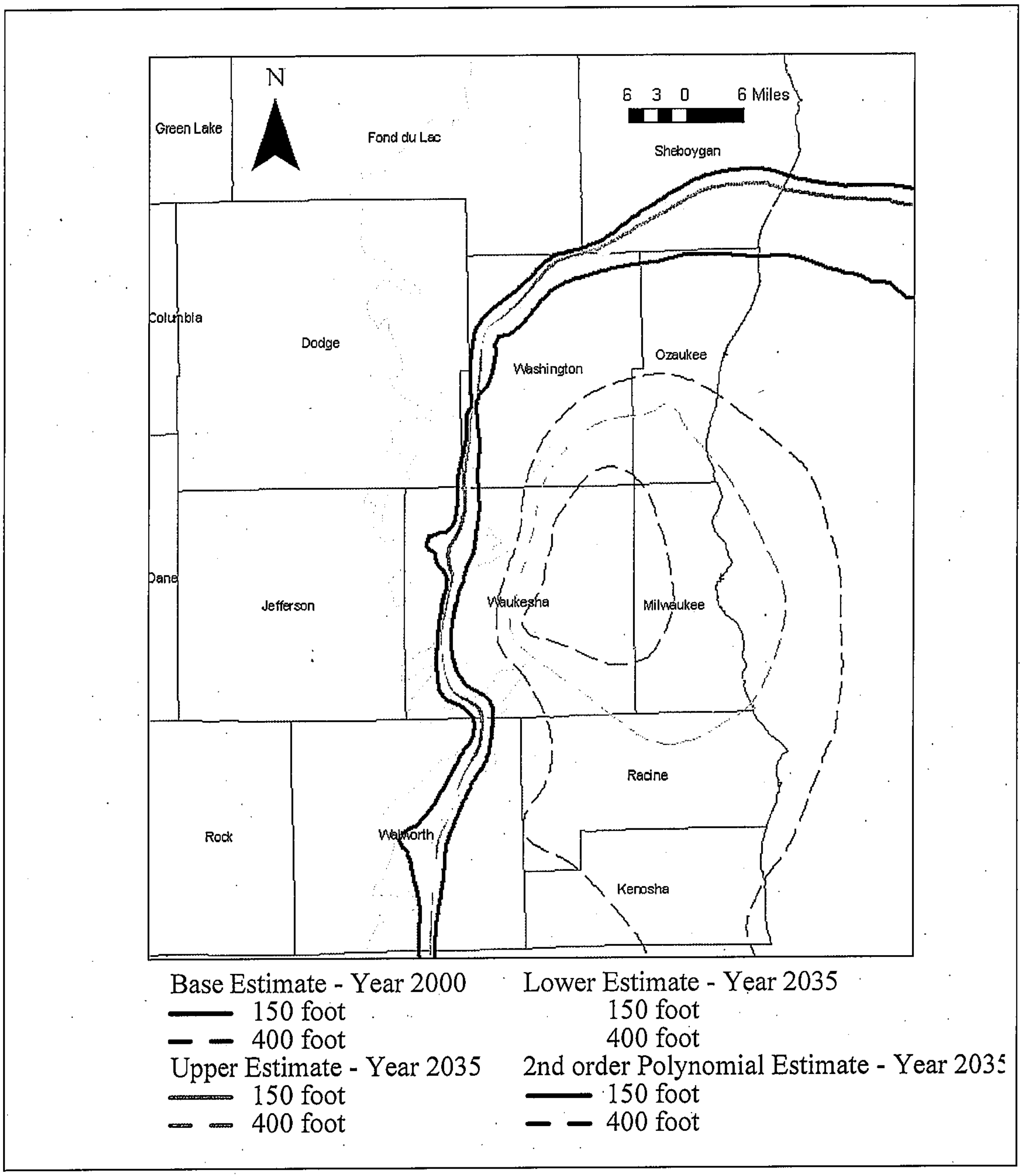


Figure 29. Model-simulated drawdown in the deep sandstone aquifer. *The grey-shaded area shows the extent of the Maquoketa shale.*

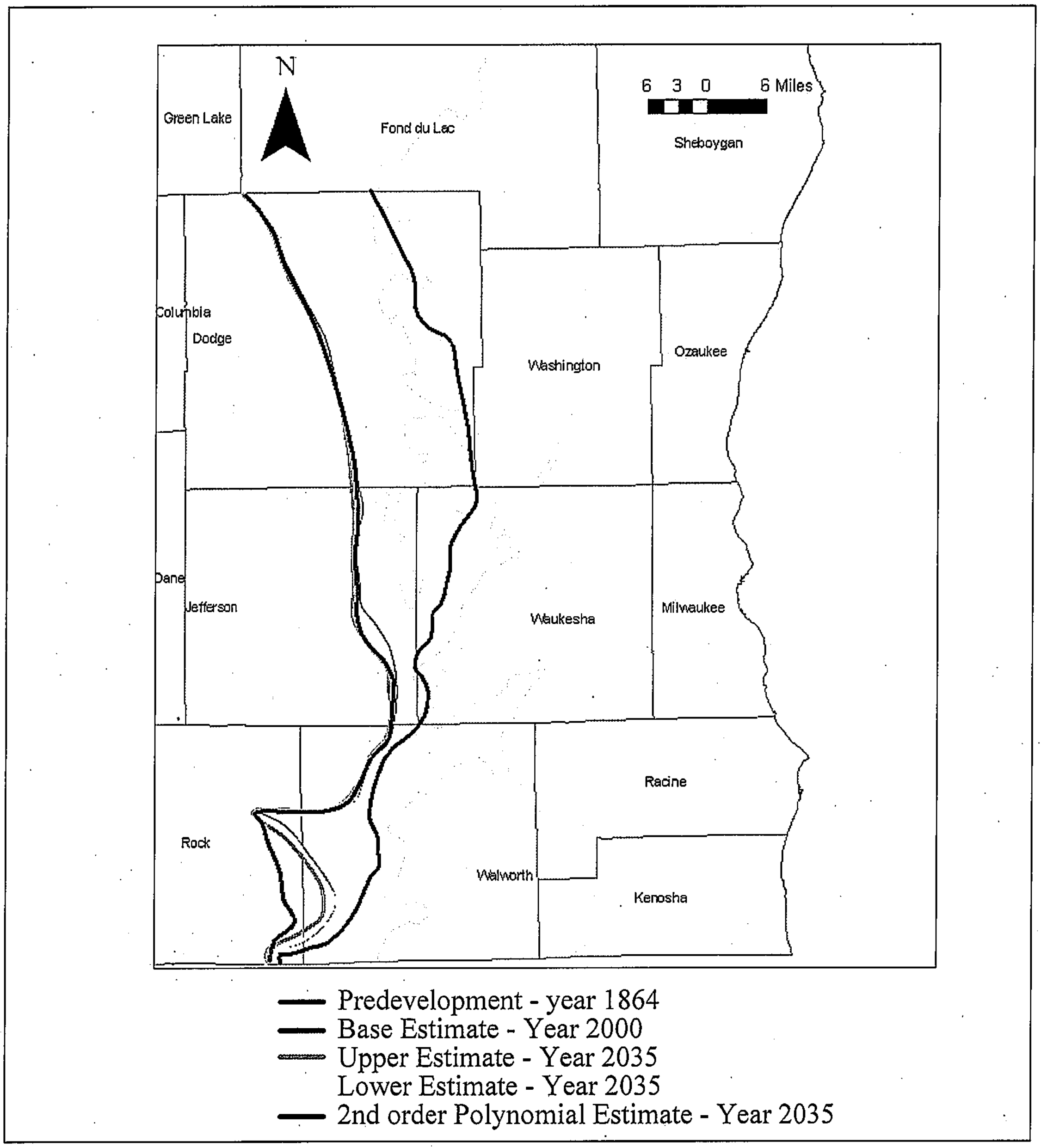


Figure 30. Model-simulated location of the groundwater divide under pre-development conditions, base conditions, and three estimates of 2035 pumping.

APPENDIX A: POPULATION DATA

Table A-1. Population and projected population of Sauk and Waukesha Counties

Year	Sauk Co.	Source	Waukesha Co.	Source
1860	18,963	1	26,831	1
1870	23,860	1	28,274	1
1880	28,729	1	28,957	1
1890	30,575	1	33,270	1
1900	33,006	1	35,229	1
1910	32,869	2	37,100	2
1920	32,548	2	42,612	2
1930	32,030	2	52,358	2
1940	33,700	2	62,744	2
1950	38,120	2	85,901	2
1960	36,179	2	158,249	2
1970	39,057	2	231,365	2
1980	43,469	2	280,326	2
1990	46,975	2	304,715	2
2000	55,225	2	360,767	2
2005	57,746	2	378,971	2
2010	60,930	4	391,500	3
2015	63,520	4	404,100	3
2020	65,821	4	417,400	3
2025	68,208	4	429,600	3
2030	70,185	4	440,300	3
2035	--	--	446,800	3

Sources:
1 http://fisher.lib.virginia.edu/collections/stats/histcensus/php/newlong3.php
2. U.S. Bureau of the Census, downloaded from http://quickfacts.census.gov/qfd/states/55/55111lk.html on 6/29/2006
3. SEWRPC Technical Report 11, 4th Edition
4. U.S. Bureau of the Census, downloaded from http://quickfacts.census.gov/qfd/states/55/55111lk.html on 9/13/2006

SEWRPC Technical Report 11, 4th Edition (source 3, above) includes a medium, high and low population forecast for Waukesha County for the year 2035:
Low: 411,000 people; medium: 446,800 people; high: 504,900 people

Table A-2. Average Household Size, Sauk and Waukesha Counties.

	Average number of people per household	
Year	Waukesha Co.	Sauk Co.
1940	3.82	3.69
1950	3.51	3.43
1960	3.73	3.40
1970	3.74	3.22
1980	3.17	2.80
1990	2.83[1]	2.61
2000	2.63[1]	2.51

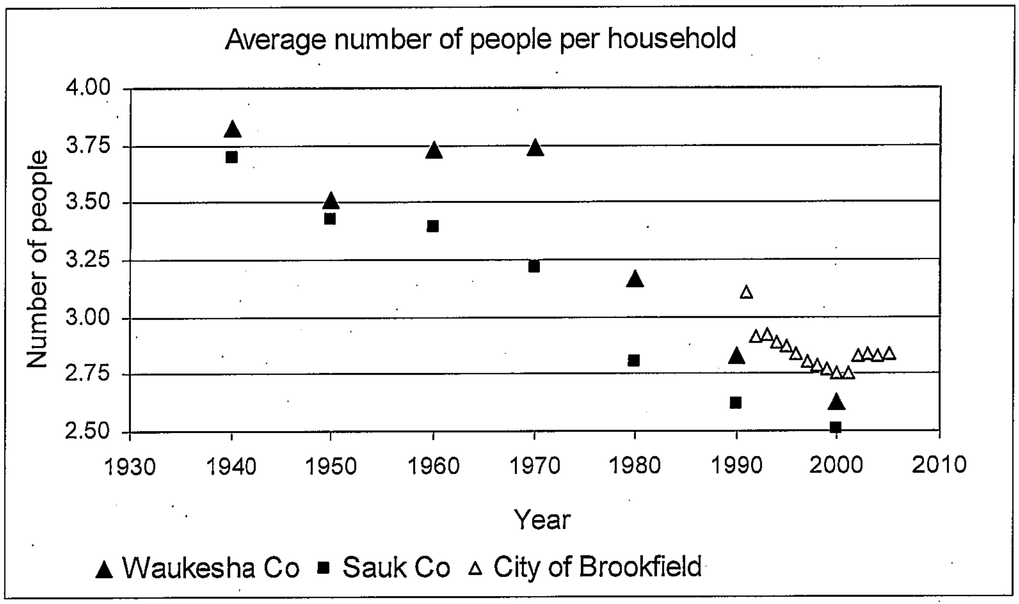
Sources of data:
1940 –1980: personal communication from James Beaudoin, Applied Population Laboratory, July 10, 2006. The 1980 and 1970 values were calculated by dividing the total population by total number of householders. The 1960 and 1940 values calculated by dividing total population by occupied housing units. In 1950, persons per household was a provided value in the Census.
[1] SEWRPC Technical Report No. 11, 4th edition, Table 16; 1990 and 2000 Census of Population and Housing. Values in table are calculated from the population in households and the number of households reported in the Census data.

Table A-3. Average household size in the City of Brookfield, Waukesha County

Year	Number of people per 1-2 family residence
1991	3.11
1992	2.91
1993	2.92
1994	2.89
1995	2.87
1996	2.84
1997	2.8
1998	2.79
1999	2.77
2000	2.75
2001	2.75
2002	2.83
2003	2.84
2004	2.83
2005	2.84

Source: personal comm., Robert Tischer, City of Brookfield Water Utility, Jan. 9, 2006. This data is used by City of Brookfield to calculate a per capita residential water consumption rate at 1- and 2- family housing units.

Figure A-2. Average household size, Sauk and Waukesha Counties and City of Brookfield, prepared from Tables A2 and A3.



APPENDIX B: CLIMATE DATA

Monthly and annual precipitation and average temperature data from 1988 to 2004 were obtained from the Midwestern Regional Climate Center for all weather stations in Sauk and Waukesha Counties. Four weather stations are available in Sauk County (Baraboo, Prairie du Sac, Reedsburg and Rock Springs) and two in Waukesha County (Oconomowoc and Waukesha). Missing values were removed from the data sets and records from stations in each county were averaged to obtain the county-wide data used in this report. These values are presented here:

Table B-1. Waukesha County precipitation data

Waukesha County, precipitation (inches)					
Year	June	July	August	September	Annual
1980	3.63	4.21	8.00	6.10	33.92
1981	2.76	3.59	6.48	4.71	30.59
1982	2.65	3.06	3.46	0.51	33.20
1983	2.30	2.52	3.51	4.14	33.35
1984	5.09	3.59	2.34	2.61	38.00
1985	2.37	2.44	3.21	4.61	35.75
1986	6.19	6.42	4.70	9.39	39.69
1987	2.41	5.88	6.34	4.31	35.04
1988	1.33	0.98	2.86	6.13	26.83
1989	2.60	7.76	5.93	1.63	29.61
1990	5.84	1.99	4.02	1.96	34.78
1991	4.53	4.04	2.12	6.27	38.95
1992	1.71	4.27	3.64	5.44	30.80
1993	6.96	5.49	3.77	4.77	38.21
1994	3.86	6.50	4.58	1.50	29.22
1995	0.58	3.14	11.11	1.12	34.94
1996	8.26	3.37	2.98	1.92	32.21
1997	6.02	5.09	5.57	1.72	32.63
1998	4.54	2.17	6.95	1.93	38.74
1999	6.12	6.10	1.84	3.68	37.59
2000	4.47	6.67	5.35	6.01	42.98
2001	4.62	1.98	5.31	5.38	37.88
2002	3.97	2.86	6.34	3.46	32.10
2003	2.39	3.15	1.87	2.93	28.90
2004	4.17	2.35	4.95	0.21	34.72

Table B-2. Sauk County precipitation data

	Sauk County, precipitation (inches)				
Year	June	July	August	September	Annual
1980	3.54	3.56	11.64	6.84	35.64
1981	4.98	4.12	6.01	3.14	30.02
1982	2.93	3.30	3.61	1.01	31.19
1983	2.88	3.99	5.21	3.12	32.52
1984	7.14	3.00	1.63	3.90	34.95
1985	3.39	6.06	3.76	7.42	40.84
1986	2.95	5.54	3.73	9.18	34.68
1987	1.36	4.18	4.98	4.00	31.77
1988	2.08	3.00	5.01	4.08	26.47
1989	2.95	3.55	6.35	2.13	25.24
1990	8.14	1.52	4.17	1.57	33.35
1991	2.58	2.94	2.24	4.22	33.16
1992	0.97	4.85	1.90	10.20	34.69
1993	5.97	11.66	4.86	2.76	43.93
1994	6.66	3.85	4.05	4.80	31.82
1995	3.04	4.03	5.13	1.28	34.45
1996	7.62	3.99	1.56	0.87	29.81
1997	4.14	7.73	3.52	1.94	31.45
1998	8.83	2.33	4.95	2.93	42.37
1999	4.23	7.14	3.28	1.66	37.48
2000	10.34	5.18	4.35	3.74	39.46
2001	6.05	1.73	8.72	5.01	39.03
2002	6.57	2.38	3.14	3.38	30.67
2003	3.57	3.70	2.73	3.41	30.44
2004	7.43	5.39	5.14	0.61	42.56

APPENDIX C: MUNICIPAL WATER UTILITY PUMPING RECORDS

These data are compiled from reports to the PSC. In years where some of the municipal utility reports from Sauk or Waukesha County were missing, the average of reported pumping from the previous and following year was used as an estimate of the missing year's pumping. Estimates were not made if several consecutive years were missing from a utility's records, as noted in Table C1). Prior to 1940, most data gaps result from inconsistent reporting by utilities. Since 1940, most of the missing data are attributed to misplaced reports at the Historical Society or PSC.

Table C-1. Total municipal pumpage in Waukesha and Sauk Counties

Total Municipal Pumpage, 1910-2003		
year	Waukesha Co. (mgd)	Sauk Co. (mgd)
1910	0.747	0.963
1915	**0.605**	**0.896**
1920	1.495	0.905
1925	1.832	**0.865**
1930	**1.157**	0.595
1935	**1.165**	0.843
1940	1.954	**0.905**
1945	4.005	0.441
1950	--	--
1955	--	--
1960	**10.330**	1.719
1965	**10.119**	2.369
1970	14.369	2.714
1971	15.024	2.791
1972	14.958	2.857
1973	15.546	2.806
1974	**16.441**	2.987
1975	**16.800**	3.101
1976	17.980	3.375
1977	18.472	3.683
1978	18.781	**3.470**
1979	20.292	3.398
1980	**19.762**	**3.352**
1981	18.930	**2.987**
1982	**18.363**	2.939
1983	18.250	3.579
1984	**19.460**	3.894
1985	**20.390**	**3.764**
1986	**19.442**	**3.846**
1987	**19.623**	**4.252**
1988	23.978	5.192
1989	21.616	5.273
1990	**21.953**	5.341
1991	23.472	5.368
1992	23.682	5.650

Total Municipal Pumpage, 1910-2003		
year	**Waukesha Co.** (mgd)	**Sauk Co.** (mgd)
1993	23.443	5.624
1994	25.301	6.357
1995	25.886	6.544
1996	26.096	6.548
1997	26.228	6.838
1998	27.467	6.679
1999	27.541	6.968
2000	26.950	7.123
2001	27.837	7.255
2002	28.301	7.279
2003	28.266	7.463

bold indicates estimated value

-- indicates several consecutive reports were missing, estimates were not made for these years

APPENDIX D: RESIDENTIAL WATER USE FROM MUNICIPAL SYSTEMS

Estimates are based on municipal water utility records of total annual metered residential pumping, total number of residential customers (that is, the number of meters), and the estimated average household size (Appendix A). The average household size may be low because the average size of a household in single-family residences may be larger than the average household size residing in multi-family dwellings. Therefore, this estimate might be improved upon by more proficient use of US Census data.

Robert Tischer, Utility Accountant for the City of Brookfield, provided an independent check on estimates of household size and residential water use (personal communication, 9 January 2006). Mr. Tischer calculated the per household and per capita consumption rates for one and two-family units (residential category) in Brookfield, and the number of residential units served through multi-family (commercial category) accounts. Per capita consumption rates were calculated with an average household size that is higher than that we calculated for Waukesha County overall (see table A2 of Appendix A). Mr. Tischer used estimates of household size that change over time for 1-2 family residence per capita calculations, but he did not estimate household size for multi-family units. We calculated this for the second graph below by applying estimates of household size presented in Appendix A.

Figure D-1.

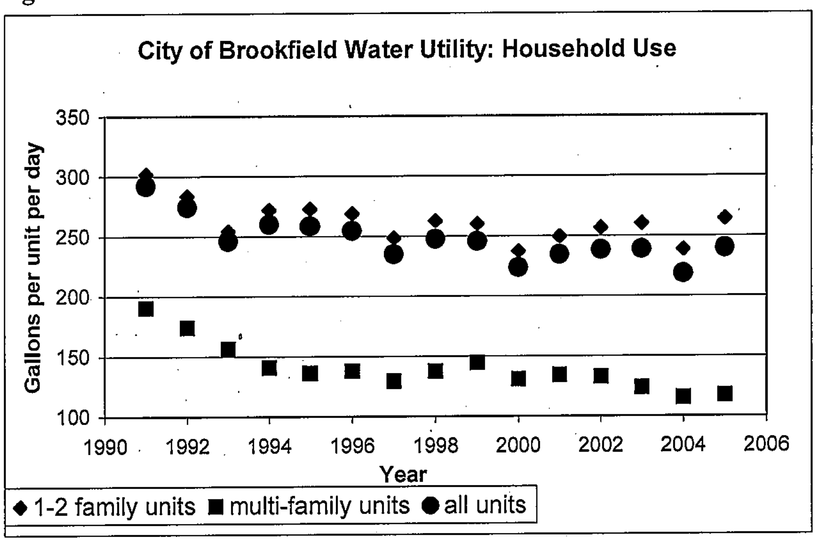
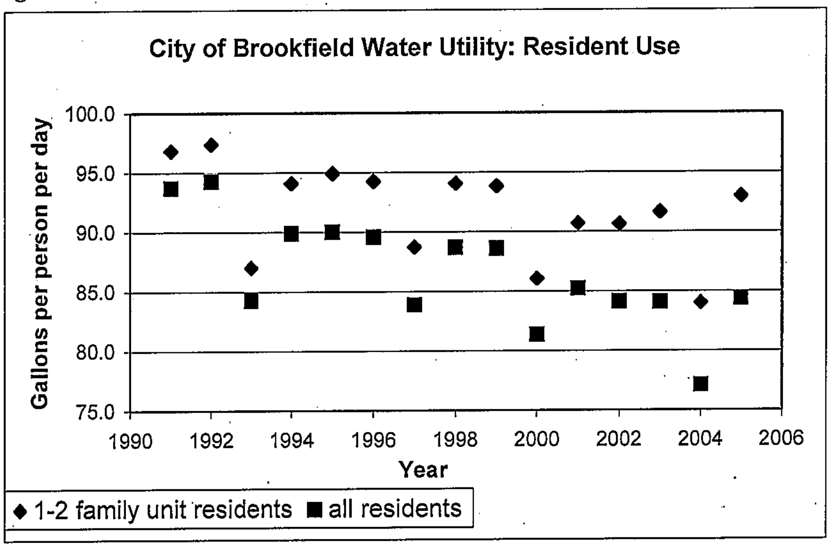
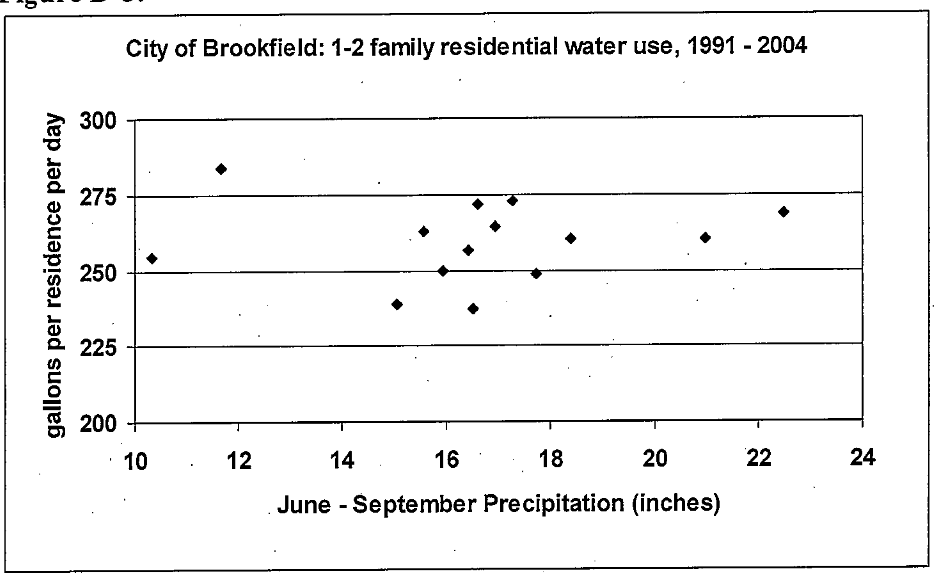


Figure D-2.



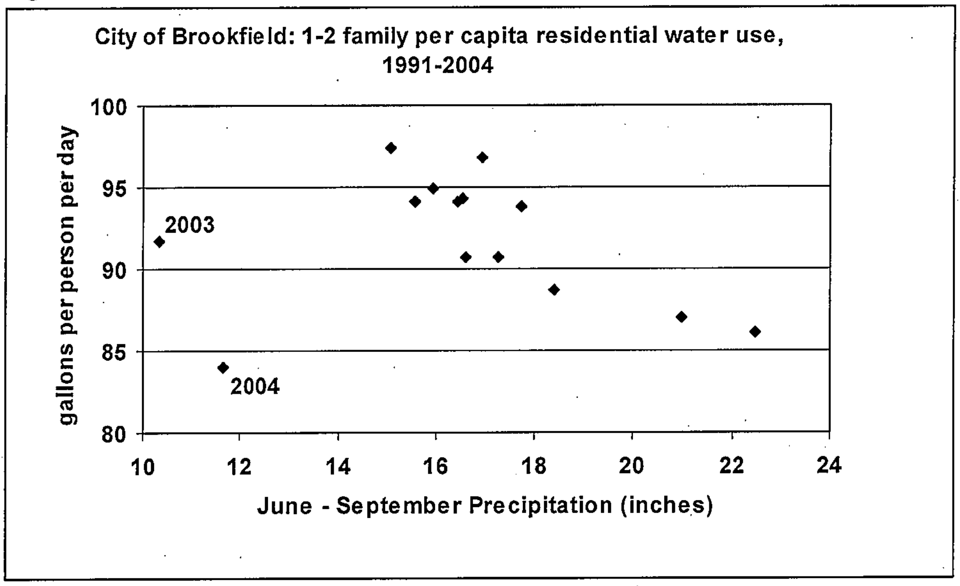
Per capita residential use is decreasing in all types of housing. 1993, 1997, 2000 and 2004 are years of low per capita use.

Figure D-3.



Residential water use on a per household basis does not show a correlation to summer precipitation. This is because changes in household size bear a large effect on household use.

Figure D-4.



Per capita residential water use is strongly correlated to summer precipitation. There are two outliers, both of which could be explained by water conservation efforts in 2003 and 2004.

APPENDIX E: SELF-SUPPLIED DOMESTIC WELLS AND RESIDENTIAL WASTE WATER DISPOSAL

Table E1. Number of residences with self-supplied water and on- or off-site waste disposal

	Sauk County			Waukesha County		
year	**Self-supplied water**	**on-site disposal**	**off-site disposal**	**self-supplied water**	**on-site disposal**	**off-site disposal**
1980	6,730[1]	6,727[1]	3	46,521[1]	35,245[1]	11,276
1990	8,643[1]	8,074[1]	569	48,936[1]	32,332[1]	16,604
2000	10,452[2]	9,764[4]	688	46,622[3]	29,951[3]	16,671

[1] 1980 and 1990 Census of Population and Housing, STF3: Source of Water, Year Round Housing Units & Sewage Disposal, Year Round Housing Units, accessed through Applied Population Lab, Department of Rural Sociology, University of Wisconsin

[2] Number of new private well construction records in Sauk County from 1991 to 2000 in 2006 Water Well Data Files compiled by the Wisconsin Department of Natural Resources.

[3] Personal Communication, Robert Biebel, Southeast Wisconsin Regional Planning Commission, 14 August 2006. Based on 2000 Census data of total households in Waukesha County and SEWRPC surveys of numbers served by public water and sewer utilities.

[4] Estimated by applying the ratio of residences with self-supplied water to residences with on-site disposal reported in Sauk County in 1980.

APPENDIX F: SURVEY OF SELF-SUPPLIED HIGH CAPACITY PROPERTY OWNERS

Survey and responses

In February of 2006, we mailed 330 questionnaires to high capacity property owners in Sauk and Waukesha Counties (Figure F-1). Of the 330 surveys, fifty-one (15%) were not deliverable due to an incorrect address. The total number of responses was 113 (34%), including 78 completed questionnaires, thirty three phone contacts, and two by letter or email. The phone contacts were made following the mail survey (discussed below).

Figure F-1. Water Use Questionnaire

How many wells do you operate? _______ How many wells are never in operation? _____

Do you meter your water use or pump-operating time? Yes _____ No_____

If not, how do you estimate your water use? ____________________________

____

What are your typical water-use rates on a daily, monthly, or annual basis? (Some examples: Our wells pump 20 million gallons per year; our wells pump 800 gallons per minute for 3 hours per day for the entire year; our wells pump only 3 months of the year, but pump 20 million gallons during that time)

____

____

Additional information ____________________________

____

____

____

Would you like me to contact you regarding these questions? Yes _____ No_____

Survey responses fell into five general categories (Table F-1). Some responses were quantitative, either reporting a metered water use or an owner-estimated water use (Table F-2). Some responses supplied characteristics of water use, for example the number of acres and type of crop irrigated. Many owners reported that wells had been abandoned or were no longer in use (Table F-3), while some responded with the number of wells in use but without any information on the quantity of water pumped. The fifth category included well owners listed in the database that indicated they no longer owned or operated the wells.

Table F-1. Survey Responses, Sauk and Waukesha Counties

Response Types	number	percent
Quantitative	47	42%
Characteristics of use	29	26%
Wells abandoned or not in use	25	22%
No estimated use or characteristics	7	6%
No longer own or operate wells	5	4%
Total Responses	113	100%

Table F-2. Quantitative Responses, Sauk and Waukesha Counties

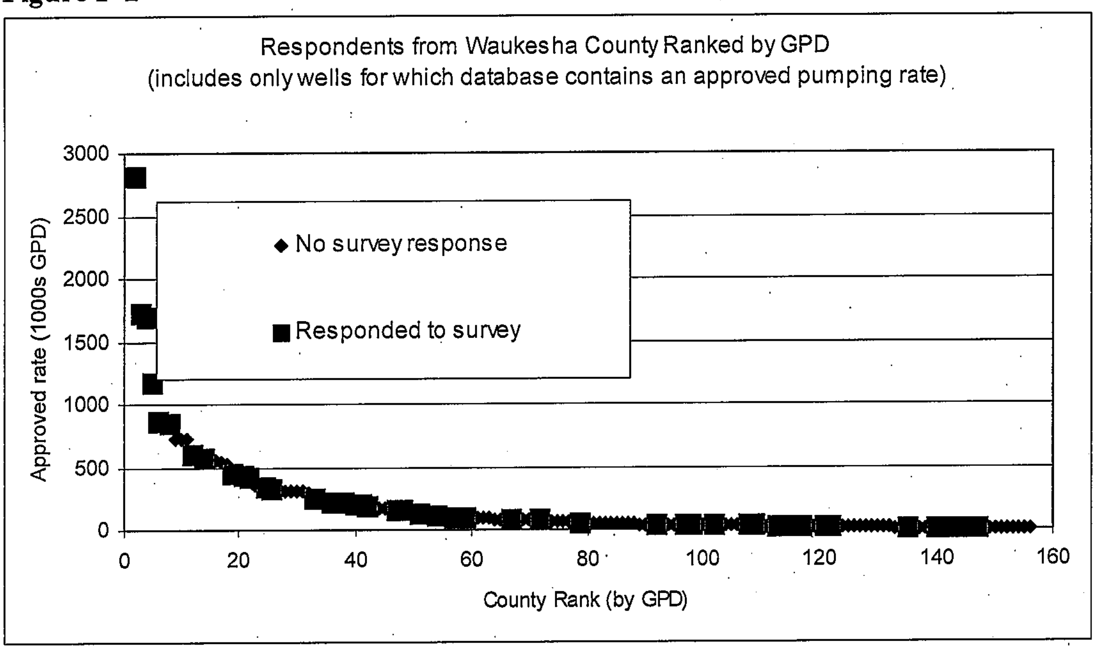
Quantitative Survey Responses	number	percent
Metered	29	62%
No information about reported value	11	23%
Estimated from operating time & pump rate	6	13%
Estimated from number of tenants	1	2%
Total quantitative responses	47	100%

Table F-3. Responses of wells not in use, Sauk and Waukesha Counties

Wells abandoned or not in use	number	percent
Switched to municipal water	13	52%
Wells no longer used, but not abandoned	9	36%
Wells abandoned	3	12%
Total responses of abandoned or not used	25	100%

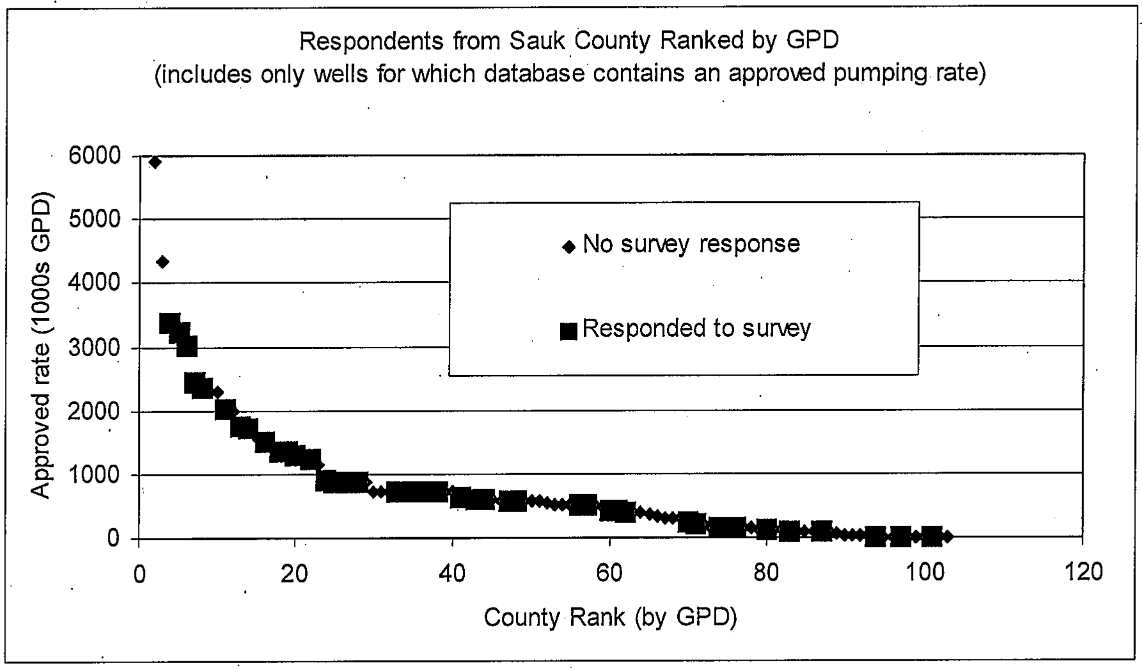
In order to determine which questionnaire non-respondents to contact by telephone, we ranked survey respondents by the approved pumping rates in the high capacity database. Figures F-2 and F-3 show high capacity properties in the databases ranked by this rate (fourteen records without an approved pumping rate are not included). The properties successfully contacted by mail or by phone are indicated. A range of high- and low-volume water users in both counties responded by mail or phone.

Figure F-2



Note: figure excludes the respondent with the highest approved pumping rate (8 mgd).

Figure F-3



Note: figure excludes the respondent with the highest approved pumping rate (10 mgd).

Evaluation of the DNR high-capacity well database

Number of wells in use

The DNR high-capacity database "status" field describes a well as active, inactive, or permanently abandoned. We used the subset of 65 survey responses that included the number of wells on the property and the number that are never in operation to evaluate the accuracy of the database. Of the wells reported as never in operation by their owners, the database record was correct (listed the well as inactive or permanently abandoned) 72% of the time (47 of 65 reports) and in disagreement 28% of the time (18 of 65 reports). Forty-three percent (28 of 65) of survey responses reported more wells on their property than were recorded in the database. Overall, the database was in agreement 57% of the time (37 of 65 reports) with respect to the number of wells on each property.

Seasonality of pumping

The database field for seasonal water use is poorly populated. Many annual permitted pumping volumes appear to be based on assuming year-round operation at a constant rate of water use. The database can be updated in this regard by assuming seasonal water use for certain water use categories. Schools were assumed to operate for nine months of the year based on the assumption that summer activities will be less than during the school year. Facilities that only operate during the summer or winter months (e.g. ski resorts, summer camps and outdoor water parks) can be adjusted to a reasonable number of months of operation.

Permitted pumping rates and survey responses

The following graphs compare information reported by survey respondents (reported pumpage) to the information in the high capacity database (permitted normal pumping rate). As demonstrated in figures F-4 through F-8, there is poor correlation between permitted and survey-reported water use rates. Figure F-4 shows the relationship between reported and permitted water use in both counties, for all types of water use, such as agricultural and golf course irrigation, campgrounds, schools, hotels, restaurants, and industrial facilities. Figures F-5 and F-6 present the data by county. All three graphs suggest that pumping rates in the database will not be a reliable indication of reported pumping.

Figure F-4. Permitted versus reported pumping, Sauk and Waukesha Counties. Note the log scale, n = 44. Dashed line shows line of equal values.

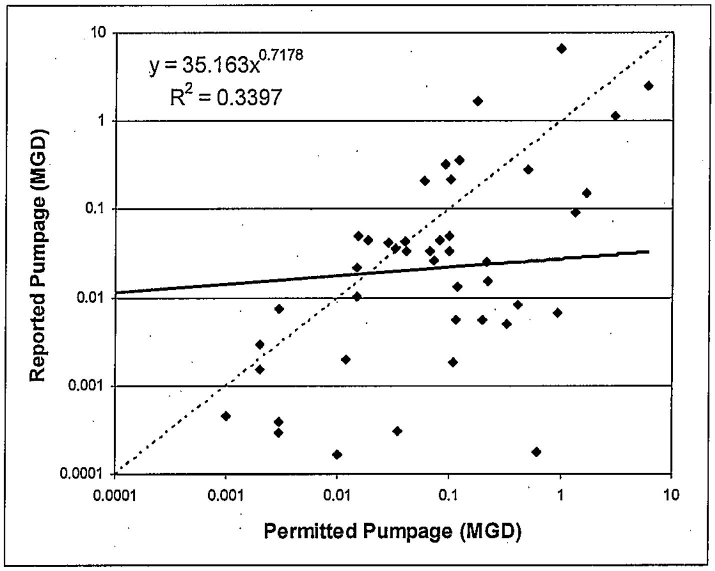


Figure F-5. Permitted versus reported pumping, Sauk County. Note the log scale, n = 16. Dashed line shows line of equal values.

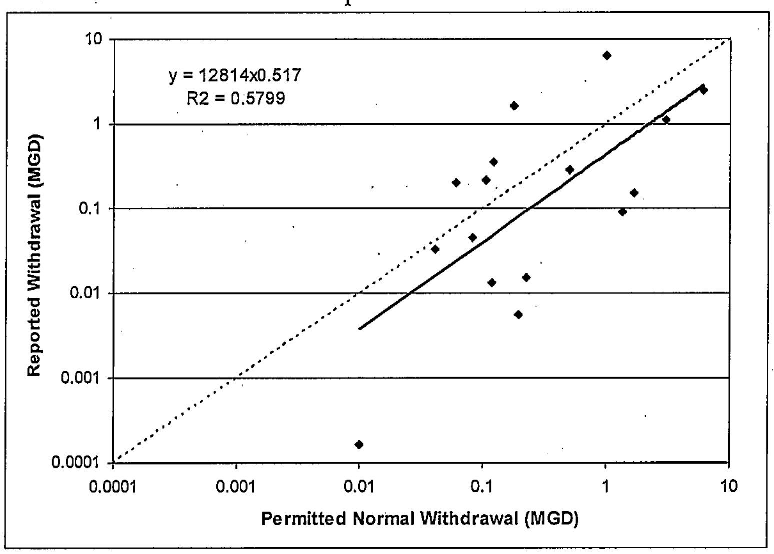
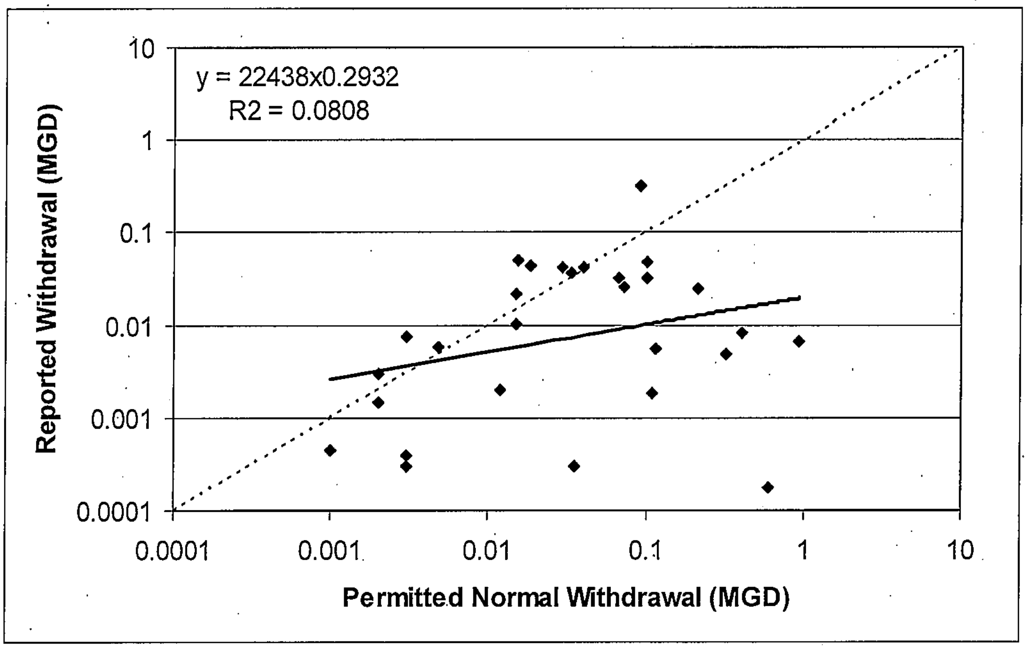
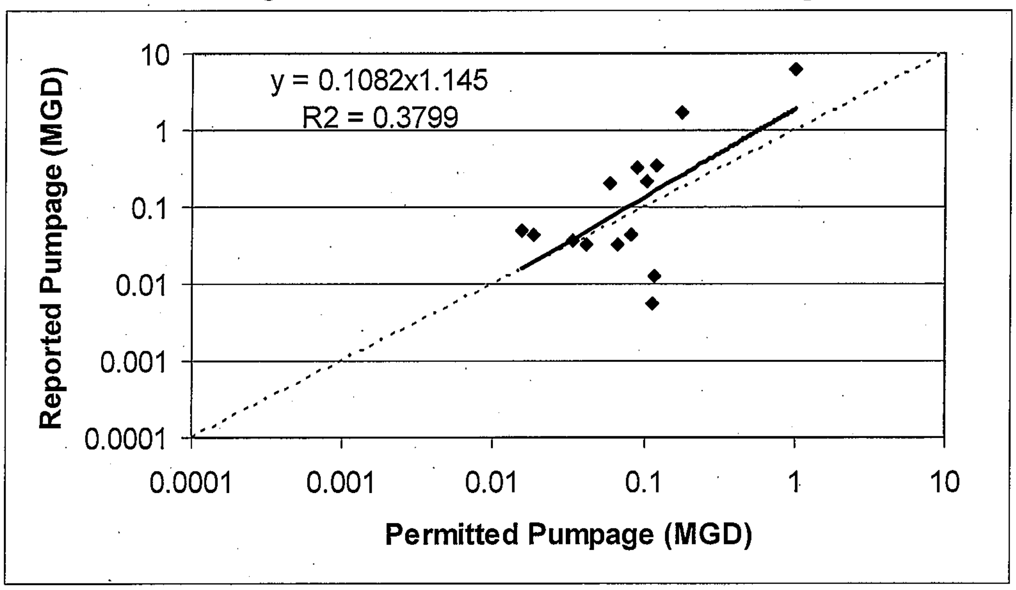


Figure F-6. Permitted versus reported pumping, Waukesha Co. Note the log scale; n = 28. Dashed line shows line of equal values.



In Figure F-7 permitted pumping is compared to pumping reported by survey respondents for irrigation wells only. The graph indicates that the majority or irrigators report pumping more water than permitted.

Figure F-7. Permitted versus reported pumping at irrigation wells, Sauk and Waukesha Counties. Note the log scale; n = 14. Dashed line shows line of equal values.



The series of graphs below were developed to further evaluate the use of the database to estimate pumping for the largest users because the database may be useful if the permitted value is in reasonable agreement with the reported water use for the largest users. In these graphs, data fall near a value of 1 on the y-axis if the permitted volume is close to the reported volume. If the permitted rate exceeds the reported rate, data plot above 1. Data plot below 1 if the permitted value is less than the owner/operator survey response. These graphs demonstrate that permitted values of pumping most often exceed the reported rate, especially for wells permitted to pump in excess of 0.1 mgd.

Figure F-8. Comparison of permitted to reported pumping, all wells in Sauk and Waukesha Counties, n = 44.

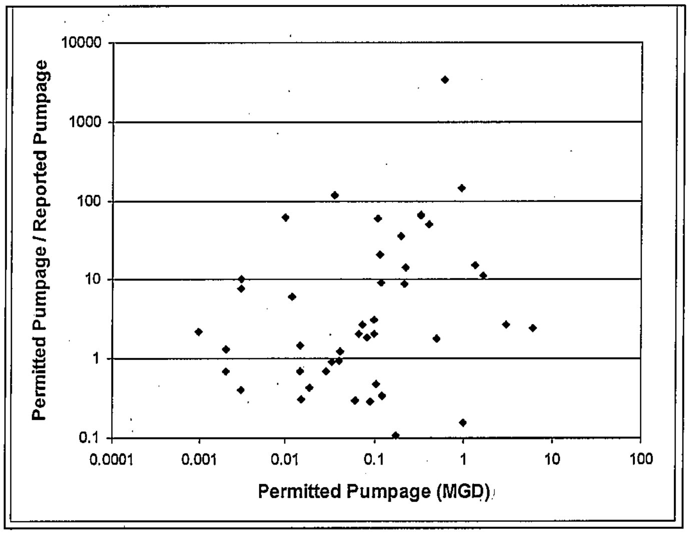


Figure F-9. Comparison of permitted to reported pumping, all wells in Sauk County, n = 16.

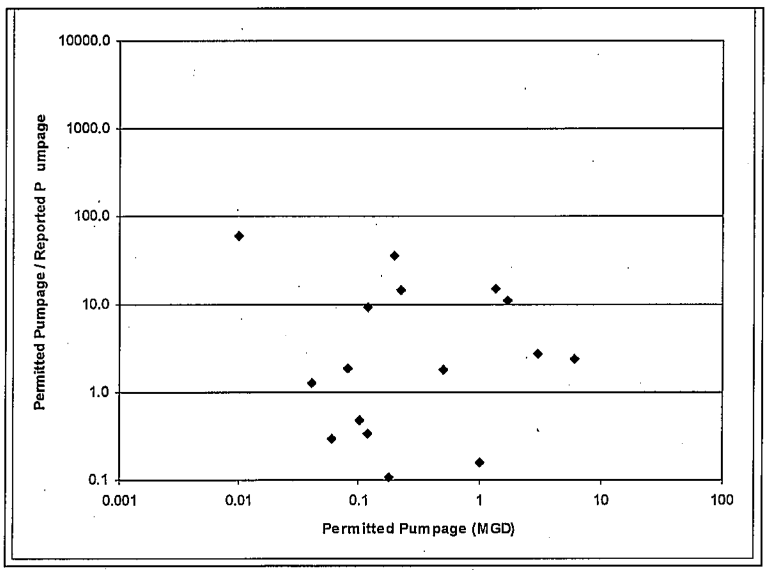
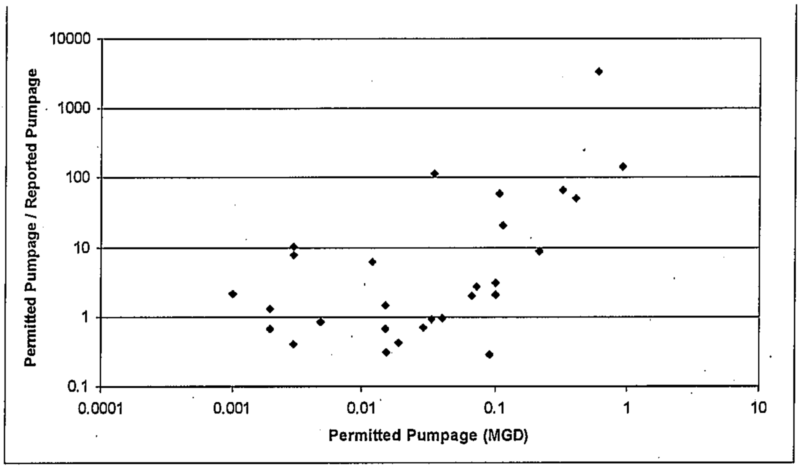


Figure F-10. Comparison of permitted and reported pumping, all wells in Waukesha County, n = 28.



Conclusions with respect to use of the DNR high-capacity well database to estimate pumping

The database is not accurate with respect to wells in use; the database incorrectly described the number of wells in use in 43% of the test cases (28 of 65). This suggests that a random sampling method to estimate pumping (see for example, NRC 2001) is not currently feasible in Wisconsin because the total number of wells is not known with an acceptable degree of certainty. Focusing additional surveys and data collection efforts on the number of wells, and which ones, in use at each high capacity property largest by volume permit holders could substantially improve the database as a resource for tracking groundwater pumping.

The permitted pumping rates in the database generally overestimate reported pumping by the largest permitted users. Use of the permitted pumping rates in an estimate of water use would over-estimate groundwater withdrawals. Focusing additional surveys on the largest by volume permit holders could substantially improve the database as a resource for water use estimates.

APPENDIX G: GOLF COURSE IRRIGATION

Golf course irrigation water use was estimated by counting the number of golf courses and the number of holes at each course in Sauk and Waukesha Counties. Our primary source for this was an internet site: <http://wisconsingolfonline.com>. We cross checked these lists with the WDNR high capacity well database to determine which courses have self-supplied groundwater. We attempted to contact courses in Waukesha County that did not appear to have records of wells in the DNR high capacity well database to determine if the course is irrigated with groundwater.

A range of estimates of pumping at courses with self-supplied groundwater irrigation water was obtained using three application rates. Tom Schwab, manager of the O.J. Noer Turf Grass Research & Education Facility, provided Cheryl Buchwald of the U.S. Geological Survey with maximum and minimum irrigation rates of 10 to 12 million gallons per year per 18 hole course. The course operator at Songbird Hills Golf Course responded to our water use survey with an estimated water use of 16 million gallons per year, or 0.89 million gal/year per hole. This range of estimates may reflect a range in irrigation rates over years with high and low summer precipitation.

Table G1. Golf courses and estimated water use

	Number of [3]		Irrigation Rate (mgal/year/18 hole course)		
County	**Courses**	**Holes**	**10[2]**	**12[2]**	**16[1]**
Sauk	9	171	0.26 mgd	0.31 mgd	0.42 mgd
Waukesha	21	405	0.62 mgd	0.74 mgd	0.99 mgd

Rates are reported as the total million gallons/day (mgd) applied in each county.

[1]Estimate of 16 mgal/yr based on survey response from Songbird Hills Golf Course

[2]Estimate 10 to 12 mgal/year for 18-hole course based on Turf Management reference

[3]Number of courses and holes in each county are those using self-supplied groundwater for irrigation purposes

APPENDIX H: AGRICULTURAL IRRIGATION

This estimate is based on the number of acres in irrigated agricultural land in each county reported by the US Department of Agriculture. These estimates are independent of crop type and weather, which likely have a significant impact on the volume of irrigation applied across the state each year.

Table H-1.

Estimate of groundwater pumped for agricultural irrigation Sauk and Waukesha Counties application rate is averaged over one year to yield an estimate in million gallons per day

County Sauk	Irrigated land[4] Acres	1262[1] (mg/d)	1008[2] (mg/d)	830[3] (mg/d)	County Waukesha	Irrigated land[4] acres	1262[1] (mg/d)	1008[2] (mg/d)	830[3] (mg/d)
2002	12470	15.737	12.570	10.350	2002	769	0.970	0.775	0.638
1997	10110	12.759	10.191	8.391	1997	1173	1.480	1.182	0.974
1992	8034	10.139	8.098	6.668	1992	4220	5.326	4.254	3.503
1987	8530	10.765	8.598	7.080	1987	3238	4.086	3.264	2.688
1982	6316	7.971	6.367	5.242	1982	NA	NA	NA	NA
1978	7137	9.007	7.194	5.924	1978	6553	8.270	6.605	5.439
1974	5183	6.541	5.224	4.302	1974	1535	1.937	1.547	1.274
1969	556	0.702	0.560	0.461	1969	442	0.558	0.446	0.367
1964	84	0.106	0.085	0.070	1964	541	0.683	0.545	0.449
1959	43	0.054	0.043	0.036	1959	130	0.164	0.131	0.108
1954	1	0.001	0.001	0.001	1954	121	0.153	0.122	0.100
1949	0	0.000	0.000	0.000	1949	78	0.098	0.079	0.065

[1]1262 gal/day/acre from Curwen and Massie, report an average rate that is not crop or weather specific
[2]1008 gal/day/acre from survey response from Hartung Brothers, average of rates applied to corn and soybeans in 2005 growing year
[3]830 gal/day/acre average rate of application, reported by RMT Inc. based on DNR pumping records from 1999 to 2003
[4]acres in irrigated crops provided by email on October 9, 2006 by Audra Hubbell, USDA, NASS- Wisconsin Field Office, (608) 224-4836

The three application rates shown above are in good agreement with that reported by another survey respondent, Koepke Farms, of 1083 gal/day/acre.

A second method of estimating agricultural irrigation is based on the number of irrigation wells reported in the DNR high capacity well data base (Appendix F). This method suffers from the uncertainty of the database accuracy with respect to the number of wells, the number of wells in use, and the number of acres each well irrigates (these factors in addition to the crop type and precipitation, as noted for the method above). Krohelski (1986, Estimated use of ground water for irrigation in Wisconsin, USGS WRI 86-4079) used the number of irrigation wells and multiplied by an average pumping rate (11.6 million gallons per year, or 0.032 million gallons per day) he measured at wells across the state. Based on this approach and the number of irrigation wells reported in 2003 in the high capacity well database, approximately 3.24 mg/d were pumped from 102 active wells in Sauk County and 0.73 mg/d were pumped from 23 irrigation wells in Waukesha County. This method yields consistent with the method above for 2002 irrigation in Waukesha County. This method yields significantly lower results for Sauk County with respect to the method above. One cause could be under-reporting of new high capacity irrigation wells to the DNR or installation of irrigation wells that do not require high capacity permits.

APPENDIX I: DISCHARGE DATA AND RETURN FLOW ESTIMATES

These data are 2005 discharge volumes reported to the Wisconsin Department of Natural Resources by Wisconsin Pollutant Discharge Elimination System (WPDES) permit holders (personal communication, Gail S. Mills, Wisconsin DNR, August 2006). Storm-water discharge volumes are not included.

Table I-1. Waukesha County

WPDES permit number	Facilities in Waukesha County	Discharge type	Average discharge (mgd)
0023469	BROOKFIELD, CITY OF	Surface Water	7.216
0032026	DELAFIELD HARTLAND POLLUTION CONTROL COMM	Surface Water	1.670
0021351	DOUSMAN WASTEWATER TREATMENT FACILITY	Surface Water	0.227
0020265	MUKWONAGO WASTEWATER TREATMENT PLANT		0.769
0029998	NEW BERLIN PUBLIC SCHOOLS		0.012
0021181	OCONOMOWOC WASTEWATER TREATMENT PLNT		2.189
0053627	PABST FARMS INC	Surface Water	0.019
0020559	SUSSEX WASTEWATER TREATMENT FACILITY	Surface Water	1.845
0029971	WAUKESHA CITY	Surface Water	8.700
0060267	WI DOC ETHAN ALLEN SCHOOL WWTF	Land Treatment	0.024
		total:	**22.672**

Note: discharge reported as million gallons per day (mgd)

Table I-2. Sauk County

WPDES permit number	Facilities in Sauk County	Discharge type	Average discharge (mgd)
0043974	BADGER ARMY AMMUNITION PLANT	Land Treatment	0.049
0043974	BADGER ARMY AMMUNITION PLANT	Surface Water	2.448
0051781	CARR VALLEY CHEESE FACTORY INC	Land Treatment	0.002
0050245	CEDAR GROVE CHEESE FACTORY	Surface Water	0.008
0000035	FOREMOST FARMS USA REEDSBURG	Surface Water	0.154
0057738	LAKESIDE FOODS INC. - REEDSBURG PLANT	Surface Water	0.295
0057738	LAKESIDE FOODS INC. - REEDSBURG PLANT	Surface Water	0.314
0057738	LAKESIDE FOODS INC. - REEDSBURG PLANT	Surface Water	0.298
0057738	LAKESIDE FOODS INC. - REEDSBURG PLANT	Surface Water	0.327
0057738	LAKESIDE FOODS INC. - REEDSBURG PLANT		0.221
0057738	LAKESIDE FOODS INC. - REEDSBURG PLANT		0.238
0059404	SAPUTO CHEESE USA INC REEDSBURG	Surface Water	0.055
0004421	TEEL PLASTICS CO INC	Surface Water	0.154
0004421	TEEL PLASTICS CO INC	Surface Water	0.109
0004421	TEEL PLASTICS CO INC	Surface Water	0.091
0060241	WI DNR DEVILS LAKE STATE PARK	Surface Water	1.32
0020605	BARABOO WASTEWATER TREATMENT FACILITY	Surface Water	1.694
0031801	CAZENOVIA WASTEWATER TREATMENT FACILITY	Surface Water	0.102
0036048	PLAIN WASTEWATER TREATMENT FACILITY		0.077
0036064	CHRISTMAS MOUNTAIN SANITARY DISTRICT WWTF	Land Treatment	0.135
0036064	CHRISTMAS MOUNTAIN SANITARY DISTRICT WWTF	Land Treatment	0.024
0060968	DEVILS HEAD RESORT & CONVENTION CENTER WWTF		0.027
0035483	HILLPOINT SANITARY DISTRICT WWTF	Surface Water	0.033
0049824	HO-CHUNK NATION WWTF	Land Treatment	0.048
0028878	LA VALLE WASTEWATER TREATMENT FACILITY	Surface Water	0.023
0036447	LIME RIDGE WASTEWATER TREATMENT FACILITY	Surface Water	0.009
0029114	LOGANVILLE WASTEWATER TREATMENT FACILITY	Surface Water	0.026
0061042	MERRIMAC WASTEWATER TREATMENT FACILITY	Land Treatment	0.03
0028011	NORTH FREEDOM WASTEWATER TREATMENT FACILITY	Surface Water	0.031
0020371	REEDSBURG WASTEWATER TREATMENT FACILITY		1.553
0029041	ROCK SPRINGS WASTEWATER TREATMENT FACILITY	Surface Water	0.023
0030929	SAUK COUNTY HEALTH CARE CENTER WWTF	Surface Water	0.194
0060534	SAUK PRAIRIE SEWERAGE COMMISSION WWTF	Land Treatment	0.821
0060801	SPRING GREEN WASTEWATER TREATMENT FACILITY	Surface Water	0.197
0031402	WI DELLS LK DELTON SEWERAGE COMMISSION WWTF	Surface Water	1.495
		total:	**12.624**

Note: discharge reported as million gallons per day (mgd)