PUBLIC REVIEW DRAFT

Dane County Groundwater Protection Planning Framework

Appendix G: Groundwater Element Of the Dane County Water Quality Plan

Adopted

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Chapter 5: Inventory of Potential Pollution Sources 164

Chapter 6: Groundwater Management 206

Chapter 1: Introduction

Background

In the 1960s and 1970s, national environmental concerns focused mainly on natural resources and pollutants that could be easily seen and monitored. Generally, government agencies and the public were less concerned with groundwater since, hidden from view, there was little recognition of how seriously this resource was jeopardized. In the 1980s, however, the importance of groundwater emerged as pollution incidents were exposed across the nation. As groundwater contamination has increased in the public eye, there has been a growing concern about the health implications of tainted drinking water. As concerns have increased, so have demands for expanded protection of groundwater. With greater emphasis on groundwater protection at the national and statewide level, funding and technical resources have been directed to promote increased state and local management.

The *Dane County Groundwater Protection Plan* was originally developed and adopted as the "Groundwater Element" of the *Dane County Water Quality Plan* in 1987 and updated in 1999. This 2014 framework incorporates new information and tools developed since 1999. Current information on groundwater location and flow, pollution sources, quality conditions, and management controls are presented. The document also promotes strategies to improve the protection of this critical resource now and into the future. The Dane County Groundwater Protection Planning Framework is intended to provide the basis for more detailed evaluations and strategic planning at the local level.

Purpose

The Dane County Groundwater Protection Planning Framework was developed to identify and recommend management actions to address existing and potential groundwater quality and quantity issues in Dane County. This document is an element (Appendix G) of the *Dane County Water Quality Management (WQM) Plan*, developed under federal and state law since 1987. The WQM Plan and particularly this Groundwater Element are maintained and updated with a consortium of partners and stakeholders to help garner all available information, resources, and management alternatives to help ensure the long-term integrity of aquatic resources in the county.

Objectives

The objectives of this groundwater protection framework mirror the goals and objectives of the larger Dane County WQM Plan and include:

- Identify and characterize the location of groundwater and related physical resources (soils, geology, water table depth, springs, etc.).
- Evaluate, characterize and portray existing groundwater quality and quantity data for the county.
- Inventory and assess existing and potential pollution sources in Dane County.
- Describe and evaluate existing federal, state, and local programs that pertain to groundwater management.
- Recommend groundwater protection strategies to improve groundwater management and prevent groundwater pollution.
- Evaluate alternative management strategies for addressing groundwater quantity issues.
- Provide regional water supply planning information for subsequent water supply planning purposes required under Wis. Stats. 281.348.

- Create and share new products including Zone of Contribution and Groundwater Contamination Risk maps.
- Introduce the use of groundwater budget indices and fish response curves to assess the sustainability of local water supply plans within a regional framework

This Dane County Groundwater Protection Planning Framework provides the basis for more detailed evaluations and strategic planning at the local level.

Summary

Dane County is fortunate to have an adequate supply of high quality groundwater. Groundwater is the source of all public and domestic water supplies. Protection of groundwater resources is critically important. However, groundwater pollution sources and threats are present. Identifying and putting into place better pollution prevention and resource management practices has long been recognized as a need. An inventory and assessment of physical resource conditions, water quality data, pollution sources and existing groundwater management controls provide the core of this plan. Based on the groundwater assessments, specific management actions are proposed to safeguard the groundwater resource of Dane County.

Inventory work for this document raised concerns in several areas, notably:

- High nitrate-nitrogen levels (above the recommended drinking water standard) in a significant percentage (25%) of private wells in the county;

- Increasing salt levels (concentrations) in municipal wells;

- Organic chemical detections in some water supply wells near abandoned landfills and underground storage tanks;

- A general lack of information on, and monitoring of, the possible effects of emerging pollutants (e.g., pharmaceuticals, personal care products, endocrine disrupters);

- Lack of rigorous enforcement in regulating land disposal of septage;

- Reductions in ground and surface water levels due to high-capacity well water withdrawals.

The following management actions are recommended to address groundwater concerns in the region:

- Utilize information, tools, and guidelines identified in this plan for decisions involving site approvals or permits that could impact groundwater in Dane County (e.g., well proposals, WPDES permits, land application of waste, rural subdivisions, among other land use decisions or inquiries);

- Promote effective local wellhead protection programs and source water protection plans for all municipal wells in Dane County;

- Increase monitoring of existing and potential pollution sources, particularly in geologically sensitive areas and in areas most likely to affect municipal water supplies;

- Provide information, guidelines, and sources for more information to rural homeowners regarding household hazardous waste use and disposal, maintaining onsite septic systems, and testing drinking water;

- Increase County and UW-Extension training and education for farmers, landowners, and commercial applicators on pesticide use and fertilizer application by the use of integrated pesticide management and nutrient management planning;

- Consider providing an expanded role for the Department of Health – Madison and Dane County in the approval of septage land disposal sites;

- Reduce the use of road salt by local units of government, homeowners, motorists, and commercial applicators in part through the Wisconsin SaltWise Partnership;

- Support an ongoing proactive and collaborative regional groundwater planning and management framework among Dane County communities to address water availability and sustainability issues.

  More specifically, CARPC recommends that its staff:

  a. Support the conduct of water supply service area planning required by Wis. Stats. 281.348.

  b. Assist municipalities and resource management agencies incorporate and utilize information, tools, and guidelines in this plan in decisions involving land use, site approvals, or permits that may impact groundwater.

  Decision areas may include but are not limited to well proposals; WPDES permits discharging to groundwater, biosolids and septage land spreading sites; stormwater infiltration; sanitary landfills; large manure storage lagoons or feedlots; large unsewered subdivisions; prioritization of remediation sites and monitoring.

  c. Assist municipalities and resource management agencies provide public information, education, and technical resources to citizens and landowners concerning groundwater quality protection and management throughout the region.

Literature Review and Data Sources

This plan is based on available data on pollution sources, water quality and physical resource features. Existing data and literature were reviewed from numerous agency sources including the documents, publications and online materials from the Wisconsin Department of Natural Resources (WDNR), the Department of Agriculture, Trade and Consumer Protection (DATCP), and the Wisconsin Geological and Natural History Survey (WGNHS), as well as personal communications with state and local agency staff.

The most comprehensive reference regarding the groundwater resource in Dane County came from reports developed from the Dane County Regional Hydrologic Study. The interagency Dane County Regional Hydrologic Study, started in 1992 and completed in 1997, was conducted to provide information on the impact of urban development, well pumping and wastewater diversion on lakes, streams, wetlands and groundwater in Dane County. This work is part of ongoing collaborative work among the Capital Area Regional Planning Commission (RPC), the Wisconsin Department of Natural Resources (WDNR), the Wisconsin Geological and Natural History Survey (WGNHS), the U.S. Geological Survey (USGS), and other state and local governments. Information from the original model has been augmented with a more sophisticated and improved regional groundwater model coordinated and sponsored by CARPC and completed in 2014. This updated model builds on research and studies conducted since the original model was first developed in the 1990s.

Information developed from the Regional Hydrologic Study, including the ground and surface water models, provide modern computer technology output to assist planning activities and management decision-making. As part of the original work, the groundwater flow model was used to simulate: changes in groundwater levels due to pumping and urban development; identify groundwater recharge and discharge areas; provide estimates of the direction and rates of groundwater movement; delineate sources of municipal water; and better define ground and surface water relationships in Dane County.

A Yahara Lakes Reservoir Routing model was also used to simulate and specify lake levels and operating conditions to achieve the desired goal of restoring pre-diversion baseflow conditions through the Yahara River system.[1] Groundwater Contamination Risk Maps were developed to rate the relative susceptibility or risk (extreme, high, moderate, low) of groundwater contamination from surface and subsurface pollution sources. More recently, an Ecological Limits of Hydrologic Alteration (ELOHA) model was developed which correlates reductions in baseflow and increases in runoff due to urban development (specifically high capacity well withdrawals and groundwater recharge loss, respectively) with the biologic health in streams. Groundwater Budget Indices have also been developed to aid in developing and assessing water supply plans in Dane County, as required by state statute.

Findings from the Regional Hydrologic Study, and associated spinoff research projects, provide clear evidence that aggressive management of ground and surface waters is essential to preserve streams, lakes, wetlands, and drinking water supplies in the county. Fortunately, most of Dane County's surface and groundwater originate locally, so resource agencies potentially have the unique ability to maintain and protect these waters. The models, maps and reports described in this plan provide management tools to better understand and evaluate the effects of water and land use decisions and to develop management strategies that avoid and possibly mitigate adverse ground and surface water impacts.

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[1] In 1959, groundwater pumped by municipalities and treated by the Madison Metropolitan Sewerage District (MMSD) was diverted around the Yahara Lakes System from its original location on Nine Springs Creek, to its present discharge point on Badfish Creek. Mean annual flow in the Yahara River was reduced by nearly one-third.

Chapter 2: The Groundwater Resource

Physical Setting

Dane County is an area of geologic and geographic contrasts. The eastern part of the county is a slightly rolling plain of low hills interspersed with wetlands drained by sluggish streams and man-made ditches. The western part of the county has steep valleys and ridges drained by fast flowing, spring-fed streams. In the center of the county is the Yahara River with its large scenic lakes and adjacent marshes. These geographic differences may be explained by the geologic history and physiography of the area, **Map 1**.

The bedrock in the county is comprised of many layers of sandstone and dolomite (up to 1,700 feet thick) formed from sediments deposited by an ancient sea 420 to 600 million years ago. Under these layers of sedimentary rock is an even older crystalline rock, mostly rhyolite, granite, and basalt. The crystalline rock allows little water penetration, and forms a floor under the water-bearing sedimentary rocks. All the sedimentary rocks can contain water in places where they are below the water table, and all these units form aquifers in some parts of Dane County. The ancient sea that deposited the sedimentary rocks disappeared millions of years ago when geological forces raised the land in Wisconsin above sea level. A well-developed drainage pattern had been cut into the sedimentary rock when the climate changed about 70,000 years ago and glaciers began to be formed in the northern portions of the continent. At least four glaciers moved across what is now Wisconsin. The last glacier reached the Dane County area from 14,000 to 18,000 years ago.

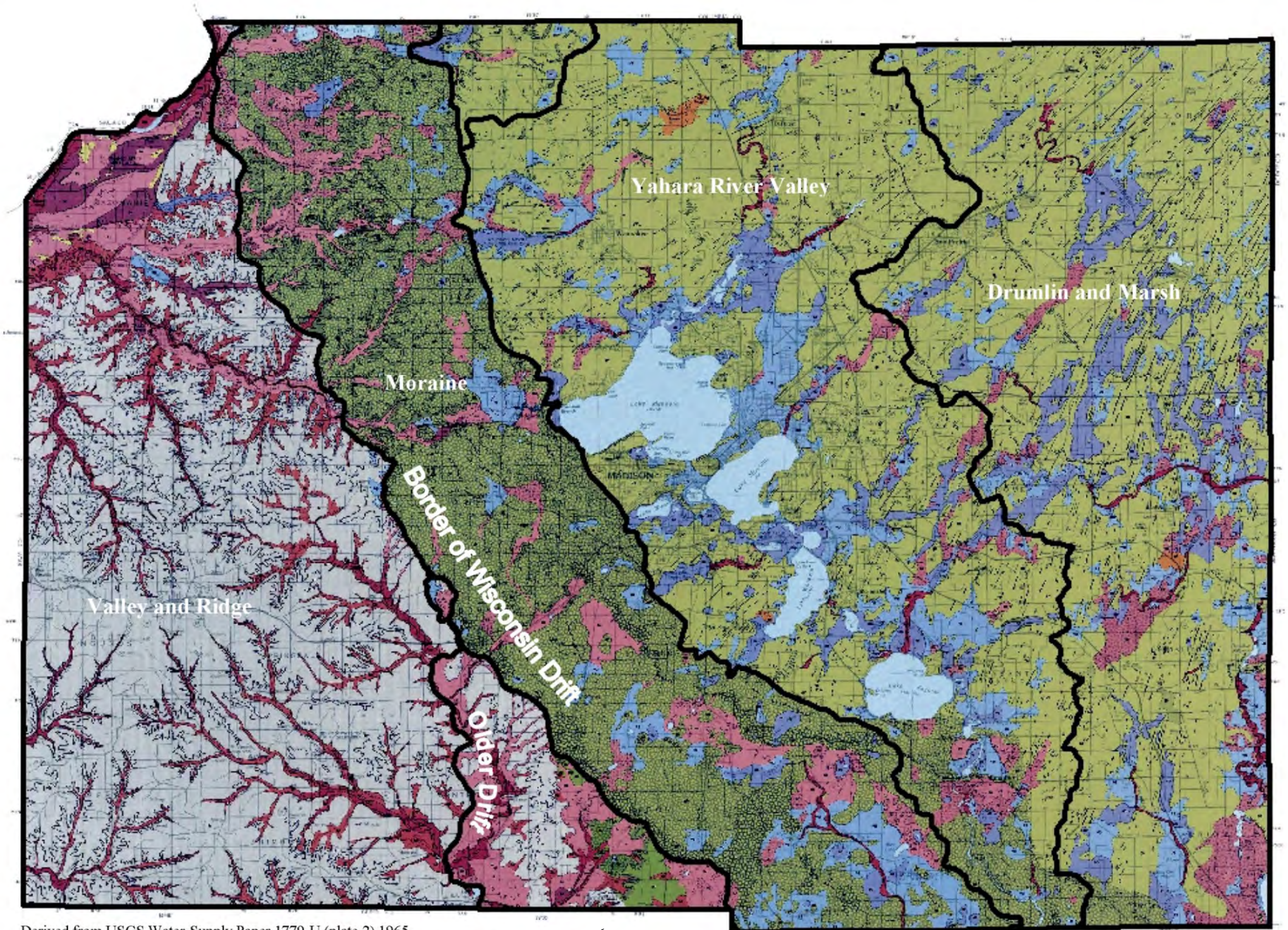
The western third of Dane County is part of the driftless area -- an area that was not covered by the most recent Wisconsin glaciation. The forces of wind and water have eroded the bedrock in this area into steep ridges and valleys drained by fast- flowing streams. Most of the streams are fed by springs and seeps, which flow from water-bearing layers of sandstone or dolomite exposed along the hillsides. An irregular layer of soil formed from the disintegration of the bedrock or blown in from the western plains covers the hills. In many places there is only a thin layer of soil with moderate or moderately slow permeability over fractured dolomite and sandstone.

The large valley of the Wisconsin River and its benches have deep alluvial deposits of sand and gravel with some organic material. The soil along the river valley is mostly poorly-drained sand with organic inclusions. This area is subject to seasonal high water tables and frequent flooding. Poorly-drained silty soils with mineral and organic material are also found in lowlands along some of the smaller streams. The benches and outwash terraces along the streams have well-drained to excessively drained silty or sandy soils underlain by sand and gravel.

On the eastern edge of the driftless area are numerous moraines – a band of hills made up of debris which was scraped up by the glacier and left behind when the ice melted. There are two main moraines in Dane County: the terminal moraine or Johnstown moraine at the far eastern edge of the glaciated area, and the recessional moraine or Milton moraine which formed when the glacier stopped retreating and dumped unstratified and unsorted clay, silt, and boulders with sand lenses. The moraines once included blocks of ice left behind by the glacier. These blocks melted, leaving pot holes or kettles, some of which remain as small ponds, marshes, and bogs. The moraines are a drainage divide where many of the headwater streams of the Yahara River, Sugar River, and Wisconsin River watersheds are located.

East of the moraines, in the center of the county, is the Yahara River Valley. In this area glacial deposits, over 350 feet deep in some places, dammed up large pre-glacial valleys, forming a chain of large lakes and wetlands. The formation of peat in these wetlands seems to have been rapid. Today the peat deposits are extensive and deep, reaching over 90 feet deep in some spots.

Map 1. Physiographic Areas and Deposits of Pleistocene Age in Dane County, WI



Derived from USGS Water-Supply Paper 1779-U (plate 2) 1965.
For more detailed information see Pleistocene Geology of Dane County, WI. (WGNHS Bull. 95, 1997)

In many places, an aquifer in the bedrock of adjacent hills supplies springs that maintain high water levels in the peat and assist peat formation. The streams of this area of the county are slower flowing than the streams of the driftless area, and fewer are spring fed.

Farther east, the glacier filled the flatter watersheds of smaller pre-glacial streams, and the resulting lakes and wetlands are much shallower. The wetlands in this part of the county are interspersed by drumlins - long, low, whale-back shaped parallel hills which formed as the glacier advanced and retreated, flowing over piles of material, which it had deposited earlier. In addition to creating drumlins, the glacier deposited a sheet of debris 25 to 100 feet deep over most of the landscape when it retreated. The glacial deposits blocked old drainageways creating an extensive system of interconnected wetlands with a poorly defined drainage pattern. Small streams wind slowly through the lowlands. Since the groundwater contribution from the glacial deposits is minimal, there are few springs in this part of the county, and stream flow is primarily very dependent on overland runoff. During the summer months, the water level in these streams may be very low. The only lakes in this part of the county are small stream impoundments and shallow marshy lakes.

Climate

The climate of Dane County is typical of the Great Lakes states. Winters tend to be cold and snowy, while summers are sometimes humid. Average annual precipitation is about 34.5 inches, with 67% falling from April through September. Average groundwater recharge in Dane County is estimated to be 9 to 10 in/yr; however, this varies by location from 5 to 15 in/yr, with the highest rates in the southeast part of the county. Most recharge occurs in late fall, and early spring when vegetation is dormant and evapotranspiration is minimal. Runoff and evapotranspiration vary widely due to seasonal conditions and land use. June is the wettest month with 4.5 inches of precipitation (1981-2010[1]), and January is the driest with about 1.2 inches. About 83% of the precipitation events are half an inch or less. Snowfall averages 51 inches per year. The ground usually begins to freeze at the end of November and thaws in mid-April. The potential for runoff and severe erosion is often highest in March and early April when heavy rainstorms and snowmelt occur on ground sparsely covered by dead vegetation. Climate change studies and historical data suggest changes in intensity and timing of precipitation have already occurred in our region, and additional changes are expected.

Hydrogeology

Groundwater, compared to other physical resources, is not easy to comprehend because it is not readily seen. To dispel popular myths (such as groundwater existing as underground streams) a better public understanding of groundwater is necessary. Groundwater is just one component of the full water cycle, which provides fresh water to our planet (**Figure 1**).

Water beneath the land surface may be classified into two major zones – the unsaturated and saturated zones (**Figure 2**). The unsaturated zone consists of small openings partially filled with water and partially filled with air. In the soil layer of the unsaturated zone plant roots are present and the greatest amount of biological activity takes place. Many introduced chemicals may be broken down (or *attenuated*) by chemical, physical and biological processes. The soil zone is only three to six feet deep, but it is often the most important layer in determining the fate of pollutants spread on the land surface and resulting groundwater quality. An intermediate layer lies below the soil layer, which varies in thickness from place to place. Although less biological activity takes place there, pollutants may be further attenuated by physical and chemical processes.

[1] Source: National Centers for Environmental Information, http://www.aos.wisc.edu/~sco/clim-history/sta-data/msn/MSN-monthly/GHCND_USW00014837_2010-1-1.pdf

Figure 1

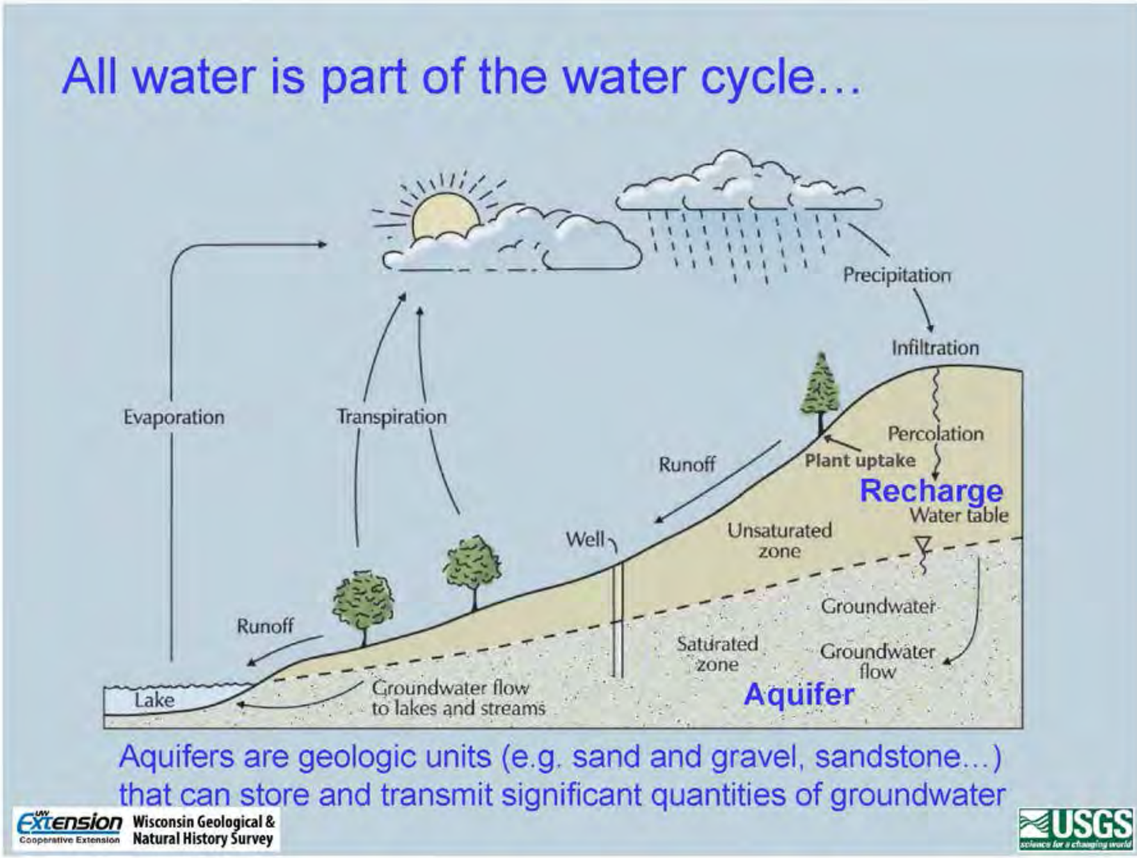
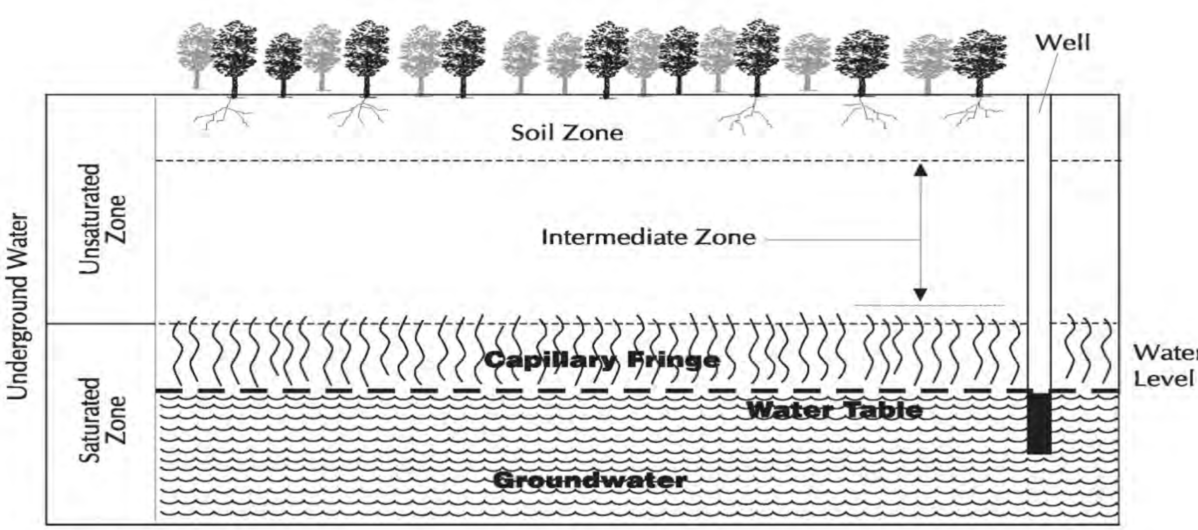


Figure 2

Shallow Groundwater Zones



Source: Heath, 1983.

Groundwater is found in saturated rock and soil formations below the unsaturated area. Aquifers occur where such saturated formations will yield usable amounts of water to a well. These formation may be *consolidated* bedrock, often limestone or sandstone, or *unconsolidated* deposits of sand, silt, and gravel. Water is stored in void spaces between the rock or soil particles.

Groundwater is comprised of the portion of rainfall that does not run off to streams and rivers and that does not evaporate or transpire from plants. This water percolates down through the soil until it reaches the saturated zone of an aquifer. This process is called *aquifer recharge.*

Unconfined or surficial aquifers occur where only unsaturated porous material overlies the saturated formation. In such cases, the upper surface of the saturated zone is called the *water table*. The water table generally follows the contours of the overlying terrain and can be determined by mapping the water levels in wells tapping the surficial aquifer. Because pollutants move with the groundwater as it flows, the important aspects of this zone are the direction and rate of groundwater flow.

Aquifers may also be bounded at the top and bottom by relatively impermeable formations called *confining beds* (or *aquitards*), typically of clay or shale. These are called *confined* aquifers. Water in these aquifers may be under greater-than-atmospheric pressure, raising water levels in wells above the top of the aquifer, thus creating an *artesian aquifer*. Wells in these aquifers may flow without pumping, like artesian springs.

When an aquifer is confined, the concept of a "water table" is not used to define its hydrology. Instead a concept called *potentiometric* (or *piezometric*) *surface* is used. It describes the heights (or pressure) that the groundwater reaches in wells tapping the confined aquifer.

Both the water table and the potentiometric surface gradients help define the characteristics of the hydrologic system and the rate and direction of groundwater flow. Under natural conditions, the regional flow of water in aquifers is generally a subdued reflection of the surface topography above. Groundwater recharges all across the landscape, flowing from upland areas to low-lying areas where water discharges to springs, streams, and wetlands. Groundwater discharge is important because it nourishes springs, streams and wetlands, especially during dry summer conditions but also during cold winter months in the case of trout streams.

A summary and analysis of the hydrogeology of Dane County was conducted based on work associated with the Dane County Hydrologic Study, which provides a framework for understanding the groundwater resources in the county.[2] **Figure 3** shows the general arrangement and approximate relative thicknesses of bedrock geologic units across Dane County.[3]

The Mt. Simon aquifer is the most important aquifer in Dane County for the purposes of water supply to high-capacity wells. This aquifer consists of sandstones of the Mt. Simon and lower Eau Claire Formations. The lower boundary of the aquifer is the Precambrian granite surface. The upper boundary is the bottom of the shaley facies of the Eau Claire formation. The aquifer ranges in thickness from about 100 feet to over 700 feet. It is thickest in southern Dane County and thinnest in the northwest and northeast as it approaches the Baraboo Quartzite and Waterloo Quartzite, respectively. The average thickness of the aquifer is about 500 feet.

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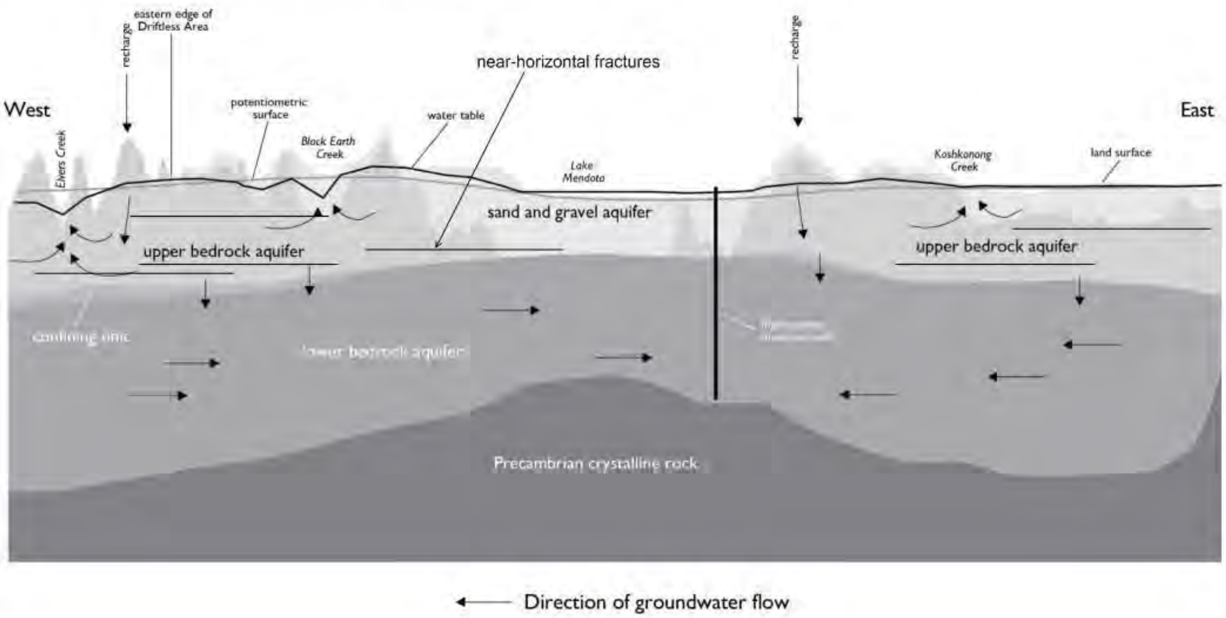
[2] Bradbury, et al. 1999. *Hydrogeology of Dane County, Wisconsin.* WGNHS Open File Report 1999-2004,

[3] Wisconsin Geological and Natural History Survey. 2016. *The 2016 Groundwater Flow Model for Dane County, WI.*

Figure 3. Conceptualized Model of the Groundwater Flow System, Dane County, WI.



GENERAL BEDROCK STRATIGRAPHY — GROUNDWATER FLOW MODEL

Era	Period	Group	Formation	1996 model		2016 model		Type
				1	Sand and gravel	1	Unlithified I (fine-grained lacustrine deposits within the glacial Lake Yahara area)	aquifers
						2	Unlithified II (till and meltwater stream deposits)	
Paleozoic	Ordovician		Maquoketa	2	Upper bedrock	3	Upper bedrock	
		Sinnipee	Galena					
			Decorah					
			Platteville					
		Ancell	Glenwood					
			St. Peter					
		Prairie du Chien						
	Cambrian	Trempealeau	Jordan			4	Jordan	
			St. Lawrence			5	St. Lawrence	
		Tunnel City	Lone Rock, Mazomanie			6	Tunnel City—Upper	
						7	Tunnel City—Mid *(fracture layer)*	
						8	Tunnel City—Lower	
		Elk Mound	Wonewoc			9	Wonewoc—Upper	
						10	Wonewoc—Lower *(fracture layer)*	
			Eau Claire	3	Eau Claire	11	Eau Claire	aquitard
			Mount Simon	4	Mount Simon	12	Mount Simon	aquifer
Precambrian		Various unnamed units		No-flow boundary				

Hydrostratigraphic columns showing the relation of model layers to the general bedrock geology of Dane County, and also showing the differences between the 1996 and 2016 regional groundwater models.

Source: Wisconsin Geologic and Natural History Survey, 2016.

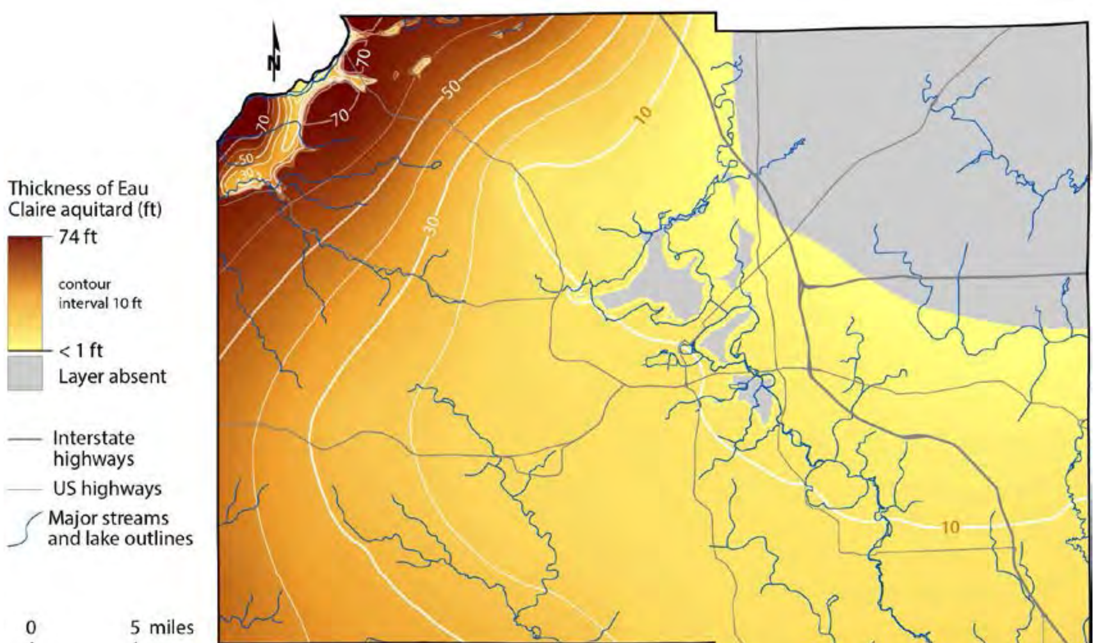
The shaley facies of the Eau Claire Formation forms an important aquitard over much of Dane County, limiting the movement of groundwater between the lower Cambrian sandstones and the upper Paleozoic sandstones and dolomites. The Eau Claire shale formation is up to 70 feet thick in western Dane County, but thins to the east, and is probably absent in the northeastern parts of the county (**Map 2**).

The Eau Claire aquitard appears to be patchy and partially absent in the central Yahara Lakes area, where the preglacial bedrock surface is believed to have been eroded deeply into the underlying Mt. Simon Formation. Where it occurs, the Eau Claire formation helps limit the movement of water between the upper and lower bedrock units.

The Upper Bedrock aquifer consists of all saturated Paleozoic rocks between the top of the Eau Claire aquitard and the bedrock surface. Although the Upper Bedrock aquifer contains a variety of materials ranging in lithology from sandstone to siltstone to dolomite and the hydraulic properties of these materials may be somewhat dissimilar, on a regional scale all these units appear to be hydraulically interconnected. The thickness of the Upper Bedrock aquifer ranges from zero, where it is absent beneath the Yahara Lakes, to over 200 feet in the western part of the county.

The uppermost aquifer is a shallow unlithified aquifer, consisting of saturated unlithified materials primarily of Quaternary age. These materials range in lithology from clayey lake sediment to sand and gravel. The bottom of this aquifer unit is the bedrock surface, and the top of the aquifer unit is the water table. The saturated thickness of these materials ranges from zero to over 300 feet. Due to the heterogeneity of these materials in Dane County, the materials have been further divided into several aquifer types.[4] The most permeable parts of this aquifer occur in river valleys, such as lower Black Earth Creek, and along the Wisconsin and Yahara Rivers. This aquifer is unconfined in some places and in others is confined by clayey lake sediment.

Map 2. Lateral Extent of the Eau Claire Aquitard in Dane County.



Source: Wisconsin Geological and Natural History

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[4] Fritz, A. 1996. *Aquifer Contamination Susceptibility of Dane County, Wisconsin.* Master's thesis. University of Wisconsin, Madison.

Groundwater Recharge

All groundwater in Dane County originates as precipitation (rainfall and snowmelt) in or just outside of the county. Groundwater recharge is the addition of water to the water table. Knowledge of the location of groundwater recharge areas and the rates of groundwater recharge is essential for groundwater flow models and for water resources planning.

For example, impervious urban development in Dane County can have an adverse effect on groundwater resources. The problem is caused by the replacement of farmland or open space with impervious areas such as rooftops, parking lots, streets and sidewalks. These impervious areas prevent the infiltration of rainfall and snowmelt so that groundwater recharge is decreased. Generally, decreases in groundwater recharge (without mitigation) would range from 30 to 70 percent, with increases in flood peaks exceeding 300 percent.[5] To address this issue, stormwater management standards have been implemented to maintain natural recharge rates and minimize dramatic alteration of the hydrologic cycle.

Swanson (1996) attempted an improved delineation of groundwater recharge rates and locations in Dane County based on a combination of mass-balance and water-balance models. The results of this procedure suggest that recharge areas occur over about 48 percent of the total land area of the county. Recharge usually occurs in the higher parts of the landscape, along the crests and flanks of broad ridges. Lower areas of the landscape, including broad floodplains, wetlands, and stream valleys, are more often areas of groundwater discharge. Controls on groundwater recharge include precipitation timing and intensity, topography, vegetative cover, surface roughness, and soil properties, and these parameters are rarely known in detail over large areas.

In 2012, the Wisconsin Geological and Natural History Survey published a report estimating the existing groundwater recharge rates in Dane County based on the soil water balance method. The study found that the groundwater recharge rates generally ranged from 5 to 15 inches per year in Dane County, with the majority of the county being 9 to 10 inches per year as shown in **Map 3.** CARPC has generally recommended that pre-development groundwater recharge rates be maintained based on the WGNHS report (and updates) or by a site specific analysis. Experience has shown that this criterion is generally met when a municipality's stormwater volume control standard is achieved by infiltration practices. Enhanced recharge is also recommended, where circumstances and opportunities permit, to help make up for municipal well withdrawals.

In 2006 the Capital Area Regional Planning Commission developed relative infiltration maps for Dane County. **Maps 20, 21, and 22** (**Reference in Chapter 3**) show various opportunities or strategies that can help minimize the impacts of future development as well as retrofit previously developed areas. The maps are available on the CARPC web site.[6] They are meant to be used as a screening tool to identify relatively high infiltration areas as well as areas that might be enhanced through engineering techniques, such as engineered soils.

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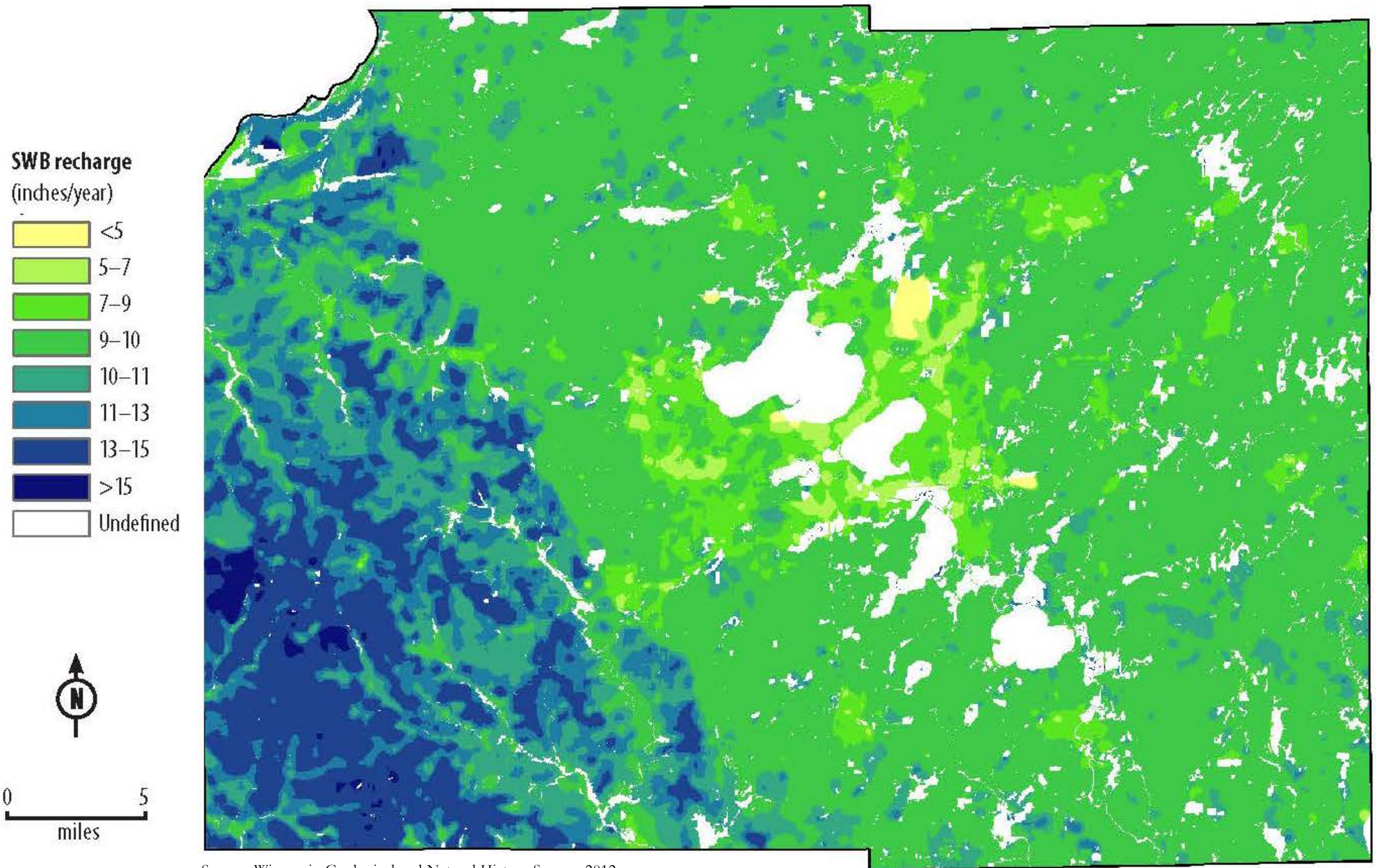
[5] Shaver, et al. 2007. *Fundamentals of Urban Runoff Management: Technical and Institutional Issues.*

[6] http://www.capitalarearpc.org/infiltration.html

Map 3. Groundwater Recharge Map for Dane County.



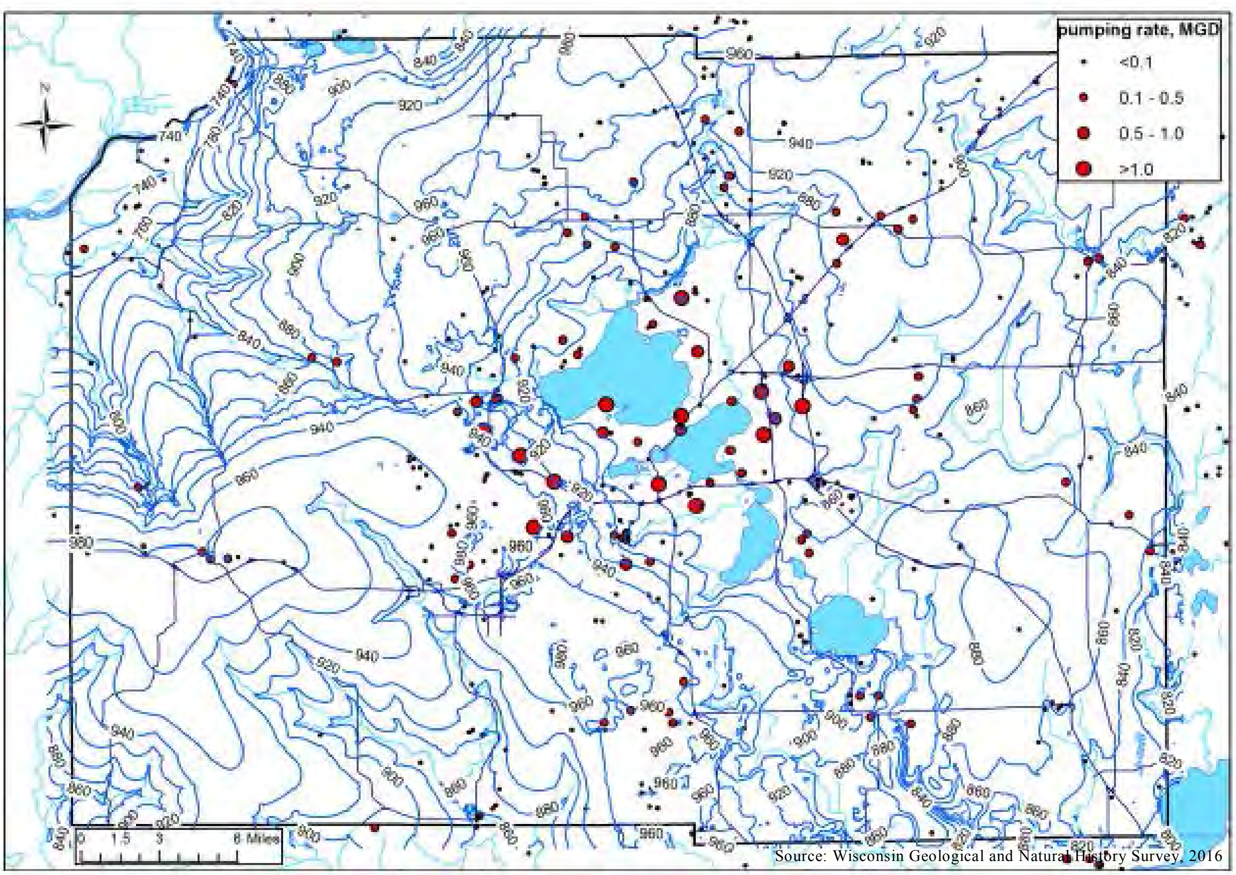
Source: Wisconsin Geological and Natural History Survey, 2012.

Maintaining baseflow discharge to streams and the water supply to springs and wetlands is an important resource objective. The maps promote various opportunities and strategies that can be used to help minimize the impacts of future development and possibly retrofit previously developed areas. Areas with naturally high infiltration potential should be used to recharge the groundwater to the greatest extent possible. They may also be prime locations for regional stormwater facilities that could be used to infiltrate stormwater generated in other parts of the watershed. Other areas, such as clay soils with low permeability, are less suitable for infiltration. Stormwater generated in these areas could be reduced on site to some extent, such as through rain gardens, but the majority will likely need to be routed to facilities down-gradient. These facilities would need to be adequately sized to accommodate the rates and volumes of stormwater generated by the proposed development.

Groundwater Flow Systems

Surface water, shallow groundwater, and deep groundwater are intimately connected in Dane County. Almost all groundwater in Dane County originates as recharge occurring within the County. Most lakes and streams in the county are discharge points for groundwater where the water table intersects the land's surface.

In general, the water table is a reflection of the county's topography. The depth to groundwater in the county ranges from zero at the fringes of lakes and wetlands to over 200 feet beneath the ridges in the southwest. **Map 4** shows the configuration of the water table in Dane County. The water table is highest (nearly 1,000 feet above sea level) in the western part of the county near Mt. Horeb and Blue Mounds, and is lowest (less than 840 feet) along the Yahara River in the southeast.

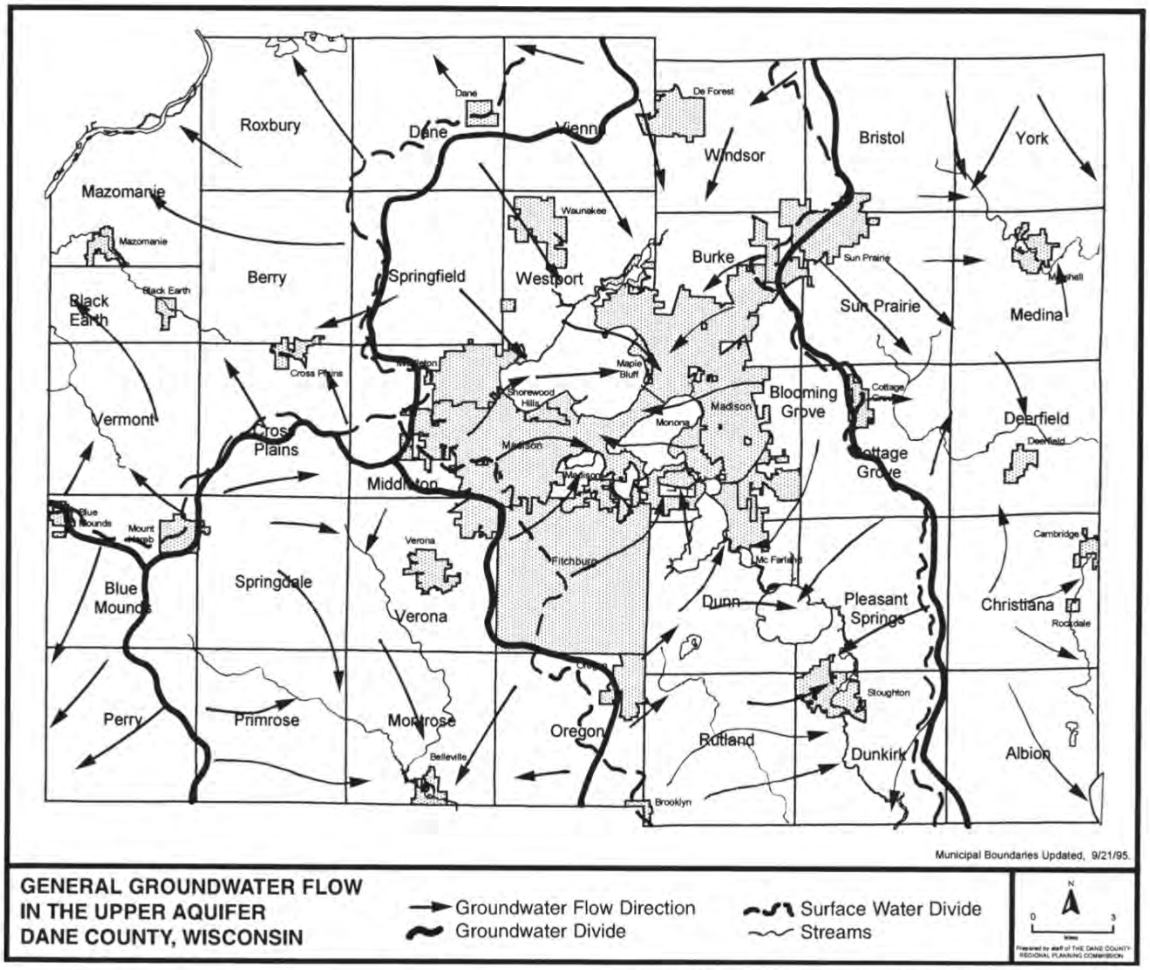


Map 4. Calibrated simulated steady-state water table (2010 conditions). Dots show locations of wells active in 2010; diameter proportional to pumping rates.

The shallow water table in Dane County forms several naturally occurring basins, analogous to but not entirely coincident with surface water basins (**Map 5**). Shallow groundwater moves radially away from, and does not cross groundwater divides. Near major lakes, streams and wetlands shallow groundwater flows toward the surface water bodies. Note that groundwater and surface water divides in Dane County are not wholly coincident. There are places in the county where shallow groundwater can move horizontally beneath topographic divides, sometimes in an opposite direction to surface water flow.

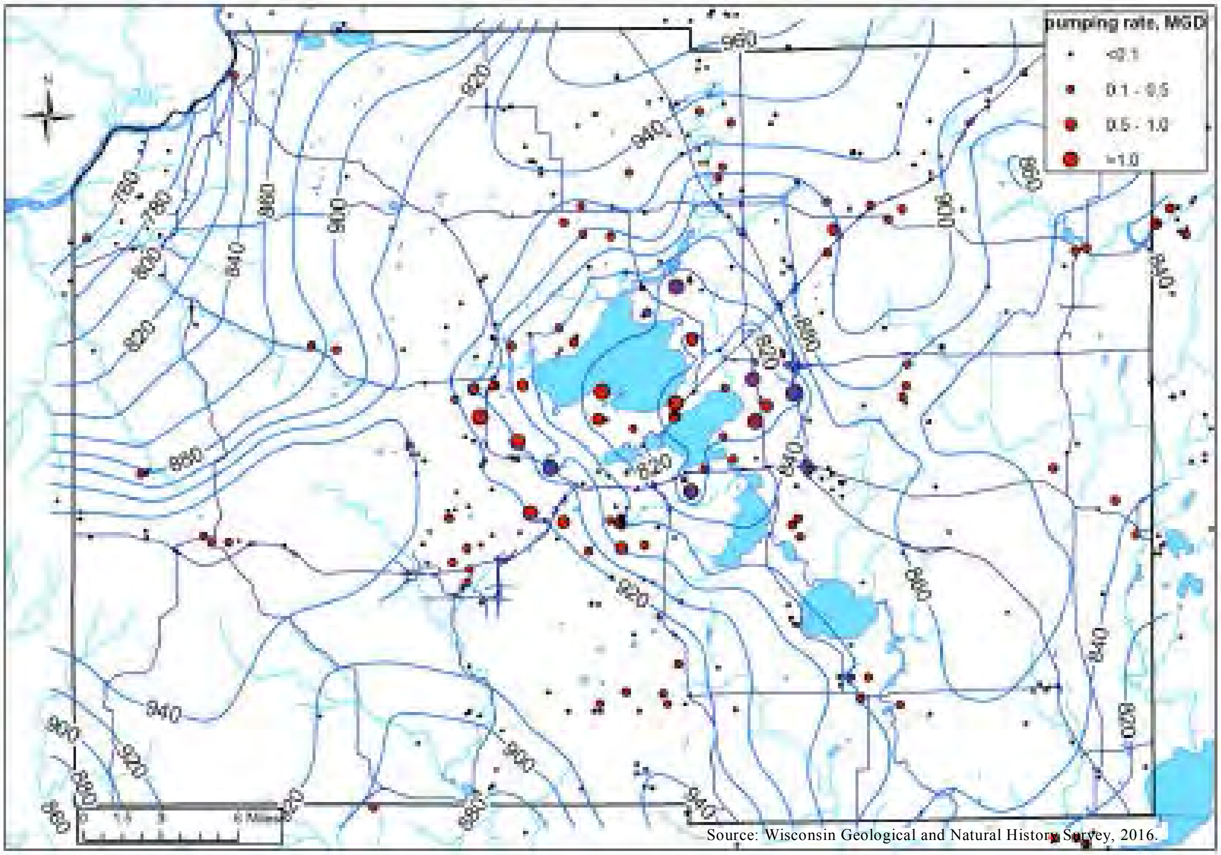
Reference Map 5 superimposes the two types of divides, and shows that they differ significantly in several areas, notably between Madison and Verona and just west of Middleton. In these areas, groundwater passes beneath surface topographic divides. For example, just east of Verona surface water drains to the southwest toward the Sugar River while groundwater moves northeast toward the Yahara River. West of Middleton, surface water drains south toward the Sugar River, but groundwater moves north toward Black Earth Creek.

Map 5



Source: Wisconsin Geological and Natural History Survey, 1995.

The deeper potentiometric surface, representing hydraulic head in the sandstone aquifer, also forms basins roughly but not exactly coincident to surface topography. The elevation of the potentiometric surface of the Mt. Simon aquifer ranges from about 800 feet above sea level in central Madison to over 900 feet near Verona and in western Dane County near Blue Mounds (**Map 6**). A significant low in the potentiometric surface beneath Madison results from long-term pumping of municipal wells there. In this area the potentiometric surface has been lowered until it is below the level of the Yahara Lakes in some places.

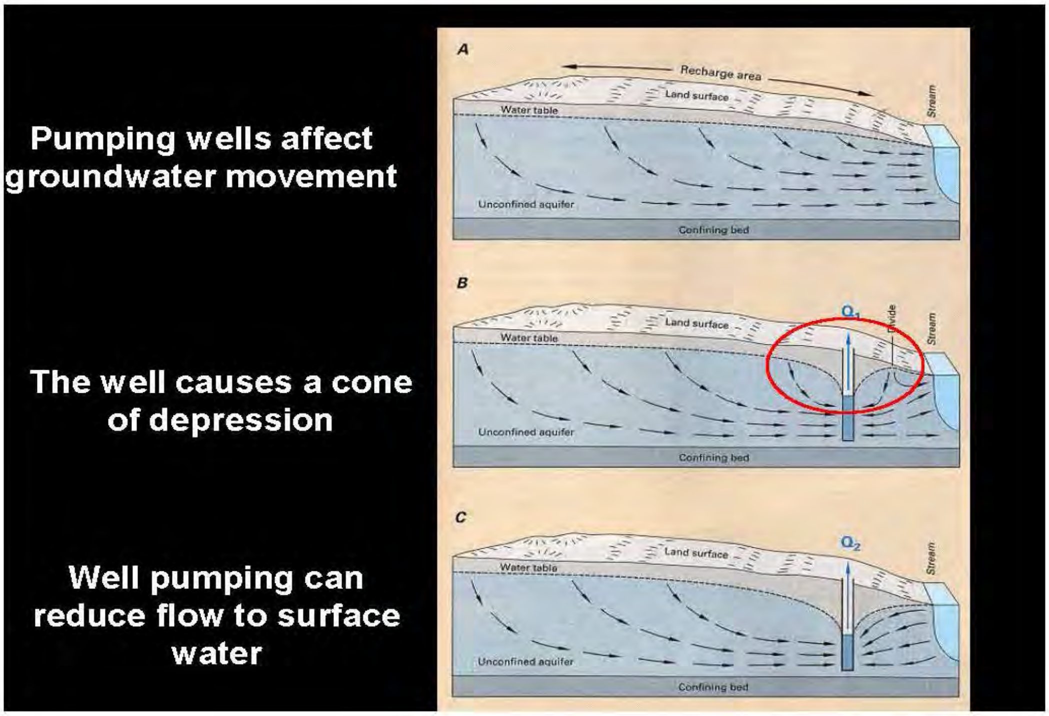


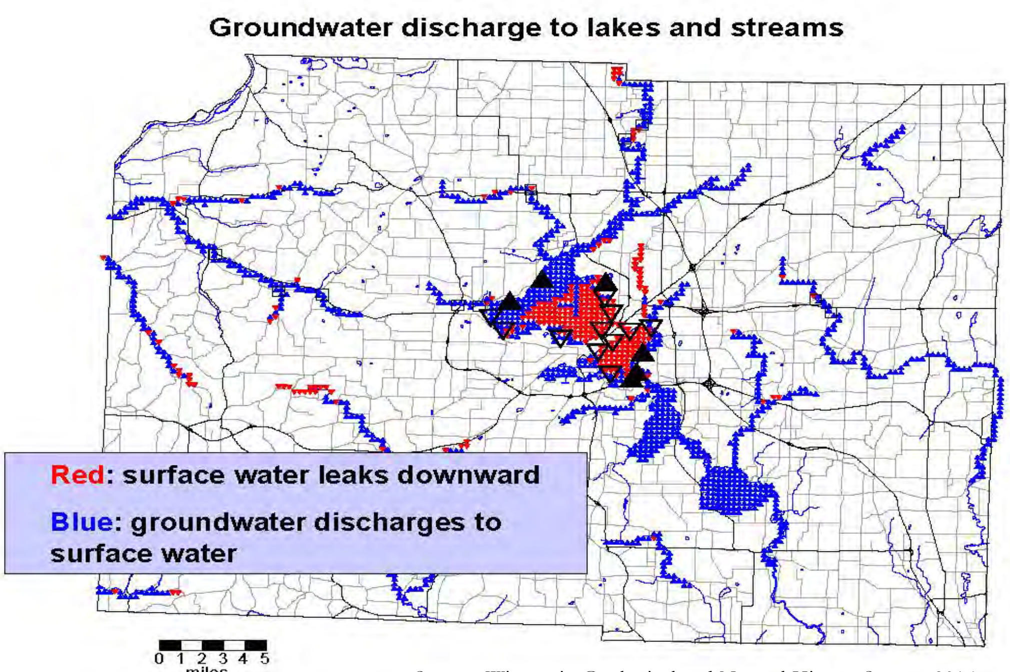
Map 6. Calibrated simulated steady-state potentiometric surface for the Mount Simon aquifer (2010 conditions). Dots show locations of wells active in 2010; diameter proportional to pumping rates.

Figure 4 shows these ground-surface water relationships. Groundwater withdrawals by pumping from high-capacity wells in the Madison metropolitan area since the turn of the century have lowered hydraulic heads in the deep sandstone aquifer. These head declines have propagated upward to the surface and have reduced groundwater discharge to lakes, streams, and wetlands in the Madison Metropolitan area. In fact, in the isthmus area of central Madison the historic direction of groundwater flow from the aquifers to the lakes has been reversed so that now parts of Lakes Mendota and Monona are losing water to the groundwater system. Wells located near the Yahara lakes draw significant quantities of water from downward leakage out of the lakes.

Conversely, the presence of the Eau Claire aquitard can help mitigate the localized impact of high capacity well water withdrawals on surface water features. The presence or absence of the Eau Claire aquitard is an important control on vertical groundwater movement between shallow and deep bedrock aquifers in Dane County. The absence of the aquitard in central Dane County, where pumping stresses are greatest (see Lakes Mendota and Monona, **Reference Map 2**), allows pumping to have much more effect on shallow ground and surface water resources than might otherwise occur.

Figure 4. The Effect of Well Withdrawals on Area





Source: Wisconsin Geological and Natural History Survey, 2016.

Preferential groundwater flow to springs

Numerous springs occur in Dane County and serve as natural points of groundwater discharge (**Map 7**). The largest springs occur at low topographic elevations near major surface water bodies. Many small springs also occur at higher elevations, particularly in the driftless part of the county, and probably receive local flow from the upper Paleozoic aquifer. Certainly many more springs occur in the county than have been mapped in spring surveys.

Springs can be adversely affected by groundwater withdrawals. The U.S. Geological Survey has investigated several springs in the Madison area and documented relationships between pumping of deep municipal wells and reductions in spring flows and water levels. They have shown that pumping of Madison well 14 (715 feet deep; cased to 117 feet) influences the level of Merrill spring, located on the southwest shore of Lake Mendota. They have also documented a direct correlation between the pumping of Madison city well #1 (since abandoned) and shallow groundwater levels near Council Ring springs, located on the western shore of Lake Wingra. It should be noted that the Eau Claire formation is relatively thin or absent in these areas indicating, where the shallow and deep groundwater systems are fairly well connected. Where the Eau Claire formation is more significant, shallow springs may be better protected from high capacity wells drawing from the deeper (and confined) Mt Simon aquifer.

As a case study, springs in the Nine Springs watershed have been found to contribute a consistent source of water to remnant, but locally-diverse, sedge meadows and fens located there. The springs discharge water at rates of up to 2 cfs (~900 gpm) and typically show little or no response to precipitation and/or seasonal groundwater recharge events – suggesting (initially) deep groundwater sources.[7] Recent work, however, suggests that shallow sandstone aquifers can generate springs with steady flow even in areas where seasonal or higher frequency recharge occurs.[8] Steady flow in such a system can result from diffuse recharge through unlithified deposits or sandstone, followed by focused flow through thin, laterally extensive, high-permeability zones in sedimentary bedrock.

Research was conducted in the Nine Springs watershed to test conceptual models of the hydrogeology that contributes to the abundance of springs in the region and their unique flow characteristics using geochemistry, field-based hydrologic measurements, and numerical modeling approaches.[9,10,11] Results of the research suggests that springs may develop in the area where laterally–extensive, high-permeability zones in the Tunnel City geologic group intersects buried bedrock valleys (**Figure 5**). The Yahara Chain of Lakes and the surrounding wetlands were once part of a large river valley before glaciers filled them with sediment. Many springs in the area tend to occur at the edge of the bedrock, next to the sediment-filled valley.

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[7] Swanson, S. 2001b. *Hydrogeologic Controls on Spring Flow Near Madison, WI.*. UW-Madison Ph.D. Dissertation.

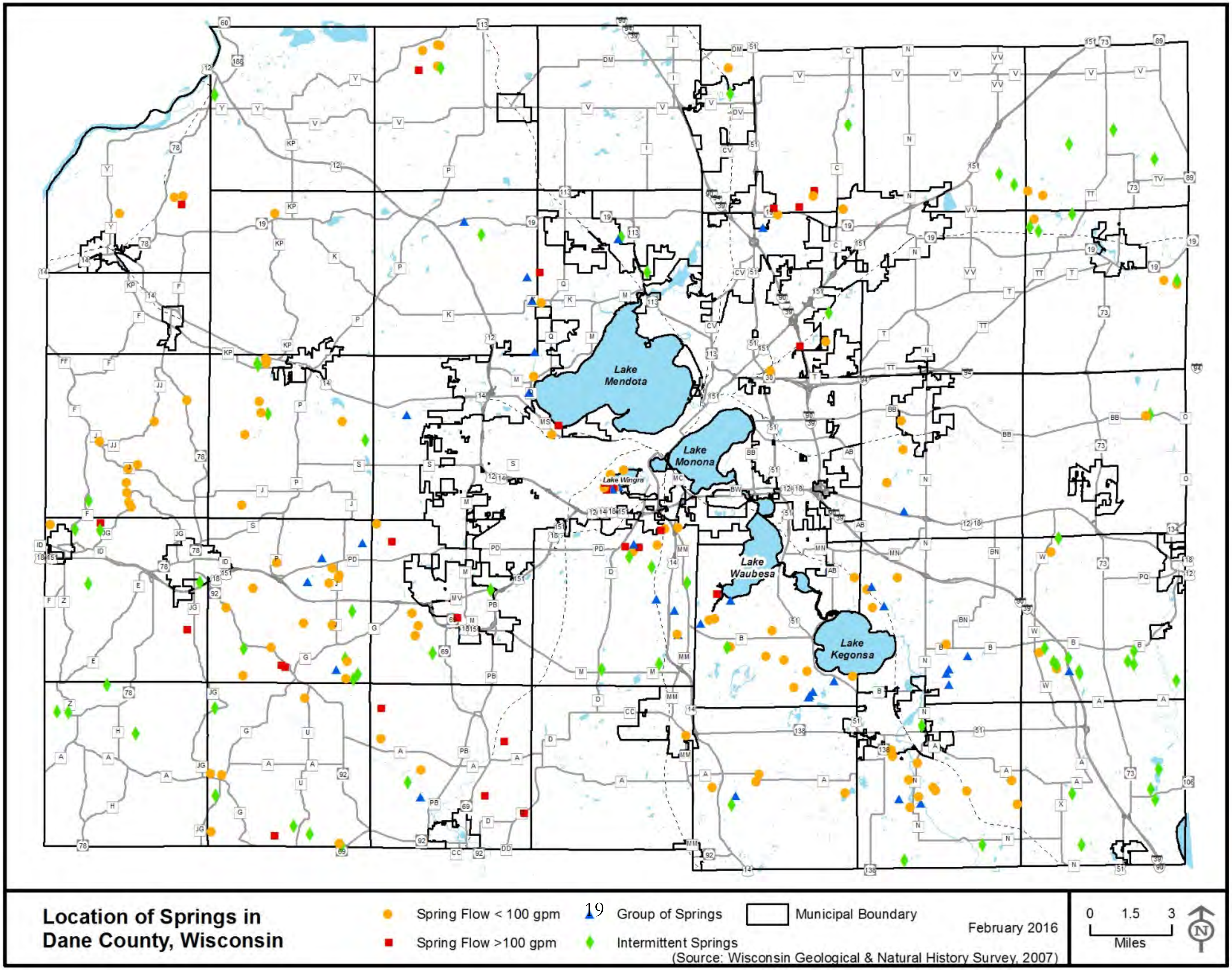
[8] Swanson, S. 2004. *Analytical and Numerical Models to Explain Steady Rates of Spring Flow.* Groundwater Vol. 42, No. 5: 747-759.

[9] Swanson, S. et al. 2001a *Two-Way Cluster Analysis of Geochemical Data to Constrain Spring Source Waters.* Chemical Geology 179: 73-91.

[10] Swanson, S. et al. 2004. *Analytical and Numerical Models to Explain Steady Rates of Spring Flow.* Groundwater Vol. 42, No. 5: 747-759.

[11] Swanson, S. et al. 2006. *Evidence for Preferential Flow Through Sandstone Aquifers in Southern Wisconsin.* Sedimentary Geology 184: 331-342.

Map 7


Lake Mendota
Lake Monona
Lake Wingra
Lake Waubesa
Lake Kegonsa
Location of Springs in
Dane County, Wisconsin
Spring Flow < 100 gpm
Spring Flow >100 gpm
Group of Springs
Intermittent Springs
Municipal Boundary
February 2016
(Source: Wisconsin Geological & Natural History Survey, 2007)
0 1.5 3
Miles
N

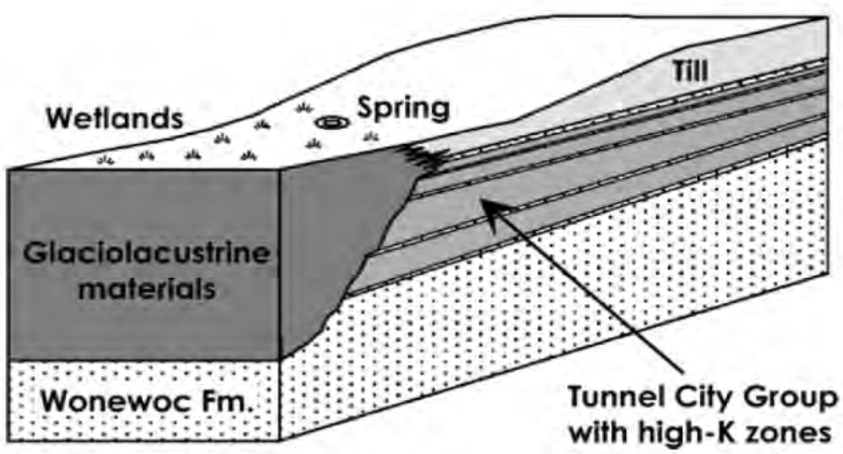


Figure 5. Conceptual model used in the design of the Nine Springs Inset Model. Springs form where high permeability zones in a shallow sandstone aquifer are truncated by a bedrock valley (the Yahara River in this case).

Source: Swanson 2006

Using a refined conceptual model that includes the high-permeability features, a three-dimensional groundwater flow model was developed for the Nine Springs area. Simulation results indicate that spring flow is potentially vulnerable to the loss of groundwater recharge if future urban development is not mitigated for adverse groundwater impact. In addition, spring flow and water quality could be affected by land use changes as far as 2 to 3 miles west of the topographic watershed for Nine Springs Creek, because the groundwater basin does not coincide with the surface watershed. According to the study, groundwater pumping has reduced spring flow by approximately 10 percent over pre-development conditions. Projected increases in municipal pumping over the next 20 years, however, are not likely to result in dramatic changes in spring flow as long as groundwater is withdrawn from the well-confined lower bedrock aquifer (Mt. Simon sandstone).

Borehole monitoring of wells located near the margin of the buried bedrock valley and several large spring complexes in Nine Springs Creek shows that a head drop of ~18 m occurs across the Eau Claire shale layer. The lower heads in the lower bedrock aquifer are the result of municipal pumping in central Dane County. The large difference in head implies that the Eau Claire aquitard effectively restricts flow between the upper bedrock aquifer and the lower bedrock aquifer in the Nine Springs Creek region. It is believed this situation may exist in other areas having similar hydrogeologic conditions. The existence of high-permeability zones suggest that sandstones should be subjected to detailed hydrogeologic characterization in, for example, aquifer contamination and/or wellhead protection studies, where preferential groundwater flow can have major implications. Similar studies should also be conducted in other critical spring areas taking preferential groundwater flows into account.

According to Professor Jean Bahr, a hydrologist and chair of the UW-Madison Department of Geology and Geophysics, most springs in the Nine Springs area are largely replenished by relatively shallow groundwater sources and would probably not be appreciably affected by another deep well in the area. In part, that is because of the relatively impermeable layer (the Eau Claire shale formation) separates the two aquifers. Although several springs have dried up in the area, the situation reflected previous land use practices and wells that breached the aquifers, not the removal of water from the deep aquifer. Stormwater standards have also improved in recent years and new techniques have been employed, including enhanced infiltration from developed areas. These actions are expected to help mitigate the impacts on these biologically important groundwater features.

Chapter 3: Groundwater Quantity Management

Dane County occupies 1,230 square miles in south-central Wisconsin (**Map 8**), and is the second most populous county in the state with an estimated 2010 population of 488,073. Most of the land in the county is very productive farmland. At the geographic center of the county is the City of Madison, the state capital and the main campus of the state university system. Most of the work force is employed in trade or service industries.

As the county population has grown, the City of Madison and other cities and villages have expanded into neighboring agricultural land. In addition, many individual houses and subdivisions with on-site wastewater systems have been built outside of these urban areas. Both the pressures of urbanization and changes in the farm economy have pushed farmers to convert more land to cash crops such as corn and soybeans. Pastureland has been converted to hay, and drainage in wet areas has been improved to provide more land for corn or pasture.

Population Trends and Forecasts

Dane County is currently the second largest metropolitan area in Wisconsin. **Figure 6** illustrates the changes in Dane County population from 1930 to 2010. Dane County experienced rapid growth (around 30 percent per decade) in the 1940s through the 1960s. More moderate growth rates, ranging from 11 to 16 percent per decade, have prevailed since the 1970s. Dane County is expected to reach a total population of nearly 606,620 people by the year 2040 –an increase of about 24 percent over the 2010 population.

The population growth in Dane County's cities and villages has essentially mirrored that of the county as a whole. Cities and villages experienced rapid growth rates (around 39 percent per decade) in the 1940s through the 1960s, followed by a slow growth rate of 9 percent per decade in the 1970s and more moderate growth rates, ranging from 15 to 17 percent per decade, since the 1980s. The population growth in Dane County's towns exhibits a different pattern. Towns experienced slow growth rates (around 10 percent per decade) in the 1940s through the 1950s, followed by almost no growth (1 percent per decade) in the 1960s. In the 1970s the town growth rate increased dramatically to 24 percent per decade. Slow to moderate growth rates, ranging from 6 to 12 percent per decade, have prevailed in the towns since the 1980s. The trend since the 1980s of a greater growth rate in cities and villages compared to towns is expected to continue into the future.

In 2010, almost two-thirds of the population of the county resided in the central urban area, one-quarter of the population was located in the smaller cities and villages surrounding the central urban area, and 12 percent was scattered throughout the rural areas of the county. **Tables 1 and 2** summarize population trends in the county. Urban Service Areas in the county are displayed in **Map 11.** A growth and development trend which is expected to continue into the future is a slightly greater proportion of new growth occurring in outlying urban communities compared to the central urban area, with rural areas maintaining the present percentage of total population.

Figure 6. Dane County Population Trends

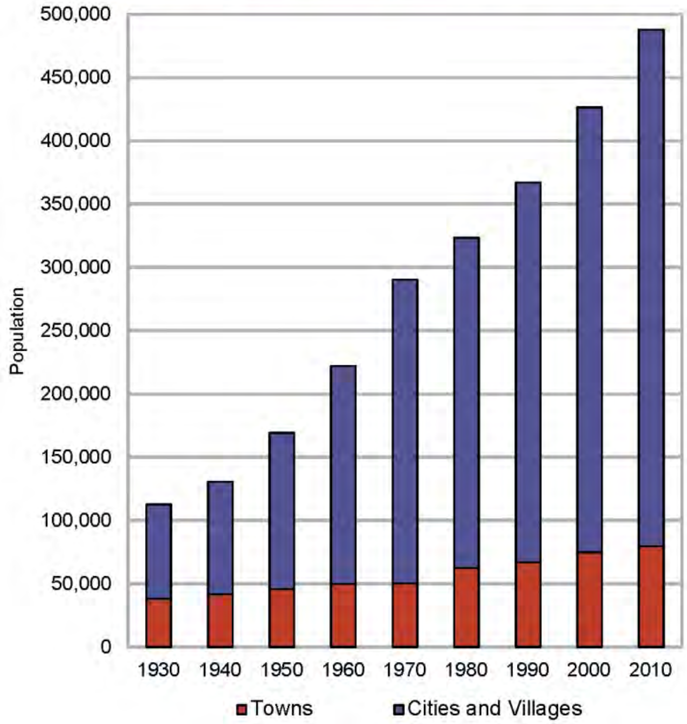


Table 1: Dane County Population Growth

	1980		1990		2000		2010	
Category	Pop.	Percent County	Pop.	Percent County	Pop.	Percent County	Pop.	Percent County
Towns	74,473	23.0%	66,989	18.2%	74,740	17.5%	78,882	16.2%
Villages	33,940	10.5%	41,748	11.4%	59,626	14.0%	73,056	15.0%
3rd & 4th Class Cities	44,516	13.8%	67,582	18.4%	84,106	19.7%	102,926	21.1%
City of Madison	170,616	52.7%	190,766	52.0%	208,054	48.8%	233,209	47.8%
Dane County	323,545	100.0%	367,085	100.0%	426,526	100.0%	488,073	100.0%

*Fitchburg (pop.11,973) included in Town Total in 1980. Fitchburg changed from a town to a 4th class city in 1983.

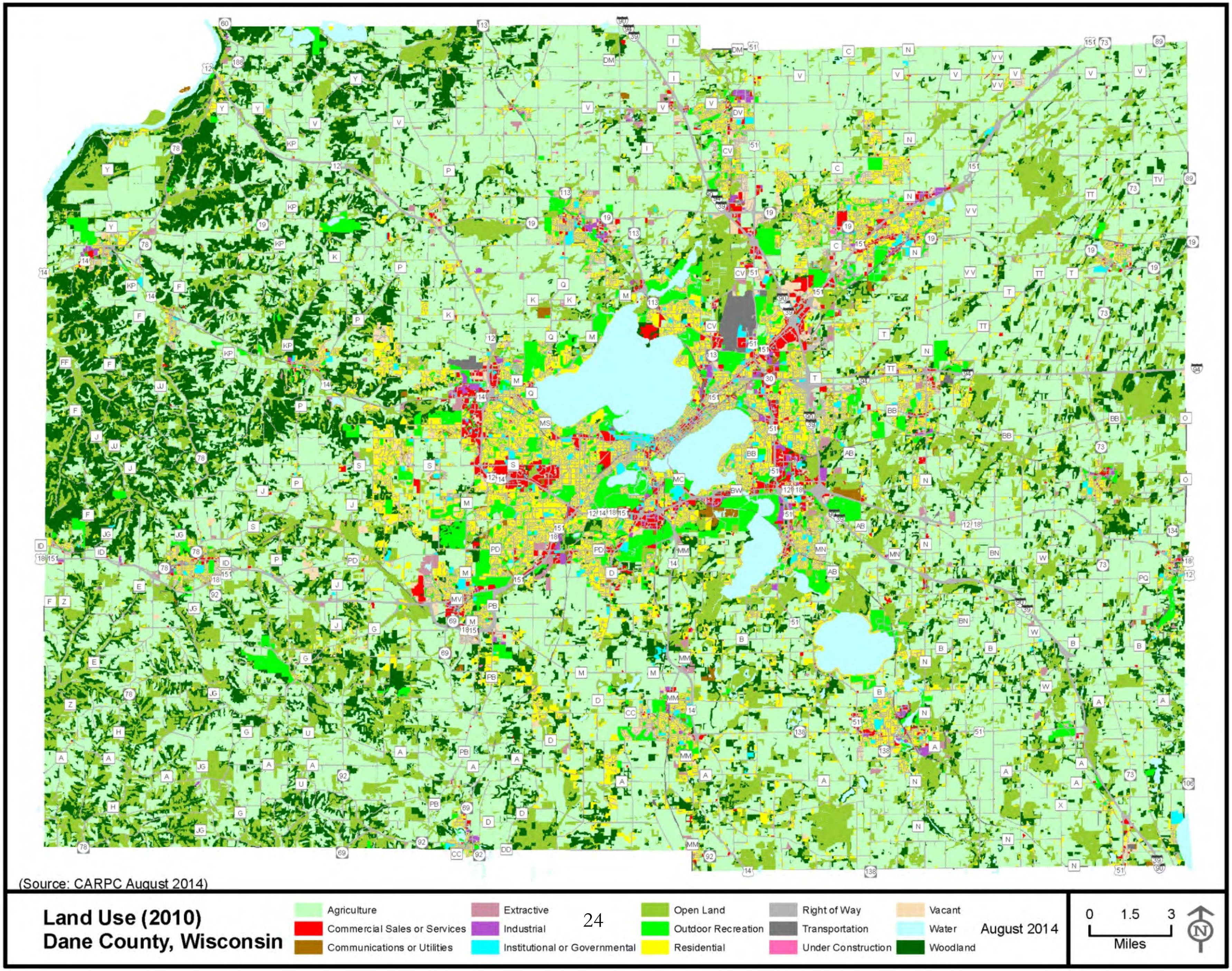
Source: U.S. Bureau of the Census (April of 1980, 1990, 2000, and 2010)

Table 2 Population Projections for Urban Service Areas (USAs) Dane County, WI.						
	Census	Urban Service Area Projections			Change 2010-2040	
USA	2010	2020	2030	2040	Number	Percent
Belleville*	1,848	2,003	2,218	2,333	485	26%
Black Earth	1,338	1,370	1,400	1,395	57	4%
Blue Mounds	855	965	1,090	1,185	330	39%
Brooklyn*	936	1,120	1,350	1,510	574	61%
Cambridge*	1,348	1,476	1,651	1,771	423	31%
Central	302,224	325,690	350,225	364,385	62,161	21%
Cottage Grove	6,192	7,190	8,465	9,470	3,278	53%
Cross Plains	3,538	3,795	4,125	4,320	782	22%
Dane	995	1,135	1,285	1,400	405	41%
Deerfield	2,319	2,560	2,830	3,015	696	30%
Edgerton*	97	294	519	640	543	560%
Koshkonong	620	657	695	732	112	18%
Marshall	3,862	4,100	4,440	4,635	773	20%
Mazomanie	1,652	1,730	1,825	1,865	213	13%
Mount Horeb	7,009	7,625	8,415	8,945	1,936	28%
Northern	12,997	14,896	17,111	18,863	5,866	45%
Oregon	9,231	10,300	11,620	12,580	3,349	36%
Stoughton	12,611	13,130	13,800	14,080	1,469	12%
Sun Prairie	29,364	34,770	40,830	45,580	16,216	55%
Verona	10,619	12,800	15,070	16,850	6,231	59%
Waunakee	12,097	13,850	15,940	17,530	5,433	45%
Urban Total	421,752	461,456	504,903	533,085	111,333	26%
Rural Total	66,321	69,164	72,397	73,535	7,214	11%
Dane Total	488,073	530,620	577,300	606,620	118,547	24%

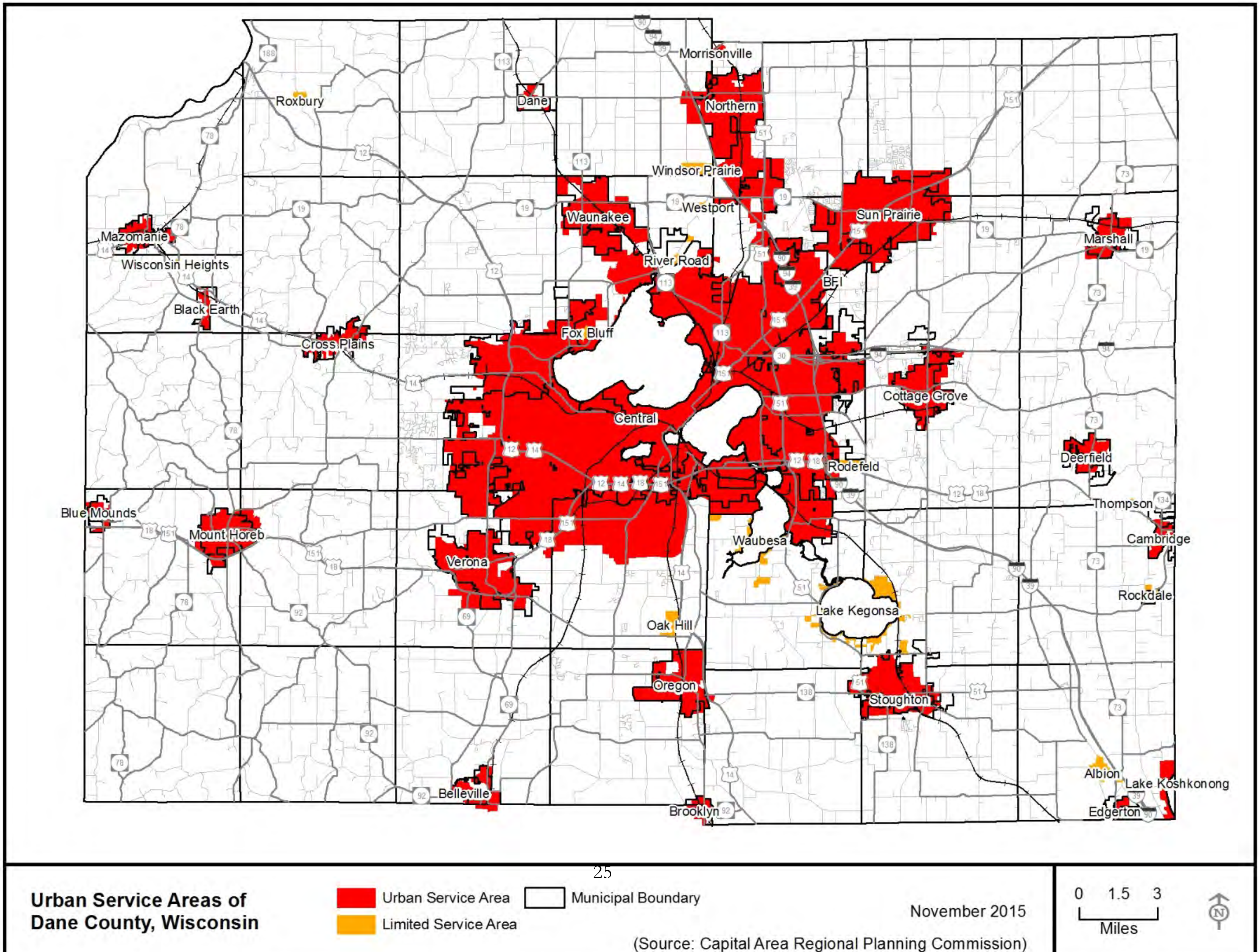
*Dane County portion

Source: Capital Area Regional Planning Commission 10/9/15

Map 8


(Source: CARPC August 2014)
Land Use (2010)
Dane County, Wisconsin
Agriculture
Commercial Sales or Services
Communications or Utilities
Extractive
Industrial
Institutional or Governmental
Open Land
Outdoor Recreation
Residential
Right of Way
Transportation
Under Construction
Vacant
Water
Woodland
August 2014
0 1.5 3
Miles
N

Map 9


Morrisonville
Roxbury
Dane
Northern
Windsor Prairie
Westport
Sun Prairie
Waunakee
Marshall
Mazomanie
River Road
Wisconsin Heights
BFI
Black Earth
Fox Bluff
Cross Plains
Cottage Grove
Central
Deerfield
Rodefeld
Thompson
Blue Mounds
Mount Horeb
Cambridge
Waubesa
Verona
Rockdale
Lake Kegonsa
Oak Hill
Oregon
Stoughton
Albion
Lake Koshkonong
Belleville
Brooklyn
Edgerton
Urban Service Areas of
Dane County, Wisconsin
Urban Service Area
Limited Service Area
Municipal Boundary
November 2015
(Source: Capital Area Regional Planning Commission)
0 1.5 3
Miles

Groundwater Sources and Uses

Groundwater supplies nearly all of the water for our domestic, commercial, and industrial uses in Dane County. Although there is a relatively unlimited groundwater supply in the county for these purposes, it is critically important that the quality of groundwater be protected for its continued use by future generations. Groundwater is also very important in providing baseflow discharges to wetlands and streams, which supports and nourishes these resources and the biological communities that live there.

Groundwater that is withdrawn and used in Dane County is for the most part recharged locally from infiltration of precipitation. Water supplies are drawn from the upper sandstone and unconsolidated aquifers, which provide water for shallow domestic wells in rural areas; and the deep sandstone (Mt. Simon) aquifer, which is a source of water for nearly all of the deep municipal wells in the county.

Approximately 50 million gallons per day (gpd) of groundwater is withdrawn from high-capacity wells and used in Dane County – about 100 gallons per capita per day (gpcd). Public water supplies account for about 83 percent of total groundwater use (**Fig. 7**). This includes water withdrawn by public water systems and distributed in both municipal and private systems for residential, industrial, and commercial purposes. Private sources of water supply used for activities such as irrigation, stock watering, self-supplied industry, and rural domestic make up the remaining groundwater use.

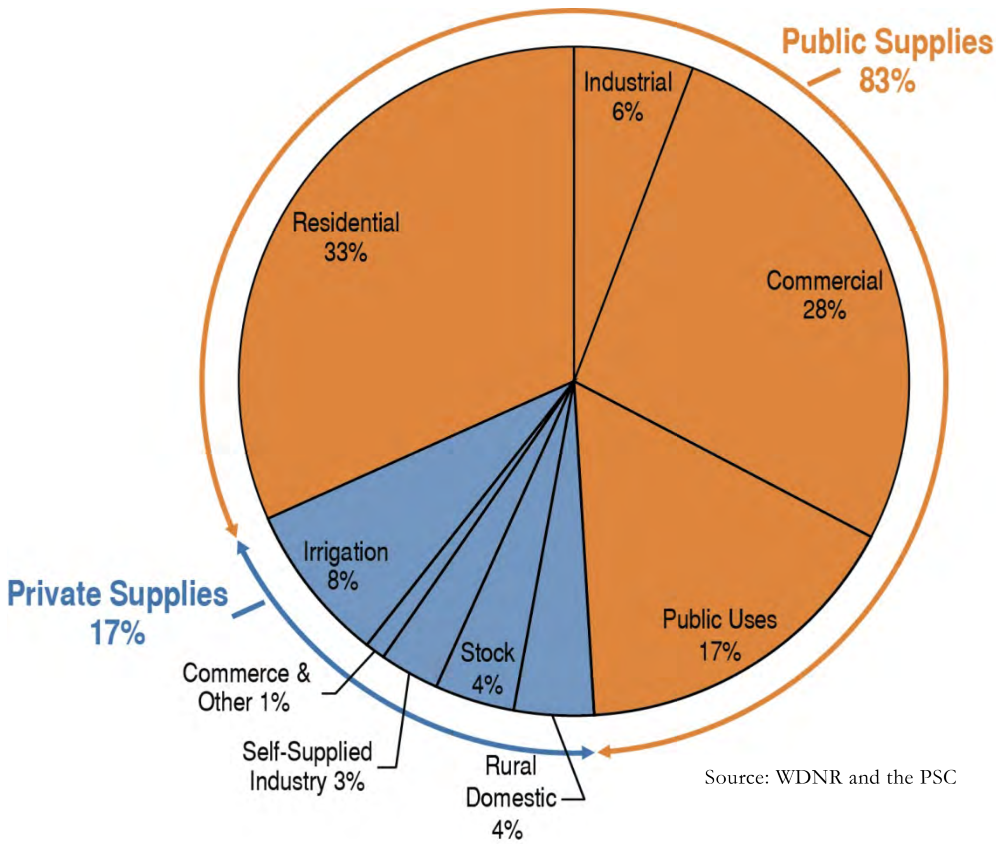
The City of Madison is the largest single consumer, withdrawing over 27 mgd and accounts for over half of the total use in the county (**Table 3 and Map 10**). Most of this water is returned to surface water after use, most often in a location different from where it was withdrawn. In the Madison Metropolitan area wastewater is treated at the Madison Metropolitan Sewerage District (MMSD) and primarily discharged to Badfish Creek – by-passing the Yahara Chain of Lakes entirely.

Trends in Water Use

Growing concern in Dane County over the effects of rapid urban growth and development on ground and surface water resources requires an improved understanding of the effects of urbanization and associated increased groundwater withdrawals on local water resources. Groundwater is the sole drinking water supply for county residents and sustains area lakes, streams and wetlands. Municipalities benefit from a relatively unlimited source of clean, healthy drinking water drawn from the deep Mt. Simon sandstone aquifer. However, local planning officials are faced with decisions that balance the need for increased groundwater withdrawals while maintaining the quantity and quality of groundwater-fed surface water resources.

Historically, the greatest increase in water use and wastewater flows in the Madison metropolitan area occurred between 1970 and 1979 when pumpage increased 6 mgd from 31 to 37 mgd (**Fig. 8**). **Fig. 8** includes public, private and domestic groundwater withdrawals. Even though the population of the area has grown by about the same amount (10-15 percent per decade), an apparent stabilization in water consumption since the 1970s is attributed to reduced industrial use and more efficient household fixtures and appliances.

Fig. 7 Estimated Groundwater Use in Dane County



Source: WDNR and the PSC

Table 3. Classification of Water Use for Dane County Communities (mgd)

7/6/16

	Residential	Commercial	Industrial	Public	Multi-Family	Non-Revenue	2014 Total Gals	2014 Pop. Served	gpcd	Active Wells (inactive)	Projected 2040 Pop.	2040 Water Use	2014-40	2040 Wells
Belleville	0.10 (59%)	0.02 (9%)	0.00 (1%)	0.01 (7%)	0.01 (6%)	0.03 (18%)	0.161	2,393	67	2	2,870	0.193	0.032	2
Black Earth	0.06 (56%)	0.02 (16%)	0.00 (0%)	0.00 (1%)	0.00 (0%)	0.03 (27%)	0.100	1,350	74	2	1,395	0.103	0.003	2
Blue Mounds	0.04 (52%)	0.00 (4%)	0.00 (0%)	0.00 (1%)	0.00 (1%)	0.03 (43%)	0.075	855	87	2	1,185	0.103	0.029	2
Brooklyn	0.06 (73%)	0.00 (3%)	0.00 (0%)	0.00 (4%)	0.00 (0%)	0.02 (21%)	0.081	1,417	57	2	1,975	0.113	0.032	2
Cambridge	0.07 (36%)	0.02 (11%)	0.00 (1%)	0.03 (15%)	0.00 (0%)	0.07 (37%)	0.181	1,383	131	2	1,880	0.246	0.065	2
Cottage Grove*	0.32 (66%)	0.05 (9%)	0.08 (16%)	0.01 (1%)	0.00 (0%)	0.04 (8%)	0.493	6,324	78	3(1)	9,470	0.738	0.245	3
Cross Plains	0.15 (51%)	0.02 (6%)	0.01 (2%)	0.01 (2%)	0.03 (10%)	0.08 (28%)	0.296	3,503	84	2	4,320	0.365	0.069	4
Dane*	0.04 (63%)	0.00 (3%)	0.00 (5%)	0.00 (0%)	0.00 (6%)	0.02 (23%)	0.069	1,038	66	2(1)	1,400	0.093	0.024	2
Deerfield	0.11 (65%)	0.01 (7%)	0.02 (10%)	0.01 (7%)	0.00 (0%)	0.02 (11%)	0.166	2,424	68	2(1)	3,015	0.206	0.040	2
DeForest*	0.37 (49%)	0.10 (13%)	0.05 (7%)	0.02 (3%)	0.05 (7%)	0.16 (21%)	0.760	9,240	82	5	12,010	0.988	0.228	6
Edgerton	0.19 (49%)	0.04 (11%)	0.00 (1%)	0.03 (8%)	0.02 (6%)	0.10 (26%)	0.395	6,000	66	3	6,755	0.445	0.050	3
Fitchburg*	0.76 (40%)	0.32 (17%)	0.14 (8%)	0.01 (1%)	0.60 (32%)	0.04 (2%)	1.878	22,000	85	6	32,670	2.789	0.911	6
Madison*	8.67(31%)	5.54 (20%)	1.44 (5%)	2.44 (9%)	5.63 (20%)	3.96 (14%)	27.671	254,797	109	22	292,030	31.714	4.043	29
Marshall	0.12 (54%)	0.01 (6%)	0.00 (0%)	0.01 (4%)	0.06 (26%)	0.02 (9%)	0.227	3,861	59	4	4,635	0.272	0.045	3
Mazomanie	0.09 (55%)	0.01 (3%)	0.03 (16%)	0.00 (2%)	0.00 (2%)	0.03 (21%)	0.159	1,664	96	2	1,865	0.179	0.019	2
McFarland*	0.37 (66%)	0.06 (10%)	0.00 (0%)	0.01 (2%)	0.04 (8%)	0.08 (14%)	0.566	8,045	70	3	9,895	0.696	0.130	4
Middleton*	0.73 (33%)	0.64 (29%)	0.22 (10%)	0.08 (4%)	0.26 (12%)	0.26 (12%)	2.182	17,733	123	6	23,230	2.859	0.676	7
Monona*	0.31 (34%)	0.43 (45%)	0.00 (0%)	0.01 (1%)	0.10 (11%)	0.08 (9%)	0.938	8,000	117	3	6,560	0.769	-0.169	3
Morrisonville*	0.02 (90%)	0.00 (3%)	0.00 (0%)	0.00 (1%)	0.00 (0%)	0.00 (6%)	0.022	390	55	2(1)	457	0.025	0.004	2
Mt Horeb	0.33 (62%)	0.05 (9%)	0.00 (0%)	0.02 (3%)	0.02 (3%)	0.12 (22%)	0.531	7,092	75	4	8,945	0.670	0.139	4
Oregon	0.45 (54%0	0.08 (10%)	0.02 (3%)	0.04 (4%)	0.05 (6%)	0.18 (22%)	0.827	9,420	88	3	12,580	1.104	0.277	4
Stoughton	0.57 (40%)	0.16 (12%)	0.47 (33%)	0.02 (1%)	0.07 (5%)	0.12 (9%)	1.415	12,800	111	4	14,080	1.556	0.141	4
Sun Prairie	1.34 (55%)	0.41 (17%)	0.10 (4%)	0.04 (2%)	0.23 (9%)	0.33 (13%)	2.452	30,871	79	6(1)	45,580	3.620	1.168	7
Verona	0.50 (34%)	0.37 (25%)	0.10 (7%)	0.05 (3%)	0.09 (6%)	0.38 (25%)	1.480	11,105	133	5	16,850	2.246	0.766	4
Waunakee*	0.67 (51%)	0.09 (7%)	0.25 (19%)	0.02 (2%)	0.07 (6%)	0.21 (16%)	1.315	12,840	102	5	17,530	1.796	0.480	5
Westport*	0.05 (47%)	0.02 (16%)	0.00 (0%)	0.00 (0%)	0.03 (27%)	0.01 (10%)	0.110	800	138	2	4,380	0.604	0.494	2
Windsor*	0.15 (56%)	0.07 (25%)	0.02 (7%)	0.00 (1%)	0.00 (0%)	0.03 (12%)	0.276	2,625	105	2	6,917	0.728	0.451	2
Total	**16.647 (37%)**	**8.525 (19%)**	**2.956 (7%)**	**2.873 (6%)**	**7.381 (16%)**	**6.504 (14%)**	**44.887**	**439,970**		**116 (5)**	**544,479**	**55.219**	**10.394**	**118**

*MMSD Urban Service Areas

Source: Public Service Commission and the Capital Area Regional Planning Commission

Map 10

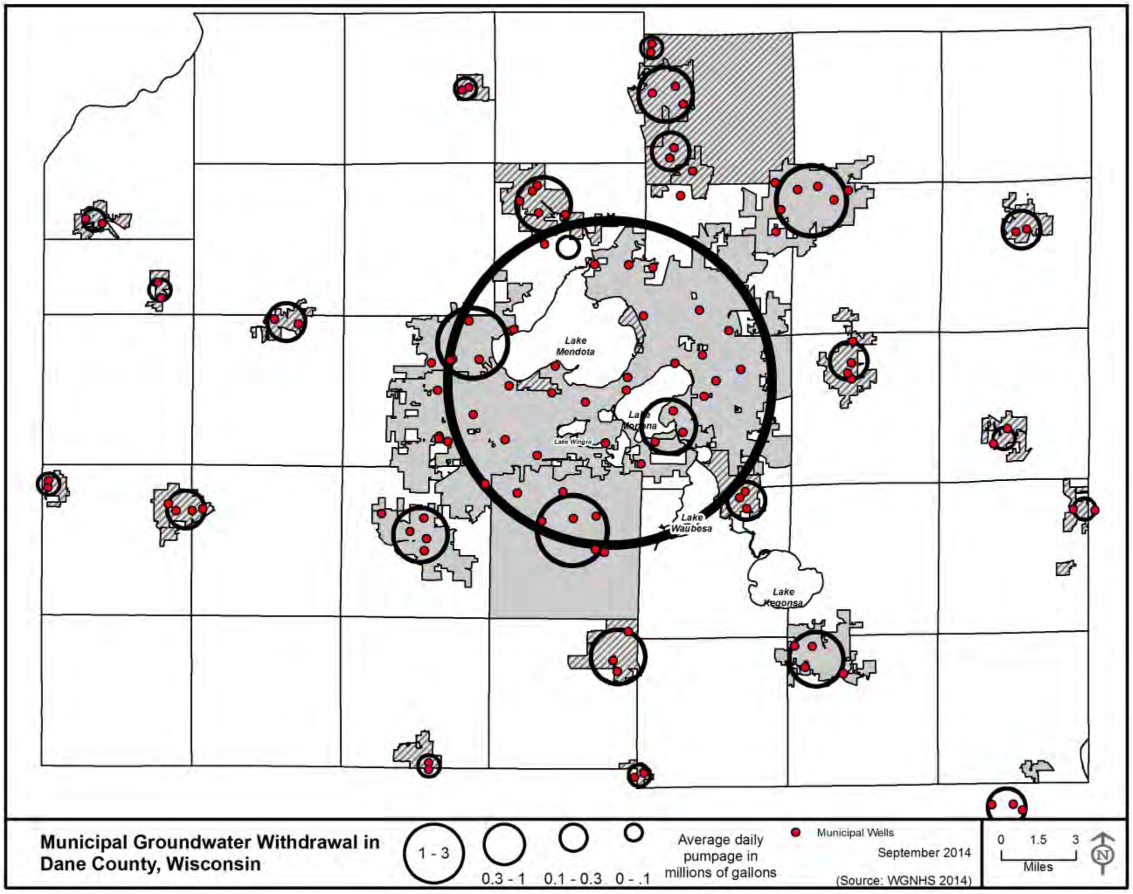
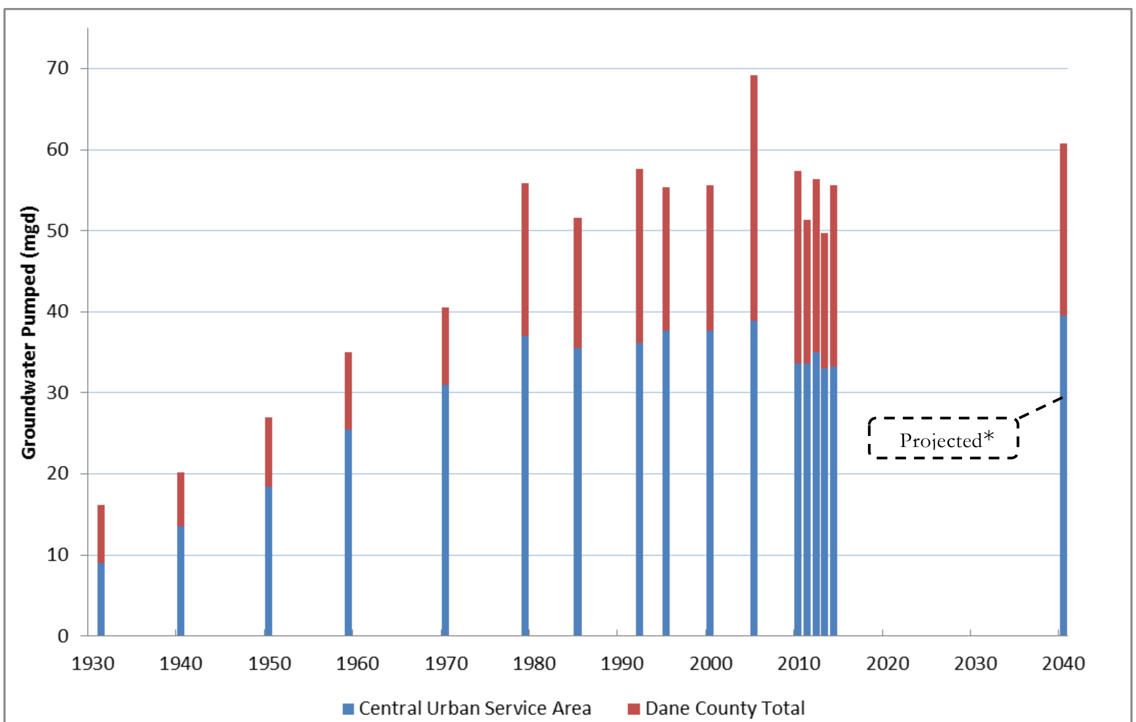


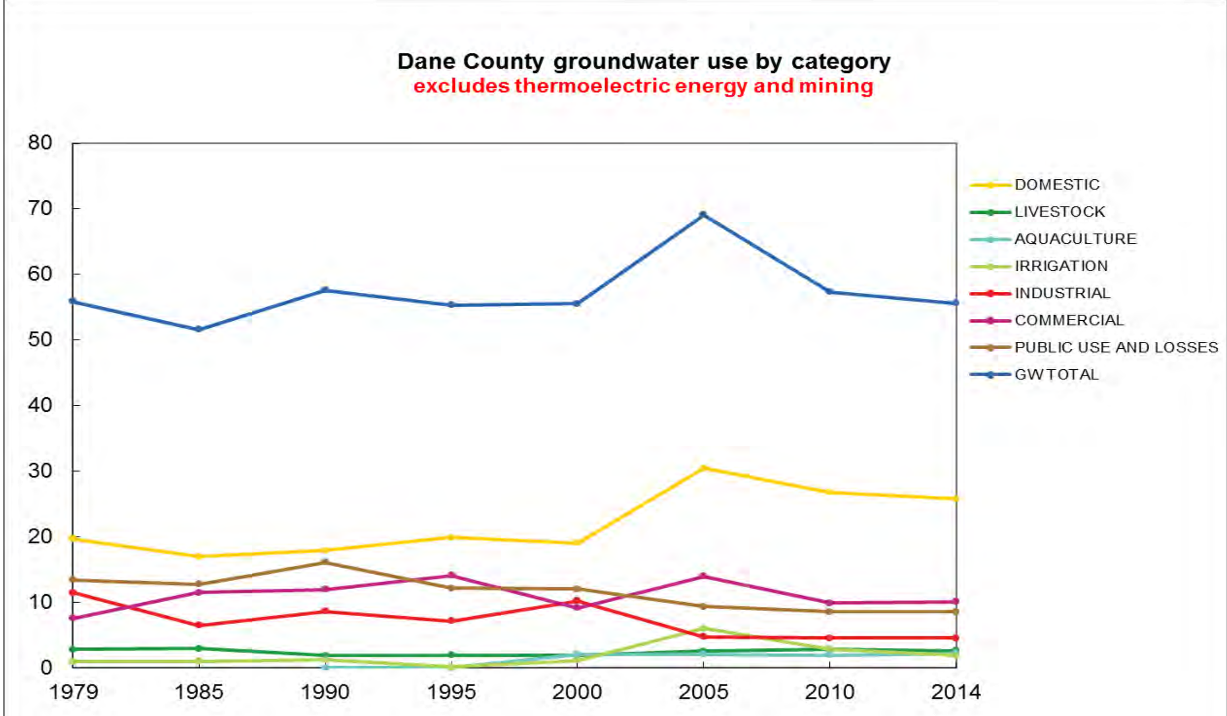
Fig. 8. Reported and Projected Groundwater Withdrawals in Dane County.



* Based on current per capita rate times projected 2040 population. Source: DCRPC, PSC, WDNR, and USGS.

Figure 9 shows Dane County water use by category. Compared to groundwater use, surface water use is a small percentage of the County total (**Table 4**).

Fig. 9



Source: USGS

Table 4
Dane County Water Use by Year (mgd)

	1979	1985	1990	1995	2000	2005	2010	2014
Surface Water Use	0.28	1.34	1.41	0.81	0.25	1.05	2.21	2.40
Groundwater Use	55.88	51.57	57.61	55.34	55.56	69.11	57.36	55.60
Total Water Use	56.16	52.91	59.02	56.15	55.81	70.16	59.57	58.00

Source: USGS

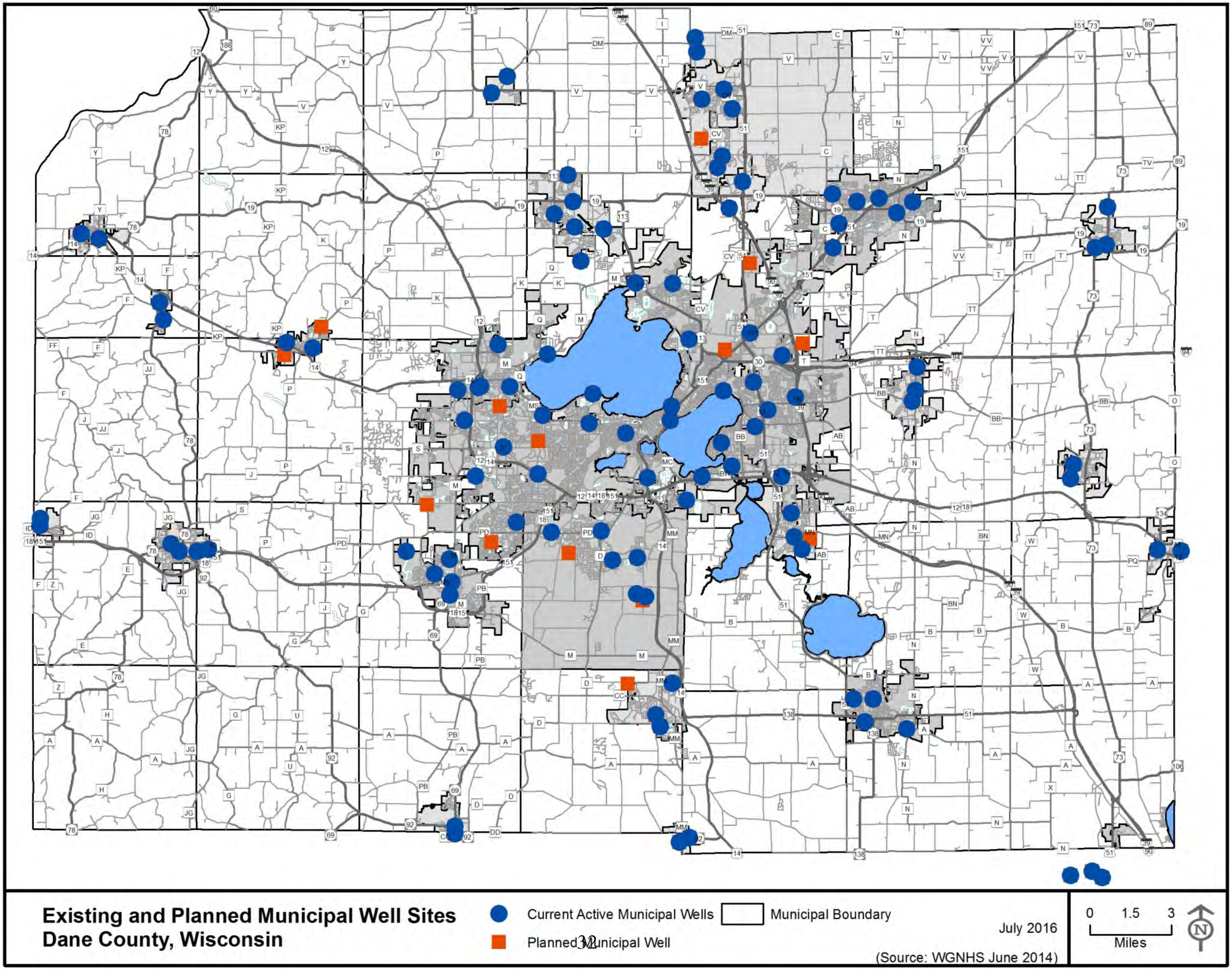
Table 3 summarizes reported 2014 and projected 2040 water use. **Map 11** shows the locations of existing and proposed wells for each community in central Dane County. Note, specific locations of existing and planned wells may change. Municipal water supply agencies can provide more recent and detailed information for a well site. Also note that the 2040 population and water use projections include a somewhat slower pace of growth than earlier projections. This is consistent with the Wisconsin Department of Administration methodology which takes into account the effect of the 2008 recession.

Water use in Dane County is expected to increase by about 23 percent (10.32 mgd) between 2014 and 2040. Projected water use was estimated using current per capita use multiplied by projected 2040 population. In central Dane County, water use by communities served by MMSD is expected to increase by about 21 percent (7.5 mgd or 11.6 cfs). Most of this water will be diverted out of the original basin from which it was withdrawn, further decreasing water table levels and groundwater discharge to local water bodies.

Pumping or withdrawal of groundwater, and its eventual return to surface waters in a different location, can have indirect but serious impacts on local hydrology and water quality conditions. These impacts can be particularly pronounced in urban areas, where concentrated pumping of groundwater lowers the water table, reducing baseflow contributions to streams and lakes. The impacts are also heightened in urban areas as a result of historic paving and impervious areas, which reduces local infiltration of precipitation to recharge groundwater (where mitigation measures have not been implemented).

In Dane County, these effects are most apparent for the central urban area, where most of the groundwater used in the county is withdrawn in a concentrated urban setting, and the water used is subsequently diverted, after treatment, around the natural Yahara River flow system and discharged further downstream at Badfish Creek. As a result, there have been important effects of lowered groundwater levels on wetlands and stream baseflow in the central urban area, including lower baseflows in the Yahara River system downstream from Lake Mendota. In addition, the concentrated withdrawal of groundwater in the central urban area has enlarged the area influenced by groundwater drawdowns to include a larger recharge area, and induces more rapid movement of potential contaminants to groundwater and municipal water supplies. These issues are discussed more fully in the following sections.

Map 11



Existing and Planned Municipal Well Sites
Dane County, Wisconsin
Current Active Municipal Wells
Planned Municipal Well
Municipal Boundary
July 2016
(Source: WGNHS June 2014)
0 1.5 3
Miles
N

Dane County Regional Hydrologic Study

To better identify existing and potential future impacts of urban development, groundwater withdrawals and interbasin water diversions on the county's ground and surface water resources, a Regional Hydrologic Study was completed in 1997. The work was conducted cooperatively by the Dane County Regional Planning Commission (now CARPC), the Wisconsin Geological and Natural History Survey, and the U.S. Geological Survey, and sponsored by the Department of Natural Resources, Dane County, the Madison Metropolitan Sewerage District, and the City of Middleton.

As part of the study, a groundwater flow model was developed to simulate changes in groundwater levels due to pumping, identify important recharge and discharge areas, provide estimates of the directions and rates of groundwater movement, and better define ground and surface water relationships. The model was updated by WGNHS and its partners in 2014 to include greater understanding, knowledge, and technology since the original model development in the mid-1990s.

Final products of this investigation include reports and maps describing the hydrogeology of Dane County as well as an evaluation of alternative management strategies to offset future groundwater and streamflow declines. Strategies such as water conservation, concentrated pumping in the City of Madison, maximizing infiltration, and return of highly treated wastewater show promising opportunities to mitigate the impacts resulting from historic and future wastewater diversion around the Yahara Lakes system. An electronic Yahara Lakes reservoir routing model was also developed which demonstrates pre-diversion dry-weather baseflows could be maintained by operating the lakes as surface water reservoirs to store and release more slowly during critical summer periods.

The addition of Verona to the Madison Metropolitan Sewerage District in 1996 has increased the effects of high capacity municipal well withdrawals on baseflows in the Sugar River Basin. In response, MMSD treated effluent generated in the Upper Sugar River is returned to the Sugar River basin at an outfall on Badger Mill Creek. Only the amount of effluent generated in the basin will be returned (maximum 8 mgd or 12.4 cfs). This effort has gained wide public support and has revitalized a stream that had lost most of its baseflow due to the extensive development in the area. The innovation here is treating wastewater as a resource, rather than something simply to be disposed of.

Results of the modeling effort show that most of the groundwater in the county originates within the county boundaries. This highlights the need for water conservation and water supply planning to maintain groundwater supplies and baseflow to county streams. The model serves as an ongoing management tool to evaluate the effects of selected management strategies to mitigate adverse ground and surface water impacts. The model also provides a regional framework for undertaking more detailed local hydrologic studies and spin-off research projects that will still be required to provide refined information for site-specific development and resource management investigations.

Effects of Pumping and Wastewater Diversion

Following use, most of the municipal and industrial well water from central Dane County is conveyed to the Madison Metropolitan Sewerage District's (MMSD) Nine Springs Wastewater Treatment Facility. The treated effluent is then pumped to Badfish Creek and diverted around the Yahara River/Lakes system. As a result, groundwater is removed from the original basin from which it was derived.

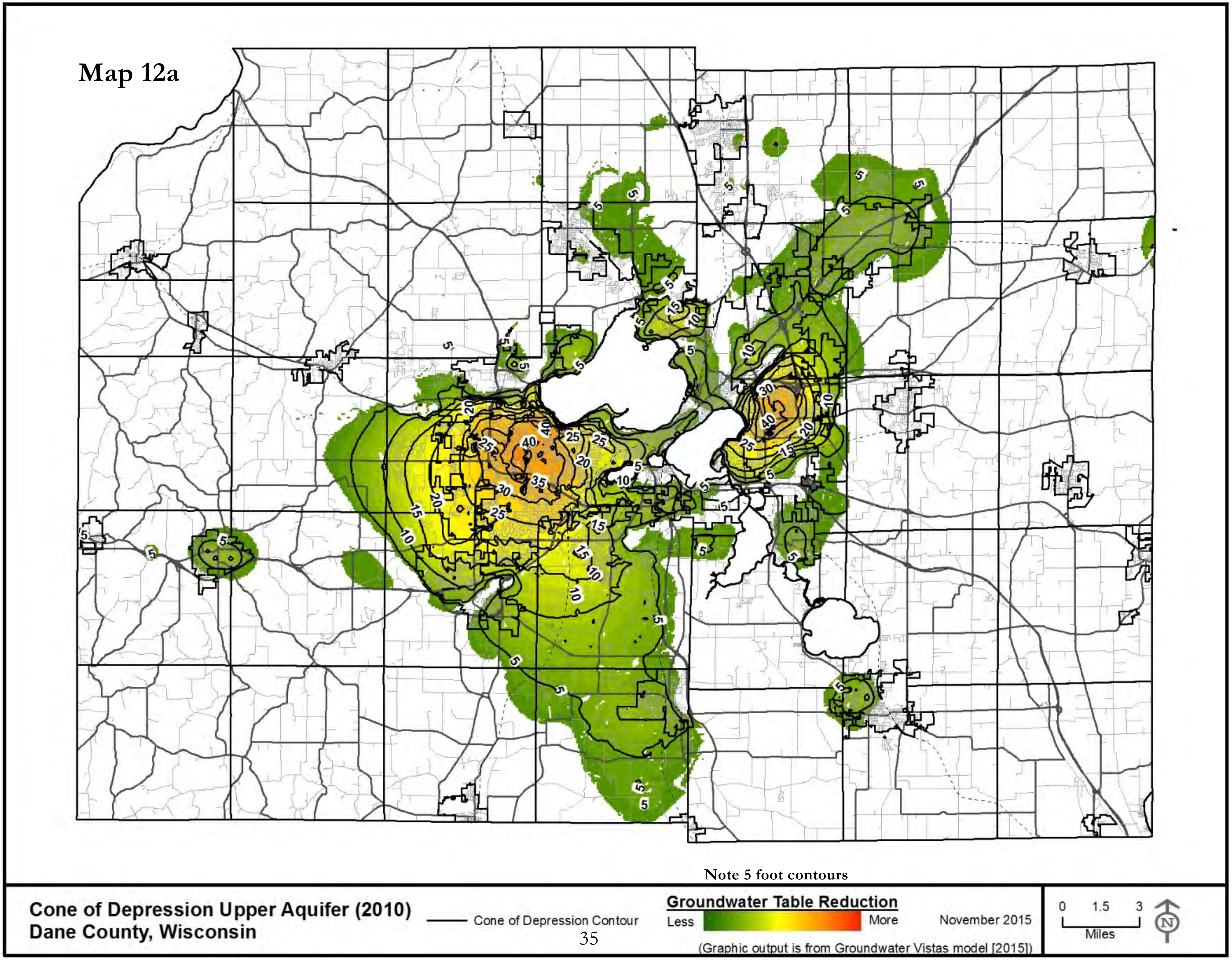
Pumping or withdrawal of groundwater, and its eventual return to surface waters in a different watershed, can have indirect but serious impacts on local hydrology and water quality conditions. The most serious

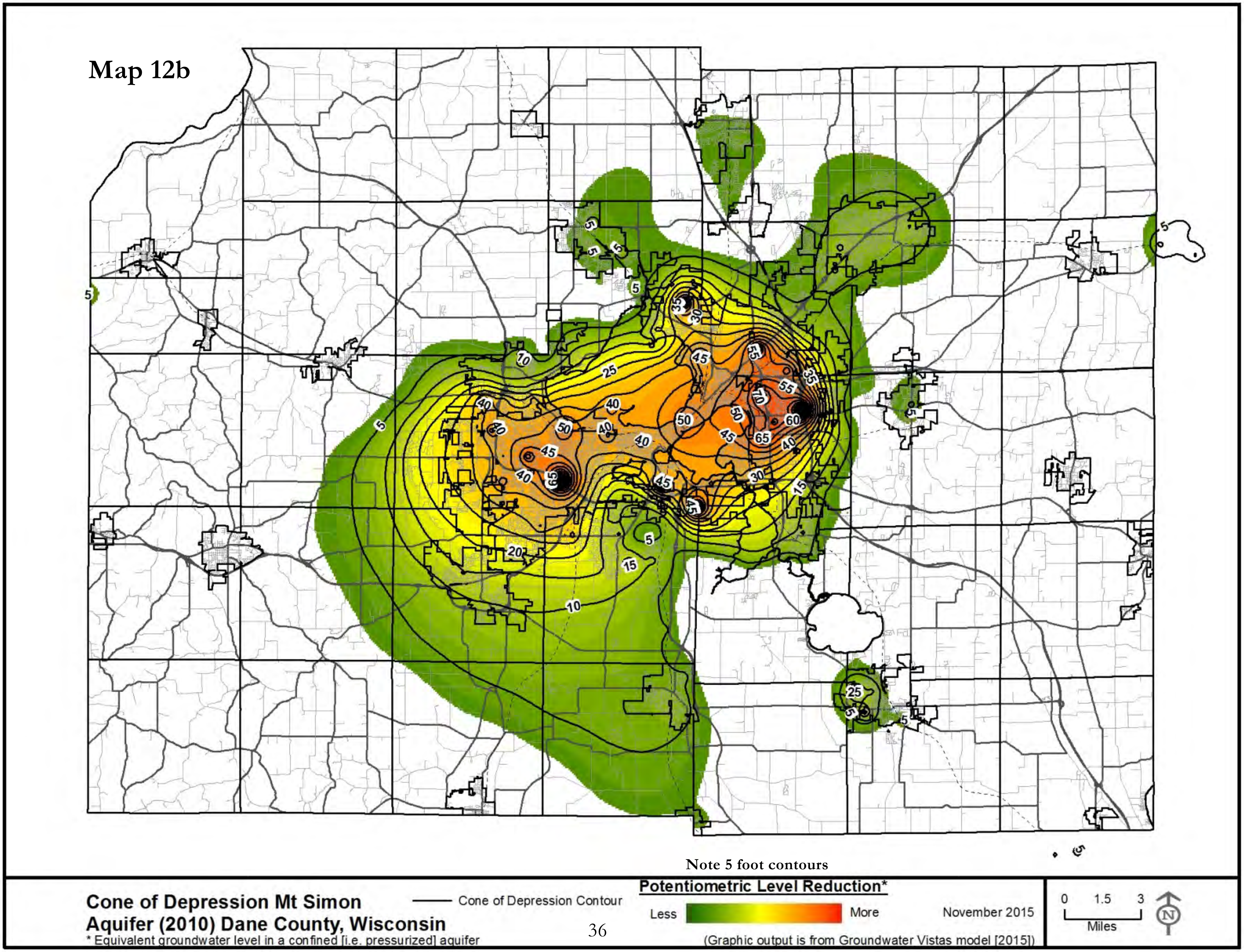
impacts are evident in the urban and urbanizing areas surrounding the Yahara Lakes. Although there is no shortage of groundwater available for future needs, pumping has already lowered groundwater levels, significantly reducing baseflow from groundwater to urban streams and wetlands.
The greatest effect of pumping on groundwater levels occurs in the Madison metropolitan area (**Maps 12a and 12b**). In the vicinity of Madison, the potentiometric level of the Mt. Simon aquifer and the water table level of the shallow aquifer have declined over 50 feet compared to predevelopment conditions. There are also two major cones of depression generally east and west of Lakes Mendota and Monona. This is because the upper sandstone and lower Mt. Simon aquifers are in close hydraulic connection to the lakes, and the semi-confining Eau Claire shale formation is largely absent or very thin in this area. The presence of two distinct cones of depression indicates the lakes are significant water sources that contribute to municipal wells.

The effects of the cone of depression and subsequent drawdown are particularly evident where the water table meets the land surface: at springs, streams, and wetlands. For example, modeling results show pumping from municipal wells has caused noticeable reductions in dry weather baseflow in small Yahara River tributary streams (**Table 5 and Map 13**). Baseflow through the Yahara River system itself at McFarland has been reduced approximately 30 percent (48 cfs) as a result of pumping and wastewater diversion around the Yahara River lakes. This supports earlier studies which find a direct relationship between the reduction in flow through the Yahara River system and the amount of MMSD wastewater diverted around the Yahara Lakes and discharged to Badfish Creek. This is a conservative estimate of the overall impacts since it does not account for the recharge losses resulting from impervious urban development, just well water withdrawals.

Urbanization also changes infiltration and groundwater recharge. This results from impervious surfaces like buildings, roads, and parking lots being constructed over previously undeveloped land. Water then runs off the land surface instead of infiltrating and replenishing groundwater supplies, resulting in additional water table declines. Extensive effort by the Regional Planning Commission and local municipalities since the late 1990s to require stormwater infiltration practices in new development areas, and inclusion of infiltration standards in the Dane County and local stormwater ordinance have addressed this concern in these areas.

Map 12a


Note 5 foot contours
Cone of Depression Upper Aquifer (2010)
Dane County, Wisconsin
Cone of Depression Contour
Groundwater Table Reduction
Less
More
November 2015
(Graphic output is from Groundwater Vistas model [2015])
0 1.5 3
Miles
N



Map 12b
Note 5 foot contours
Cone of Depression Mt Simon Aquifer (2010) Dane County, Wisconsin
* Equivalent groundwater level in a confined [i.e. pressurized] aquifer
Cone of Depression Contour
Potentiometric Level Reduction*
Less
More
November 2015
(Graphic output is from Groundwater Vistas model [2015])
0 1.5 3
Miles
N

Table 5
Modeled Stream Baseflows for Selected Sites (cfs)

Station	Predevelopment Baseflows[1]	2010 Pumping Conditions[2]	2040 Pumping Conditions[3]
Spring Cr. nr Lodi	22.23	21.70	21.65
Black Earth Cr abv Cross Plains	4.95	3.52	3.50
Black Earth Cr. nr Black Earth	33.33	31.36	31.23
Mt. Vernon Cr	19.19	18.49	18.32
West Br. Sugar R. at Hwy 92*	18.96	19.20	19.13
Badger Mill Cr. south of Verona*	3.65	4.23	3.65
Sugar River abv Confluence	16.58	13.66	13.01
Pheasant Br. at Middleton	2.85	1.19	1.13
Dorn Cr. at CTH M	6.27	5.65	5.50
Sixmile Cr. Waunakee at Mill Rd.	9.07	5.59	7.06
Token Cr. at USH 51	20.35	17.99	16.81
E. Br. Starkweather Cr at Milwaukee St.	3.01	0.73	0.41
W. Br. Starkweather Cr at Milwaukee St.	8.86	4.16	3.27
Murphy (Wingra) Cr. at Beld St.	2.89	1.83	1.64
Nine Springs Cr. at USH 14	11.84	6.69	6.45
Door Cr. nr Cottage Grove	7.69	5.69	5.30
Badfish Cr. at CTH A*	11.59	75.49	75.22
Yahara R. nr Windsor	6.77	6.28	6.13
Yahara R. outlet L. Waubesa	157.12	109.09	102.02
Yahara R. south of Stoughton	207.46	156.65	148.91
Maunesha R. south of USH 151	17.25	16.44	16.16
Koshkonong Cr. nr Sun Prairie*	0.77	5.02	4.76
Koshkonong Cr. nr Deerfield*	27.35	29.79	28.84
Koshkonong Cr. nr Rockdale*	62.84	65.02	63.99

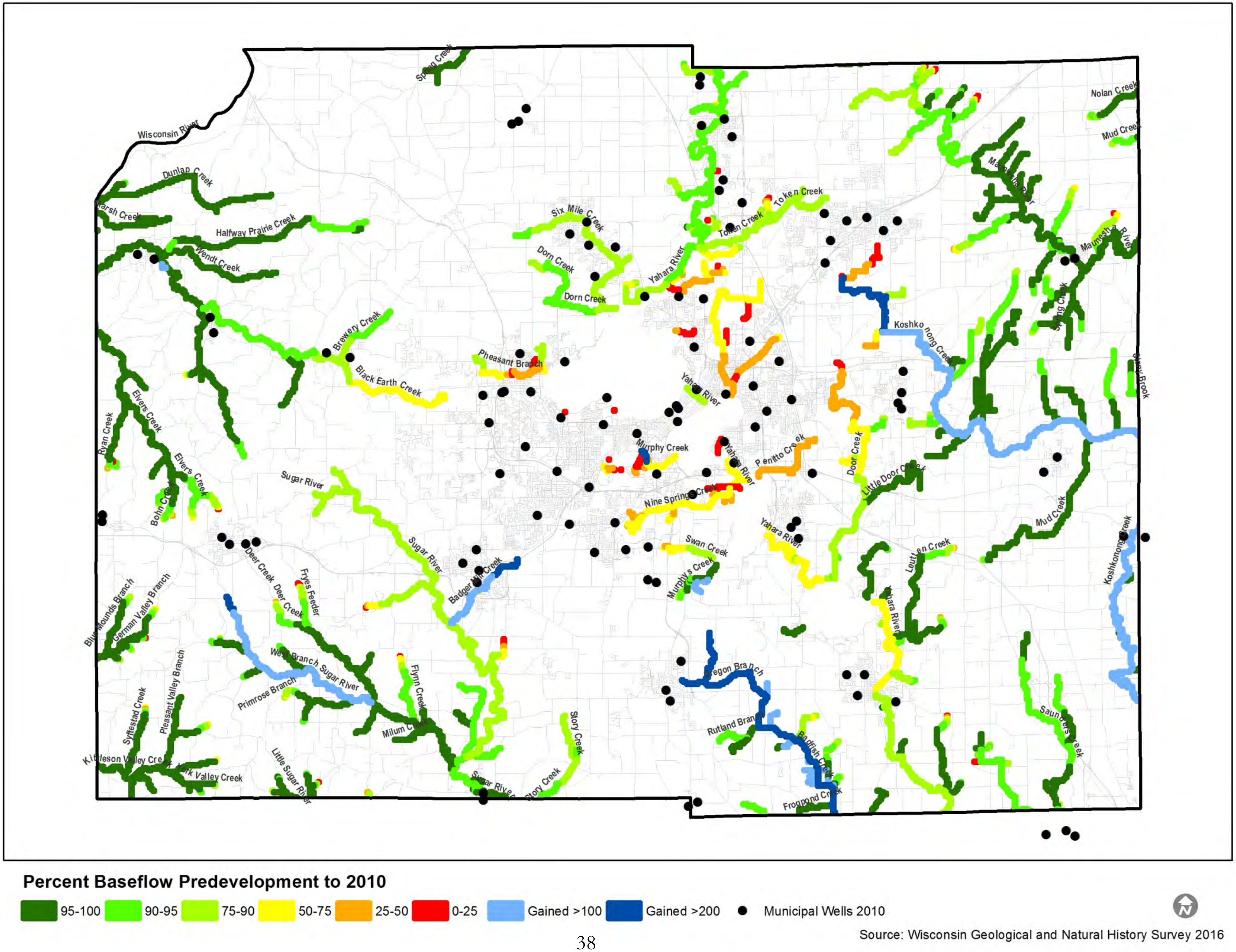
[1] Simulated predevelopment results were estimated by removing all well pumping from the regional groundwater model resulting in a subsequent rebound in water table levels and stream baseflows. Predevelopment flows do not include wastewater treatment plant discharges present in 2010. Asterisks (*) indicate where the 2010 flows include WWTP additions.

[2] 2010 condition streamflow results were estimated using the calibrated regional groundwater model based on measured baseflow results (n=210) from representative streams throughout Dane County and surrounding areas. Estimated wastewater discharges to streams have also been included, where these occur. Note, the modeled differences in streamflows are generally more accurate than the actual values due to regional calibration and seasonal variations. Streamflows are provided for reference purposes.

[3] 2040 baseflow results were estimated using the regional groundwater model and projected 2040 well water withdrawals by municipalities spread equally among both existing and planned wells. Increases in wastewater discharges above current conditions have not been included.

Source: Wisconsin Geological and Natural History Survey and Capital Area Regional Planning Commission.

Map 13. Modeled comparison of changes in streamflow between Predevelopment (no pumping and no WWTP discharges) and 2010 conditions. Streams which actually gained flow receive additional water as discharge from wastewater treatment facilities.



Model runs conducted as part of the Regional Hydrologic Study indicate that well pumping accounts for a significant amount (80 percent) of the baseflow reduction through the Yahara system, while recharge losses from impervious areas (20 percent) causes additional declines.[1] This may vary for individual stream segments based on the degree of development in the sub-watershed and proximity to pumping wells, but overall well water withdrawals are the dominating influence. Also, with improved stormwater volume controls there is no recharge loss resulting from new development (as compared to previous development where these controls have not been put into effect). Modeling conducted by the WGNHS indicates recharge loss due to future development is not expected to be significant because of the adopted stormwater controls (Dane County Chapter 14 and local ordinances), which help maintain pre-development groundwater levels.[2]

It should be noted, in the Madison area near areas of heaviest groundwater pumping, the original direction of groundwater flow towards the lakes and Yahara River has been reversed and instead flows towards the municipal wells in areas of heaviest withdrawals as induced groundwater recharge (**Ref Figure 7**). Heavy municipal pumping can accelerate downward leakage of "shallow" groundwater and surface water, which may increase the flow of associated contaminants to municipal wells.

Finally, the expanding cone of depression appears to have also shifted the regional groundwater divide to the southwest, causing groundwater which previously discharged to the Sugar River, to be diverted to the Yahara River basin (**Ref Map 5**). Groundwater diversion may also be occurring from other adjacent river basins to a lesser extent. In 1998, MMSD began returning treated wastewater to Badger Mill Creek, equal to the amount of water pumped out of the basin. This has helped to restore the water balance between the Upper Sugar River and Yahara River watersheds (resulting from diversion) and remove low flow as a limiting condition. This project has had widespread public support and success. In 2008 Badger Mill Creek was designated a Class II trout stream by the WDNR, largely attributed to the treated effluent return.

2040 Baseline Conditions[3]

As part of the Regional Hydrologic Study a future baseline condition was modeled which incorporated specific assumptions for anticipated future water use and wastewater diversion. This effort was repeated using the updated groundwater model in 2014.

Map 14a shows the additional groundwater declines that can be expected by the year 2040 (from current conditions) due to increased well pumping and continued wastewater diversion. Noticeable additional water table declines would occur northeast and southwest of Madison metro area. Similar potentiometric surface declines would occur in the deeper Mt. Simon aquifer (**Map 14b**), although the effects are more pronounced near new urban well sites.

Note many of the white areas in the urban metropolitan region are the result of an actual water table *rebound* compared to exiting conditions. The area along the west beltline (Madison wells 10, 12, 26, and 20) is a good example. This occurs where current pumping at an individual well site currently exceeds the 2040 pumping assumption where future water use is spread out equally among both existing and planned well sites. Though imprecise, the equal withdrawal scenario provides a useful comparison among communities in the region and represents an average condition or equal likelihood of withdrawal among existing and planned municipal wells. That is usually not the case under actually conditions, which can change year to year and community to community. The modeling indicates the kinds of analyses that can

[1] Dane County Regional Planning Commission. 1997. *Evaluation of Alternative Management Strategies, Dane County Regional Hydrologic Study*.

[2] Professor Ken Brandbury, WGNHS, personal communication 5/13, and Stormwater Performance Standards contained in Dane County Chapter 14.51(2)(e)(3). https://pdf.countyofdane.com/ordinances/ord014.pdf.

[3] Assumes no mitigating actions being taken.

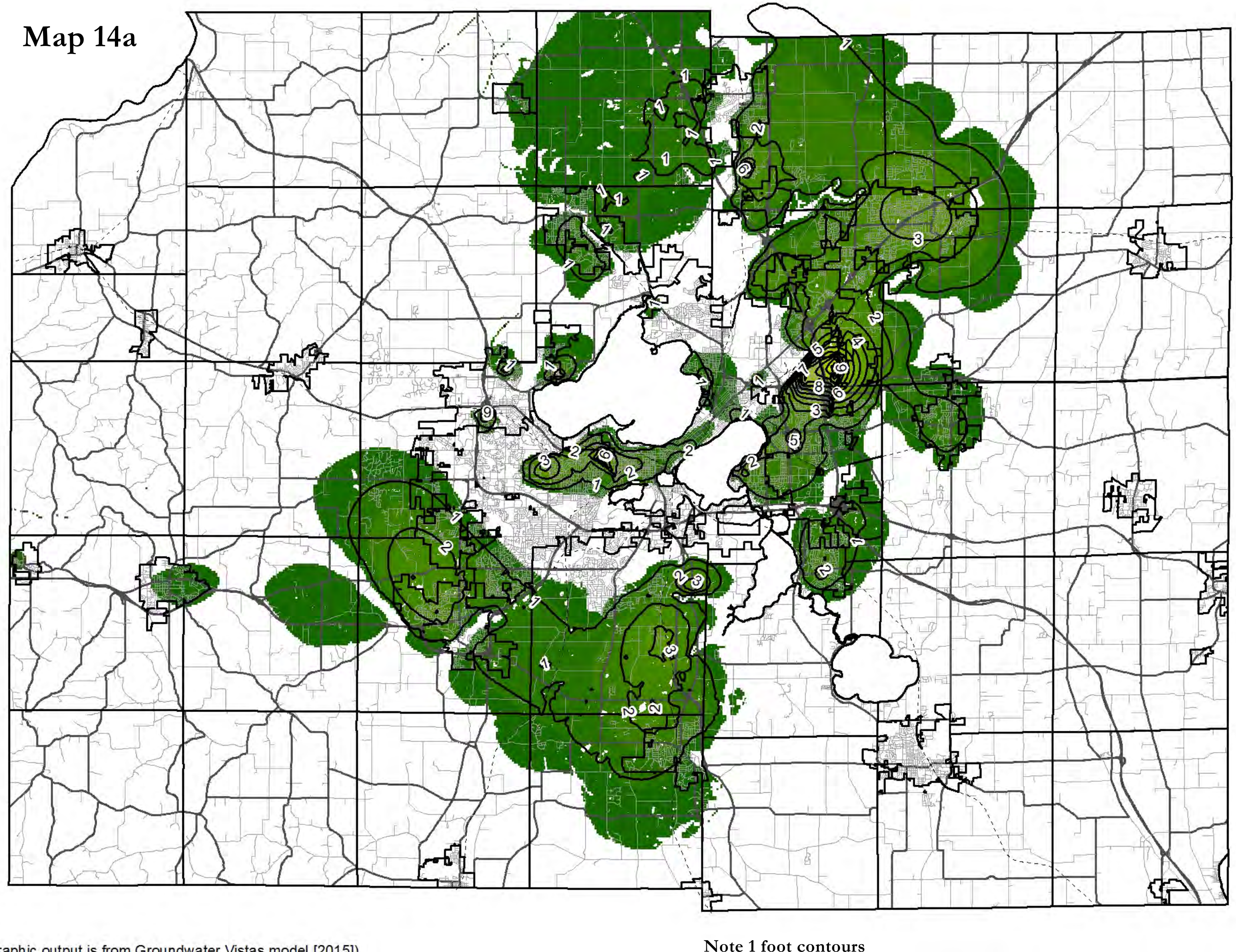
be conducted for individual communities depending on different well strategies or alternatives based on varying well locations and withdrawal rates. As such, this modeling scenario represents an average future condition.

Baseflows in small tributary streams are also affected, particularly near the Central Urban Area (**Reference Map 13 and Table 5**). Baseflows could decrease 50 percent or greater in Murphy, Nine Springs, Pheasant Branch, and Starkweather Creeks compared to predevelopment conditions. Baseflow through the Yahara River system at McFarland is expected to decline an additional 8 cfs from 2010 to 2040, a total 36 percent reduction compared to predevelopment conditions.

The 2040 baseline condition was modeled in order to determine the most likely impacts to water resources if the region grew as expected, mitigating measures were not employed, and wastewater diversion continued as usual. These impacts would be in addition to those experienced in 2010 (**Reference Maps 12a and 12b**). The 2040 baseline condition also serves as a very useful reference point for evaluating various management alternatives or combination of alternatives that may be undertaken to help mitigate future groundwater level declines and reductions in stream baseflow.

As part of the original study, an evaluation of alternative management strategies was also conducted which could potentially offset groundwater and streamflow declines. Strategies such as aggressive water conservation, maximizing infiltration, selective pumping patterns in the City of Madison, improved lake management, and return of highly treated wastewater showed the most promising opportunities for mitigating the water table level declines and reductions in baseflows (See **Reference Table 7** below).

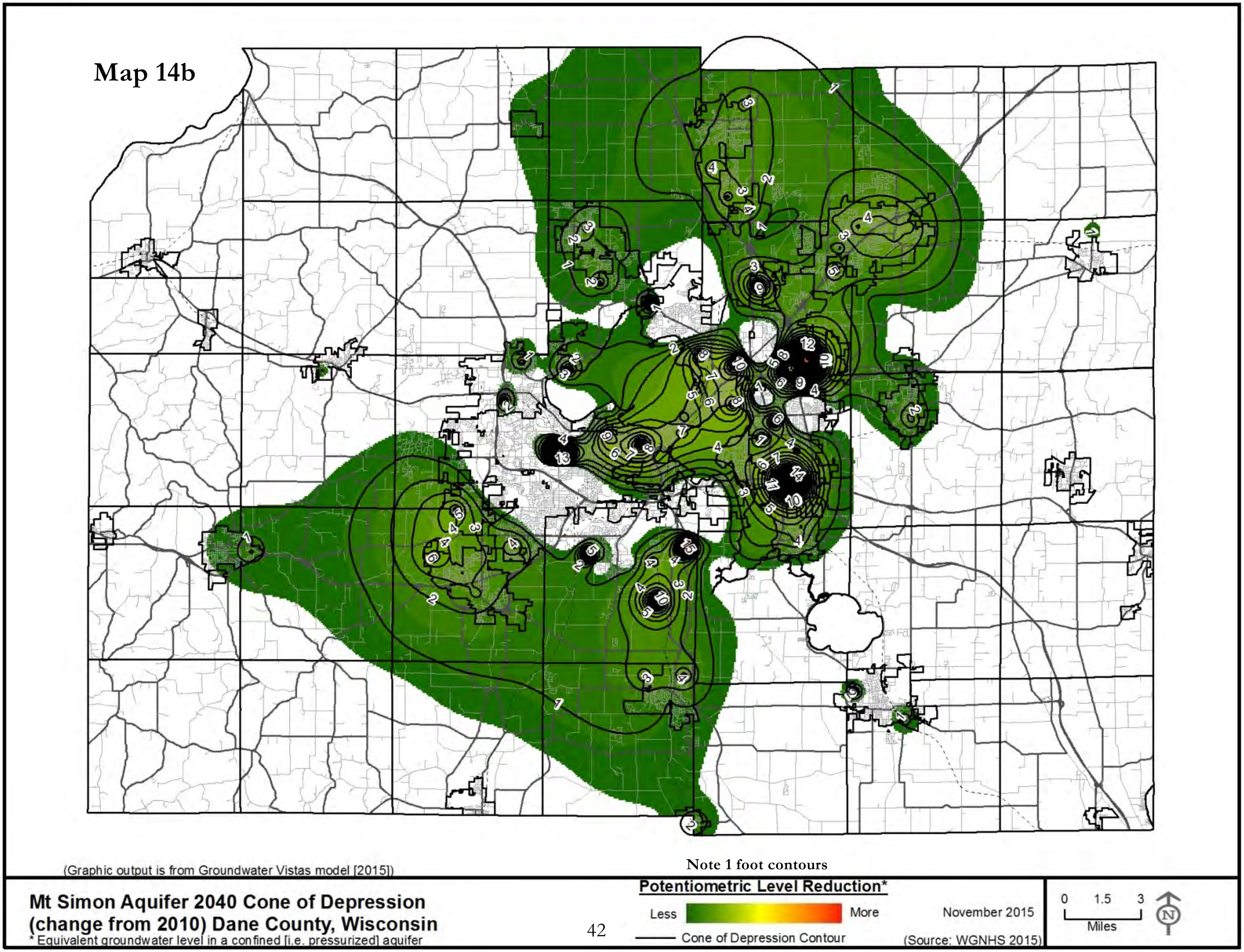
Map 14a



Upper Aquifer 2040 Cone of Depression (change from 2010) Dane County, Wisconsin

November 2015

(Source: WGNHS 2015)


Map 14b
(Graphic output is from Groundwater Vistas model [2015])
Note 1 foot contours
Mt Simon Aquifer 2040 Cone of Depression
(change from 2010) Dane County, Wisconsin
* Equivalent groundwater level in a confined [i.e. pressurized] aquifer
Potentiometric Level Reduction*
Less
More
Cone of Depression Contour
November 2015
(Source: WGNHS 2015)
0 1.5 3
Miles
N

Groundwater Budget Indices and Water Supply Plans

Based on work conducted by Douglas S. Cherkauer, Ph.D., UW-Milwaukee, as part of the groundwater modeling conducted by Southeast Wisconsin Regional Planning Commission, groundwater budget indices have been developed to assess water supply plans in southeast Wisconsin. These indices can similarly be used to augment and provide more detailed information than the drawdowns or cones of depression analyzed as part of the earlier Dane County regional hydrologic study. In addition to drawdown, the model can be used to determine the magnitudes of all the individual components of a groundwater budget (**Table 6**).

Table 6. Definition of Flow and Storage Terms.

	Inflows	**Outflows**	**Storage**
	R = recharge		
Shallow Aquifer – upper sand and gravel glacial deposits and underlying sandstone and dolomite bedrock	**SW_{in}** = flow from surface waters to groundwater	**SW_{out}** = discharge to surface waters from groundwater	Volume of water in the aquifer below the water table and above the Eau Claire shale formation
	Sh_{in} = lateral inflow through the aquifer	**Sh_{out}** = lateral outflow through the aquifer	
	L_{up} = leakage up from the deep aquifer	**L_{down}** = leakage down to the deep aquifer	
	H_r = human inputs (e.g., artificial or enhanced recharge)	**$Well_{sh}$** = pumpage from the shallow aquifer	
Eau Claire Shale – semi-confining unit			
	Inflows	**Outflows**	**Storage**
Deep Aquifer – lower Mt. Simon sandstone formation	**D_{in}** = lateral inflow through the deep aquifer	**D_{out}** = lateral outflow through the deep aquifer	Volume of water in the aquifer below the Eau Claire shale formation and the base of the Mt. Simon formation
	L_{down} = leakage down from the shallow aquifer	**L_{up}** = leakage up to the shallow aquifer	
	H_{dp} = human inputs = 0	**$Well_{dp}$** = pumpage from deep aquifer	

More specifically:

- How does the quantity of water being removed from an aquifer by wells relate to the aquifer's natural supply?
- What effect does human alteration of the groundwater system have on surface waters?

The indices presented, called demand to supply ratio (DSR), and baseflow reduction index (BRI) address the two questions above. They were developed by Weiskel, et al (2007), and Cherkauer (2010), respectively. In terms of cause and effect, it is useful to think of the DSR as being the "cause" (increasing demand compared to supply) and BRI as the "effect" (reduction in baseflows). The results of an analysis conducted for Dane County using these two indices follows.

Demand to Supply Ratio (DSR)

One measure of an aquifer's groundwater budget comes from comparing the net amount of water humans are extracting (volume pumped) to how much water is replenished at any given time. The Demand to Supply Ratio (DSR) is basically the ratio of groundwater demand to the available supply. It can be expressed as:

Demand/Supply = (Well pumping out – Human replacement in)/(Sum of natural inflows).

The net extraction (outflows induced by humans pumping wells minus any human returns to the same aquifer) is used as an indicator of human stress on the aquifer. In terms of scale, it is expressed as a percentage of the natural inflows (i.e., precipitation and groundwater recharge). The natural inflows include groundwater recharge, leakage between aquifers, flow from surface water bodies, and lateral flow through the aquifer shown in **reference Table 6**. Note that current law requires all new development projects in Dane County to maintain pre-development recharge, meaning no recharge loss.[4] Whereas human water replacement for well withdrawals are assumed to be generally zero at this time (as in the equation above), there are certainly opportunities to mitigate well withdrawals in the future, such as enhanced infiltration of runoff or treated wastewater. Note this would specifically not include projects making up for lost recharge resulting from new development, which is already required under existing law. Therefore, changes in recharge were not included as part of this analysis, focusing primarily on high capacity municipal well withdrawals. A human replacement project (e.g., enhanced infiltration in a particular area to make up for well withdrawals) could certainly be included in the analysis. But this would be the focus of more detailed local water supply modeling and planning conducted for individual communities.

Maps 15 and b show the spatial distribution of the DSR attributed to well withdrawals. DSR values range up from zero. A value of zero indicates that the groundwater budget remains in the same balance as it did before municipal well withdrawals. As ratio values increase, this indicates that pumping is moving the budget out of its natural balance. When a value of 100 percent is reached, net pumping is pulling out the same amount of water as would be naturally replenished. Values greater than 100 percent indicate that pumping has moved the aquifer into groundwater budget deficit; and the further the ratio is above 100 percent, the further it is out of balance.

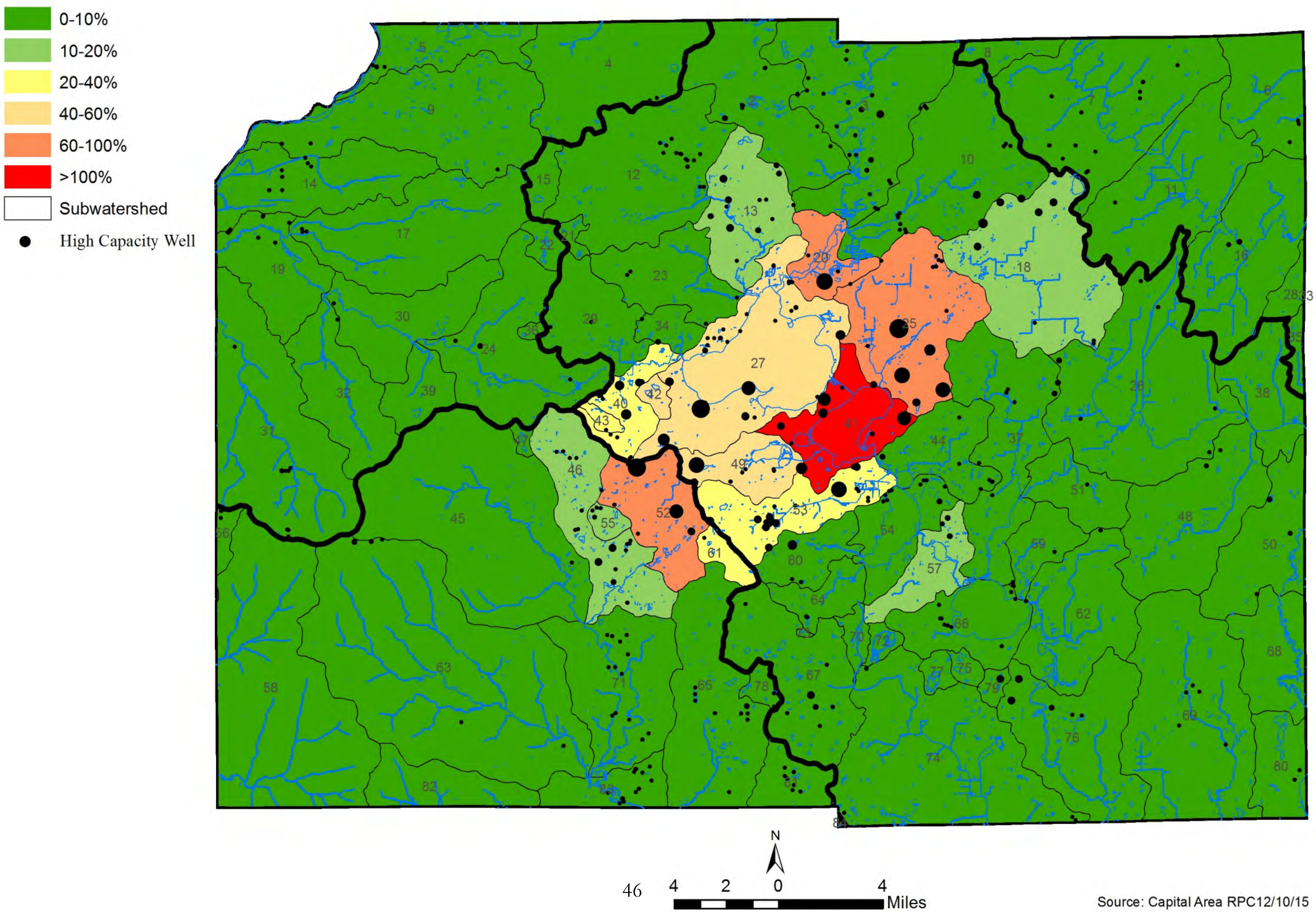
The highest DSRs are in the Madison Metropolitan Area, with the Lake Monona value being in excess of 100 percent (demand greater than supply). The result is that water is being induced from the Yahara Chain of Lakes. Whereas groundwater discharged to Lakes Monona and Mendota during pre-development conditions, this situation has since reversed with surface water now being drawn into and augmenting groundwater supplies as a result of well water withdrawals. This has an accompanying effect on surface water features that depend on groundwater supplies, described in the next section.

Overall, the DSR serves as a good example of the kind of information that could be analyzed as part of a municipality's water supply plans. As such, more detailed modeling of wells and mitigation strategies can and should be conducted in coordination with CARPC staff using the tools outlined in this report. For example, note the improvement in the Upper Badger Mill Creek (52) and Cherokee Marsh (20) subwatersheds from 2010 to 2040. This is the result of the 2040 pumping assumption used, where a community's total well withdrawal is drawn equally from both existing and planned wells. This represents an average or equal likelihood of future wells and withdrawals for a community. Under this configuration (among many other different possibilities or alternatives) a well may indeed be pumping less in 2040 than actually occurred in 2010, particularly if it is being heavily used currently. This could result in an apparent decline in the DSR for a particular subwatershed in the future, as here. This re-enforces the point that the DSR is indeed sensitive to changes in pumping rates and locations. The utility of this index is that it is possible to test different locations of wells and configurations of withdrawals to evaluate alternative pumping patterns and mitigation strategies. More specifically, the index provides useful information and methodology for testing alternative growth

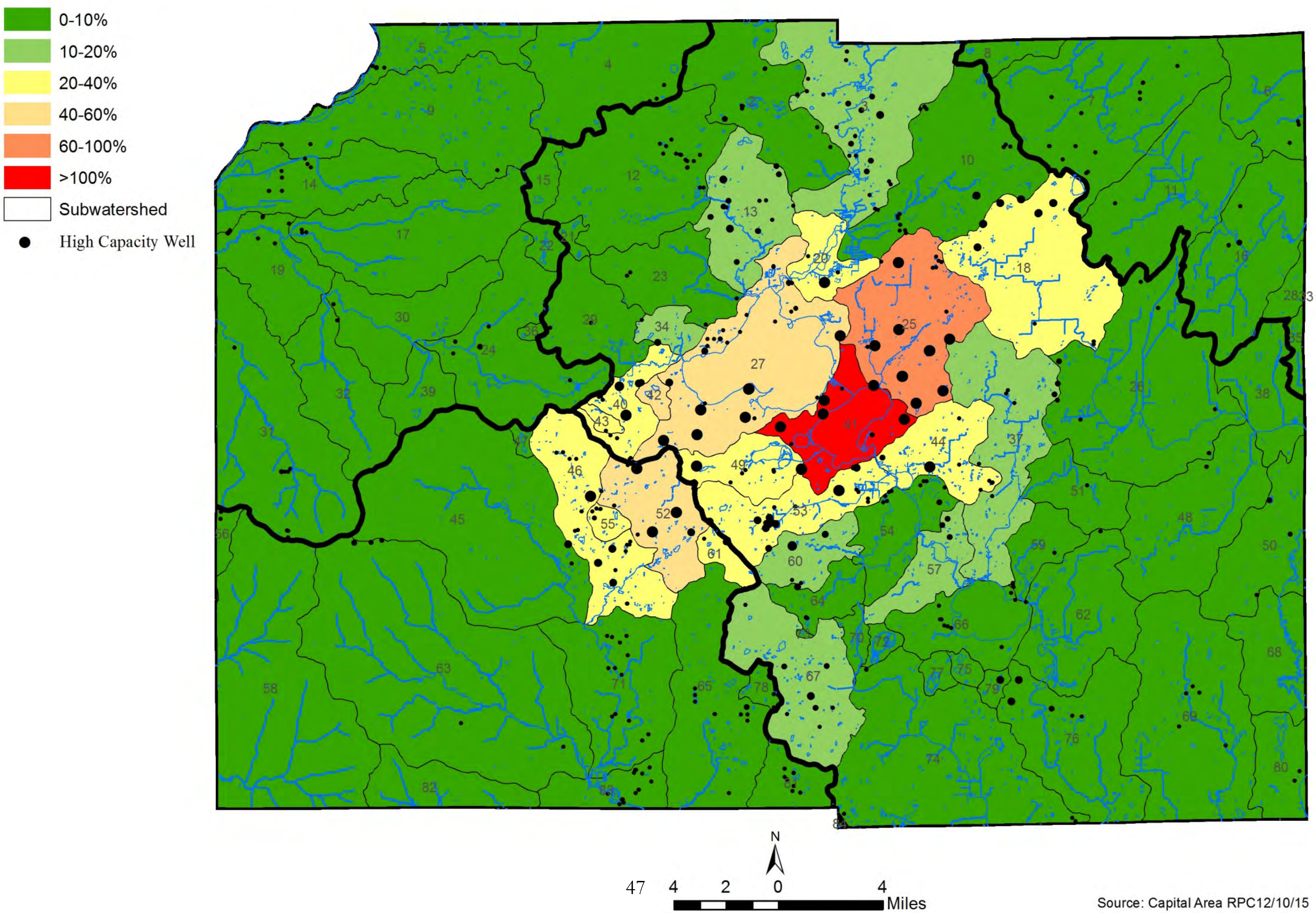
[4] See the Stormwater Performance Standards contained in Dane County Chapter 14.51(2)(e)(3). https://pdf.countyofdane.com/ordinances/ord014.pdf

scenarios, impacts, and mitigation strategies by varying the different variables (i.e., well withdrawals and locations, human inputs, etc.). While only highlighted here, this could certainly be the focus of more detailed local water supply modeling and planning conducted in coordination and cooperation with and among individual communities.

Map 15a. 2010 Demand to Supply Ratio (DSR)



Map 15b. 2040 Demand to Supply Ratio (DSR)



Baseflow Reduction Index (BRI)

Groundwater discharge is the outflow that keeps surface waters flowing during dry periods when there is no runoff. Pumping intercepts groundwater that would have discharged to surface water bodies as baseflow. As pumping increases the baseflow discharge to streams, wetlands, and lakes decreases. The actual amount is the result of a complex exchange among different variables such as the proximity of a well to a waterbody, neighboring wells, the amount(s) of withdrawal, the geologic layers being drawn upon, hydrogeologic variables of transmission and resistance, as well as climatic variations. Similar to DSR, the baseflow reduction index (BRI) has been developed to help quantify that loss in subwatersheds throughout Dane County. It is the ratio of the change in groundwater discharge between a base time period and the time of interest, divided by the base period discharge. Here it is expressed as the change between Pre-Development Conditions (circa 1900) and Current Conditions (2010):

$$BRI = [(\text{Net Baseflow}_{2010} - \text{Net Baseflow}_{1900})/\text{Net Baseflow}_{1900}] * 100,$$

Where Net Baseflow is $SW_{out} - SW_{in}$ (**Reference Table 6**).

In the analysis of Future Conditions, it is expressed as the change in baseflow between 1900 and 2040.

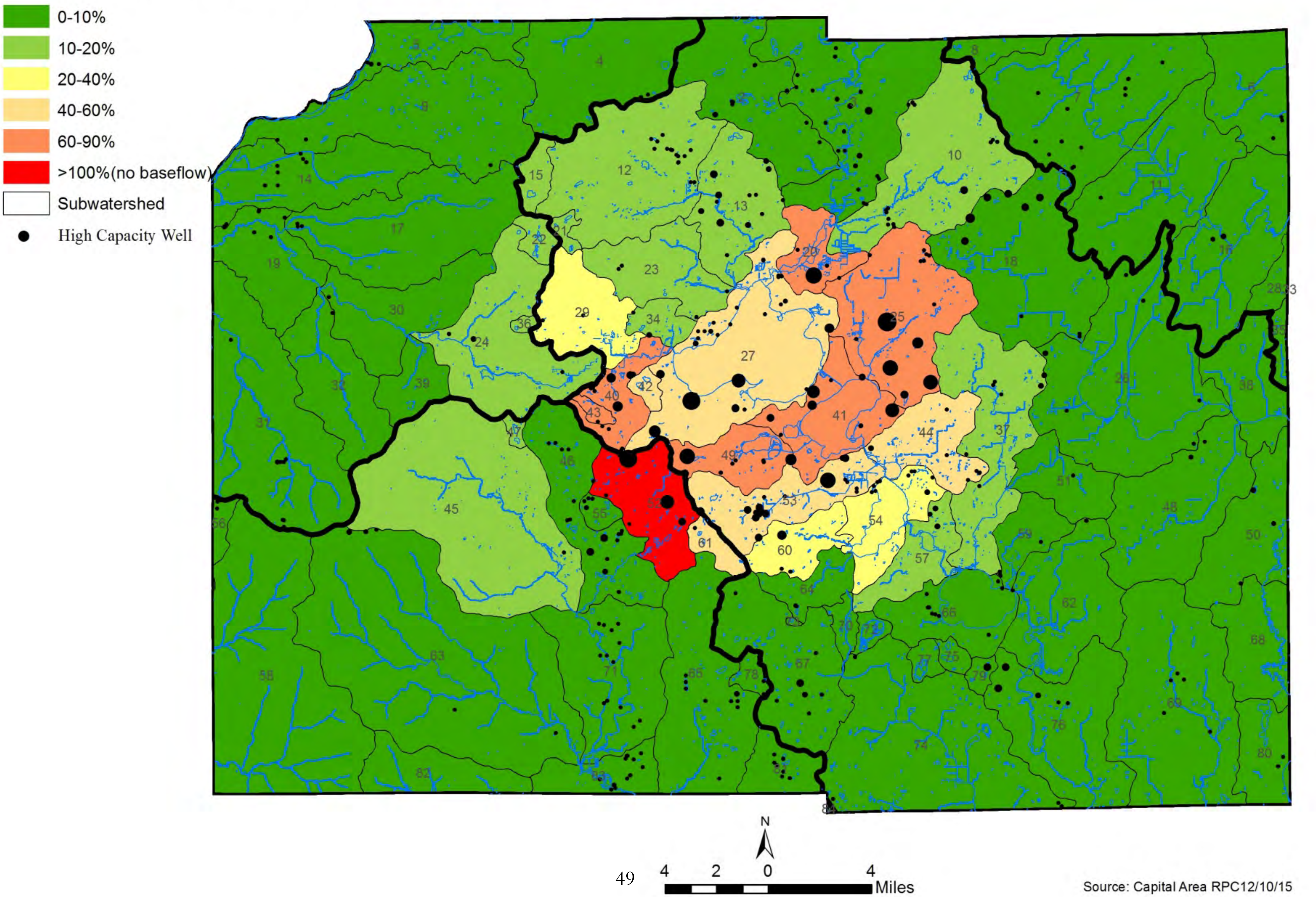
The values, expressed as percent, are presented in **Maps 16a and b.** There has been a baseflow reduction of 20 percent or greater throughout much of the central region (shown in yellow, orange, and red). This shows a strong parallel to DSR, **Reference Maps 15a and b.** Also, BRIs generally increase in developing areas due to future well withdrawals. Madison is by far the largest groundwater user, pumping 29 mgd in 2010 and a projected withdrawal of 33 mgd in 2040 (an 11 percent increase over the period analyzed). The areas where the shallow aquifer is most stressed by human activities have experienced the greatest baseflow reduction.

Reference Maps 16a and b show the effect of pumping on baseflows for individual subwatersheds. In dry periods, virtually all of the flow in a river is groundwater discharge (baseflow), so the effects will be most apparent in the summer, fall, and early winter. These periods are particularly critical for biologic life and the health of stream communities. Baseflow reductions due to pumping will also be greatest on a percentage basis on smaller waterbodies, such as springs, headwater streams, small lakes, wetlands, and ponds. During wet periods flow in surface water bodies is dominated by surface runoff of rain or snowmelt. During these periods the effects of the pumping would probably not be discernible.

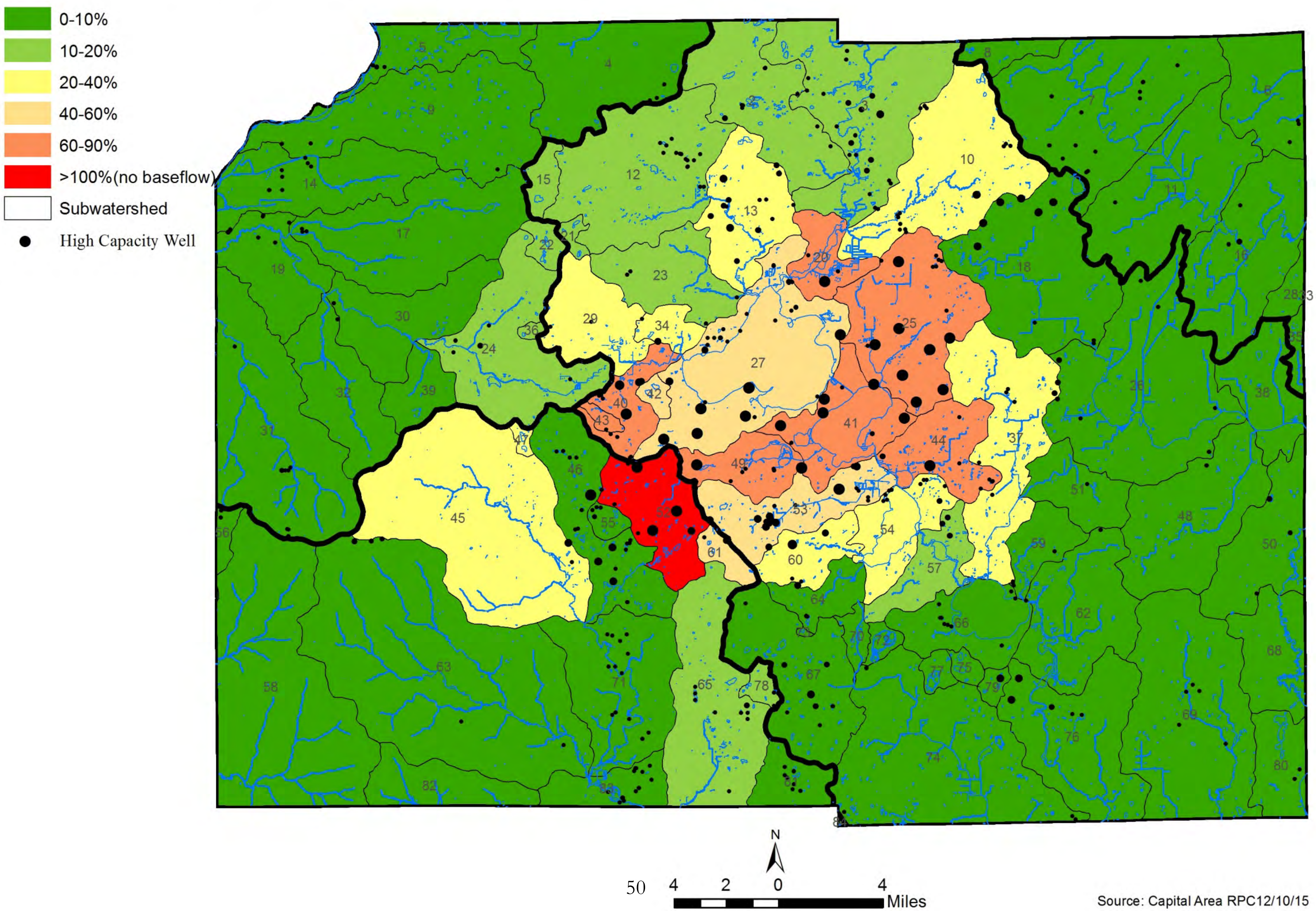
Similar to the DSR above, the utility of this index is that it is possible to test different configurations of wells and withdrawals to evaluate alternative pumping patterns and management strategies. More specifically, the index provides useful information and methodology for testing alternative growth scenarios, impacts, and mitigation strategies by varying the different variables (i.e., well withdrawals and locations, human inputs, etc.). While only highlighted here, this could certainly be the focus of more detailed local water supply modeling and planning conducted in coordination and cooperation with and among individual communities.

For example, note in **Reference Map 13** that the treated effluent discharge from wastewater treatment plants has resulted in a *gain* in baseflow in some streams. While perhaps not as pristine as groundwater discharge, treated wastewater is a reliable source of water during dry periods and is therefore considered baseflow under the technical definition of the term. With the advent of more effective treatment technologies, wastewater is being considered a beneficial resource in some areas. Two notable examples, Badger Mill Creek and Badfish Creek, now support populations of trout because of the highly treated effluent being returned to the stream. The innovation here is promoting wastewater as a *resource* and not simply something flushed downstream. This is discussed further in the following section.

Map 16a. 2010 Baseflow Reduction Index (BRI)



Map 16b. 2040 Baseflow Reduction Index (BRI)



Ecological Limits of Hydrologic Alteration

It is important to point out or emphasize that flow regime is a primary determinant of the structure, function, and health associated with rivers and streams. Indeed, streamflow has been called the "Master Variable," [5] or the "Maestro…that orchestrates pattern and processes in rivers."[6] Much evidence exists that modification of streamflow induces ecological alteration. In terms of groundwater, decreased baseflow during dry weather conditions increases stream temperature, reduces oxygen level, and available habitat.

Both ecological theory and abundant evidence of ecological degradation in flow-altered rivers and streams support the need for environmental flow management. [7] In addition, strategies that focus on reducing runoff (i.e., maintaining infiltration and recharge) also reduce pollutant loads – since pollutant concentrations and loading are a direct function of runoff volume. Certainly, environmental factors other than streamflow have been recognized. But as society struggles to conserve and restore freshwater ecosystems, flow management is needed to ensure that existing ecological conditions do not decline any further, and that it may even be possible for these resources to be *improved*.[8]

The Ecological Limits of Hydrologic Alteration (ELOHA) is a management framework offering a flexible, scientifically defensible approach for broadly assessing environmental flow needs when in-depth studies cannot be performed for all rivers and streams in a given region.[9] ELOHA builds upon the wealth of knowledge gained from decades of river-specific studies and applies that knowledge to specific geographic areas. In practice, ELOHA synthesizes existing hydrologic and ecological databases from many rivers and streams within a region to generate flow alteration/ecological response relationships for other rivers and streams with similar hydrologic regimes. These relationships correlate measures of ecological condition, which can be difficult to manage directly, to streamflow conditions, which can be managed through water-use strategies and policies. Detailed site-specific data need not be obtained for each river or stream in a region.

For example, the State of Michigan has proposed a standard on groundwater pumping that protects fisheries resources for each of the 11 classes of streams in the state.[10] The state has also launched a web-based Water Withdrawal Assessment Tool (WWAT)[11] designed to estimate the likely impacts of a proposed water withdrawal on a nearby stream or river. This approach shows significant promise to the extent it could be applied to evaluating reductions in baseflow resulting from urban and agricultural land uses in Wisconsin. The WDNR is currently using an ELOHA-based process in its high capacity well reviews. Fish response curves are one of the tools used to determine significant adverse impacts to streams and rivers.

More specifically, using existing fish population data across a gradient of hydrologic alteration (i.e., median August flow reduction – considered critical), Michigan scientists determined two flow/response relationships between populations of "thriving" (intolerant) fish species and "characteristic" (more tolerant) fish species for 11 stream types in Michigan (**Figure 10**). In developing the flow/response curves, fisheries ecologists examined the range of variation in the biological response across the flow alteration gradient and effectively smoothed the statistical scatter to create a trend line. Cut-points (vertical lines) were identified by consensus through a stakeholder process (**Figure 11**).

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[5] Poff, N. 2010a. *The Ecological Limits of Hydrologic Alteration (ELOHA): A New Framework for Developing Regional Environmental Flow Standards.*

[6] Walker, K. et al. 1995. *Rainfall-Runoff Modeling in Gauged and Ungauged Catchments.*

[7] Poff, N. 2010b. *Ecological Responses to Altered Flow Regimes: A Literature Review to Inform the Science and Management of Environmental Flows.* Freshwater Biology 55: 194-205.

[8] Palmer, M. 2008. *Climate Change and the World's River Basins: Anticipating Management Options.*

[9] http://www.conserveonline.org/workspaces/eloha

[10] Michigan Groundwater Conservation Advisory Council. 2007. *Report to the Michigan Legislature in response to Public Act 34.*

[11] http://www.miwwat.org/

A diverse stakeholder committee proposed a ten percent decline in the thriving (sensitive) fish population as a socially acceptable or sustainable resource impact (Region A). A ten percent decline in the characteristic (tolerant) fish population was deemed to be an unacceptable adverse impact (Region D).[12] The Adverse Resource Impact (ARI) is defined as when a fish population can no longer succeed because of reduced "index flow" during critical summer months (August and September). Intermediate flow alterations (Regions B and C) trigger preventative or corrective environmental flow management actions depending on a stream's ecological condition. The Michigan "ten-percent rule" applies to each of the 11 stream types, but the shapes of the curves – and therefore the allowable or sustainable degree of hydrologic alteration – vary by stream type. Similar fish response curves are being developed by Michigan resource managers for high flow events.[13]

CARPC recently contracted with WDNR Division of Science Integrated Services to construct these flow alteration/ecological response curves based on USGS flow and WDNR fisheries data in Wisconsin and the Capital Region.[14] It should be noted that, whereas the fish response curves for individual stream segments have been combined and averaged for the general stream classes in Michigan presented here (**Reference Figure 10 above**), individual curves for individual fish species for individual stream segments throughout Dane County have been developed for analytical purposes. Common analyses include modeling the response of individual species in affected stream segments due to planned well withdrawals or impervious development, as well as the effect of practices to mitigate these impacts.

Together, these two ecological response models (baseflow reduction and increased stormflow) promise to be important tools for guiding more effective approaches to water resources management issues relating to the sustainability of urban development amid the backdrop of a historically agricultural landscape.

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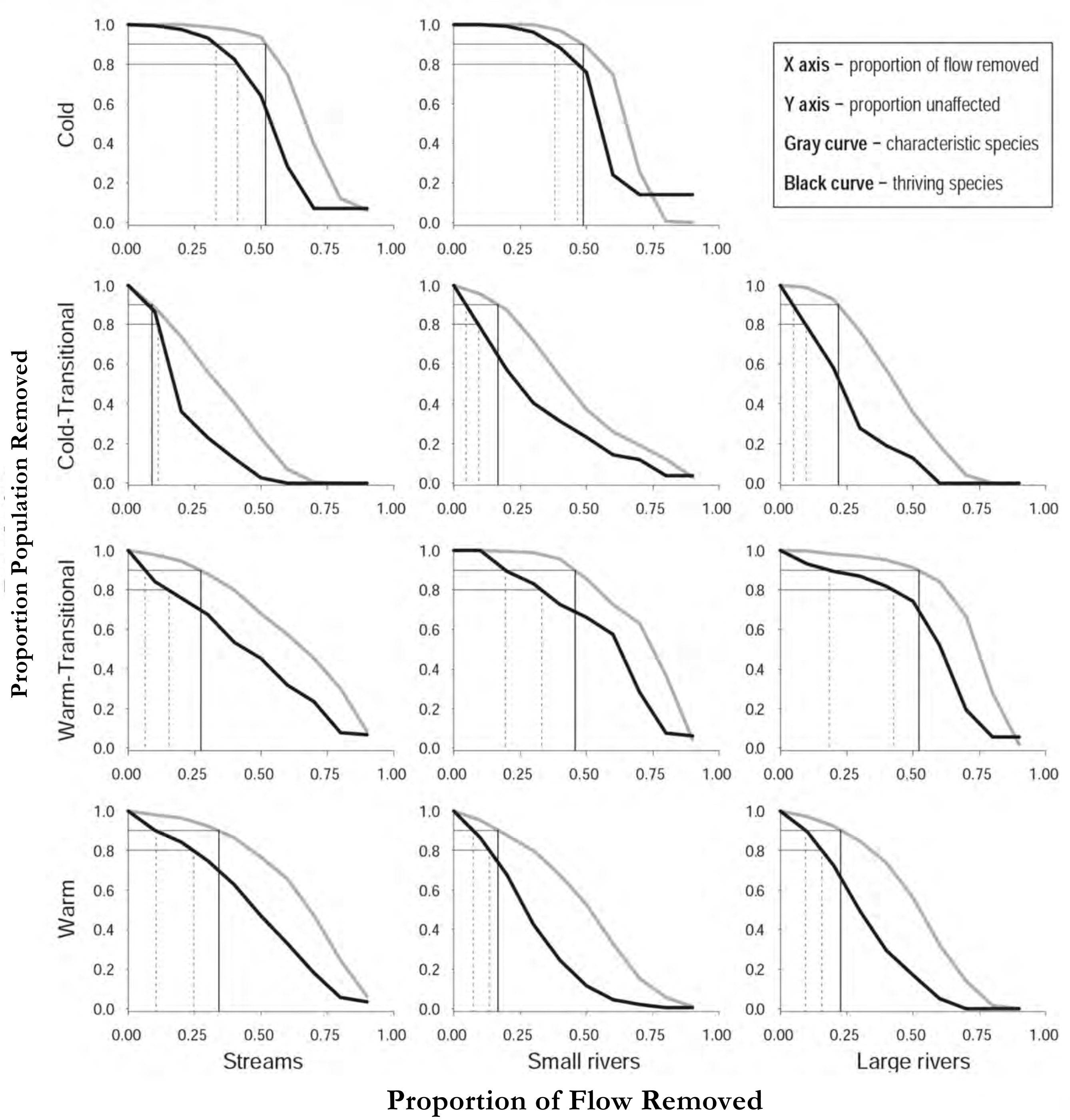
[12] Bartholic, J. Undated. *Michigan's Water Withdrawal Assessment* Tool.
[13] Troy Zorn, Ph.D., Michigan DNR; unpublished results, August 2010.
[14] Diebel, M. et al. 2014. *Ecological Limits of Hydrologic Alteration in Dane County Streams.*

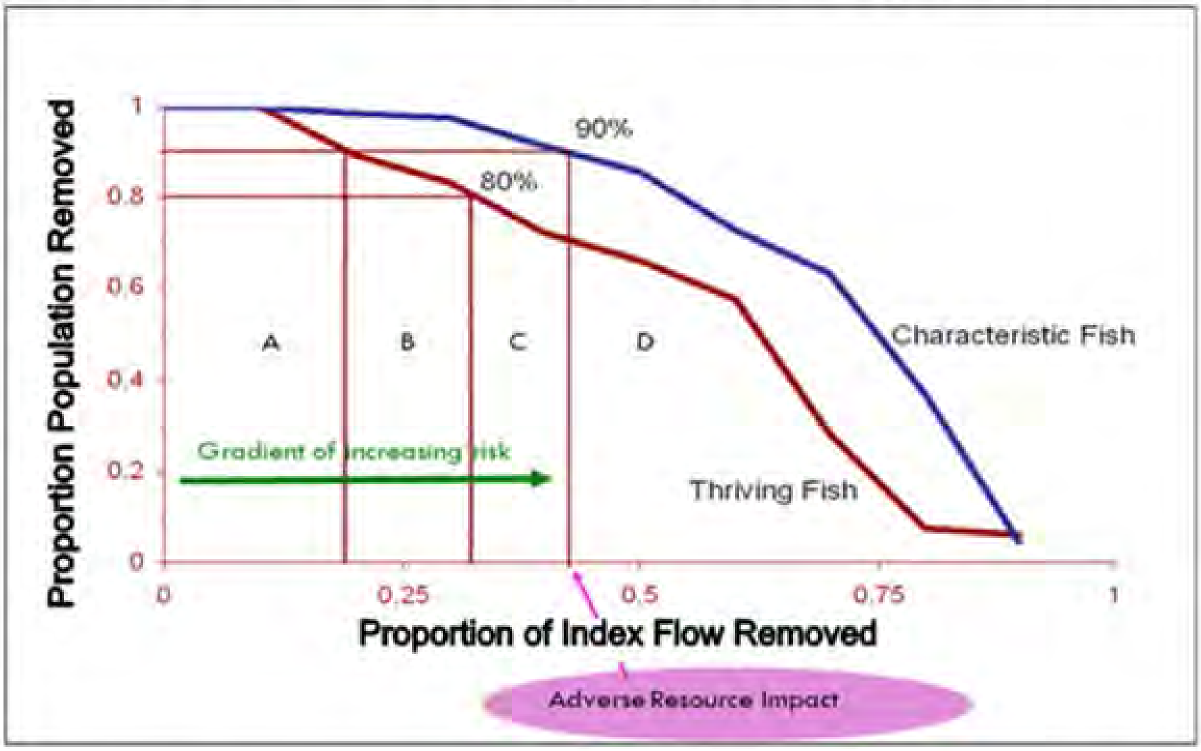
Figure 10. Actual Flow Alteration-Ecological Response Relationships.



Curves describing fish community responses to water withdrawal for Michigan's 11 river types, as defined by size and July temperature characteristics. Axes are identical to those in Figure 12. The black curve describes the proportion of more sensitive "Thriving Species" at each increment of flow reduction. The gray curve quantifies the proportional change in more tolerant "Characteristic Species" at each level of water withdrawal. The right-most vertical line in each plot identifies the flow associated with an Adverse Resource Impact (Figure 12), while other vertical lines identify water withdrawal levels associated with undefined management actions to be taken in anticipation of the river baseflow yield (index flow) approaching the Adverse Resource Impact level.

Source: Zorn et.al., 2008.

Figure 11. Interpreting the Fish Response Curves with an Eye Toward Policy.



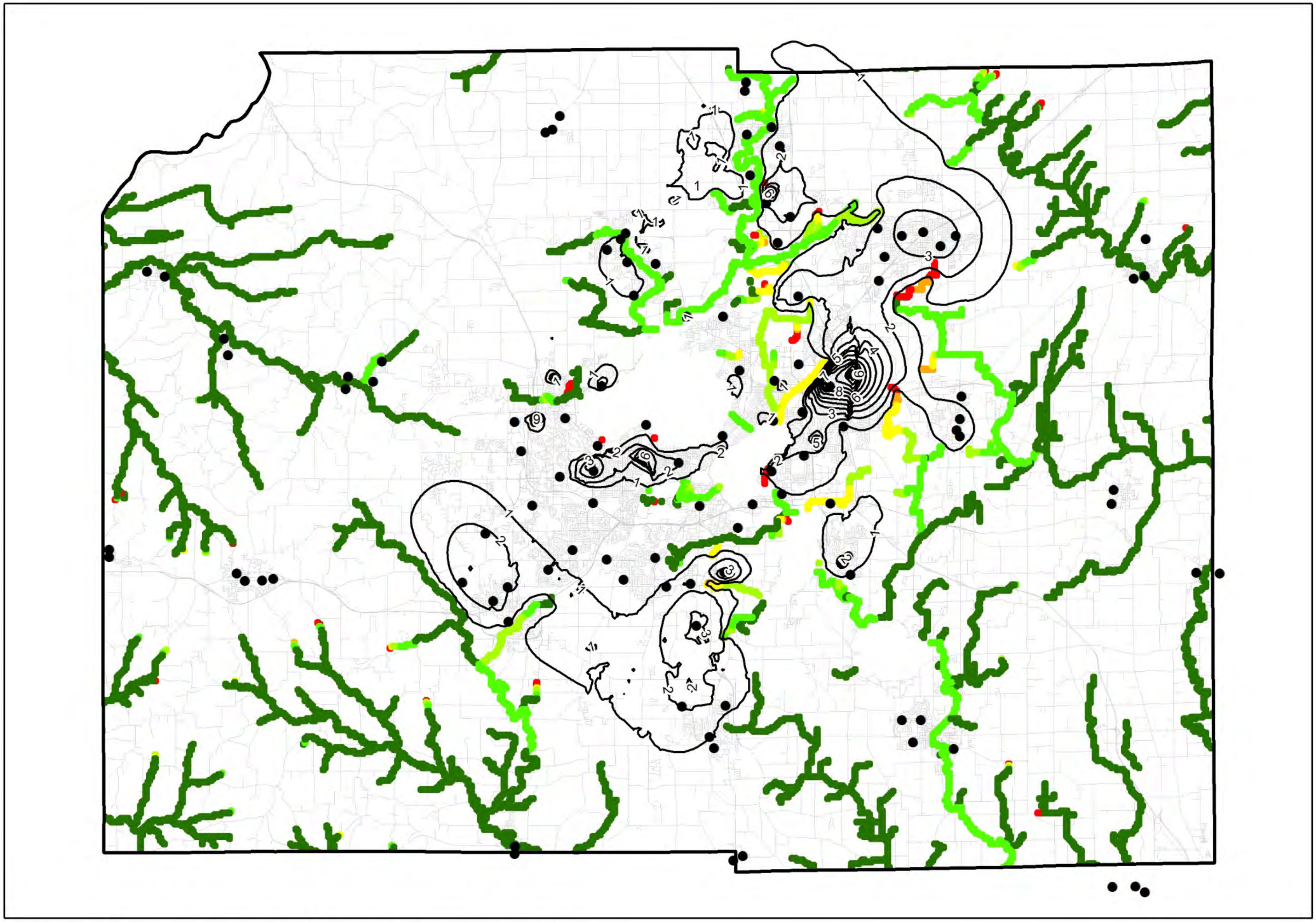
The two function response curves were interpreted using horizontal lines representing preservation of 80 and 90 percent of the initial fish population metrics. At points where these lines intersected the two curves, a vertical line was dropped to indicate the proportion of Index Flow removed associated with that point on the curves. Selected points were chosen to reflect the Council's interpretation of degrees of impairment and restrictions set by legislation. Region D indicates the range of Adverse Resource Impact, defined as when a fish population can no longer succeed because of a reduced amount of water available.

Source: Michigan Groundwater Conservation Advisory Council, 2007.

The ecological models use fish species composition as a surrogate for overall biological integrity. The objective of this analysis was to predict the response of stream fishes to changes in stream flow that are expected to occur by 2040 due to changes in land use and groundwater use in Dane County. The results can be used to identify streams where mitigation of flow changes should be addressed in the near future. For example, by 2040 significant changes to fish communities are expected to occur in about 5 percent (34 miles) of the stream length in Dane County due to reduction in summer baseflow resulting from well water withdrawals. These streams are primarily headwaters in or near Madison and the Yahara River downstream of Lake Waubesa. **Map 17** shows the 2040 reduction in baseflow as a percent of 2010. **Map 18** shows the Fish Community Status as a percent of current conditions. Note that relatively little change is expected in most streams between 2010 and 2040, typically less than a 10 percent. reduction. This is because fish communities in many impacted streams are already largely acclimated to reduced flow conditions, being composed of more tolerant fish species. In addition, as evidenced by the shallower initial slopes in **Reference Figure 10,** coldwater streams are also pretty resilient, typically possessing larger quantities of cold, well-oxygenated groundwater to sustain them through more critical summer dry periods.

By 2040 significant changes to fish communities are expected to occur in about 5 percent (34 miles) of the stream length in Dane County due to reduction in summer baseflow resulting from well water withdrawals.

Map 19. Comparison of changes in streamflow between 2010 and 2040, assuming current wastewater discharges from existing treatment facilities.

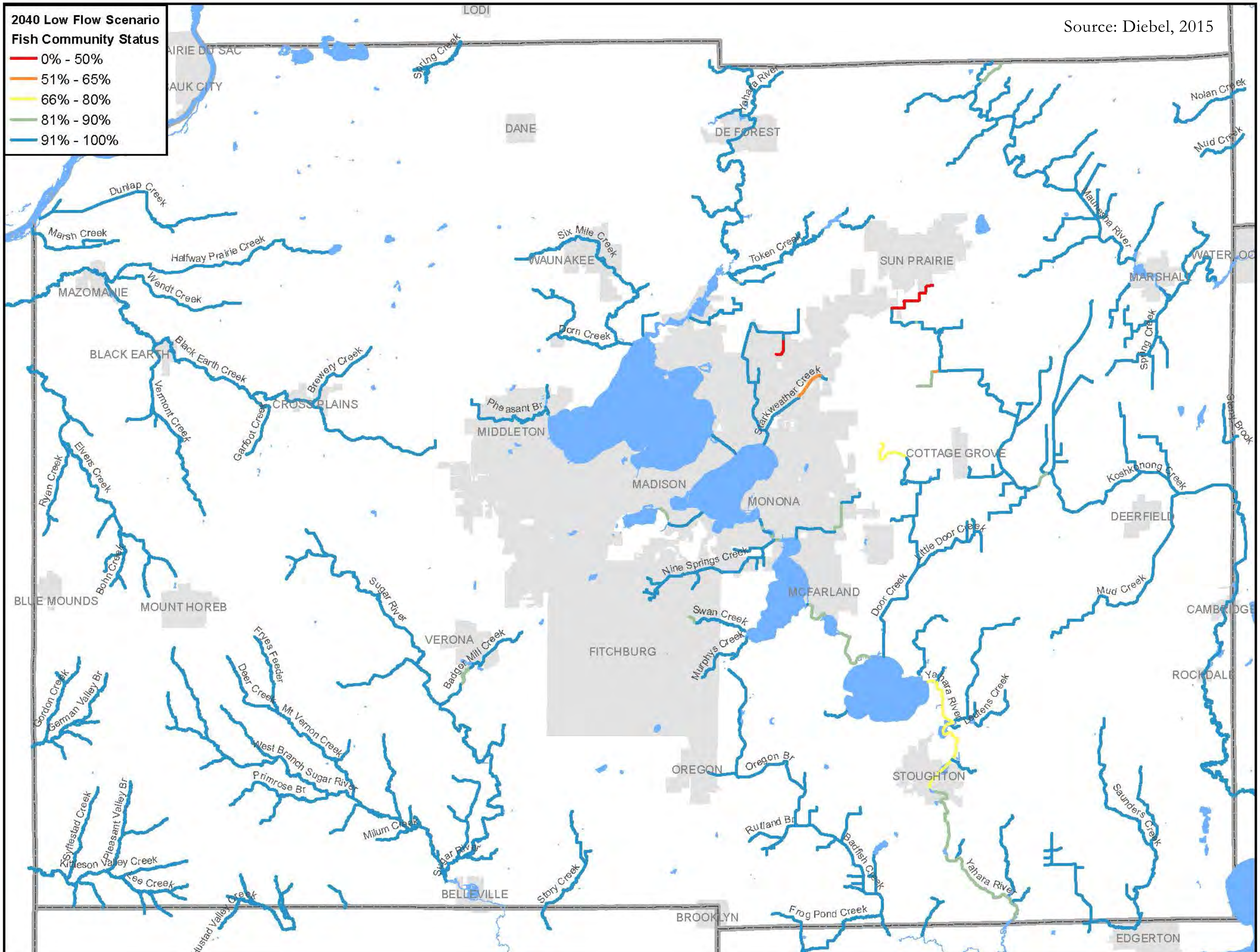


Percent Change in Baseflow 2010 to 2040 - Baseline Condition

95-100 | 90-95 | 75-90 | 50-75 | 25-50 | 0-25 | Cone of Depression Contours | Municipal Wells 2040

Source: Capital Area Regional Planning Commission 2015

Map 20. Fish Community Status in the 2040 Low Flow Scenario.



The goal of ELOHA is not to maintain or attempt to restore pristine conditions in all rivers or streams; rather, it is to understand the tradeoffs between human activity on water and resulting ecological degradation. As can be seen in the response curves in **Reference Figures 10 and 11**, increasing levels of environmental stress reflect increased levels of ecological impact. The "acceptable" ecological condition for each river segment or river type is accomplished through a well-vetted shakeholder process of identifying and agreeing on the ecological and cultural values to be protected or restored through river management. ELOHA provides the necessary basis and understanding for facilitating those discussions. It is believed that applications of the ELOHA framework in the region will help to inform decision-makers and stakeholders about the ecological consequences of flow alteration, as well as promote regional environmental flow strategies for protecting and restoring water resource conditions. While ELOHA is a new advance in environmental flow analysis and biological health, it does not supplant more specific approaches for certain water bodies that require more in-depth analysis.

Climate Change

Climate change is driven in part by the emission of green-house gases (GHG) that traps heat in the atmosphere resulting in global warming. The Wisconsin Initiative on Climate Change Impacts (WICCI)[15] temperature modeling projects an annual average temperature increase of 6-7 degrees F between 1980 and 2055 for Dane County.

Climate warming may affect surface and groundwater resources of Dane County in several ways. John Magnuson of the UW-Madison Center for Limnology notes that the average duration of ice cover on Lake Mendota and lakes in the northern hemisphere has decreased over the last 50 years while the average fall-winter-spring air temperature has increased. A trend of more intense precipitation events (i.e. the one-, two-, and three-inch storms) is also developing. Modeling shows an increased frequency of intense storms with greater than 3 inches of precipitation in a 24-hour period for Dane County.[16] Climate change is anticipated to impact every aspect of the water cycle, and many of the underlying assumptions that stormwater managers use for runoff and storm design might become outdated if these predictions become a reality. Climate change will therefore necessitate a reappraisal of existing approaches for water resource management.

In addition, A WDNR fisheries biologist working with WICCI predicts that climate change will likely cause reductions in all cold water habitats and coldwater fish species in Wisconsin.[17] Lyons et.al.[18] used water temperature models to predict the possible impacts of stream water temperature increase on certain fish species. Of the 50 species examined, 23 are predicted to decline in distribution in Wisconsin, 23 species would increase in distribution, while four fish species would see no change. The most dramatic decline of coldwater fish species would occur in small coldwater streams (**Fig. 12**). The Lyons study suggests that small increases in summer air and water temperature will have major effects on the distribution of fish in Wisconsin streams. Additional modeling and vigilant monitoring will be needed to better understand the impacts of a warming climate – both on biological communities and ground/surface water budgets overall.

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[15] See the WICCI website for more information on the effects of climate change on Wisconsin. http://www.wicci.wisc.edu/.

[16] Potter, K. 2010. *Adapting the Design and Management of Storm Water Related Infrastructure to Climate Change.*

[17] Pomplum, S. et al. 2011. *Managing Our Future: Getting Ahead of a Changing Climate.*

[18] Lyons, J et al. 2010. P*redicted Effects of Climate Warming on the Distribution of 50 Stream Fishes in Wisconsin.*

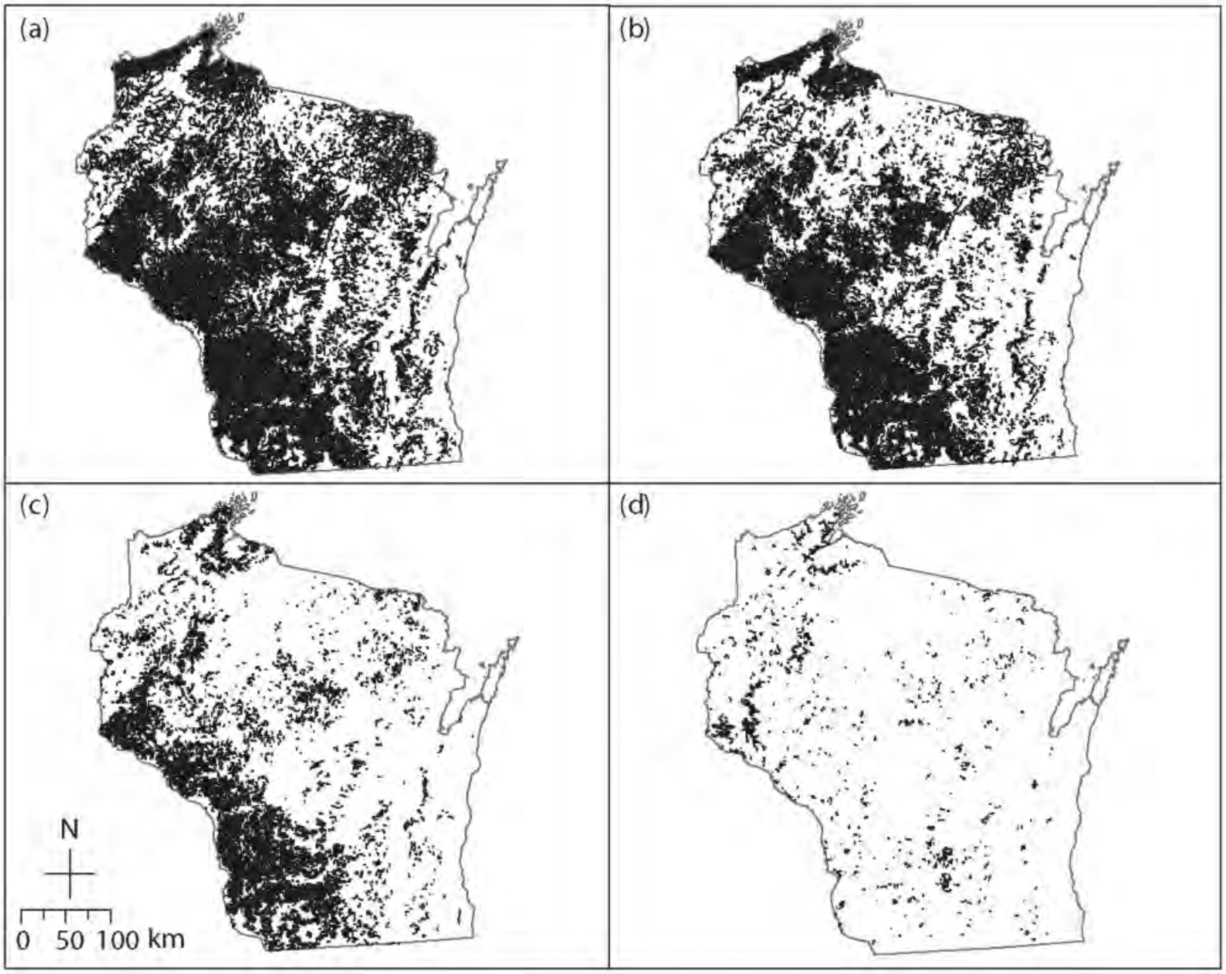


Figure 12. Predicted distribution of Mottled Sculpin, a cold-water species, under four climate warming scenarios: (a) Current conditions, (b) Limited warming, (c) Moderate warming, and (d) Major warming. Only stream segments where the species is predicted to occur are shown.

Evaluation of Alternative Management Strategies[19]

A principal objective of the Dane County Regional Hydrologic Study has been to evaluate the effects of groundwater pumping, urban development, and wastewater diversions on ground and surface water bodies. In addition, "alternative management strategies" were modelled to evaluate specific actions and levels of control that could be taken to help mitigate those impacts and improve the future baseline condition (**Table 7**). These and other strategies may involve regulatory consideration of groundwater quantity and quality, surface water resources, and public supply infrastructure. Early consultation with the WDNR, water utilities, and others will be needed to assess the relative feasibility beyond that presented more generally in **reference Table 13**.

Table 7
Potential Management Strategies—Dane County Regional Hydrologic Study

Management Alternative	Strategies to Consider
1. Alternative Well Location & Pumping Strategies (City of Madison only)	a. Maximum pumpage from central metropolitan area wells to minimize water diversion from adjacent drainage basins b. Maximum pumpage from peripheral wells (i.e., wells close to groundwater divides) to minimize impacts on Yahara lakes
2. Aggressive Water Conservation Efforts	a. Maximize conservation efforts (10-20% domestic reduction) and determine effects on water use forecasts
3. Aggressive Pursuit of Water Infiltration Practices	a. Maximize infiltration practices for future development b. Maintain 100% predevelopment groundwater recharge for future development
4. Partial/Complete Cessation of Wastewater Diversion & Return of Wastewater to Yahara River & Other Basins	a. Regional treatment alternatives with surface water discharge to: · Upper Yahara River Basin · Sugar River Basin · Nine Springs Creek b. Infiltration of Upper Yahara River treated effluent
5. Importation of Water & Deep Aquifer Withdrawals (not feasible)	a. Importation of water from other drainage basins b. Deep pumping within Northern Yahara basin
6. Management of Yahara River Lakes as Multipurpose Reservoirs for Baseflow Augmentation	a. Increase water storage in the Yahara lakes to augment flows in Lower Yahara River and restore prediversion low-flow conditions.

Alternative Well Location and Pumping Strategies (City of Madison only)

The siting and pumping of high capacity municipal wells is a management alternative that offers one of the best opportunities to reduce environmental impacts in specific geographic areas of the county. Future siting of wells can be guided by results of the groundwater computer model.

As indicated previously, the model illustrates the type and magnitude of impacts to local surface and ground water bodies likely to occur from well-water pumping at particular locations. Accordingly, siting changes can be made and alterations in water withdrawals from proposed and existing wells can be examined in finer detail if model simulations show that the impacts to adjacent water resources will be lessened or avoided from alternative pumping strategies.

[19] Dane County Regional Planning Commission. 1997. *Evaluation of Alternative Management Strategies*. Dane County Regional Hydrologic Study.

Currently, the WDNR screens each high capacity well application to assess potential impacts to "water of the state," including streams, lakes, wetlands, springs, and water supply wells. The WDNR also assesses the cumulative effects of the proposed well or wells together with existing high capacity wells for potential impacts to waters of the state. If significant impacts are predicted, the well application may be modified or the application may be denied.

Since 1993, Wis. Adm. Code Chapter NR 811 required that a wellhead protection program plan be submitted for each new municipal well-constructed in Wisconsin after April 1992. Water purveyors need to submit recharge area, zone of influence, and flow direction determinations to the WDNR for each new municipal well. However, in the absence of a regional groundwater flow model, the capability to predict and quantify possible environmental impacts (with a reasonable degree of certainty) simply has not existed. In 1998 WGNHS completed a project to use the groundwater model to delineate capture zones for all municipal wells in Dane County existing in 1992. The overall objective of the project was to delineate the 5-, 10- and 100-year zones of contribution as well as the drawdown cone produced by each existing well. As part of the annual update of the Dane County Regional Groundwater model in 2014, additional wells have been modelled to assist communities develop wellhead protection programs for wells installed after 1992 and planned wells.

In central Dane County, municipal wells are not widely dispersed in many communities. For example, in the villages of De Forest and Waunakee and cities of Middleton and Sun Prairie several existing municipal wells are in close proximity (less than one-half mile) to one another, as well as to local surface water bodies (**Reference Map 11**). This situation also exists in the downtown area of the City of Madison; though wells at the periphery of the city are wider apart (one- to two-mile separation distance). Previously, it has been unclear whether these siting and pumping conditions are causing significant resource impacts that could be addressed through alternative well placement and pumping scenarios, simulated by the groundwater computer model.

One alternative to lessen groundwater movement and diversion from adjacent drainage basins into the Yahara River Valley is to increase groundwater pumpage from the wells located in the central part of the City of Madison and decrease withdrawals from the outer wells. If additional groundwater could be withdrawn from the central wells, potential hydrologic impacts to lakes Mendota and Monona could be assessed since groundwater recharge would likely increase adjacent to and beneath these water bodies. Conversely, if impacts in the Lake Mendota and Monona watersheds show to be of greater concern than along the periphery, management approaches aimed at decreasing groundwater pumpage in the central city could be evaluated, and increased pumpage from existing or new outer wells assessed to compensate for this reduction.

There are restrictions, however, to the practical implementation of the above strategies. City of Madison Water Utility has indicated that, due to distribution system constraints, there is limited flexibility to alter withdrawals between existing municipal wells, particularly during the summer months when there is less reserve capacity in the water supply system. Five city wells are currently considered summer use wells or are used only part of the year. Remaining wells are used extensively, almost every month.

While a widespread alteration to current well-pumping strategies in the Central Urban Service Area may not be feasible, more modest changes to a smaller number of wells is still possible and worth consideration. Certain wells may be particularly problematic in terms of resource impacts; therefore, a compensating water withdrawal and delivery system for the specific area served by the well(s) could present a reasonable course of action to help resolve the problem.

Simulation

Management alternatives 1a and 1b (below) simulate the maximum range or extremes of possible alternatives believed available with a unit-well distribution system. Outer and Inner wells have been delineated based on half of Madison's wells being located either adjacent to or distant from the Yahara basin groundwater divides, respectively. If the effect/benefit of either alternative is found significant, then a more detailed analysis may be warranted to specifically evaluate new well locations, pressure gradients, transfer/delivery systems, etc., taking into account the constraints of a unit-well system.

The alternative strategies include:

1a. Pumping Inner and Outer wells to provide 75 percent and 25 percent of the total average daily water use, respectively; or

1b. Pumping Inner and Outer wells to provide 25 percent and 75 percent of the total average daily water use, respectively.

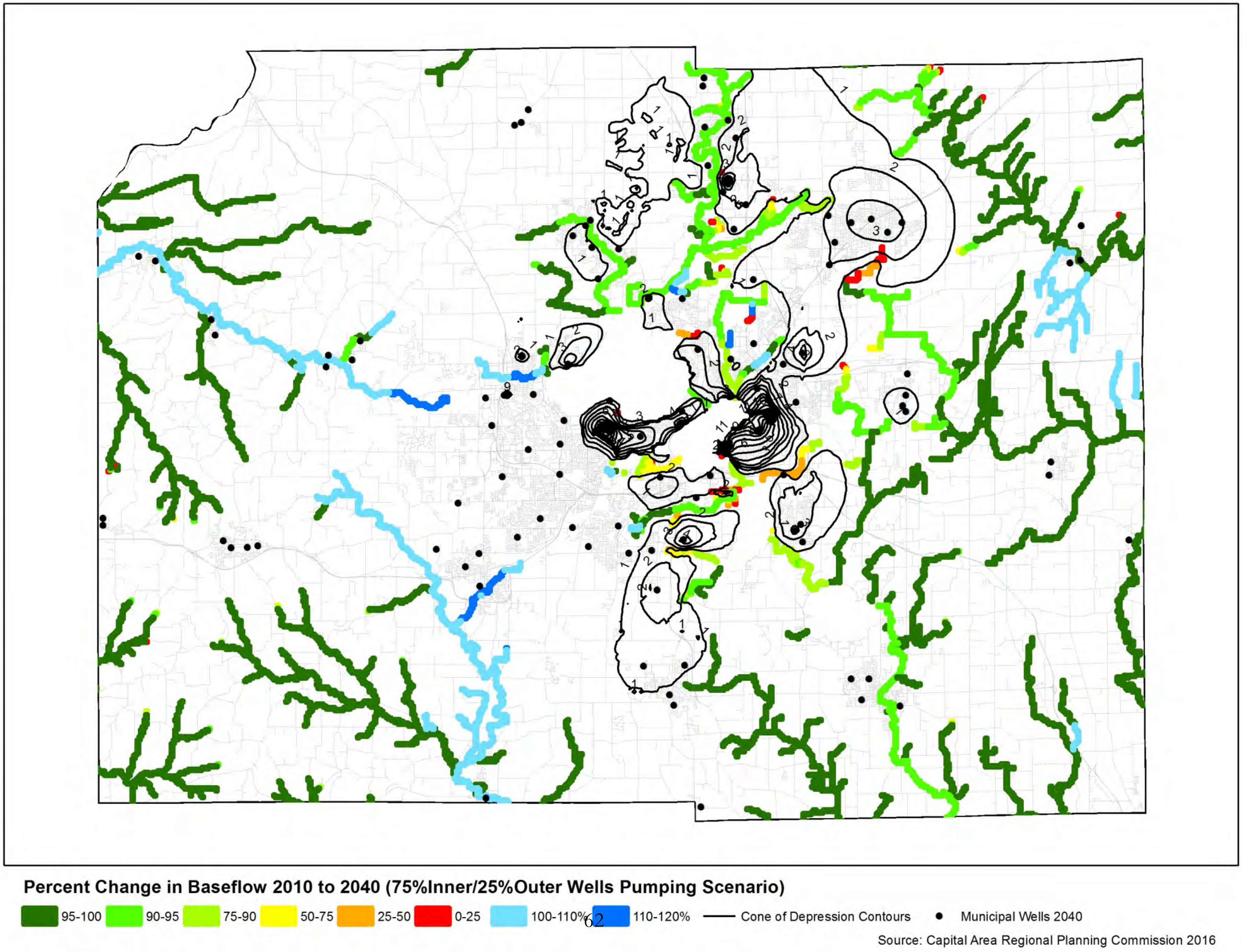
As indicated in **Map 19a**, future water table declines can be more centrally localized by pumping a larger percentage of well water from the inner Madison wells than pumping from the outer wells. The effect is more water being drawn from the Yahara Lakes and less from surrounding streams, which actually show an improvement over 2010 conditions. **Table 8** shows the associated effects on Dane County streams as a percentage of baseline 2040 pumping. Streamflow generally improves under the 75% Inner/25% Outer pumping scenario, with the exception of the Yahara River and Wingra Creek (>1% decline). Conversely, increased pumping from the outer wells results in more dramatic declines in water table levels and extends the cone of depression into the Black Earth Creek and Upper Sugar River basins (**Map 19b**), including reductions of baseflow in those systems. Combined with alternative measures such as treated effluent return to the Upper Yahara River (discussed below) and managing the Yahara Lakes as multipurpose reservoirs, pumping a larger percentage of groundwater from the inner Madison wells holds considerably greater promise for mitigating the impacts of future pumping and providing more sustainable water supplies for the Madison Metropolitan Area.

In 2000 the City of Madison explored the technical feasibility and cost of potentially altering well pump operation for the Madison Water utility so that a greater percentage of water would be produced by "central wells," defined as half the wells located furthest from the peripheral groundwater divides. The feasibility study was a follow up to a recommendation coming out of the Dane County Regional Hydrologic Study (DCRPC 1997). The study found that the additional water table declines and reductions in baseflow in tributary streams due to the projected increase in pumping could largely be mitigated or offset by drawing on wells located closer to the lakes (**Reference Map 19a**). The conclusion of the City of Madison study was that under average day conditions, the desired average ratio of central well pumping to total well pumping of approximately 75 percent could be achieved, with certain infrastructure improvements. The total capital cost of implementing these improvements was estimated to be approximately $1.45 million, with additional operating costs of approximately $250,000 per year. The 20 year present value of these incremental costs was estimated to be $2.9 million.[20] According to the Madison Water Utility, their capability to move water around their system has been improving.[21] Future pumping station projects in the coming decades will increase their ability to move water from the central area to the city boundaries.

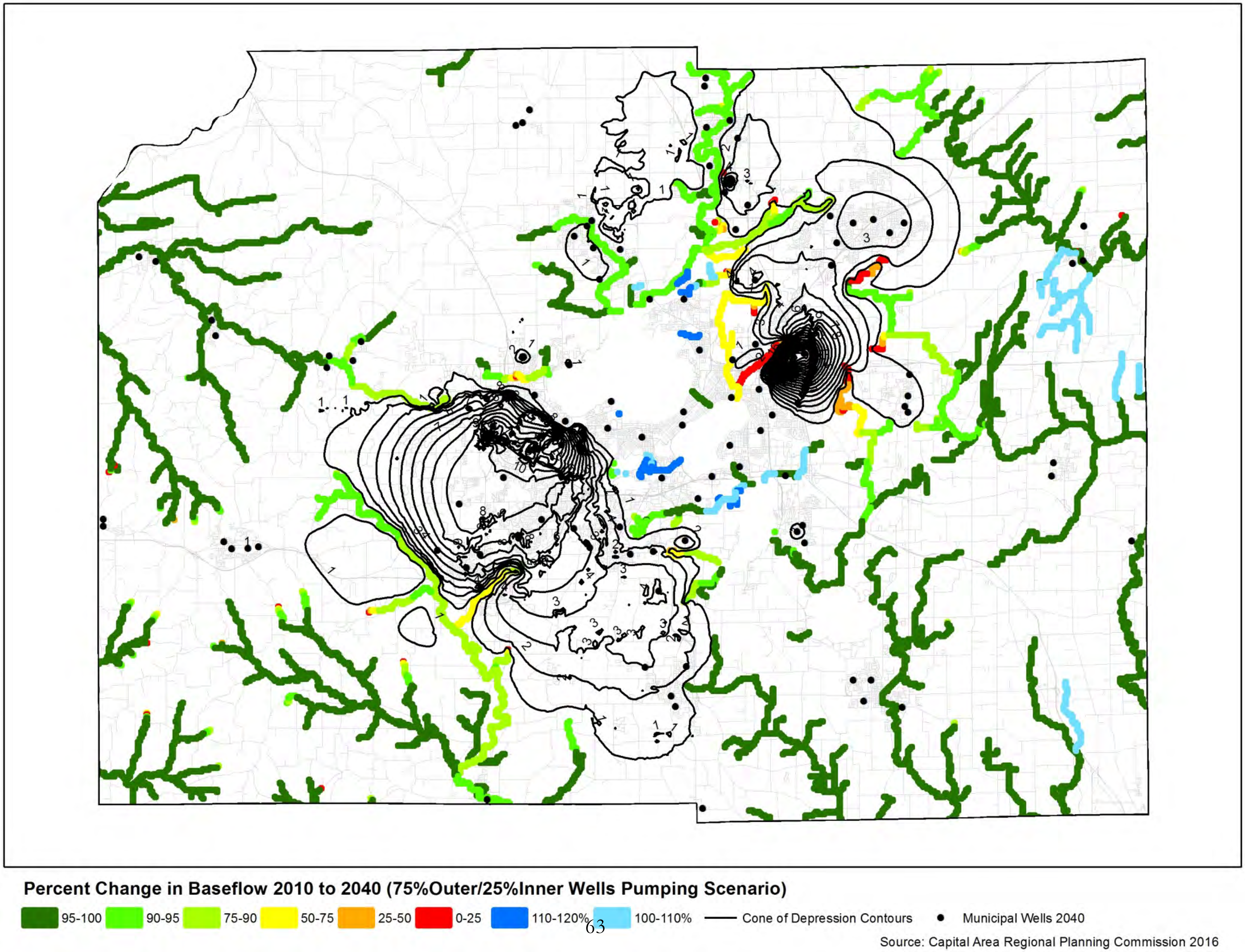
Additional alternatives should continue to be explored (as below) using the tools and technology available to find the best mix of strategies and practices to minimize impacts to our ground and surface water resources as well as maintaining a reliable public water supply (See Management of the Yahara Lakes as Multipurpose Reservoirs for Baseflow Augmentation and Drinking Water Supplies).

[20] Madison Water Utility. 2000. *Report on Task 10 – Well Pumpage Optimization*. Water System Master Planning Study.
[21] Al Larson, Principle Engineer Madison Water Utility, communication January, 2016.

Map 19a


Percent Change in Baseflow 2010 to 2040 (75%Inner/25%Outer Wells Pumping Scenario)
95-100
90-95
75-90
50-75
25-50
0-25
100-110%
110-120%
Cone of Depression Contours
Municipal Wells 2040
Source: Capital Area Regional Planning Commission 2016

Map 19b



Percent Change in Baseflow 2010 to 2040 (75%Outer/25%Inner Wells Pumping Scenario)
95-100
90-95
75-90
50-75
25-50
0-25
110-120%
100-110%
Cone of Depression Contours
Municipal Wells 2040
Source: Capital Area Regional Planning Commission 2016

Table 8
Percent Change in 2040 Baseflows Resulting from Alternative Pumping Strategies
(Pumping 75% or 25% Annual Water Withdrawals from Inner vs. Outer Madison Wells)

	From Table 5			Alternative Pumping Strategies	
Station	PD cfs	2010 cfs	2040 cfs	Map 21a 75%I/25%O cfs (%2040)	Map 21b 75%O/25%I cfs (%2040)
Badfish Cr. at CTH A*	11.59	75.49	75.22	75.24 (100.0)	75.13 (99.9)
Badger Mill Cr. at STH 69*	3.65	4.23	3.65	4.66 (127.1)	2.38 (64.9)
Black Earth Cr. abv. Black Earth	33.33	31.36	31.23	31.67 (101.4)	30.63 (98.1)
Black Earth Cr. abv. Cross Plains	4.95	3.52	3.50	3.84 (109.5)	3.08 (87.8)
Door Cr. at Hope Rd.	7.69	5.69	5.30	5.42 (102.3)	5.16 (97.3)
Dorn Cr. at CTH M	6.27	5.65	5.50	5.44 (98.9)	5.54 (100.9)
Koshkonong Cr. nr Deerfield*	27.35	29.79	28.84	28.98 (100.5)	28.58 (99.1)
Koshkonong Cr. nr Rockdale*	62.84	65.02	63.99	64.09 (100.1)	63.70 (99.5)
Koshkonong Cr. nr Sun Prairie*	0.77	5.02	4.76	4.80 (100.9)	4.70 (98.9)
Maunesha R. south of USH 151	17.25	16.44	16.16	16.06 (99.9)	16.02 (99.6)
Mt. Vernon Cr. nr STH 92	19.16	18.49	18.32	18.44 (100.6)	18.12 (98.8)
Murphy (Wingra) Cr. at Beld St.	2.89	1.83	1.64	1.18 (71.9)	2.13 (129.6)
Nine Springs Cr. at Hwy 14	11.84	6.69	6.45	6.40 (99.0)	6.42 (99.4)
Pheasant Br. at Parmenter St.	2.85	1.19	1.13	1.33 (117.0)	0.88 (77.7)
Sixmile Cr. south of Waunakee	9.07	7.59	7.06	7.01 (99.6)	6.99 (99.4)
Spring Cr. nr Lodi	22.23	21.70	21.65	21.62 (99.9)	21.61 (99.9)
Starkweather Cr. East Br.	3.01	0.73	0.41	0.64 (157.6)	0.15 (37.0)
Starkweather Cr. West Br.	8.86	4.16	3.27	3.45 (106.1)	2.97 (91.3)
Sugar R. abv. Badger Mill	16.58	13.66	13.01	13.74 (105.5)	12.01 (92.2)
Token Cr. at USH 51	20.35	17.99	16.81	16.64 (101.4)	16.05 (97.8)
West Br. Sugar R. at STH 92*	18.96	19.20	19.13	19.15 (100.1)	19.06 (99.6)
Yahara R. at Windsor	6.77	6.28	6.13	5.98 (99.7)	5.97 (99.6)
Yahara R. at McFarland	157.12	109.09	102.02	96.50 (95.5)	105.20 (104.1)
Yahara R. nr Stoughton	207.46	156.65	148.91	143.23 (96.7)	152.04 (102.7)

*Streams having wastewater treatment plant discharged to them

Aggressive Water Conservation Efforts

Even though Dane County has an abundant supply of groundwater to meet existing and projected water use needs, the benefits of water conservation programs should not be overlooked. Water conservation can be effective in achieving a number of community goals, including reducing investment requirements for meeting anticipated water demand, reducing wastewater flows/treatment costs, reducing operating costs for water supply systems and more equitably allocating an important resource. Simply stated, water conservation saves money and energy, and reduces pollution and hydrologic impacts.

The kind of water conservation program pursued by a municipality depends on community goals and should be tailored to its anticipated water demands and conservation opportunities. For example, various water supply and demand management measures can be considered by municipalities to lessen water use. These include: water audit and leak detection, metering, pricing, education, water-saving fixtures, and regulation. Community attitudes toward such conservation measures and their technical and fiscal merit need to be understood prior to the design of any specific water conservation plan.

Historically, the use of water has been declining compared to population growth in central Dane County over the last 20 years (**Reference Figure 8**). In 1970, average total groundwater use in central Dane County was 169 gallons per capita per day and by 1992 per capita water use had dropped to 151 gallons per day.[22] By 2012 groundwater use had dropped to 109 gpd and 102 gpd in 2014. A single definitive reason for this trend is not apparent, though a possible explanation is that more aggressive water conservation measures have been implemented by the City of Madison and other communities, coupled with water-saving effects of energy conservation programs. A significant decline in self-supplied industrial water use has also occurred since the 1970s, with Kraft Foods Oscar Mayer accounting for a large portion of this reduction, having moved to more efficient water processing technology.

Reference Table 3 shows the classification of water use for municipal water utilities in the county in 2014. Since residential and commercial use represents over 70 percent of the total water use for all Dane County communities, these sectors represent a logical focal point for water conservation efforts – especially the City of Madison with the largest population. Conservation programs would also postpone certain electrical costs associated with peak pumping demands and provide other economic benefits as well, such as reducing wastewater flows for regional treatment and disposal. Also, by reducing groundwater pumping, hydrologic and environmental impacts are reduced correspondingly.

Water conservation is not a new concept to the Madison Water Utility (MWU). Water conservation in Madison has a tradition reaching back more than 30 years of water use control techniques including but not limited to: metered water usage for all its customers, leak detection and abatement programs, and an outdoor water use restriction ordinance (to control water use during emergency conditions). In response to declining groundwater levels, impacts of well pumping on surface water features, and a desire to preserve the aquifer for generations to come, the MWU adopted a Water Conservation and Sustainability Plan in 2008.

[22] DCRPC. 1994. *Historic and Projected Groundwater Use and MMSD Wastewater Flow Data, Dane County, WI.*

The Plan has a primary goal of maintaining the current annual rate of groundwater withdrawal in existing areas and secondary goals of:

Residential – reduce residential water use by 20 percent by 2020 to an average use of 58 gpcd
Commercial – promote water conservation through rebate promotions and education
Industrial – develop a water conservation plan for each industrial customer
Municipal – enact water savings programs for all government buildings that support the primary goal

Interest in conservation has been in response to numerous factors including: reducing the need for adding additional or maintaining well capacity, declining aquifer levels, surface water impacts, contaminant transport, and the potential for declining water quality. In addition, there is a growing public awareness and demand for using natural resources in a more sustainable manner. Water conservation not only saves water it also reduces chemical usage and can provide a significant energy savings to a utility and reduce it's overall carbon footprint. To be successful, conservation efforts are implemented as a combination of public education, institutional regulations, monetary incentives, and physical changes which results in a change in water use patterns within the general public.

In its Conservation Plan, the MWU outlined the recommendations outlined in **Table 9**. In order to reduce residential usage by 20 percent, the MWU will need to reduce the per capita usage from a 2003-2006 average of 73 gpcd to 58 gpcd. Based on information from the *Handbook of Water Use and Conservation: Homes, Landscapes, Industries, Businesses, Farms* (Amy Vickers, 2001) changing from standard toilets to high efficiency toilets can reduce water usage by approximately 10.3 gpcd, which is one of the easiest and most effective indoor water use conservation steps. These and other literature sources provide useful information and strategies for reducing a community's water use. In 2011 Administrative rule NR 852 went into effect establishing a mandatory water conservation and efficiency program for new or increased Great Lakes Basin ground and surface water withdrawals. While Dane County is not included in the Great Lakes Compact, the rule helps guide voluntary water conservation and efficiency efforts program throughout the rest of the state. The program provides information and education, identifying and disseminating information on new conservation and efficiency measures, and identifying water conservation and efficiency research needs. As the MWU implements the Conservation Plan recommendations, as in other communities, the overall effectiveness of the program will need to be evaluated, refined, and expanded as needed.

For comparison, other northern mid-sized cities with established conservation programs were evaluated. **Table 10** summarizes the conservation results from those communities.

Table 9. MWU Conservation Recommendations		
Recommendation	**Description**	**Status as of 4/16**
Residential		
High efficiency toilets	MWU implemented a $100 per household and apartment rebate program to replace old toilets with high efficiency "Water Sense" toilets	Implemented
Install an Advanced Metering Infrastructure (AMI) billing system	Install an AMI-system and start monthly billing	Implemented
Provide customers with current consumption data through the AMI system	Instruct customers on tracking their water use	Implemented
Inclining rate structure	Change the MWU rate structure to an inverted rate structure to reward low water usage and penalize high water usage	Implemented
Outdoor water use restrictions	Restrict outdoor water use when pumping exceeds 50 mgd for 2 consecutive days	As needed/Has not been required
Residential water audit program	Allow individual residential customers to request an on-site or individual water audit of their home	Future
High efficiency washing machines/dishwashers	Develop financial incentive program for washing machines and dishwashers similar to the Utility's toilet rebate program	Future
Industrial		
Water conservation plans	Perform individual audits and develop water conservation plans for industrial customers	Future
Commercial		
Education	Target high-use customers with education/ outreach to promote water conservation	Implemented
Landscaping ordinance	Enact landscaping ordinance with water limiting requirements and drought resistant plantings for new development/major redevelopment	Planning
Appliance upgrade program	Develop appliance upgrade program for heavy water use commercial clients	Future
Certification program	Develop a certification program for water-efficient buildings	Superseded by EPA whole house certification
Car wash reclamation ordinance	Enact an ordinance requiring car washes to use water reclamation	Future
Municipal		
Quantify water use	Improve record keeping to quantify water use for municipal accounts	Implemented
Minimize reservoir dumping	Improve operational control of water reservoirs to minimize dumping	Implemented
Leak detection program	Expand leak detection program to identify and correct leaks	Future
Water utility bill	Upgrade water utility billing with new software	In progress
Meter raw water pumping	Install use meters in well buildings	In progress
Water conservation plans	Perform individual audits and develop water conservation plans for other government buildings	Future
Reduce hydrant flushing	Reduce the Utility's annual unidirectional flushing program as well as filters installed, operational changes are implemented and overall water quality in the distribution system is improved	Implemented
		Source: Madison Water Utility 4/15/16

Table 10 Comparison of Conservation Programs for Northern North American Communities			
Utility	**Start Year**	**Programs**	**Estimated Reduction in Water Demand**
Lincoln, NE[1]	1988	Increasing block rate structure Public education	7%
Waterloo, ON[2]	Early 1980s	Toilet retrofit Water efficient shower heads	13%
Wichita, KS[3]	1990s	Toilet retrofit 2 day per week watering School education program Proposed increasing block rate structure	13% (projected)
Barrie, ON[4]	1994	Toilet retrofit Water efficient shower heads	7% (16.5 gpcd)
Waukesha, WI[5]	2006	Toilet retrofit Daytime irrigation ban 2 day per week watering restriction School education program Proposed increasing block rate structure	11%

[1] From www.lincoln.ne.gov/city/pworks/water/conserve/ and *2007 Facilities Master Plan Update* (Black and Veatch, 2009).
[2] From *Regional Case Studies: Best Practices for Water Conservation in the Great Lakes-St. Lawrence Region* (Great Lakes Commission, June 2004).
[3] From "IRP: A Case Study from Kansas," *Journal of the American Water Works Association* 87, No. 6 (June 1995: pp. 57-71.
[4] From *Cases in Water Conservation: How Efficiency Programs Help Water Utilities Save Water and Avoid Costs*. (U.S. EPA, 2002).
[5] From "Waukesha, WI Promotes Water Conservation, Environmentally Responsible Water Supply Planning" by Mayor Larry Nelson, *U.S. Mayor Newspaper*, March 23, 2009 and "Proposed Waukesha Water Rates Encourage Conservation" by Lisa Kaiser, www.expressmilwaukee.com, May 20, 2009.

Source: Black and Veatch Technical Memorandum Madison Water Utility 5/20/11

In 2008, Madison's *Water Conservation & Sustainability Plan* outlined an ambitious goal: Drop daily per-person water use in the city by 20 percent – from 73 gallons to 58 gallons – by the year 2020. Madison currently uses 64 gallons of water per person per day, so it appears they are well on their way thanks to a significant commitment by area residents to water conservation, an effective widespread education program, restrictions on outdoor water use, development of other conservation programs, and an expansion of the toilet retrofit rebate program. Madison reported $227,732 in program expenditures for water conservation to the Public Service Commission in 2014. Program expenditures in other municipalities in Dane County were either very low or have not been reported. While Madison sets a good example for other communities in the region, there is additional room for improvement throughout the region (see http://www.cityofmadison.com/water/sustainability).

It is also important to note that, because of a growing population, a 20 percent reduction in water use really only postpones or delays the onset of future impacts by slowing the increase in water use. A 20 percent reduction in water use by all the communities in the Madison Metro region could reduce projected water use by 8.75 mgd (from 43.79 mgd in 2040 to 35.04 mgd., **Reference Table 3**). In any event, water conservation is an important management strategy which should be encouraged at every opportunity to provide more efficient use of available water supplies. By reducing groundwater pumping, hydrologic and environmental impacts would be reduced correspondingly. Conservation programs would also **reduce or postpone** certain electrical costs and provide other benefits such as reducing wastewater flows for regional treatment and disposal.

Each community should develop its own Water Conservation and Sustainability plan tailored to its unique opportunities and circumstances using the most cost-effective mix of practices and programs. *State of the Art*

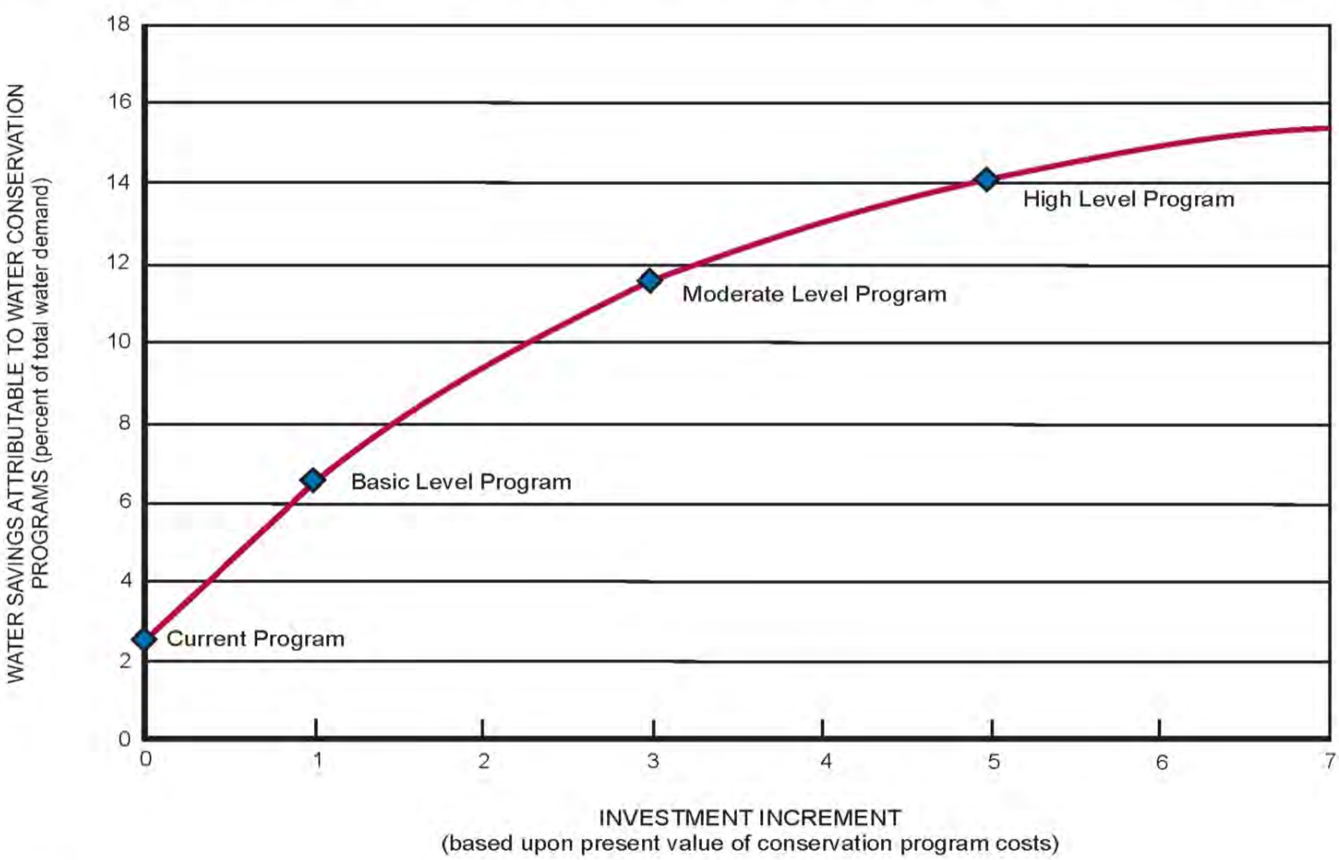
Water Supply Practices SEWRPC Technical Report 43 provides useful information including cost data for communities wishing to maximize their conservation efforts. This information should be incorporated into a public outreach campaign targeted to specific audiences.

Supply-side strategies focus on achieving efficiency in utility operations by minimizing the amount of water that must be produced and conveyed to meet user demand, primarily through he reduction of unaccounted for water. Associated practices include metering and system performance monitoring, leak detection and repair, and system operational refinements. Water supply efficiency programs and measures are well established but are system-specific in application.

Demand-side strategies focus on reducing or delaying infrastructure needs. Associated practices include water rate modifications to discourage use, use of water-saving plumbing fixtures, water recycling, and educational activities.

The conceptual conservation investment curve and cost data provided in **Figure 13 and Table 11** portray the relationship that may be expected between the costs of water conservation programs and attendant savings in water use. The actual conservation program levels and costs, as well as the attendant savings in water production costs and reductions in water use, will be utility specific.

Figure 13
Conceptual Relativity of Water Conservation Program Costs and Savings



Source: SEWRPC. 2007. *State of the Art Water Supply Practices.* Technical Report No. 43.

Table 11
Average Cost Data and Water Savings of Example Conservation Plan Options in Southeastern Wisconsin

Community Population	Conservation Plan Level	Average Annual Water Savings (millions of gallons per day)	Range of Percentage of Water Savings	Average Annual Cost of Program	Average Cost of Program per 1,000 Gallons Saved	Average Net Annual Savings[a]	
						Savings	Percent of Total Budget
3,000	Low	2	2-5	$ 1,106	$0.78	$ -562	-0.1
	Intermediate	4	5-12	2,536	0.73	-1,176	-0.3
	Advanced	6	8-20	37,821	7.07	-35,835	-8.7
70,000	Low	181	4-9	$ 26,265	$0.18	$ 23,167	0.4
	Intermediate	259	5-14	34,675	0.17	35,893	0.6
	Advanced	334	7-18	172,050	0.64	-87,857	-1.3
600,000	Low	1,953	3-7	$ 224,725	$0.14	$ 128,591	0.2
	Intermediate	3,345	4-12	689,450	0.25	-83,214	-0.1
	Advanced	4,085	5-15	1,359,450	0.41	-618,998	-1.1

NOTES: Assumptions: Energy and chemical expenses for example community of 3,000 = $16,000 per year.
Energy and chemical expenses for example community of 70,000 = $750,000 per year.
Energy and chemical expenses for example community of 600,000 = $7,250,000 per year.

Water conservation measures included are focused on the residential water customers, excepting for rate structure modification, which applies to all customers. Savings due to avoided capital costs are not included because of the variability of such costs community to community. For each community, factors such as the need for increased infrastructure, the location of new water sources, the number and size of wells that must be constructed, the cost of water that must be pumped from source waters outside community boundaries, etc., will vary greatly.

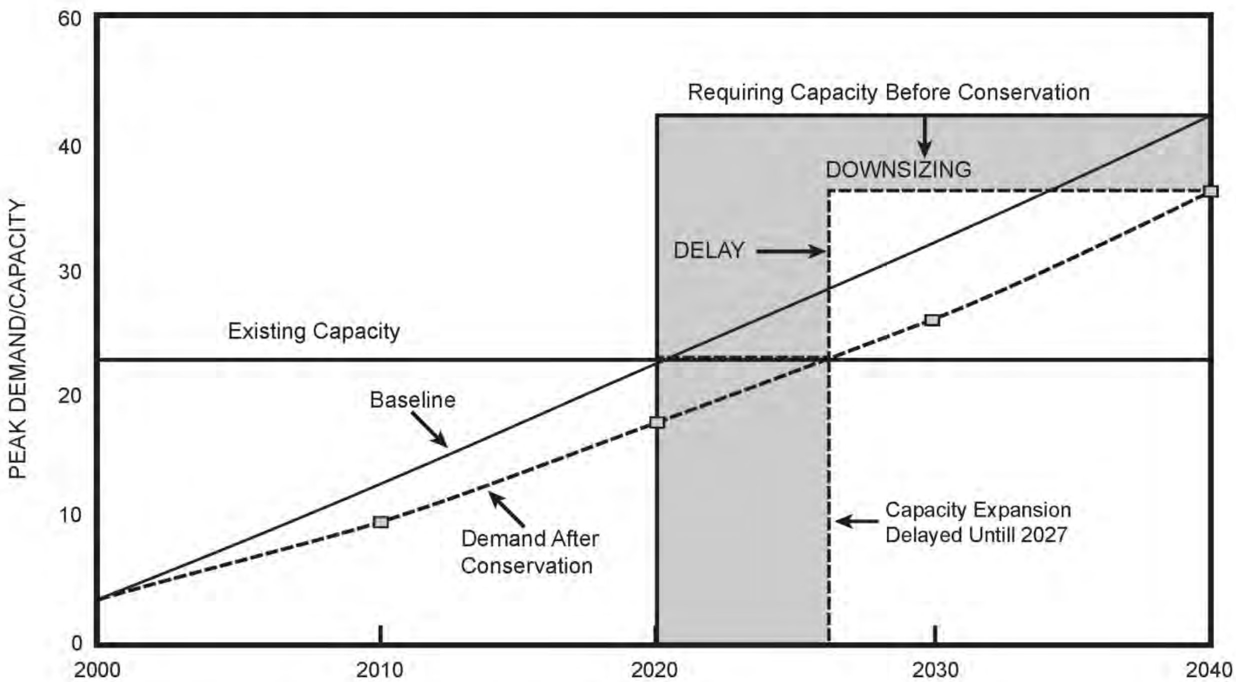
[a] *Annual savings are based on avoided chemical and energy costs associated with pumping and treating water less the cost of the conservation plan.*

Source: SEWRPC. 2007. *State of the Art Water Supply Practices.* Technical Report No. 43.

Note the cost of implementing an advanced-level water conservation program, which may be expected to achieve a 10 percent reduction in average daily water demand, could exceed the direct savings in operation and maintenance costs. All the utilities in Dane County already engage in some water conservation practices. Those practices include billing based upon metered water use, leak detection, and correction programs, some outdoor restrictions, and water main maintenance and replacement. Also note that higher levels of water conservation program may not be offset by savings in operation and maintenance costs. It may be possible to achieve a reduction from 3 to 5 percent in average daily water demand, with no significant increase in cost above the resultant savings in operational costs. Water conservation programs designed to achieve water use reductions over and above those levels will likely result in increased annual operational costs and higher water bills. Such considerations must be made on a water utility-specific basis, balanced with the community's priorities and fiscal constraints.

Even though the costs of water conservation programs may exceed the attendant savings in operational costs, there may be sound reasons to develop higher-level water conservation programs in cases where avoided capital costs and water supply sustainability are important factors. Water conservation programs may extend the useful life of municipal water supply and treatment facilities, and defer needed capital investment in increased capacity. **Figure 14** illustrates how water conservation can affect the timing of capital facilities and assist in delaying infrastructure investments. In the example shown, a 20 percent downsize in the 2040 demand could permit needed capacity expansion to be delayed by approximately seven years (from 2020-2027). The capital required for expansion of an existing water utility can be significant. The associated cost of drilling a well, installing a transmission pipeline, and constructing a new pump station can cost approximately $1 million. In situations where groundwater supplies are being depleted, however, the development of high-level water conservation programs may be warranted to promote more efficient use of existing water supplies. It should be considered along with other strategies to reduce the impacts of high capacity well water withdrawals described in other sections of this plan.

Figure 14
Example of Delaying and/or Downsizing a Capital Facility



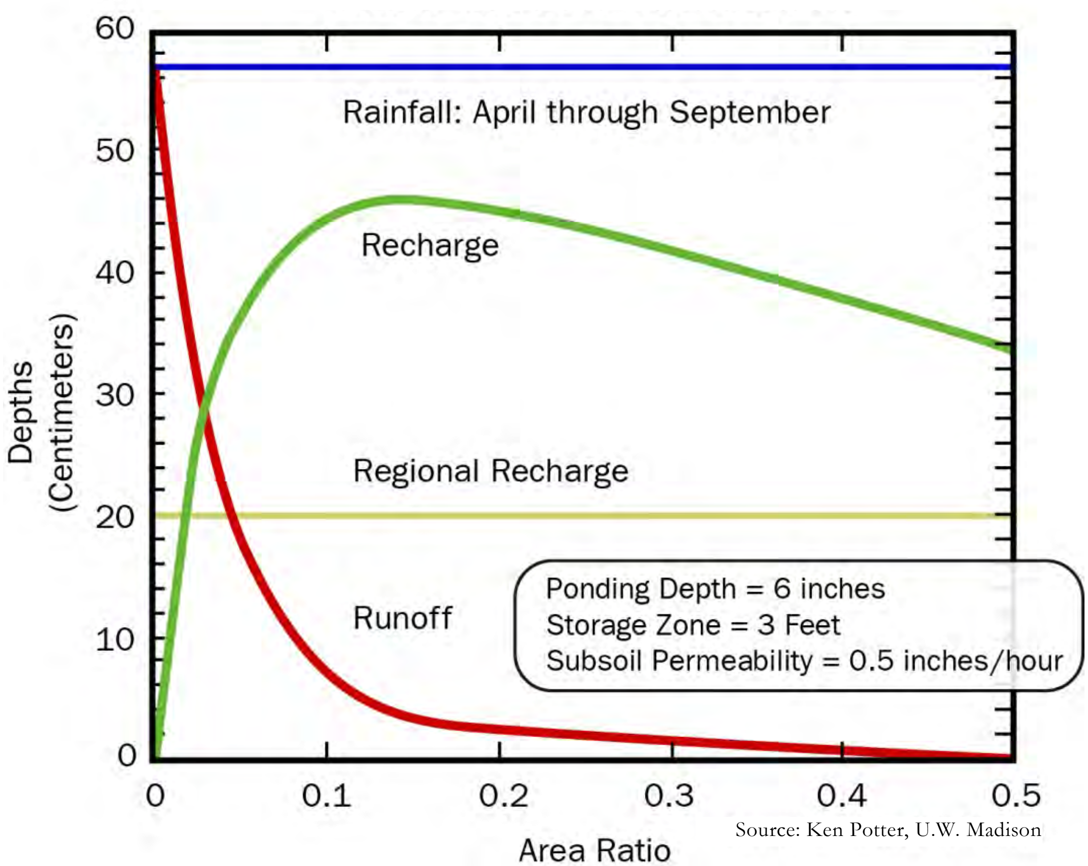
Source: Maddaus, W. et al. 1996. *Integrating Conservation into Water Supply Planning.*

Aggressive Pursuit of Water Infiltration Practices

The siting and development of practical infiltration practices in urban areas of Dane County is another management approach to be considered. Such practices can help maintain groundwater recharge and offset negative hydrologic effects associated with impervious urban development. In areas that are suitable, enhanced infiltration can also be used to help make up for well water withdrawals.For example, modeling developed at UW-Madison provides important insight into the beneficial aspects of rain gardens. It has been theorized that over 90 percent of the annual runoff can be infiltrated into the ground by using a rain garden sized only 10 percent of the impervious area draining to it (see **Figure 15**). The optimum area ratio is between 10 and 15 percent before experiencing a rate of diminishing return. In this manner, infiltration rates in rain gardens can be designed to exceed natural infiltration rates, helping to make up lost infiltration caused by past development and groundwater depression caused by well withdrawals. Infiltrating as much rainfall and snowmelt into the ground as possible has the multiple benefits of maintaining groundwater recharge, water table levels, and baseflow discharge to nearby wetlands and other surface water features. Stormwater runoff rates and volumes are also lowered through infiltration practices, reducing flooding and damage to streams. Also, since pollutant loading is a function of runoff volume, reducing runoff also results in reduced pollutant loads washing off the land surface into area waters. Rain gardens are just one example of the many options available to promote greater infiltration of precipitation, both on-site and off-site.

Infiltration practices can provide significant groundwater recharge and pollution control benefits depending on the degree of storage and infiltration achieved. Principal considerations for infiltration practices are siting, soils, stormwater pretreatment, and the need for routine maintenance.

Fig. 15. Rain Garden Simulation



Source: Ken Potter, U.W. Madison

Relative Infiltration

A key stormwater management strategy for addressing the impacts of development is to infiltrate as much rainfall and snowmelt into the ground as possible, thereby reducing overland runoff and replenishing groundwater supplies. In collaboration with Dane County, WDNR, and UW-Madison, relative infiltration maps have been developed for Dane County by CARPC. The maps are meant to be used as a screening tool early on in the planning/design/development process to identify relatively high infiltration areas, as well as areas that might be enhanced through engineering techniques (e.g., replacement with engineered soils). While the maps do not replace the need for site specific analysis, they do provide a useful planning and decision-making tool for infiltration and stormwater management. They also help promote discussion of innovative methods and design techniques to enhance infiltration, as well as potential retrofit opportunities in previously developed areas.

Map 20 shows relative infiltration as it occurs naturally. Areas with naturally high infiltration should be used to recharge the groundwater to the greatest extent possible. They may also be prime locations for regional infiltration facilities that could be used for recycling treated water and to infiltrate stormwater generated in other parts of the watershed. Wetland and floodplain areas are generally not conducive to infiltration practices. Other areas, such as clay soils with low permeability, are also less suitable for infiltration.

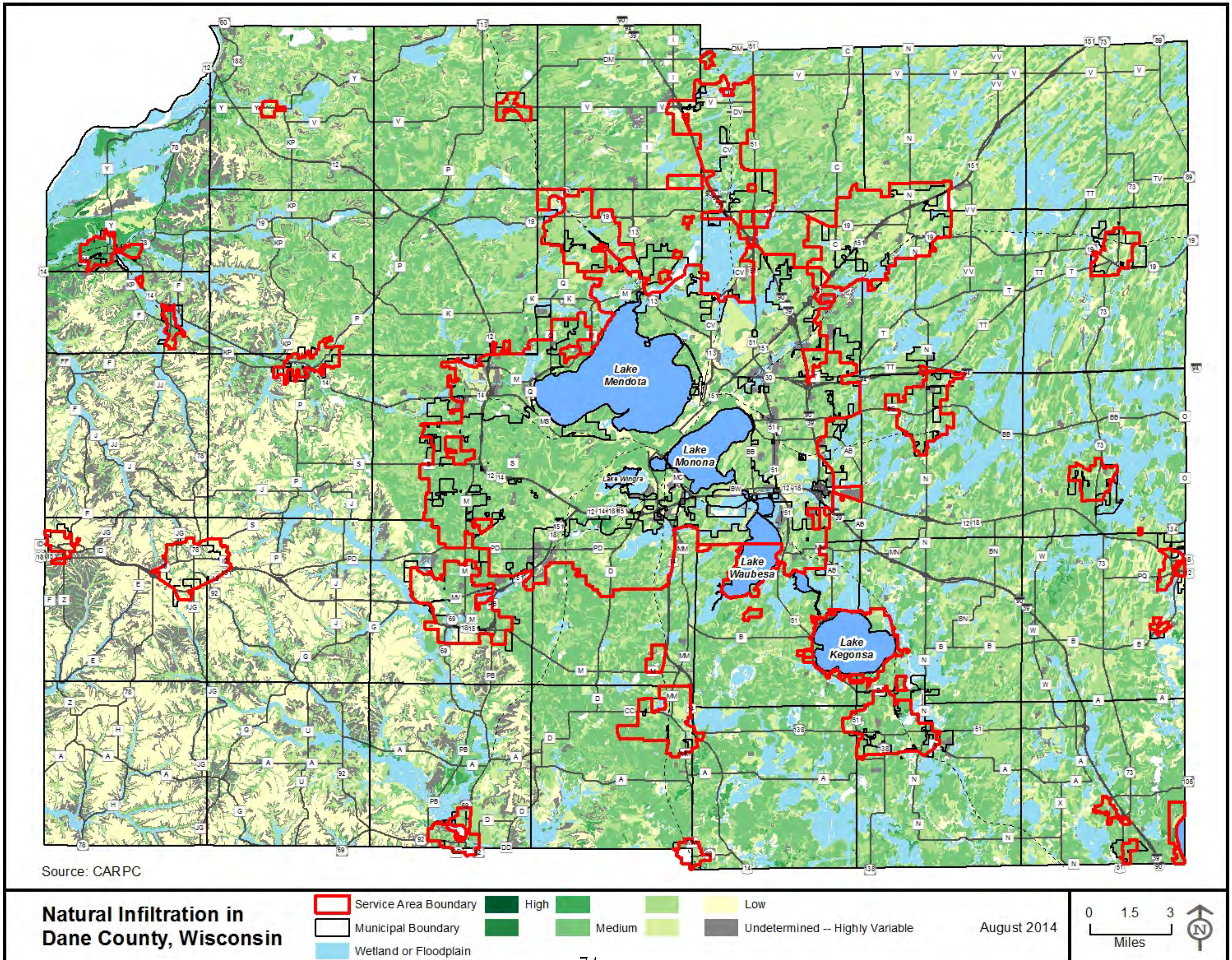
Map 21 presents enhanced infiltration that could result through removal of shallow layers of soils with low permeability and tapping into deeper sand and gravel deposits. The use of engineered soils (e.g., mixtures of sand, clay, and compost, along with native prairie plants) can enhance natural infiltration and enhance opportunities for infiltrating stormwater. There may also be enhanced opportunities or improvements that could be gained by retrofitting previously developed areas.

Map 22 indicates areas where infiltration enhancement potential may be the greatest. These areas show the greatest difference in scores between the natural and engineered states, highlighting opportunities where more permeable soils (e.g., sand and gravel deposits) may be present deeper in the soil column. These may be prime locations for regional stormwater facilities that could be used to infiltrate stormwater generated in other parts of the watershed.

A distinction between infiltration and recharge should be made. Whereas all precipitation that reaches groundwater is infiltrated into the soil, not all infiltrated precipitation actually makes it all the way to recharging groundwater supplies. Some of it may be captured by plants and evaporated or transpired back into the atmosphere. The distinction is that infiltrating stormwater runoff into the soil can reduce the volumes of runoff washing over the land surface, but not all of the infiltrated stormwater will necessarily reach the groundwater.

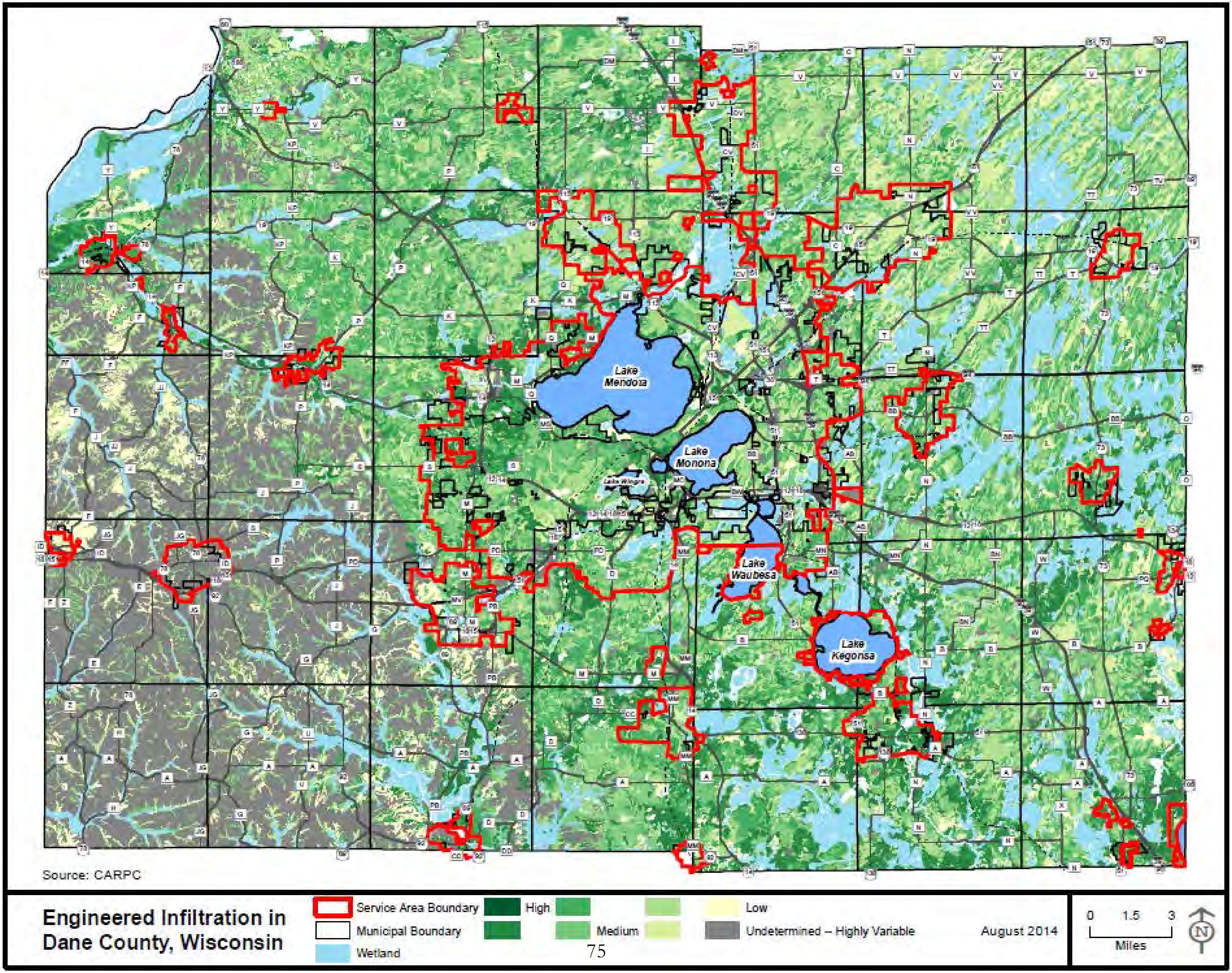
Maintaining baseflow discharge to streams and the water supply to springs and wetlands is an important resource objective. Annual groundwater recharge rates can be maintained by promoting infiltration and recharge through the use of both structural and non-structural methods. Since there are several best management practices that can be used to meet a volume control standard that do not provide groundwater recharge, it is desirable to meet this resource objective with a separate groundwater recharge standard. This approach is currently used in the City of Middleton and has been used in many urban service area amendments as well.

Map 20


Lake Mendota
Lake Monona
Lake Wingra
Lake Waubesa
Lake Kegonsa
Source: CARPC

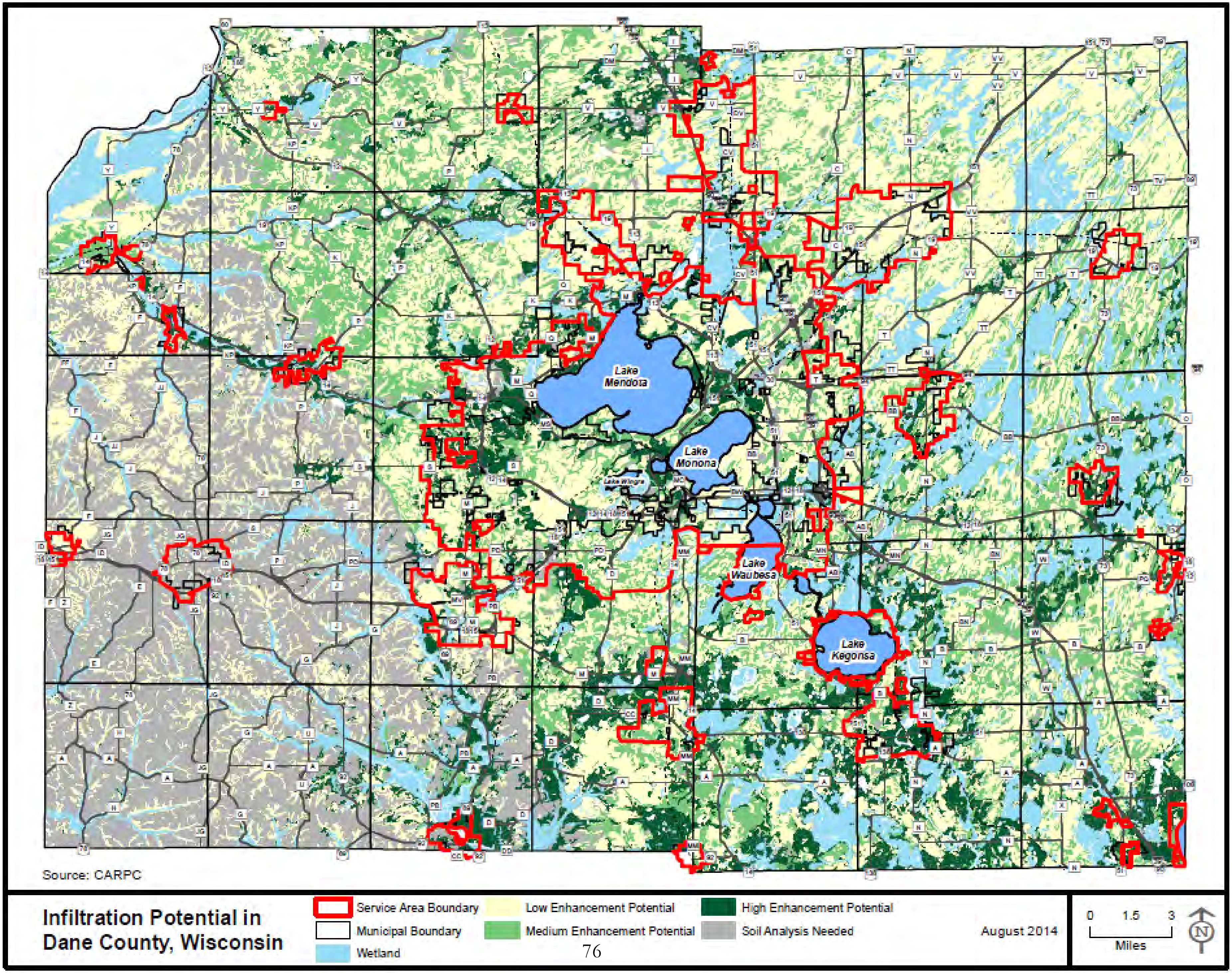
Natural Infiltration in Dane County, Wisconsin
Service Area Boundary
Municipal Boundary
Wetland or Floodplain
High
Medium
Low
Undetermined -- Highly Variable
August 2014
0 1.5 3
Miles

Map 21



Lake Mendota
Lake Monona
Lake Wingra
Lake Waubesa
Lake Kegonsa
Source: CARPC
Engineered Infiltration in Dane County, Wisconsin
Service Area Boundary
Municipal Boundary
Wetland
High
Medium
Low
Undetermined -- Highly Variable
August 2014
0
1.5
3
Miles
N

Map 22


Lake Mendota
Lake Monona
Lake Wingra
Lake Waubesa
Lake Kegonsa
Source: CARPC
Infiltration Potential in Dane County, Wisconsin
Service Area Boundary
Municipal Boundary
Wetland
Low Enhancement Potential
Medium Enhancement Potential
High Enhancement Potential
Soil Analysis Needed
August 2014
0 1.5 3
Miles
N

In most areas permeability is so variable that more detailed site investigation is needed. **Map 23** indicates depth to bedrock throughout the region, which is characteristically shallow in the unglaciated western third of the county. **Map 24** indicates shallow depth to water table, indicating low lying areas. **Map 25** indicates potential karst areas that may have vertical fractures and conduits that can dramatically increase groundwater susceptibility when present. These areas may limit the suitability of some stormwater infiltration practices due to the potential for groundwater contamination and induced flooding. Preliminary site planning and design can help maximize infiltration while protecting both existing and planned development as well as groundwater quality. This may be accomplished through on-site soil borings and analyses, engineered soils, dispersed infiltration practices of various performance and designs, as well as off-site facilities or practices in areas that may be more suitable.

It is interesting to point out that for nearly every large-scale development that might be proposed in the area there is an infiltration area located nearby that could be used to great advantage. The overall purpose of these maps, therefore, is to highlight these areas early on as important elements of site design so that they may be more fully utilized for water quality protection and groundwater recharge. While the maps do not replace the need for more in-depth analysis for a particular site, they do provide a useful planning tool to encourage the incorporation of innovative stormwater management practices into urban design.

Maintaining and enhancing groundwater recharge is a general practice promoted in the literature and throughout the country. Dane County is fortunate in that all groundwater originates as precipitation (rainfall and snowmelt) in or just outside of the county's jurisdictional boundary.[23] Dane County has adopted a stormwater volume control standard that is currently more protective than current state requirements. Municipalities have either adopted or exceeded the County requirements. This builds on work pioneered by the Dane County Regional Planning Commission requiring maximum infiltration since the late 1990s and working with the Lakes and Watershed Commission to adopt the countywide standard. Protecting and taking full advantage of high recharge areas helps offset the loss of recharge experienced locally and should be employed at every opportunity to help reduce damaging stormwater volumes and flow, treat urban runoff, and even help mitigate well water withdrawals where site conditions are favorable.

However, there are limits to the extent to which shifts in water balance can be addressed using infiltration practices alone.[24] Regional water balance transfer and large-scale recharge projects are certainly possible, but expensive. Groundwater induced flooding is another area of concern. Additional mitigation measures will likely be required to achieve the objective of minimal distortion of the hydrologic balance, and these measures will likely take the form of beneficial reuse of runoff, to supplement current infiltration approaches. Options such as aggressive conservation measures, graywater reuse, and treated effluent return to the groundwater system have been researched and successfully implemented elsewhere. In Dane County, these alternatives have substantial engineering, public health and regulatory issues that must be addressed before widespread implementation is possible. While progressive stormwater management at development sites is crucial, regional approaches to stormwater, drinking water, and wastewater management are also needed.

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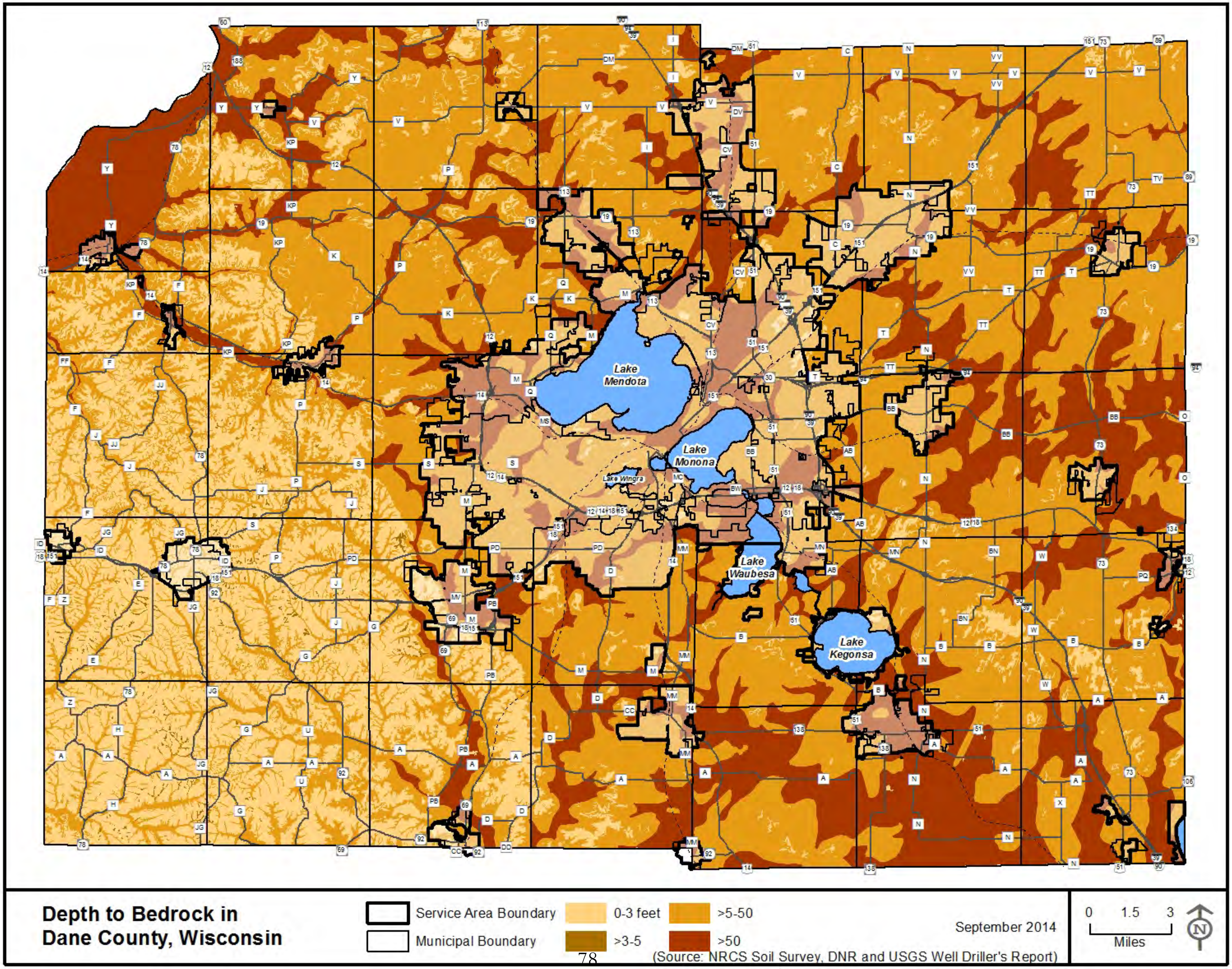
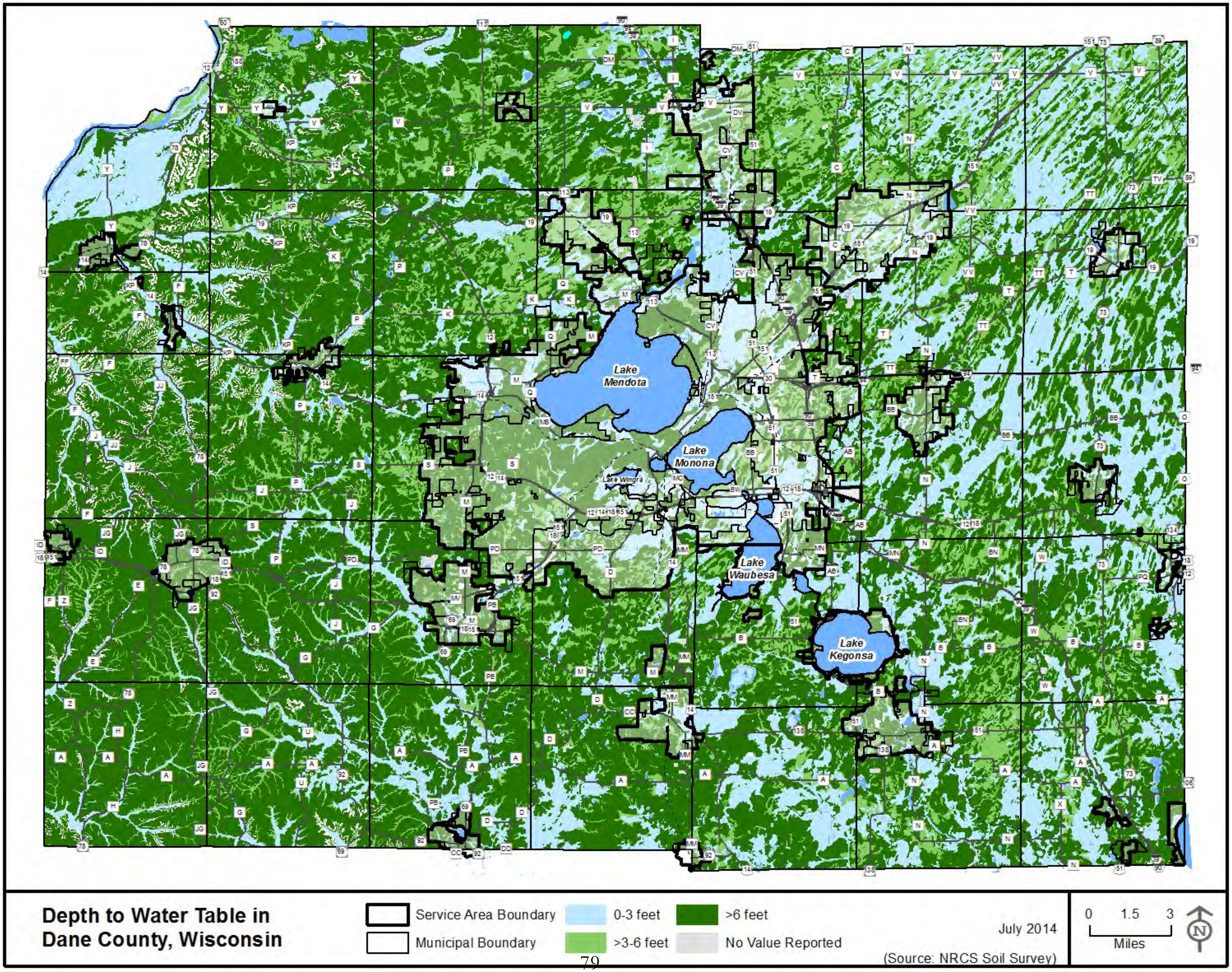
[23] Bradbury, K., et al. 1999. *Hydrogeology of Dane County, Wisconsin.*

[24] Montgomery Associates: Resource Solutions. Undated. *The Challenges of Mitigating Hydrologic Impacts of Development: Lessons Learned in Dane County, Wisconsin.*

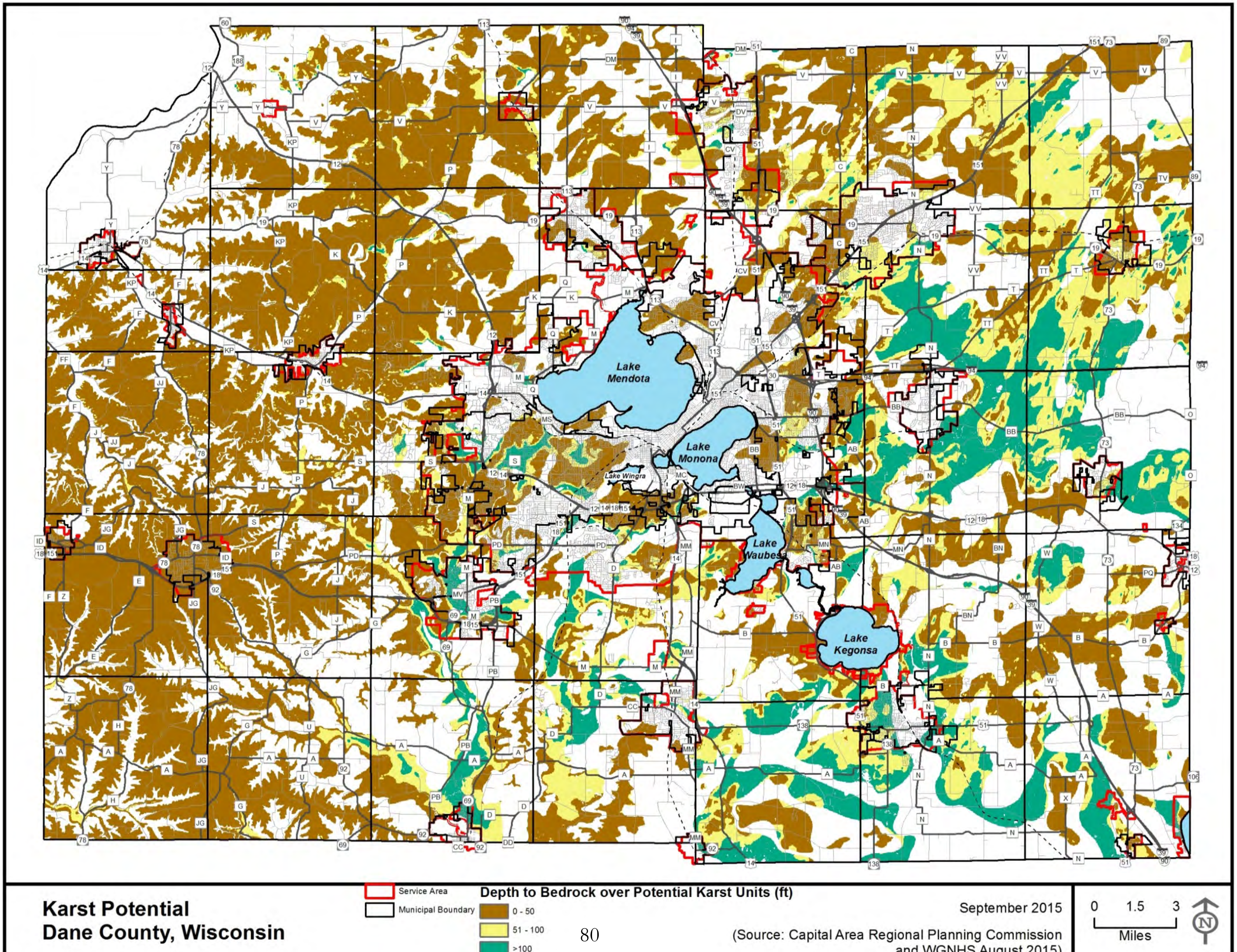
Map 23


Lake Mendota
Lake Monona
Lake Wingra
Lake Waubesa
Lake Kegonsa
Depth to Bedrock in Dane County, Wisconsin
Service Area Boundary
Municipal Boundary
0-3 feet
>3-5
>5-50
>50
September 2014
(Source: NRCS Soil Survey, DNR and USGS Well Driller's Report)
0 1.5 3
Miles
N

Map 24


Lake Mendota
Lake Monona
Lake Wingra
Lake Waubesa
Lake Kegonsa
Depth to Water Table in Dane County, Wisconsin
Service Area Boundary
Municipal Boundary
0-3 feet
>3-6 feet
>6 feet
No Value Reported
July 2014
(Source: NRCS Soil Survey)
0 1.5 3
Miles
N

Map 25



Lake Mendota
Lake Monona
Lake Wingra
Lake Waubesa
Lake Kegonsa
Karst Potential
Dane County, Wisconsin
Service Area
Municipal Boundary
Depth to Bedrock over Potential Karst Units (ft)
0 - 50
51 - 100
>100
September 2015
(Source: Capital Area Regional Planning Commission
and WGNHS August 2015)
0 1.5 3
Miles
N

Treated Wastewater Effluent Return and Reuse

Heavy groundwater pumping in the middle and upper Yahara River basins, followed by wastewater diversion around the Yahara Lakes to MMSD's effluent discharge point in Badfish Creek, causes a disruption in the region's natural hydrologic system. The reason wastewater has been historically diverted around the lakes was to protect them from water quality impacts. However, wastewater treatment technology has improved dramatically compared to when this practice was initiated in the 1930s. Due to this diversion, water bodies in the Yahara River basin are not being replenished with water that is being withdrawn, leading to reductions in groundwater discharge and stream baseflow. Pumping and diversion is also affecting water bodies in adjacent drainage basins, such as Badger Mill Creek and the Sugar River, since induced groundwater movement is suspected from these basins into the Yahara River Valley as a result of lowered groundwater levels, an expanding cone of depression, and migrating groundwater divides (**Reference Maps 12a and 5**).

The most direct method for addressing the diversion issue is to discharge treated wastewater back into the Upper Yahara River and Sugar River basins rather than conveying it all to Badfish Creek. This could be done either through a land dispersal and groundwater recharge system, or a surface water outfall. A third option, to inject treated wastewater directly into underlying aquifers, is presently prohibited in Wisconsin.

In 1998 MMSD completed a $5 million project to return treated effluent to Badger Mill Creek and the Sugar River. Similar plans are being considered for the Yahara River. The innovation here is treating wastewater as a resource to be recovered for beneficial use. Some cities such as the City of Lake Geneva in southern Wisconsin return treated wastewater to the shallow aquifer. In effect these strategies would decrease the Demand to Supply Ratio (DSR) by increasing the Human Input element of the equation (**Reference Table 6**), which is currently zero. The costs and benefits of each alternative need to be studied in much more detail, as was done in the last update of the MMSD 50 Year Master Plan in 2009.

MMSD 50 Year Master Plan

The current MMSD model is collecting all wastewater to a centralized treatment facility (the Nine Springs Wastewater Treatment Plant – NSWTP) for treatment with subsequent discharge of the treated effluent to Badfish Creek (75 mgd maximum flow rate) and Badger Mill Creek (3.6 mgd permitted flow rate). There may be advantages to altering this model by decentralizing treatment through the construction of satellite treatment plants or altering the conveyance system to route wastewater from certain parts of the service area to an existing municipal treatment plant in a nearby community. These advantages could include:

- Environmental benefits realized by returning the effluent closer to the original source of the water
- Lower capital costs in the conveyance system and at the NSWTP, and
- Reduced operational costs associated with pumping the wastewater and effluent

The purpose of the 50-Year Master Plan is to provide MMSD with a general guidance tool for providing service over the next 50 year planning period. Key areas evaluated as part of the master planning process include:

- Population growth and resulting impacts
- Collection, conveyance and treatment capacity/condition
- Centralized vs. decentralized treatment
- Mitigation of inter-basin water transfers
- Effluent reuse
- Regulatory drivers

Detailed information regarding each of the above areas is presented in a series of nine technical memoranda associated with the approved Master Plan.

"Near-Term" projects are those that would address the need for capacity expansion in the conveyance system required in the next ten to twenty years. "Long-Term" projects are those which, while still viable, cannot be implemented prior to the time the collection system capacity improvements would be required. Examples of long-term projects would include those that would discharge highly treated effluent to Lake Mendota or Lake Monona; effluent reuse projects that would be primarily driven by the economic need to reuse water; or turf irrigation projects on a larger scale that would require the development of a distribution network for the highly treated effluent, discussed below.

Near-Term Master Planning Alternatives

The following two near-term master planning alternatives have been developed. Implementation of either of these alternatives between 2010 and 2030 will address the wastewater treatment and conveyance system capacity needs in a portion of MMSD's service area, namely service in the Sugar River basin:

Alternative MP-1 – Westside Conveyance System Expansion
This alternative would expand the existing conveyance system and continue the current model of centralized treatment at the NSWTP. This alternative includes four variations for pumping treated effluent from the NSWTP to Badger Mill Creek and the Sugar River basin ranging between 3.6 mgd (currently) to 7.9 mgd, with the balance being discharged to Badfish Creek.

MP-1A (3.6 mgd, $69 million total life cycle costs) scored the highest, however it will not be able to alleviate the issue of imbalanced inter-basin water transfer. This represents the current operation by MMSD. It serves as the baseline alternative to be compared with other alternatives.

MP-1B scored second highest among the alternatives to return an additional 4.3 mgd of treated effluent to the Sugar River watershed ($103 million), whereby baseflow reduction in the Sugar River would be avoided. This is an additional cost of $34 million, assuming the current discharge limits stay unchanged. Higher quality effluent limits would likely be required for discharge in the Sugar River watershed.

Alternative MP-2 – Sugar River WWTP
This alternative includes construction of a new high quality effluent treatment plant in the Sugar River watershed to treat wastewater generated in the Verona service area and discharge its effluent to the Sugar River (4.3 mgd, $112 million). This alternative represents a decentralized approach towards an effluent reuse and watershed balanced solution.

If mitigation of the inter-basin flow imbalance between the Sugar River basin and the Yahara River basin is determined to be necessary, satellite facilities in the Sugar River Basin may be favorable from both economic and non-economic standpoints to address west side conveyance capacity issues. More detailed cost and non-economic comparisons between alternatives with centralized treatment and alternatives with satellite treatment will need to be conducted since their life cycle costs and social and environmental benefits are closely ranked.

Since the Sugar River is an Exceptional Resource Water (ERW), it is subject to more stringent anti-degradation requirements (NR 207). In general, a new discharge to an ERW needs to meet upstream water quality. For example, if the background phosphorus concentration in the Sugar River is 0.050 mg/L, the effluent limit could be set at 0.050 mg/L. The effluent limits for ammonia, BOD, total suspended solids, chlorides, and other parameters may also need to be equal to background concentrations. Regulations are not as stringent for an increased existing discharge; however, the permittee would still need to demonstrate there will either be no significant lowering of water quality or that the project has offsetting sociological and economic benefits.

Long-Term Master Planning Alternatives

Long-term alternatives are those planning alternatives that cannot be implemented soon enough to provide relief in the conveyance system; however, they remain potentially viable options beyond the year 2030 for mitigating inter-basin transfers of water, or providing high quality effluent for reuse options. Due to growing demands on available groundwater supplies and the long-term goal of stabilizing the groundwater aquifer operating level in the Dane County area, high quality effluent utilization could be a promising way to solve these issues in the future, especially if population growth occurs as expected. The following two long-term alternatives emphasizing effluent reuse were selected for further evaluation. These two alternatives have potential to be implemented after 2030 and provide high quality effluent to various locations for reuse options and to mitigate inter-basin transfer of water.

Alternative MP-3 – Centralized High Quality Effluent Treatment & Distribution
This alternative would include construction of facilities at the NSWTP for an additional 4 mgd treatment capacity ($51 million) that would produce a high quality effluent for use in various applications, including streamflow augmentation, infiltration, industrial reuse, or turf irrigation. It also includes a new effluent pumping station and effluent force main to convey the effluent from Nine Springs to a point of use near Starkweather Creek.

Alternative MP-4 – Decentralized High Quality Effluent Treatment Facilities:
This alternative would include construction of facilities northeast of the Dane County Regional Airport, for an additional 4 mgd treatment capacity ($76 million). The new treatment plant would receive wastewater flows tributary to Starkweather Creek or both Starkweather Creek and the Yahara River south of Cherokee Lake. Effluent from this facility could be used for streamflow augmentation to Starkweather Creek, wetland restoration at Cherokee Marsh, groundwater infiltration, industrial reuse, or turf irrigation.

Future service alternatives such as satellite plants in the upper Yahara River basin that would discharge to the Yahara lakes and regional service options involving Sun Prairie and Stoughton were not evaluated beyond initial screening in the Master Plan. At this time, the strict regulatory constraints, high construction and operation costs, lack of proven technology, and potential strong public resistance make these service alternatives less favorable than the services provided under the current treatment model. However, these alternatives may become more viable in the future with changes in the political environment, water resource demand, or improvements in wastewater treatment technologies.

WDNR interpretation of requirements in Wisconsin State Statute 281.47 was the driver for MMSD diverting effluent around the Yahara Lakes beginning in the late 1950s. The statute does not explicitly prohibit direct discharge of effluent to the chain of lakes, but it does place conditions that must be met for direct discharges to occur. The WDNR is given authority to determine whether these conditions are met. Based on recent phosphorus requirements, effluent quality would need to be close to background surface water quality for phosphorus prior to approval. The total phosphorus criteria for deep lowland lakes (Lakes Mendota and Monona) are 0.03 mg/l, and 0.04 mg/l for shallow lowland lakes (Lakes Waubesa and Kegonsa). For comparison, the current MMSD total phosphorus limit for Badfish Creek is 0.075 mg/l. MMSD is currently conducting an Adaptive Management pilot project with agricultural and urban partners in the Yahara River watershed to promote and take advantage of potentially more cost-effective nonpoint source phosphorus removal practices. So-called "nutrient trading" conducted between point and nonpoint pollution sources promises a more cost-effective alternative to expensive wastewater treatment plant upgrades in achieving water quality standards.

WDNR has indicated that a discharge to wetlands may be subject to less stringent requirements than a discharge to an ERW stream or the Yahara Lakes, particularly for restored wetlands. This option may also be useful in lieu of a direct stream or lake discharge in the vicinity of the Sugar River or Nine Springs Creek and Lake Waubesa. Wetland discharges are regulated under NR 103. NR 103 applies to natural and restored wetlands but not to constructed wetlands for wastewater treatment or polishing; the latter systems typically constructed with liners separating them from natural waters and are considered a wastewater treatment unit process.

Implementation of projects to decentralize treatment will take a decade or longer to implement, either because of issues related to the receiving water into which effluent from the satellite plant would be discharged, or due to the length of time it would take to reach agreement with a community with an existing treatment plant.

Future regulatory requirements could also significantly impact MMSD's planning and operations over the 50 year planning period. Areas of particular importance include: phosphorus criteria, anti-degradation, total nitrogen, chlorides, mercury and other toxics, thermal standards, micro constituents in effluent (such as pharmaceuticals, personal care products, and endocrine disrupting compounds), water quality assessments, Rock River TMDL development, water balance issues, and groundwater rules for discharges to land and subsurface waters.

Groundwater Recharge Using Treated Effluent

Groundwater recharge using effluent is being practiced in several locations around the state, particularly in the Wisconsin River Valley and other locations where soils are sandy and thus conducive to infiltration. A typical method of effluent groundwater recharge is to use seepage cells (also called absorption ponds), which are regulated under NR 206. Current effluent limitations for discharge to absorption ponds include: Biological oxygen demand (50 mg/l), total nitrogen (10 mg/l), total dissolved solids (500 mg/l), and chloride (250 mg/l).

Groundwater monitoring is also usually required for absorption ponds and the relevant groundwater standards at the design management zone boundary (250 feet from the seepage cell boundary) or at the property line. These are contained in NR 140. The groundwater preventive action limit (PAL) for chloride in drinking water is 125 mg/l and the enforcement standard (ES) is 250 mg/l.

For this type of discharge, it appears the greatest hurdles for MMSD to overcome would be total nitrogen (TN) and chloride effluent concentrations. Biological nitrogen removal can be used to reduce TN to below 10 mg/l. If a variance could not be obtained, chloride concentrations would need to be reduced through source reduction or reverse osmosis treatment prior to discharge to an infiltration gallery and may also need to be reduced prior to a discharge to absorption ponds.

As part of the 1997 Regional Hydrologic Study, estimated 2020 wastewater discharge generated in the Upper Yahara River basin (4.4 mgd) was land-applied north of Lake Mendota over areas exhibiting high infiltration characteristics (typically glacial outwash deposits). The confining unit between the upper and lower aquifers exists generally north and west of the Yahara lakes in this area and to a large degree inhibits transmittance of water between them. This resulted in apparent mounding of the water table, rising less than 20 feet locally and generally less than 10 feet over an 11-square-mile area.

Considering depths to water table in the areas examined are more than 10 feet and generally greater than 25 feet, sufficient soil depth is available to "polish" highly treated effluent before reaching the water table. Further iterations of the model will be needed to minimize the surface area needed, yet assure adequate percolation distances. The principal objective here was to screen the benefits/validity of using this approach initially, and conduct more in-depth analysis if this alternative appears promising compared to the others presented in this report.

Nonresidential Irrigation

The current MMSD permit contains provisions related to use of effluent on the Nine Springs Golf Course in Fitchburg as a demonstration project. This type of discharge would be regulated under NR 206. Current regulations include a BOD effluent limitation of 50 mg/l. Hydraulic loading rates and load and rest cycles are determined on a case-by-case basis and generally depend on the soil type. Likewise, Total Nitrogen and fecal coliform limits are determined on a case-by-case basis. Groundwater monitoring is often required for these systems, particularly when significant pretreatment is not provided. Groundwater standards for chloride (125 mg/l PAL and 250 mg/l ES) may be of greatest concern for MMSD's effluent.

Nonresidential irrigation would generally involve spray or drip irrigation of treated wastewater onto agricultural fields, grass lands, golf courses, or similar areas. Generally Total Nitrogen applications are limited to crop uptake rates, which are on the order of 165 lb/acre-year for corn and 300 lb/acre-year for certain grasses like reed canary grass. Groundwater monitoring is often required for determining compliance with groundwater standards.

Residential Reuse

Water reuse – using the same water to perform more than one function – enables us to get the most out of every drop. Water reuse is becoming increasingly popular as a tool for Wisconsin citizens and communities to achieve their water conservation goals. Only 15 percent of the water used in homes actually needs to be potable. By reusing water that would normally just go down the drain, people can begin to dramatically cut down on their daily water consumption without having to change their daily routines. Stated simply, water reuse saves money, energy, and – ultimately – our water supply.

There are already a small but growing number of on-site water reuse systems that are operating safely and successfully in Wisconsin. When water reuse systems are *properly installed and maintained*, the health and safety concerns are no greater than those from existing municipal or private well water supplies. Because on-site reuse is largely a plumbing issue, it is regulated by the Wisconsin Department of Safety and Professional Services under the provisions of SPS 382.70.

Water reuse is not for everyone. Retrofitting plumbing systems in existing homes and businesses is often cost-prohibitive for remodeling projects. Owners interested in water reuse should be aware that additional time, cost, and maintenance are necessary to keep these systems running safely and efficiently. Homes or businesses that use large amounts of water will see the most economic benefit from the reduction in water use. Water reuse may simply be fulfilling water-use reduction standards for LEED building certification. New construction is often best when it is a part of an overall goal of making a new or existing building more water efficient or suited to installing water reuse systems. Local governments can play a major role in promoting water reuse and conservation in proposed developments, particularly in cases where tax increment financing or other incentives are awarded.

Public acceptance has been one of the major obstacles to implementing water reuse in many parts of the country. Because water reuse is still a relatively new practice in modern homes and businesses, the public often has reservations about health risks or aesthetic concerns. As more water reuse systems are properly installed and put to productive use, these concerns are expected to lessen over time. Water reuse is the next great advance in water conservation because of its tremendous potential to increase water use efficiency and reduce water consumption.

MMSD's customers have been supportive of the master planning process and would like to see MMSD investigate wastewater reuse alternatives. Many commenters suggested that new subdivisions could start requiring that wastewater reuse infrastructure be constructed with other utilities. Effluent reuse options should be evaluated during future facilities planning efforts, but will require partnerships to implement.

Partnerships could potentially include other municipalities, water utilities, or public/private partnerships. Other areas of the country, especially the south and west, are already reusing treated wastewater.

It has been proposed that treated effluent could be reused for toilet flushing, residential lawn irrigation, and other residential nonpotable water uses. Such a concept would require effluent treatment to a very high level (potentially California Title 22 standards for food crop irrigation), require force mains to convey the treated effluent to the residential developments, and require a new infrastructure similar to the "purple pipe" reuse water distribution systems used in the Southwest and elsewhere. This concept may be worth considering for new developments where installation costs would be lower compared to existing developments. However, it is likely that costs of such systems would outweigh the benefits, at least in the short term in the Madison area. For the short term, it appears that residential water conservation measures may provide similar benefits at a significantly lower cost. Due to the long planning horizon, specific effluent reuse projects cannot be clearly defined for long term alternatives. Preliminary evaluation shows that the most cost effective approach to providing effluent for reuse options is to continue to treat wastewater centrally and construct an effluent delivery system(s).

Industrial or Commercial Reuse

Wastewater effluent can be used for industrial noncontact cooling and other noncontact uses. Wisconsin currently has no standards for the treatment of effluent for use in an industrial facility. Commercial car wash use may be another viable alternative; however, the locations of such facilities may be too diffuse for cost-effective conveyance of the treated effluent. The concept should be initially explored with the largest water users in Dane County who use fresh water for nonpotable uses.

Prospects for Effluent Discharge and Reuse

Increasing regulatory pressure and energy costs may limit the long term viability of pumping all treated effluent to Badger Mill Creek and Badfish Creek. The volumes and locations where MMSD discharges its effluent will be a major factor in sustaining water levels in streams and aquifers throughout the watershed. Also, water conservation within the watershed is considered a primary issue to address the timing and location of needed improvements. As part of the MMSD facilities planning process the following issues on effluent discharge and reuse were identified for more in-depth discussion and consideration:

- The most apparent variable is the ability to discharge effluent into the Yahara Lake system. This will depend heavily on effluent quality limits, regulatory judgment, and public perception. Legislative changes may also be required.

- Decentralized local treatment plants could be a direction in the future. These facilities could reduce inter-basin water transfers by reusing effluent within the basin that it was generated. They would also eliminate the need to pump effluent long distances, thereby reducing energy costs associated with pumping.

> Current pumping of groundwater is lowering the groundwater table levels and reducing baseflow to streams and springs.

- Who would ultimately be responsible for running the decentralized facilities? If operational responsibilities remain with MMSD, there may be workforce availability and other technical issues associated with operating multiple facilities.

- Conservation of water on the intake side of the water system will be essential to achieve sustainability. Current pumping of groundwater is lowering the groundwater table and reducing baseflow to streams and springs. Energy conservation and water conservation should be considered equally important.

- Augmenting low water flow areas with treated effluent is an option, but the ability is needed to divert or manage the effluent in some other manner during high flow events. Nine Springs WWTP can utilize its lagoons for storage, but they can only hold 66 million gallons, a volume of water equal to approximately one and one-half days' worth of dry-weather plant influent volume.

- Reintroduction of treated effluent back into the groundwater through infiltration or recharge could be a viable option to address water quantity concerns, but would there be enough available land area to implement effluent reuse options involving infiltration to an extent that it would have a significant impact on groundwater quantity?

- Micro constituents found in treated effluent such as pharmaceuticals, disinfection byproducts and viruses may be subject to increased regulation and create public perception issues that could limit the viability of using effluent for groundwater recharge.

- From an ecological perspective it may be better to augment existing baseflows than to recharge aquifers.

- Use of wetlands for effluent polishing and use of effluent in reclaiming wetlands need to be further investigated.

- The reuse of "gray water" in non-drinking applications appears to be a sensible option for the reduction of water consumption. How to go about implementing and integrating such systems remains an issue.

- Major water consumers such as industrial parks and golf courses should be targeted first for instituting water reuse systems.

- Public perception can influence the ability to institute water reuse options, and information/education efforts will need to be undertaken to impact public perception. The discussion in 2003 related to using effluent for cooling water at the UW cogeneration energy facility on campus highlighted the need for information/education activities. Staff from the University of Wisconsin expressed concerns related to reusing effluent because of public perceptions that use could impact human health.

- The majority of wastewater flow is generated by residential sources. The residential capacity to take on new gray water systems needs to be investigated.

The Master Plan is a dynamic document and will be reviewed and updated periodically to reflect the impact of these key factors. Signposts developed by MMSD such as technology improvements, regulatory trends, population growth/shifts, and changes in water use should be closely monitored to allow MMSD to make appropriate adjustments to the Master Plan.

Importation of Water from Other Drainage Basins and Deep Aquifer Withdrawal

As part of the 1976 Madison Metropolitan Sewerage District's (MMSD) *Wastewater Facilities Plan,* potential water quantity augmentation measures were presented including importation of water from other drainage basins and deep aquifer withdrawals.

Importation of water from the adjacent Wisconsin River Basin, through pumping and transport of groundwater from high-capacity wells, was one approach that was evaluated. At that time, the required pumping capacity to make up the estimated water deficit in the Yahara River and lakes system was determined to be 36 cfs (23 mgd). This is the balance of flow needed to offset evaporation (27 cfs) and maintain the required minimum of 25 percent of the $Q_{7,2}$ (9.0 cfs). Water importation was suggested only as a contingency during an extremely low-flow year. Capital costs for importation (i.e., well-pumping and distribution system) were projected to exceed $15 million. Most of the expense was associated with extensive force main construction.

In addition to expense, the importation of water from other drainage basins raises complex and conflicting water rights issues surrounding the interbasin transfer of water. To protect these rights, the WDNR has been charged through 1985 Wis. Act 60 with approving and permitting any proposed new or expanded use of the state's waters which results in a consumptive loss or interbasin diversion averaging more than 2 mgd in any 30-day period. Overall, flow augmentation by importing water from other drainage basins, particularly the Wisconsin River Basin, has been found to be prohibitively expensive and politically unfeasible (as evaluated in the 1976 MMSD Facility Plan). Rather, a much more favorable approach would be to augment streamflow through careful management of ground and surface water levels within the Yahara lakes' own drainage system, through more viable alternatives presented in this plan.

Another strategy to augment low flows in the Yahara River would be to pump water from the deep aquifer system near the basin divide or areas within the basin where geologic confining units are known to exist (these separate the deep and shallow groundwater flow systems). It was thought well water drawn from the deep aquifer system could be used to augment shallow water table levels, which sustain stream baseflows and lake levels. Upon closer examination, however, this alternative is seen as providing negligible long-term benefit given the close association and transmittance of water between the upper and lower aquifers, particularly in the Yahara lakes area and eastern portion of the county where the confining unit is largely absent. This alternative could be employed to mitigate short-term severe drought conditions, by augmenting streamflow with well water during critical conditions. This is currently being implemented to mitigate surface water withdrawals for the UW Co-generation energy facility during drought conditions. Further evaluation will be undertaken only if more viable long-term alternatives presented here fail to adequately satisfy prescribed management goals and objectives.

Management of the Yahara Lakes as Multipurpose Reservoirs for Baseflow Augmentation and Drinking Water Supplies

Baseflow Augmentation

The effect of municipal well water withdrawals and wastewater diversion on the lower Yahara River is of historical concern. The 1976 *Madison Metropolitan Sewerage District's Facilities Plan* proposed lake level and outflow manipulation of the Yahara River lakes as a possible management approach that could mitigate the baseflow impacts of diversion. Other studies have also recognized the need for a well-formulated lake-level management program (including specific outlet control guidelines) to address this concern.[25] However, refined operating rules for the Yahara lakes had yet to be developed, primarily because lake levels and outflows had not been technically simulated and evaluated. A critical question to address is the timing and daily quantity of water to release from the lakes' outlets preceding and during low-flow periods, which can only be accurately simulated by a routing model.

As a component of the Dane County Regional Hydrologic Study (1992-1997), a daily reservoir storage routing model for the Yahara lakes was developed. The purpose of the Yahara Lakes Reservoir Routing model was to simulate the flow through the Yahara Lakes/River system under varying conditions to determine whether or not the substantial baseflow reductions resulting from wastewater diversion can be mitigated through lake level manipulation and flow control.[26] The goal is to restore prediversion low-flow conditions ($Q_{7,2}$=36 cfs at McFarland)[27] within the tight constraints of WDNR lake level and flow limits. The Reservoir Routing Model demonstrates that, using a set of operating rules, lake levels and streamflows could be better managed and that it would be possible to restore prediversion low-flow conditions in the Yahara River system in all but the driest years without lowering the lake levels more than they have been lowered during the study period 1974 to 1994. This is accomplished using a rather detailed set of operating procedures and computations.

Achieving this result in practice, however, would require detailed computations to reach decisions on lake levels and dam operations. A USGS operations model linked to real-time lake levels and flows was subsequently developed and used to help guide the County's operation of the lakes; however, without success. A more sophisticated Yahara Lakes INFOS model[28] developed by the UW-Madison, City of Madison, and Dane County is currently being used to better manage the lake levels. This model should be expanded and configured to evaluate alternative management/mitigation strategies using the more sophisticated models and software than was available to USGS in the late 1990s.

This is part of a regional effort to help balance often conflicting goals and expectations by multiple user groups. At times the physical limits of the dams and outlet channels make it impossible to keep the lake levels within prescribed limits. Yahara lake limits were established over a century ago based primarily on human interests (recreation, property damage, etc.), possibly at the expense of natural areas. There may be some interest in revisiting the maximum/minimum lake levels. According to the USGS study, setting somewhat higher stage limits in the spring or lower in the fall would more easily accommodate restoring prediversion low-flow conditions in the Yahara River system. However, this could conflict with riparian landowners' expectations of so-called "normal" lake levels they have become accustomed to. Overall, greater flexibility on the part of all user groups will be needed to find an area of common agreement among the various interests on how best to operate the lakes to satisfy all interests – a challenge indeed.

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[25] *City-County Lakes Committee Report* (DCRPC, 1978) and *Dane County Water Quality Plan* (DCRPC, 1979).

[26] USGS. 1999. *Simulation of the Effects of Operating Lakes Mendota, Monona, and Waubesa, South-Central Wisconsin, as Multipurpose Reservoirs to Maintain Dry-Weather Flow*. Open-File Report 99-67.

[27] The 7-day 2-year low flow ($Q_{7,2}$) is a statistical estimate of the lowest average flow that would be experienced during a consecutive 7-day period with an average recurrence interval of two years.

[28] Integrated Nowcast/Forecast Operating System for the Yahara Lakes http://www.infosyahara.org/

Drinking Water Supplies

In 2010 the Madison Metro Region diverted an average of 63 cfs (40.7 mgd) of groundwater from the Madison Metro Region (from municipal well withdrawals) and discharged the treated effluent to Badfish Creek. Under steady state conditions, every gallon of water pumped is a gallon of water lost from groundwater discharged to surface waters. Approximately 80 percent of this amount (51 cfs[29]) is being drawn from waters other than the Yahara Lakes. Streams and small water bodies are particularly sensitive to changes in flow. Large drainage lakes such as the Yahara Lakes, on the other hand, are considered relatively insensitive or resilient from a biological standpoint.[30] In addition, the flow in the Yahara Lake chain system is artificially managed by dams at the outlets of Lakes Mendota, Waubesa, and Kegonsa. This offers some prospect for possibly pumping more water from the wells, inducing withdrawals from the Yahara Lakes, and thereby relieving some of the impact on the more sensitive tributary streams, ponds, and wetlands in surrounding areas.

Much of this additional withdrawal could be accounted for through the normal daily operation of the dams (i.e., holding more water back, to account for the withdrawal, and releasing less runoff), providing an alternative source of drinking water previously released downstream as runoff. Since this pumping represents a relatively constant demand, it could be managed or accounted for on a daily basis through stop log changes (as is currently done) at each of the three dams. The lakes could function as water supply reservoirs, either directly (i.e., surface water withdrawal, although cost prohibitive[31]) or indirectly (i.e., induced recharge by pumping, as done presently). Note that about a third (20.43 cfs or 32 percent) of municipal well withdrawals in the MMSD service area is being taken out of the Yahara lakes through induced recharge (**Tables 12a and b**). Being a more resilient and renewable resource (as reservoir storage), taking *more* water out of the lakes could actually help reduce the impact on more sensitive surrounding streams.[32]

Figure 16 and Tables 12a and b illustrate the increased losses and decreased gains for each of the Yahara Lakes resulting from the three pumping scenarios. Note there are relatively small losses from Lakes Waubesa, Kegonsa, and Upper and Lower Mud Lakes under the 2010 and 2040 development scenarios. This indicates that municipal well withdrawals are inducing relatively little groundwater recharge from these water bodies. In the case of the urbanized lakes (Mendota, Monona, and Wingra), water losses to groundwater are increasing (induced recharge) and lake gains (from groundwater discharge) are decreasing as a result of municipal well withdrawals. **Table 12b** indicates the losses for each water body between indicated time periods taken from **Table 12a.** For example, the additional lake loss for Lake Mendota between 2010 (0.86 cfs) and 2040 (1.11 cfs) in **Table 12a** equals 0.25 cfs in **Table 12b.** Likewise, the total net loss between 2010 (20.72 cfs) and 2040 (18.70 cfs) is 2.02 cfs. The greatest decrease has already occurred (20.43 cfs in 2010), with a total loss of 22.45 cfs expected by the year 2040 compared to Pre-Development Conditions.[33]

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[29] 63 cfs minus 12.33 cfs (from **Table 12b**) equals 50.67 cfs.

[30] Dane County Regional Planning Commission. 2005. *Dane County Water Body Classification Study*, Madison, WI.

[31] Roughly $5 million per mgd for treatment plant and distribution system. Note that, because of induced recharge, this is considerably more expensive (15X per mgd) than service from a new $1 million, 3 mgd well located near the lakes, with proportionally similar effects.

[32] Dane County Regional Planning Commission. 1997. *Evaluation of Alternate Management Strategies*. Dane County Regional Hydrologic Study.

[33] Conditions existing prior to large well withdrawals (circa 1800s) simulated by removing all pumping wells from the regional groundwater model with a subsequent rebound in water table levels and groundwater discharge to surface waters.

Fig. 16. Yahara Lake Gains and Losses Resulting from Groundwater Discharge and Induced Recharge.

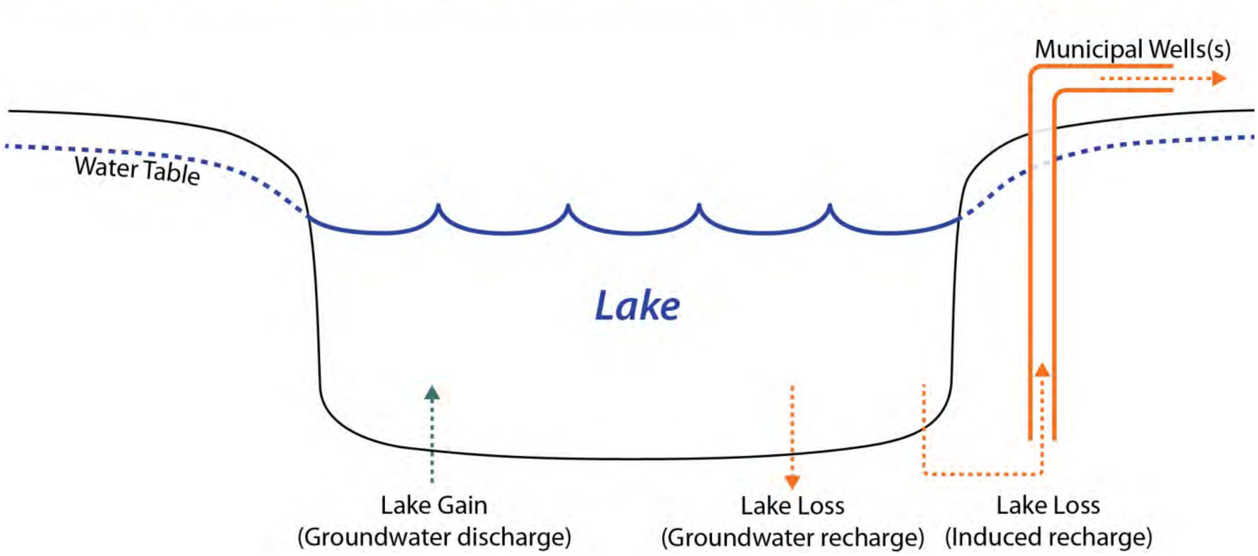


Table 12a. Modeled Losses and Gains for the Yahara Lakes For Different Time Periods (cfs)

ID*	Water Body	Pre-Development (PD)**		2010		2040	
		Loss	Gain	Loss	Gain	Loss	Gain
27	Mendota	0.00	12.22	0.86	3.69	1.11	3.27
41	Monona	0.02	4.18	0.49	0.56	0.63	0.43
49	Wingra	0.45	5.03	0.20	2.40	0.23	2.23
44	U. Mud Lake	0.00	4.65	0.01	2.10	0.02	1.55
54	Waubesa	0.00	4.09	0.01	3.02	0.01	2.84
57	L. Mud Lake	0.00	3.58	0.00	3.05	0.00	2.94
66	Kegonsa	0.00	7.88	0.00	7.47	0.00	7.44
	Sub total	0.47	41.63	1.57	22.29	2.00	20.70
Net		**41.15**		**20.72**		**18.70**	

* ID corresponds to the modeled hydrostratigraphic response units indicated on **Maps 15 and 16.**
** Pre-Development Conditions were estimated by removing all well pumping from the regional groundwater model resulting in a subsequent rebound in water table levels and groundwater discharge to surface waters.
Source: WGNHS 2014 Regional Groundwater Model

Table 12b. Differences in Modeled Losses and Gains Between Different Time Periods, from Table 11a (cfs)

ID	Water Body	PD to 2010		2010 to 2040		PD to 2040	
		Loss	Gain	Loss	Gain	Loss	Gain
27	Mendota	0.86	-8.53	0.25	-0.42	1.11	-8.95
41	Monona	0.47	-3.63	0.14	-0.13	0.61	-3.76
49	Wingra	-0.25	-2.63	0.03	-0.17	-0.22	-2.81
44	U. Mud Lake	0.01	-2.55	0.01	-0.55	0.02	-3.10
54	Waubesa	0.01	-1.06	0.01	-0.18	0.01	-1.24
57	L. Mud Lake	0.00	-0.53	0.00	-0.11	0.00	-0.64
66	Kegonsa	0.00	-0.41	0.00	-0.03	0.00	-0.44
	Sub Total	1.10	-19.34	0.44	-1.59	1.53	-20.94
Total Loss		**20.43**		**2.02**		**22.45**	

The fact that the Yahara Lakes represent a renewable water supply source or reservoir system suggests a potential mitigation strategy. Being artificially controlled, the availability of lake water is largely represented by the amount of water held in storage or released downstream during runoff events. One of the conclusions from the Dane County Regional Hydrologic Study was that concentrating pumping closer to the lakes would largely offset future water table declines in surrounding areas (**Reference Map 19a**). This has significant benefit for small headwater and tributary streams such as Badger Mill Creek, Black Earth Creek, and the Sugar River, among others, which have been significantly affected by municipal well withdrawals. The fact that the lakes are large, artificially managed, surface water-dominated systems suggests that the water quantity impact to more sensitive surrounding streams could be potentially mitigated without significant harm by inducing greater recharge from the lakes.

Conceptually, this could be accomplished by increasing withdrawals from municipal wells located closer to the Yahara Lakes. There are obviously tradeoffs associated with alternative water supply locations and configurations that would need to be evaluated in more detail. What has not been considered previously is capturing and using more runoff currently being released downstream – arguably, a more efficient and sustainable use of water. More importantly, pumping more water from the lakes could help reduce the impact to more sensitive water bodies in surrounding areas.

In 2000 the City of Madison explored the technical feasibility and cost of altering well pump operations for the Madison Water utility so that a greater percentage of water would be produced by "central wells," defined as half the wells located farthest from the peripheral groundwater divides.[34] The feasibility study was a follow up to a recommendation coming out of the Dane County Regional Hydrologic Study. The study found that the additional water table declines and reductions in baseflow in tributary streams due to the projected increase in pumping (1992 to 2020) could largely be mitigated or offset by drawing on wells located closer to the lakes. The conclusion of the City of Madison study was that under average day conditions (31.8 mgd in 1997) the desired average ratio of central well pumping to total well pumping of approximately 75 percent could be achieved with certain infrastructure improvements. The total capital cost of implementing these improvements was estimated to be approximately $1.45 million, with additional operating costs of approximately $250,000 per year. The 20 year present value of these incremental costs was estimated to be $2.9 million.

The downside to more centralized pumping would be that the groundwater discharge to the Yahara System would be reduced to a greater extent. The biological effects of this have not been studied – although, presumably, baseflow could be maintained through the capture and release of additional runoff (storage) at each of the lakes' dams under the dams' existing operation rules (i.e., leaving stop logs in longer to capture more runoff and thereby help maintain daily lake levels, storage, and streamflow). There are also potential water quality concerns of drawing increasing amounts of lake water into our public water supplies. Consider, however, that this is already occurring. While the sand and gravel layers serve as a large sand filter for deep municipal well supplies, current efforts to protect groundwater quality will need to continue. Municipal water utilities regularly monitor and routinely publish drinking water quality reports. Increasing nitrate and chloride concentrations due to fertilizers and road salt are particularly troublesome because they are more mobile. Continued monitoring is needed as well as reduction of these pollutants at the source – regardless of the amount withdrawn.

An additional concern is the drawdown of the lakes during drought. The estimated 2040 pumping from municipalities drawing from Lakes Mendota and Monona (Madison, Middleton, Monona, and Fitchburg) is estimated to be 38.13 mgd (**Reference Table 3**), or 59.00 cfs diverted from the Yahara Lakes and surrounding basins and discharged to Badfish Creek. This volume of water equates to 5.10 million cubic feet or 117 acre-feet per day. Considering Lake Mendota is 9781 acres, this is the equivalent of 0.144 inches of drawdown per day. Drawing from both Lakes Mendota and Monona (13,139 acres) this equals

[34] *Report on Task 10 – Well Pumpage Optimization.* City of Madison Water System Mater Planning Study. Earth Tech Project No. 30456.

0.107 inches of lake drawdown per day. Notice in **Figures 17a and b** lake levels frequently exceed maximums in the summer (there being too much water) and are often above winter minimums for Lakes Mendota and Monona (established to help avoid ice damage and also provide runoff storage capacity in the Spring). A casual observation would suggest that a reduction of 0.107 inches per day would not be a significant impact, considering the typical range of approximately four feet over the course of a year and average annual precipitation equal to 33 inches. This reduction may be even less apparent if it is absorbed or accounted for by the daily operation of the lakes and releasing less water downstream. In many cases there is *too much* water and this withdrawal could more easily be accounted for. It appears that summer maximum lake limits are violated considerably more than summer minimums, so there appears to be some flexibility or opportunity most years (note, 2012 was considered a drought year).

The projected amount of wastewater expected to be diverted to Badfish Creek by these same communities between 2010 (32.67 mgd) and 2040 (38.13 mgd) from **Reference Table 3** amounts to 5.46 mgd or 8.45 cfs (i.e., 59.00 cfs minus 50.55 cfs); or 0.015 inches of additional lake drawdown per day, as in the Mendota/Monona example above. That amounts to a one inch reduction in lake levels over three months (67 days). Considering more runoff could be captured daily (to maintain the same lake level targets), it is doubtful this additional drawdown would even be noticed by the casual user or riparian landowner. Also, considering the lakes can bounce as much as four feet per year, this would be well within the range experienced historically and assumes absolutely no rainfall which, of course, is atypical during the summer months.

Figure 17a. Historic Lake Mendota Levels and Regulatory Limits

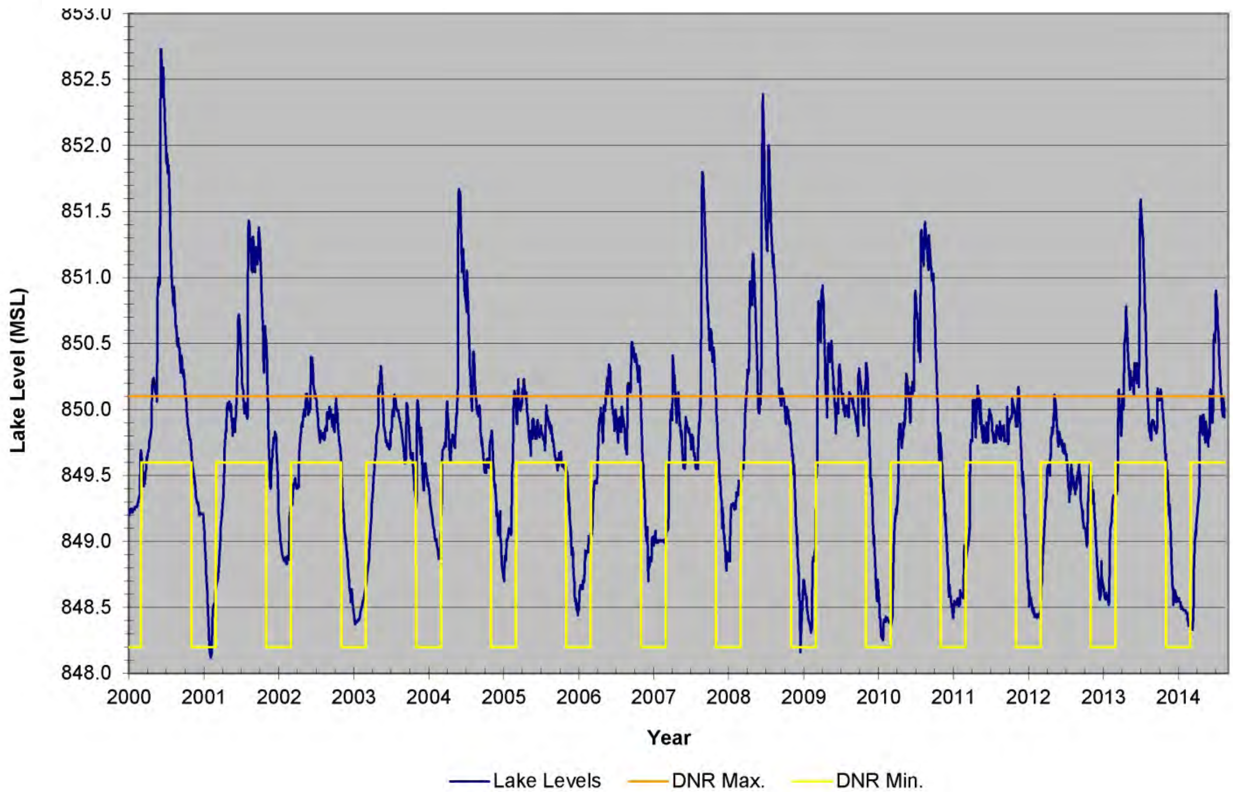
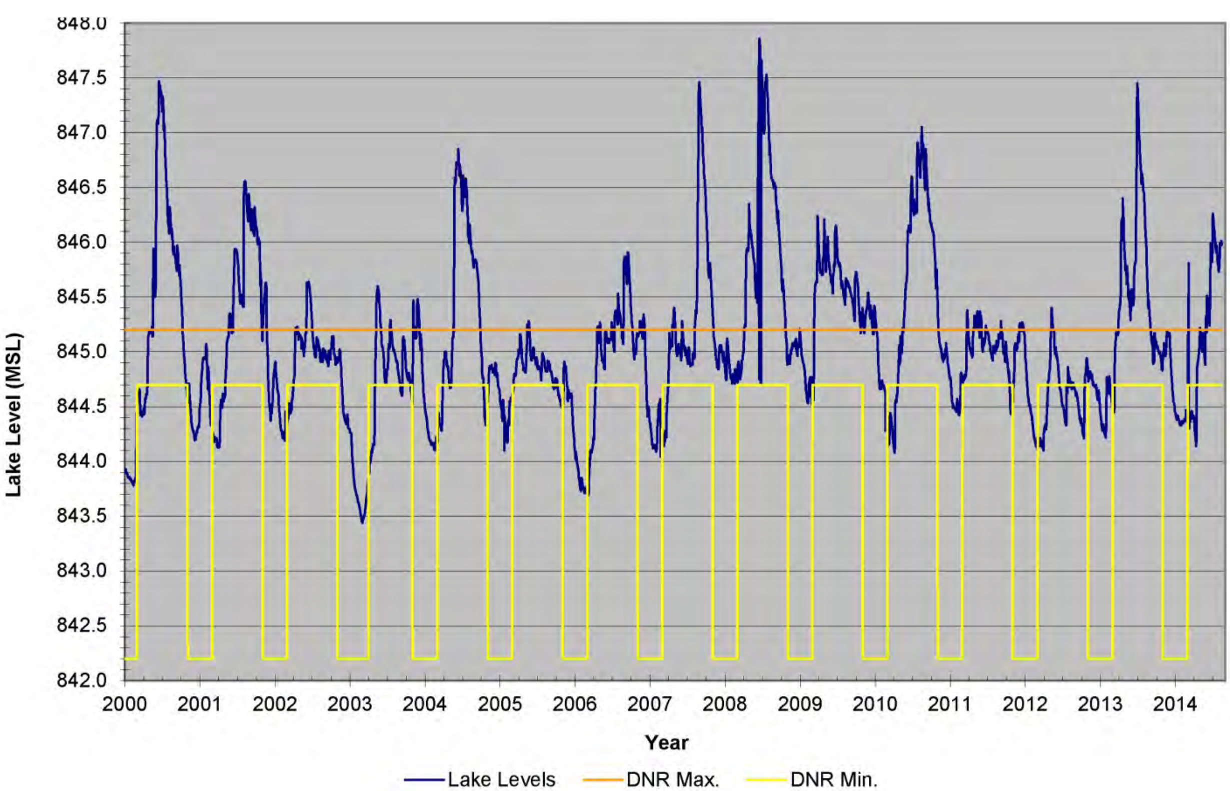


Figure 17b. Historic Lake Monona Levels and Regulatory Limits



While arguably this could result in some recreational inconvenience to riparian landowners and some boaters, note that a considerable amount of water is *already* being taken out of the lakes and will continue in the future. Taking somewhat more water out of the lakes than otherwise to help protect vulnerable streams during exceptionally stressful drought conditions may be a reasonable trade-off. Overall, every gallon of drinking water taken from the Yahara lakes (and replenished by captured surface water discharge) is another gallon available to area streams that rely more heavily on groundwater discharge.

Because of the relatively constant withdrawal and daily operation of the lake levels, this water could be captured and accounted for on a daily basis with the resultant lake levels controlled as usual to remain within prescribed limits (to the extent currently). Less water could be released downstream as runoff and more water could be used to supply our drinking water needs. This could reduce the impact on more sensitive tributary streams considerably. It is also conceivable that highly treated wastewater could at some point in the future be returned to the Yahara Lakes system – thereby "closing the loop" on a more sustainable, long-term public water supply/wastewater treatment system overall.

While obviously this is a simple analysis involving an otherwise very complicated system, there are some opportunities that should be explored in greater detail. The benefit would be mitigating water table declines and reductions in stream baseflow by drawing more surface water (storage) from the Yahara Lakes – a more resilient and renewable resource. Area trout streams such as Token Creek, Sugar River, and Black Earth Creek would be better protected from well water withdrawals. A strategy focused on capturing and storing more stormwater for domestic water supplies appears to be more sustainable over the long term – rather than simply releasing this excess water downstream. In other words, we would be shifting our drinking water source from stream baseflow (i.e., groundwater discharge) to surface water runoff (i.e., lake storage), a much less critical and more renewable water supply. MMSD has also been considering the idea of returning treated wastewater to the Yahara Lakes system to help restore the pre-diversion balance – another opportunity to make more efficient use of our limited water supplies.

The possible benefits from these alternatives should be modeled through a collaborative effort using a sophisticated Yahara Lakes (INFOS) model developed by the City of Madison and the University of Wisconsin, integrated with the Dane County groundwater model developed by the WGNHS, along with fish response curves developed by the WDNR. The alternative scenarios and results should also be vetted by the Yahara Lakes Advisory Group, an ad hoc panel of local experts seeking to balance the multiple (and sometimes conflicting) goals and objectives among the lakes' many user groups. This is a community decision-making process that needs to be facilitated through more detailed water supply planning at both the local and regional levels. The fundamental consideration is, of course, what is the optimal cost/benefit among these various alternatives to meet agreed upon community and natural resource goals and objectives that best serve us in the future. It seems that under the current water supply paradigm the health of our streams was not taken into full account, largely because the impacts could not be adequately discerned. There have been significant advancements in research and technologies over the last couple of decades and an analysis of the existing approach may indicate that it is not serving us as well as an expanded one might. We need to take a broader view than we have done in the past, and explore the full range of technologies and resources available to us in providing a more sustainable water supply system over the long term.

Relative Feasibility of Management Strategies

A preliminary feasibility ranking of all of the aforementioned management strategies is presented in **Table 13.**

The overall feasibility of each strategy is based on three judgment factors: technical feasibility, relative cost, and public/private acceptability. Relative effectiveness of mitigating future impacts is also indicated. Selected management approaches (e.g., water conservation and infiltration practices) already have been carried out to some extent in Dane County. Thus these approaches commonly have a higher ranking than other strategies (e.g., importation of water and deep aquifer withdrawals) that are either expensive and have not been demonstrated or are considered to be more speculative. More detailed regional water supply planning will be needed to develop the least cost mix of alternatives in cooperation/collaboration among municipal water utilities, MMSD, citizens, state and local resource management agencies (CARPC, WGNHS, USGS, U.W. Madison, WDNR) guided by the information and tools described in this plan.

Table 13
Relative Feasibility of Hydrologic Management Strategies

Management Strategy	Technical Feasibility	Relative Cost	Public/Private Acceptability	Overall Feasibility Ranking
Aggressive Water Conservation Efforts	High	Low	High	High*
Aggressive Pursuit of Water Infiltration Practices	High	Low-Moderate	High	High*
Alternative Well Location and Pumping Strategies	Moderate-High	Moderate- High	High	Moderate
Management of the Yahara Lakes as Multipurpose Reservoirs (16 mgd)	Low-Moderate	Low- High**	Low-Moderate	Moderate
Treated Effluent Return and Wastewater Reuse (4-8 mgd)	Low-Moderate	High	Low-Moderate	Moderate
Importation of Water and Deep Aquifer Withdrawals	Low-Moderate	High	Low	Low

*Limited effectiveness in mitigating well water withdrawals

**Cost is largely based on the infrastructure and flow conveyance improvements that might be needed to implement the desired management program

Local Groundwater Quantity Management

The water budget analysis above demonstrates that groundwater supplies are showing signs of stress. The result of this is that groundwater levels are dropping and a huge cone of depression has formed under the Madison Metropolitan Area. Smaller streams are similarly affected. The cone induces water to flow toward its center, drawing water from neighboring areas. In some areas the problem has become particularly chronic. This situation is expected to become worse as the population expands and demand for water increases. It is therefore necessary to anticipate and evaluate these impacts and to institute measures to minimize and possibly reverse them. The Dane County groundwater model and the groundwater budget indices, featured here, along with the WDNR Fish Response Curves and Yahara Lakes INFOS model, also mentioned, provide important tools and methodology for evaluating alternative future development scenarios and mitigation strategies for the region.

The impacts of pumping on surface water baseflows are widespread in Dane County. As demonstrated, drawdown is simply not the best indicator of groundwater impact. Better indicators are those that correlate well withdrawals with baseflow reductions in specific watersheds (BRI), as well as ratios of demand to supply (DSR), presented earlier. Using the groundwater model, it is possible to analyze different development scenarios featuring various combinations of shallow vs. deep aquifer withdrawals, enhanced recharge, reductions in water use, additional lake storage, etc., providing added insight into minimizing surface water impacts through alternative mitigation strategies. In addition, the WDNR Fish Response Curves could indicate how fish communities and stream health might respond to reductions (or increases) in stream baseflow. Furthermore, the Yahara Lakes INFOs model could simulate the effects on lake levels, using them as water reservoirs.

The overall focus should be on reducing demand as well as increasing supplies of available water. Water conservation and reuse, maximizing recharge with stormwater and conservation design techniques all show promise. In the Madison Metropolitan Area, the Yahara Lakes represent a renewable source of water. More importantly, they are much more resilient than smaller surrounding stream systems. In addition, the glacial sediments currently provide exceptional sand and gravel filtration system for our drinking water supplies. Concentrating pumping closer to the lakes along with proposed MMSD treated effluent return could help reverse the impacts of pumping and diversion, thereby resulting in a more sustainable condition overall. Current lake level management strategies could also help account for this relatively constant demand through current (daily) operational procedures by capturing and using more stormwater runoff. The paradigm shift here is using water and wastewater more efficiently – as a valuable resource that should not be squandered.

We are already drawing from the lakes indirectly. Often there is *too* much water, which must be passed downstream (often during the summer months when the demand is greatest). This represents a lost opportunity for drawing on lake water when it is in excess. Likewise, in the winter it is usually difficult getting the lake levels down to established winter minimums in anticipation of spring flooding and to avoid ice damage. During droughts it is believed the daily reduction in lake levels would be relatively small (particularly since we are already drawing from the lakes through induced recharge without significant or apparent effect). Some flexibility on the part of riparian landowners may be needed during extreme conditions (both flooding and droughts), as is the current situation. It may be a matter of widening the lake level limits to allow for more regulatory flexibility within the existing seasonal variability. The current six inch difference between the required summer minimum and maximum lake level limits for each the four Yahara Lakes (compared to the 4 foot seasonal range) has been described by a retired County Public Works Director as "walking a tightrope." The WDNR acknowledges that the current lake level limits may not be the best from an environmental standpoint. Setting somewhat higher stage limits in the spring or lower in the fall could more easily accommodate restoring prediversion low-flow conditions in the Yahara River system.

So, there appears to be significant prospects for addressing these water supply and demand problems by managing the lakes as multi-purpose reservoirs. Overall, a combination of techniques, cooperation, and flexibility among local units of government and residents will be necessary to meet the growing challenge if we are to maintain both the availability of our drinking water supplies and the viability and health of our more sensitive aquatic resources.

To date, there has been no serious attempt at regional management of groundwater supplies in Dane County. Individual communities have utilized the region's aquifers without coordination. The result has been problems where surface water bodies have been adversely impacted by heavy groundwater use. In other areas of the state, notably southeast Wisconsin and the Fox River Valley, this has lead to designation of these areas as Groundwater Management Areas (GMAs) by the Wisconsin Department of Natural Resources, a designation that requires development of a plan to mitigate the problems. Dane County has been identified as a Groundwater Attention Area (GAA). These are areas which are currently experiencing groundwater challenges or are likely to experience groundwater problems in the future. It serves as warning that a coordinated management plan is needed to prevent further drawdown.

Proactive management and intervention are necessary as critical components of an effective groundwater management policy overall. The indices and modeling presented earlier provide useful methodology to help quantify the relative effectiveness of various strategies and alternatives to address these challenges and meet these problems head on. Since our ground and surface waters do not recognize jurisdictional boundaries, these problems can only be successfully addressed through a cooperative and collaborative approach among units of local government, private businesses, and citizens working together towards mutually agreed-upon goals, objectives, and individual actions. In this regard, the CARPC should continue to promote regional water supply planning and provide ongoing assistance in collaboration with the WDNR, water and wastewater utilities, and local units of government. This effort would provide for regional water supply plan development, preparation of water supply service areas, and review and comment on local water supply service and facility plans as provided under Wis. Stats. 281.348.

Recommendations

Short term

- Implement comprehensive water conservation programs, including both supply-side water supply efficiency measures and demand-side water conservation measures.

- Implement stormwater management practices, including treatment and infiltration systems, which would maintain the natural recharge characteristics of proposed development and – to the extent practicable – redevelopment where circumstances and opportunity permit.

- Conduct locally proactive and preliminary analysis of all planned high capacity wells in the early stages of well siting to develop the necessary understanding of the hydrogeological conditions associated with each candidate site and the surrounding area and to assess the likelihood and minimize the impacts on nearby wells and surface water bodies.

Long-term

- Enhance rainfall infiltration systems to help mitigate the effects of high capacity municipal well water withdrawals; balanced with the need to avoid groundwater induced flooding.

- Investigate the feasibility of infiltrating treated wastewater into the shallow aquifer to supplement localized recharge of the shallow groundwater system.

- Delineate groundwater recharge areas to indicate that a high degree of protection and use of the best groundwater recharge areas in the region are needed to meet sustainability goals.

- While it is recognized that siting wells is dependent upon locating productive areas, some additional factors should be considered when siting wells. Preference should be given to site locations that are less likely to produce adverse impacts upon surface waterbodies and existing wells. In addition, preference should be given to sites located adjacent to the Yahara Lakes Mendota and Monona. This application of induced filtration has the potential to increase available water supplies without degrading the environment by drawing more water from surface water runoff (i.e., lake storage) typically released downstream.

- Consider the prospects of returning treated effluent to the Yahara Lakes system as part of an overall more sustainable or "closed loop" drinking water/reclaimed water system.

- Promote gray water systems and reclaimed water reuse.

Chapter 4: Groundwater Quality Protection

Groundwater Quality Overview

The groundwater in Dane County is generally of good quality and uniform in composition within all aquifers.[1] Calcium, magnesium and bicarbonate are the principal constituents of groundwater, relatively high in concentration and responsible for the very hard water here. Other groundwater constituents commonly found in lower concentrations are iron, manganese, sodium, sulfate, chloride and nitrate. Although good groundwater quality generally exists in the region, it has been affected by certain land use activities in Dane County. The known groundwater quality problems in Dane County have largely resulted from nitrates and bacteria, pesticides, chlorides, and volatile organic chemicals (VOCs). High levels of nitrate are present in many areas of the county's shallow groundwater system. Nitrate-nitrogen contamination (above the recommended drinking water standard) has been found in numerous private and non-community wells throughout Dane County. This is believed to be the result of extensive agricultural fertilization practices conducted in the region. Pesticides (primarily atrazine) are more prevalent in shallow private wells, while VOCs have been detected in both private and municipal wells. Common VOCs that have been found are trichloroethylene and tetrachloroethylene. These hazardous chemicals, derived from household and industrial solvents, result from disposal in landfills, leaking underground storage tanks, or simply being dumped on the ground.

High priority should be given to safeguarding existing groundwater quality from further degradation. The introduction of even small amounts of some chemicals can have a significant detrimental effect on groundwater quality. Because of the slow movement of groundwater, chemical contamination often does not become apparent for many years and then only after large amounts of contaminants have been introduced. Also, unlike surface water, little mixing occurs in groundwater; thus dilution of chemical contaminants is often slow or insignificant. Due to this poor dilution and breakdown capacity, introduced chemicals can create groundwater quality problems for many years into the future and should be avoided whenever possible.

Nitrates

Nitrate (NO3) is a compound made up of nitrogen and oxygen. It is formed when nitrogen from ammonia or other sources combines with oxygen in water. In nature, water usually contains less than 2 mg/L nitrate-nitrogen and is not considered a health concern. Significantly higher nitrate concentrations can indicate that the drinking water has been contaminated and may pose a serious health concern. In 2014 the WDNR and the Wisconsin Department of Agriculture, Trade and Consumer Protection (WDATCP) reported that nitrate-nitrogen (NO_3-N) is the most widespread groundwater contaminant in Wisconsin, and that the nitrate problem is increasing both in extent and severity.[2] Common sources of nitrate include nitrogen fertilizers, manure, septic systems, municipal sewage treatment systems, and decaying plant material. Nitrate dissolves easily in water and does not adsorb to soil particles. It can easily be carried into the groundwater by rainwater and melting snow as it percolates through the soil and bedrock into the underlying aquifer.

Nitrates in Wisconsin

The maximum contaminant level (MCL), set by USEPA, is the level of a contaminant at which no known or anticipated adverse effects on the health of persons occur and which allows an adequate margin of safety. The MCL for nitrate-nitrogen is 10 mg/L – the same as Wisconsin's enforcement standard (ES). In Wisconsin a

[1] Born, S., et al. 1987. *A Guide to Groundwater Quality Planning and Management for Local Governments.*
[2] Wisconsin Groundwater Coordinating Council., 2014. *Fiscal Year 2014 Report to the Legislature.*

preventive action limit (PAL) of 2 mg/L has also been established to serve as an indicator of potential groundwater contamination problems. Public water supplies, transient and non-transient noncommunity wells monitor for nitrate and must meet the ES. Private water supplies are largely unregulated.

Human health is the primary reason high levels of nitrate in drinking water are of concern. Nitrate can cause a condition called methemoglobinemia or "blue-baby syndrome" in infants under six months of age. Nitrate in water used to make baby formula converts to nitrite in the child's stomach and changes the hemoglobin in blood to methemoglobin. The infant's body is then deprived of oxygen and appears blue-gray or lavender in color. In extreme cases, methemoglobinemia can be fatal; the long-term effects of lower-level oxygen deprivation are unknown. The Wisconsin Department of Health Services (DHS) has investigated several cases suspected blue-baby syndrome in Wisconsin and associated at least three with nitrate contaminated drinking water. Some scientific studies have also found evidence suggesting that women who drink nitrate contaminated water during pregnancy are more likely to have babies with birth defects. This may be because nitrate ingested by the mother may also lower the amount of oxygen available to the fetus.

Concerns are also being raised regarding the effect of nitrate on thyroid function, diabetes, and cancer. Nitrate converts to nitrite in the human body and can then convert into N-nitroso compounds (NOC's). NOC's are some of the strongest known carcinogens and have been found to induce cancer in a variety of organs. As a result, additional human health concerns linked to nitrate contaminated drinking water include increased risk of: non-Hodgkin's lymphoma (Ward et al., 1996); gastric cancer (Xu et al., 1992; Yang et al., 1998), and bladder and ovarian cancer in older women (Weyer et al., 2001). There is also growing evidence of a correlation between nitrate and diabetes in children (Parslow et al., 1997; Moltchanova et al., 2004).[3]

Wells contaminated with high nitrate levels are also more likely to be contaminated with agricultural pesticides. Evidence suggests that common pesticides (Aldicarb and Atrazine) interacting with nitrate can affect the immune, endocrine, and nervous systems (Porter 1999). People who have heart or lung disease, certain inherited enzyme defects, or cancer may be more sensitive to the toxic effects of nitrate than healthy individuals. Owners of wells contaminated with nitrate may also wish to have their water tested for pesticides, especially if the well is located near farm fields.

In addition to the effects of elevated nitrate concentration on human health, a number of studies have shown that nitrate can have lethal and sublethal effects on a variety of species of fishes, amphibians, and aquatic invertebrates (Crunkilton et al. 2000; Camargo et al. 1995; Marco et al. 1999; Smith et al. 2005; McGurk et al. 2006; Stelzer et al. 2010). This is significant in that many baseflow-dominated streams in agricultural watersheds can exhibit elevated nitrate concentrations, with levels in some Wisconsin streams at times exceeding 30 mg/L NO3-N. In Wisconsin, exposure of animals to potentially lethal nitrate concentrations would be most likely to occur in springs and in groundwater-fed low-order streams in agricultural or urban areas, and in nitrate-rich water bodies on farms such as ditches and ponds.

Nitrate also contributes to the eutrophication of streams and lakes and associated occurrence of water-quality issues such as harmful algal blooms. This is a particular concern in Dane County where there is a high degree of connectivity between ground and surface waters. In addition, between the late 1960s and the early 1980s, nitrate levels in waters flowing into the Gulf of Mexico more than doubled, causing a "dead zone" that in 1999 was approximately the size of the state of New Jersey.

The current drinking water limit of 10 mg/L for nitrate-nitrogen addresses only methemoglobinemia; the concentration at which these other risks occur is unknown. More research is needed in these other areas. To ensure protection of health, people of all ages are encouraged to drink water that meets the safe drinking water standard for nitrate of 10 mg/L. Common solutions include drilling a new, non-contaminated well or the removal of excess nitrate through water treatment processes. A 2012 survey of Wisconsin municipal systems found that 47 systems have had raw water samples that exceeded the nitrate ES (up from just 14

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[3] Wisconsin Groundwater Coordinating Council., 2014. *Fiscal Year 2014 Report to the Legislature*.

systems in 1999). This survey also showed that respondents had collectively spent over $32.5 million on remedies, up from $24 million as of 2004 and that 74 systems are experiencing increasing nitrate levels. Excessive nitrate levels have also forced the installation of treatment systems or the replacement of wells at hundreds of other smaller public drinking water systems.

About one third of Wisconsin families obtains water from privately owned wells and hence are at risk of excessive nitrate exposure. A 2008-9 DHS survey determined that one-third of private well owners have also never had their water tested for nitrate. The most common reasons cited by well owners who had not tested their water was that their water "tasted and looked fine." Thirteen percent listed cost as a reason for not testing their water.

Owners of nitrate-contaminated private wells do not qualify for state well compensation funding unless the nitrate-N level in their well exceeds 40 mg/L and the water is used for livestock. In order to establish a safe water supply, they may opt to replace an existing well with a deeper, better cased well or to connect to a nearby public water supply. Alternatively, they may choose to install a water treatment system or use bottled water. A study published in 1999 by DHS examined this issue. Their survey of 1,500 families found that few took any action to reduce nitrate exposure. Of those who did, most purchased bottled water for use by an infant or pregnant woman.

DATCP (2007) and DNR (2005, 2007) surveys and meta-analysis of state databases indicate 9 to 11% of private wells statewide exceeded the nitrate enforcement standard (ES) of 10 mg/L. Exceedance rates are greater in agricultural districts, with rates in highly cultivated areas in south-central Wisconsin estimated at 21 percent of wells. **Map 26** shows the prevalence of nitrate samples exceeding the health standard around in the state.

In Dane County, over 3,000 private well samples have been collected between 1994 and 2011 (**Table 14 and Map 27**):[4]

- 18% of the private wells tested exceeded the drinking water standard of 10 mg/L.
- 52% of the wells tested contained between 2 mg/L and 10 mg/L, indicating land use has likely affected groundwater quality.
- 30% of the wells tested below the preventive action limit of 2 mg/L.

While only about 27% of the over 12,000 private water wells in Dane County have had nitrate testing data entered into the WDNR database, the percentage of private wells with high nitrate has remained relatively consistent during the past decade **(Figure 18a**). The report *Private Onsite Wastewater Treatment Systems Management* (CARPC 2013) includes maps of this data for each town in Dane County. The well data is located on a quarter-quarter section basis. Where multiple test results fall within the same range (i.e., greater than the Enforcement Standard, between the Enforcement Standard and the Preventive Action Limit, and below the Preventive Action Limit) a single symbol may represent multiple test results. This is often the case within rural subdivisions.

By comparison, deeper municipal wells are found to be generally below 5 mg/L (**Map 28a**). The 2010 cones of depression resulting from high capacity well water withdrawals in the region (also mapped) do not appear to be affecting nitrate concentrations as much as the effects of individual well design/casing/depth and local contributing sources.

[4] Capital Area Regional Planning Commission. 2013. *Private On-Site Wastewater Treatment Systems* Management report. Technical Appendix I of the *Dane County Water Quality Summary Plan.*

Map 26

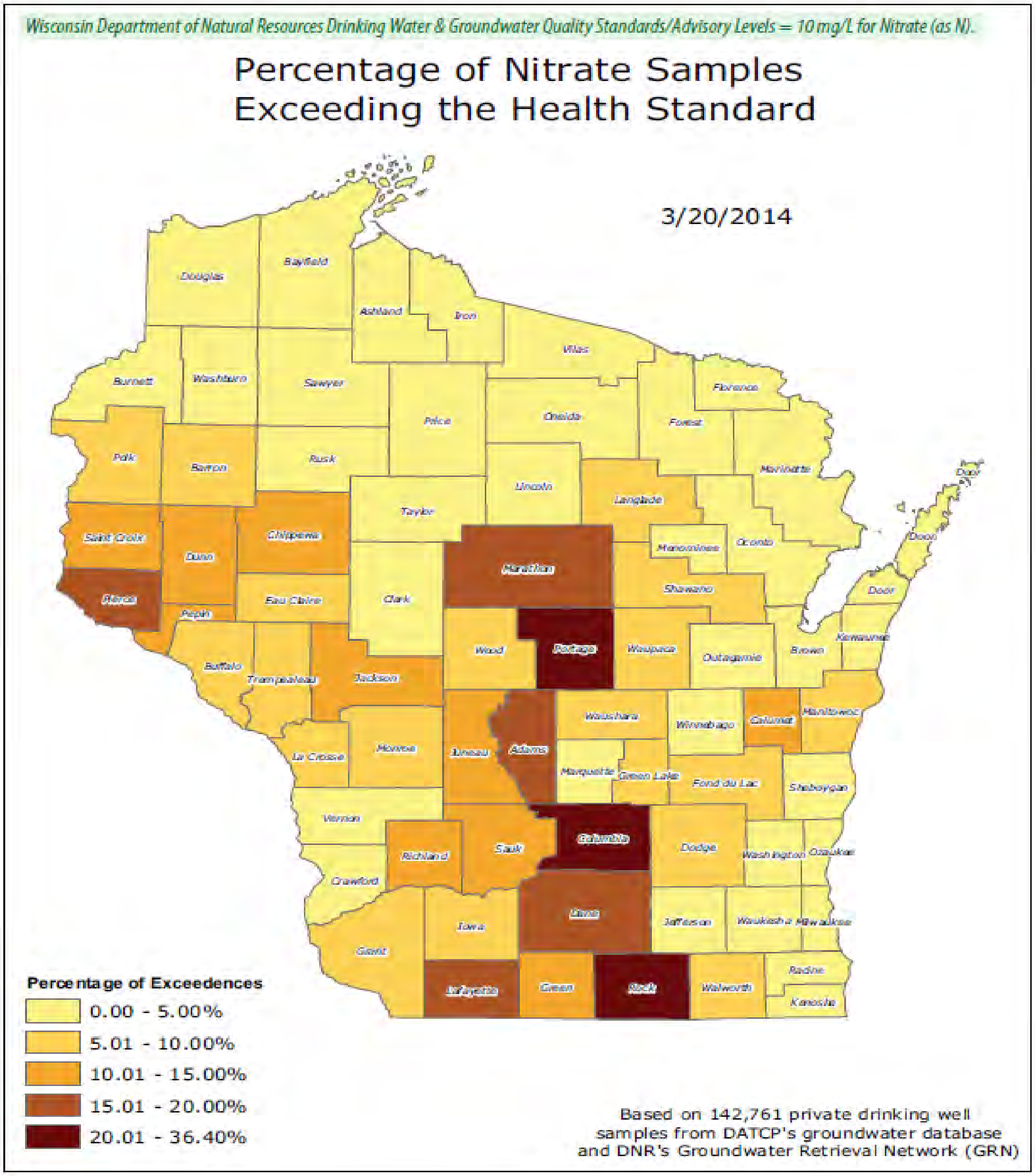

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Table 14. Private Water Well Nitrate Testing WDNR Groundwater Retrieval Network (1994-2011[1])					
Municipality	**# Tests at Unique Well Locations[2]**	**Estimated % of Total Wells Tested**	**Nitrate Test Results**		
			> 10 mg/L	2 - 10 mg/L	<2 mg/L
Albion	62	10%	31%	32%	37%
Berry	86	18%	6%	50%	44%
Black Earth	44	21%	2%	41%	57%
Blooming Grove	9	2%	44%	56%	0%
Blue Mounds	62	19%	16%	58%	26%
Bristol	228	18%	15%	61%	24%
Burke	138	12%	41%	54%	5%
Christiana	75	15%	29%	36%	35%
Cottage Grove	121	8%	22%	28%	50%
Cross Plains	98	17%	13%	61%	26%
Dane	42	11%	33%	60%	7%
Deerfield	62	11%	23%	31%	47%
Dunkirk	57	7%	32%	21%	47%
Dunn	136	20%	15%	30%	54%
Fitchburg	42	5%	31%	62%	7%
Madison	8	14%	0%	88%	13%
Mazomanie	78	16%	6%	38%	55%
Medina	50	10%	18%	42%	40%
Middleton	468	23%	19%	67%	14%
Montrose	56	13%	7%	54%	39%
Oregon	137	12%	18%	65%	18%
Perry	46	16%	13%	78%	9%
Pleasant Springs	161	19%	29%	34%	38%
Primrose	47	17%	9%	49%	43%
Roxbury	73	13%	4%	44%	52%
Rutland	101	13%	9%	49%	43%
Springdale	152	21%	11%	74%	15%
Springfield	102	10%	10%	52%	38%
Sun Prairie	106	13%	32%	52%	16%
Vermont	48	15%	2%	35%	63%
Verona	82	12%	6%	55%	39%
Vienna	70	17%	11%	43%	46%
Westport	86	21%	10%	58%	31%
Windsor	80	9%	50%	39%	11%
York	27	10%	0%	52%	48%
County-wide	***3,240***	***14%***	***18%***	***52%***	***30%***

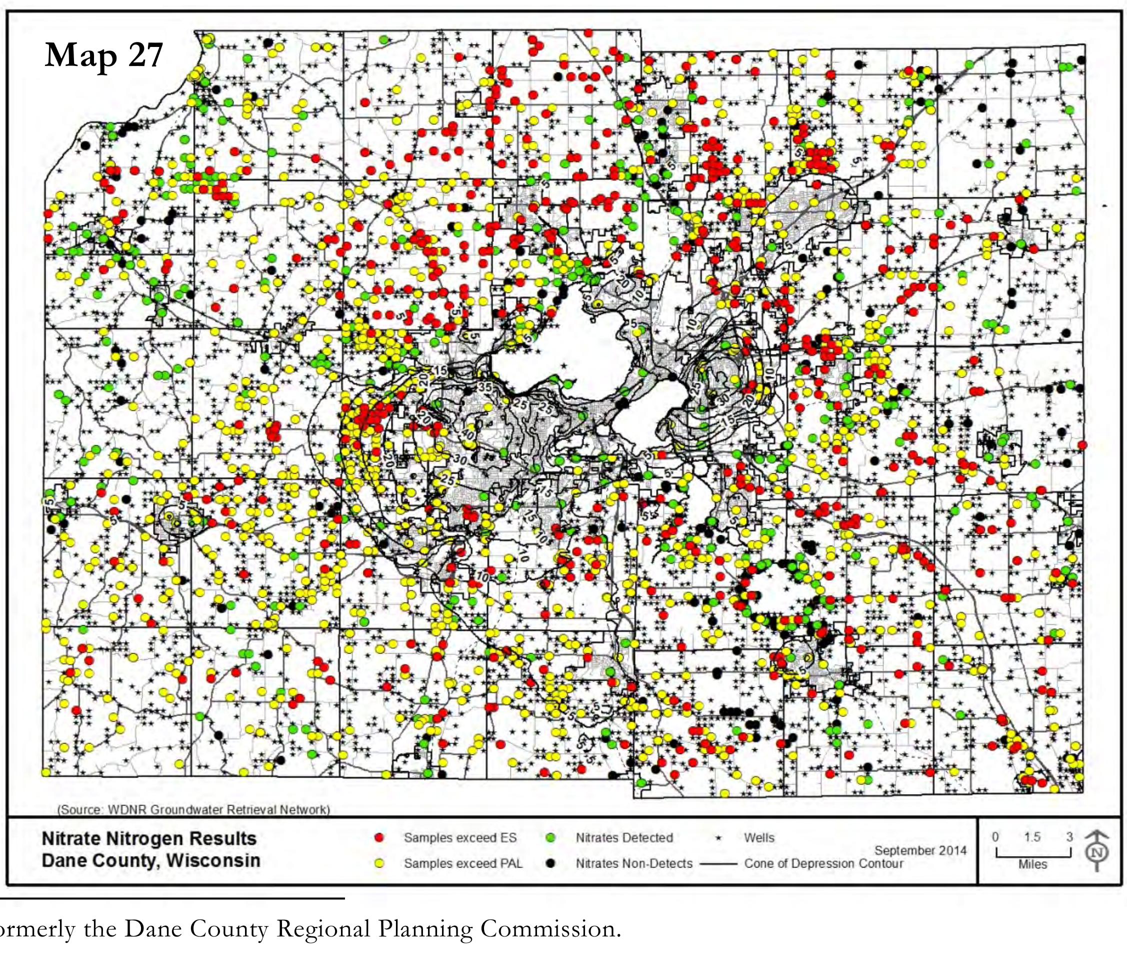
[1] 91% of the data is from tests dated 1999 to 2008.

[2] The unique well locations included in this table represent over 95% of all test data with the database, indicating very little repeat testing.

Source: Capital Area Regional Planning Commission, 2013

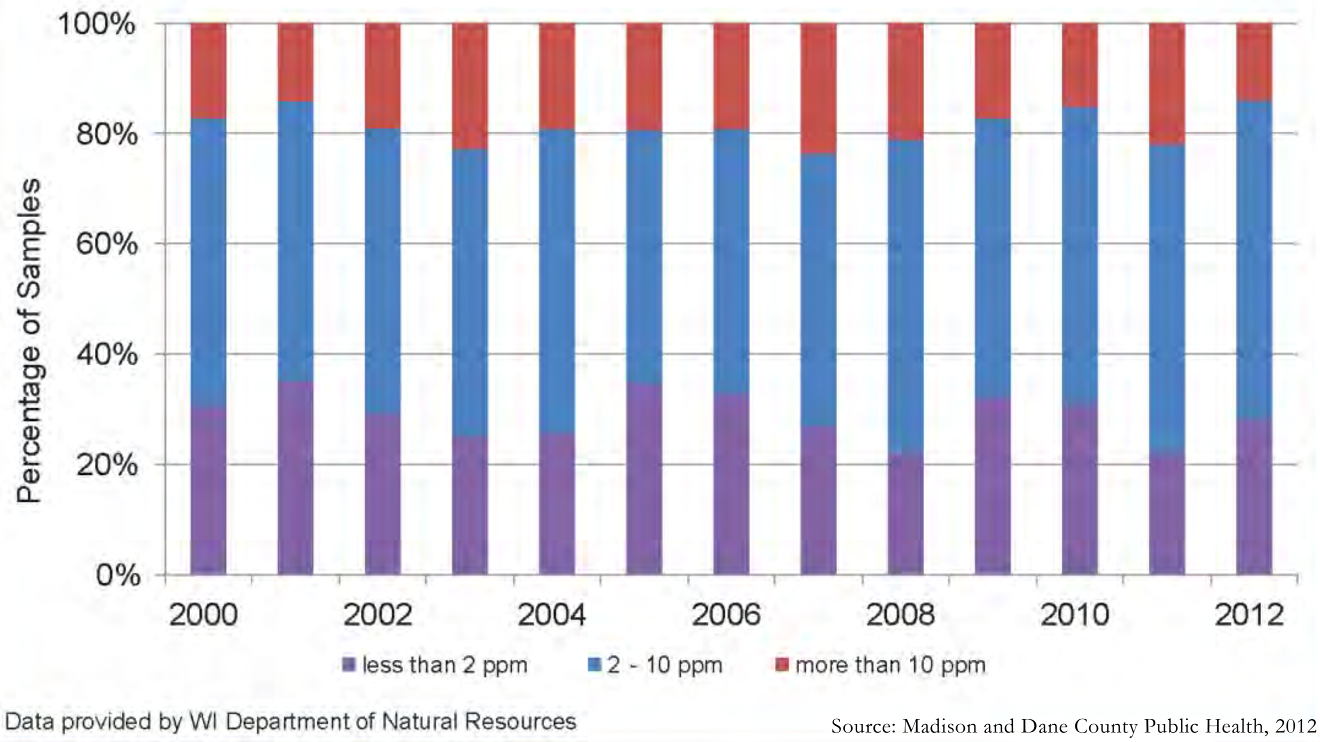
Dubrovsky (2010) states that nitrate concentrations are likely to increase in aquifers used for drinking water supplies during the next decade, or longer, as shallow groundwater with higher concentrations moves downward into the groundwater system. While nitrate concentrations exceeding regulatory standards are less prevalent in municipal drinking water samples in Dane County (because the wells are deeper than private wells), there has been an apparent increase in samples that have exceeded the 10 mg/L over the last few years (**Figure 11b**). Of the nearly 3,000 samples that have been tested for nitrate over the past decade (2000-2012), approximately 5 percent were found with concentrations greater than 10 mg/L. The remaining samples were within acceptable levels – approximately 42 percent had levels between 2 to 10 mg/L, while the remainder (approximately 53 percent) was below 2 mg/L. Since 2007 there have been notable increases in the annual percentage of samples with concentrations of nitrate greater than 10 mg/L and decreases in the percentage of samples lower than 2 mg/L, compared to the 2000-2006 time period. This is likely the result of historic nitrate levels migrating deeper into the groundwater system.

In some geologic settings improvements in nutrient management practices on the land surface can take years to decades to result in lower nutrient concentrations in groundwater because of the slow rate of groundwater flow. Slight increases in nitrates have been observed in some Municipal wells over the last 20 years (warm colors), along with some decreases (cool colors), **Map 28b.** The Capital Area Regional Planning Commission[5] has conducted a long-term surface water monitoring effort including baseflow water quality (i.e., groundwater discharge) undertaken in representative streams around the county. **Figure 19** shows that the concentration of nitrate in most county streams (representing the shallow aquifer) has seen an increase over the last 50 years. This is attributed to increasing fertilizer usage and livestock density in the county. However, nitrogen levels do appear to be declining recently in some areas, possibly the result of increased agricultural nutrient management planning and practices.



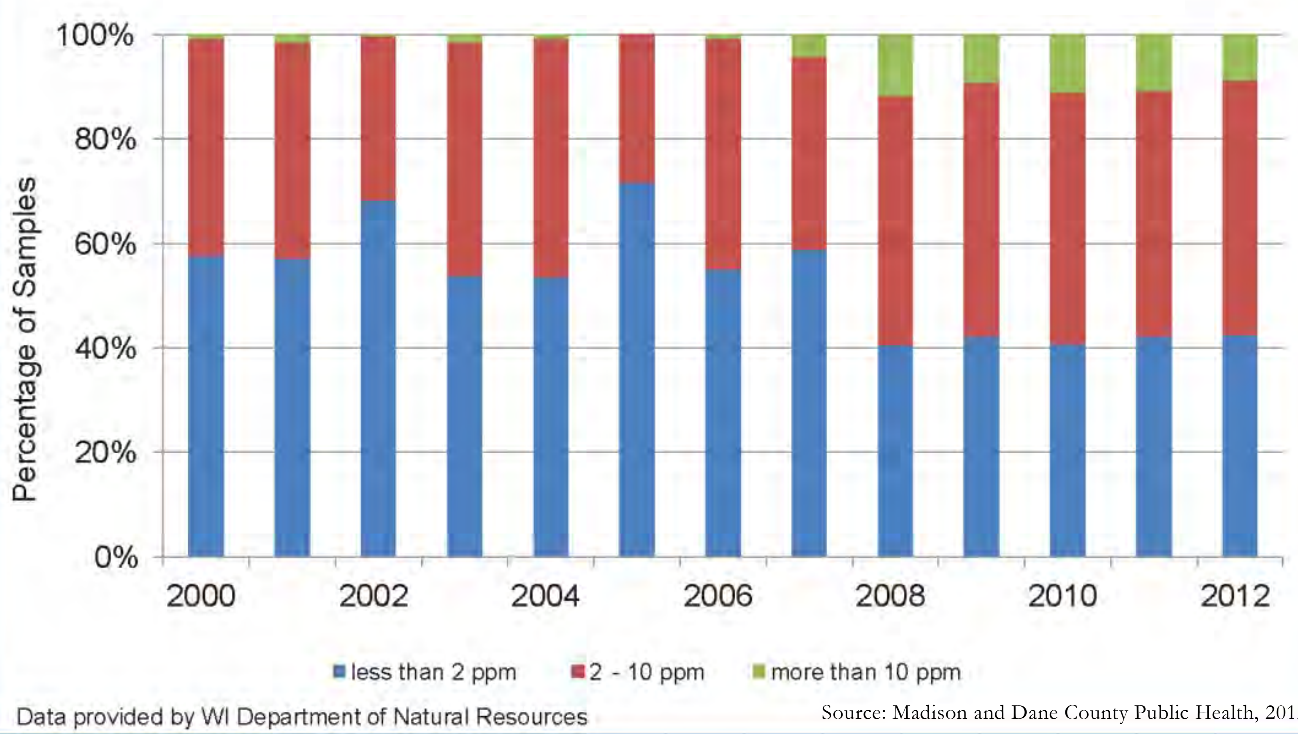
[5] Formerly the Dane County Regional Planning Commission.

Figure 18a. Results of Nitrate Testing in Private Wells, Dane County.

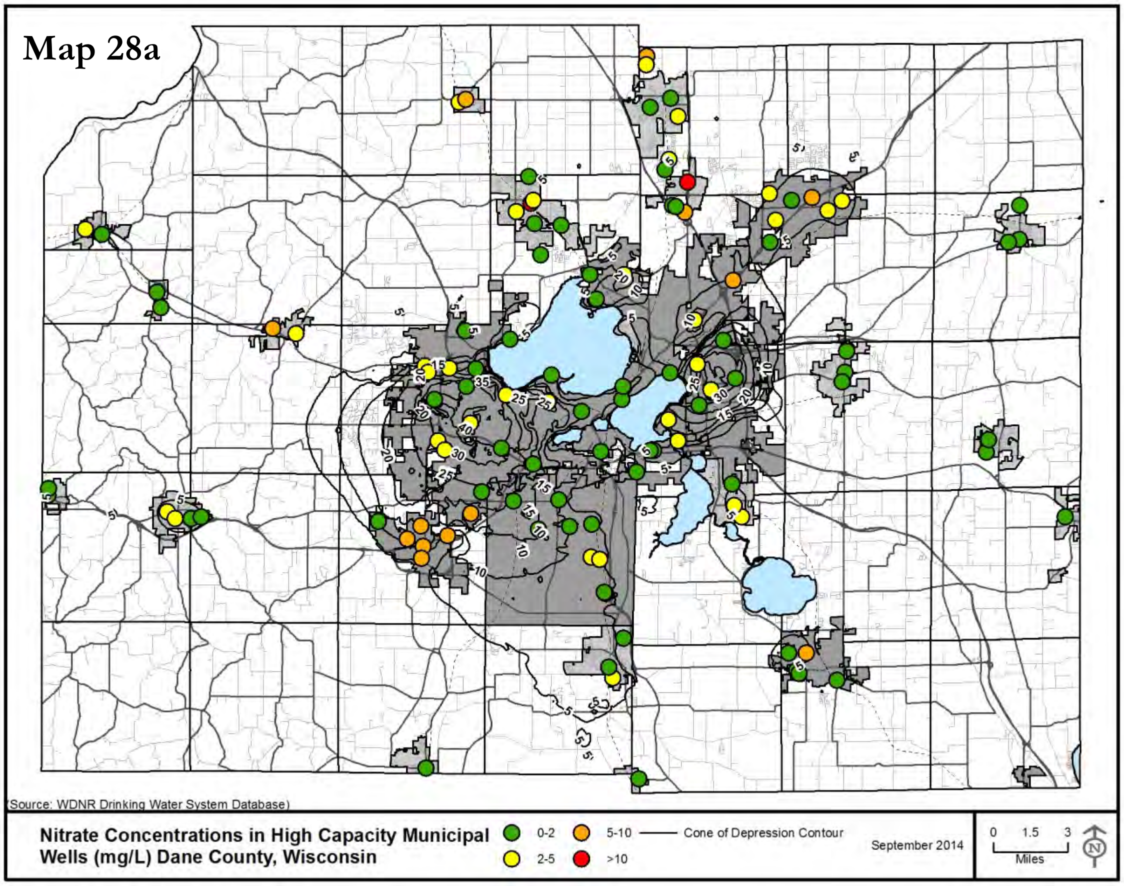


Source: Madison and Dane County Public Health, 2012

Figure 18b. Results of Nitrate Testing in Public Wells, Dane County.



Source: Madison and Dane County Public Health, 2012


Map 28a
(Source: WDNR Drinking Water System Database)
Nitrate Concentrations in High Capacity Municipal Wells (mg/L) Dane County, Wisconsin
0-2
2-5
5-10
>10
Cone of Depression Contour
September 2014
0 1.5 3
Miles

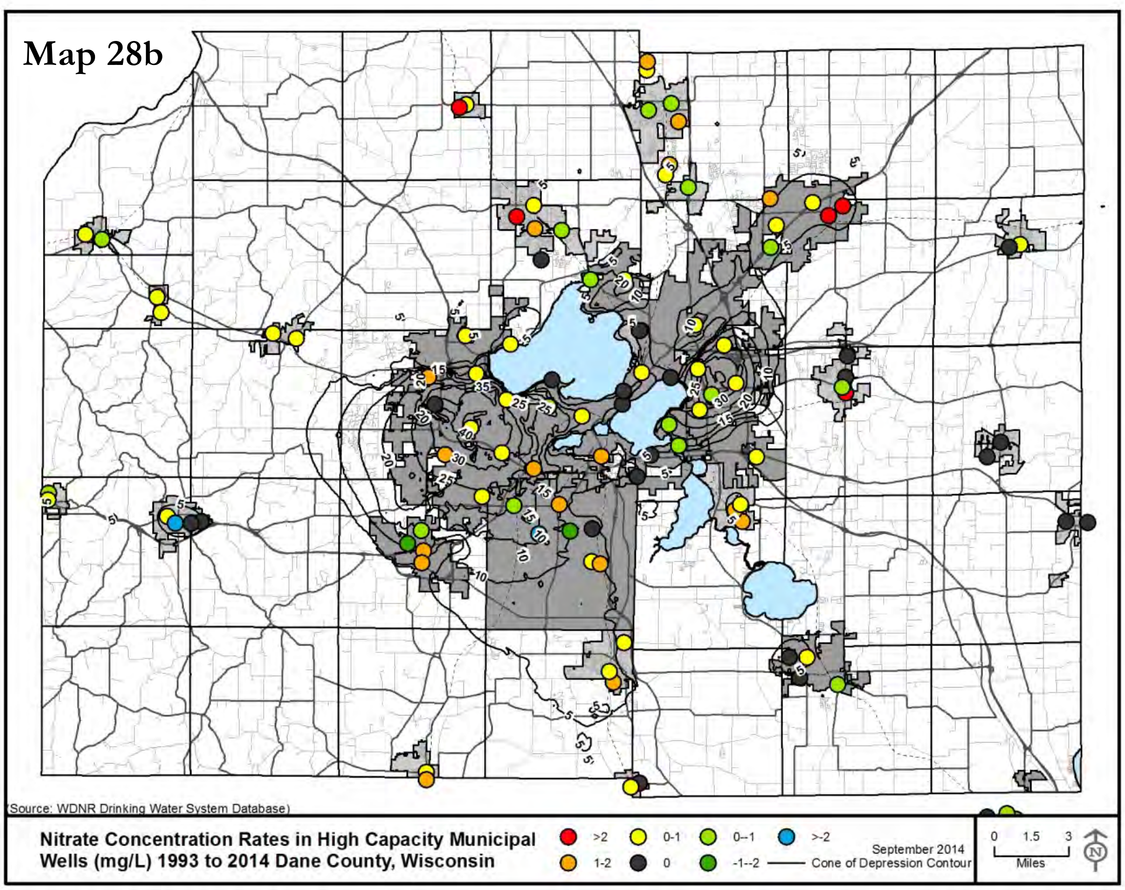
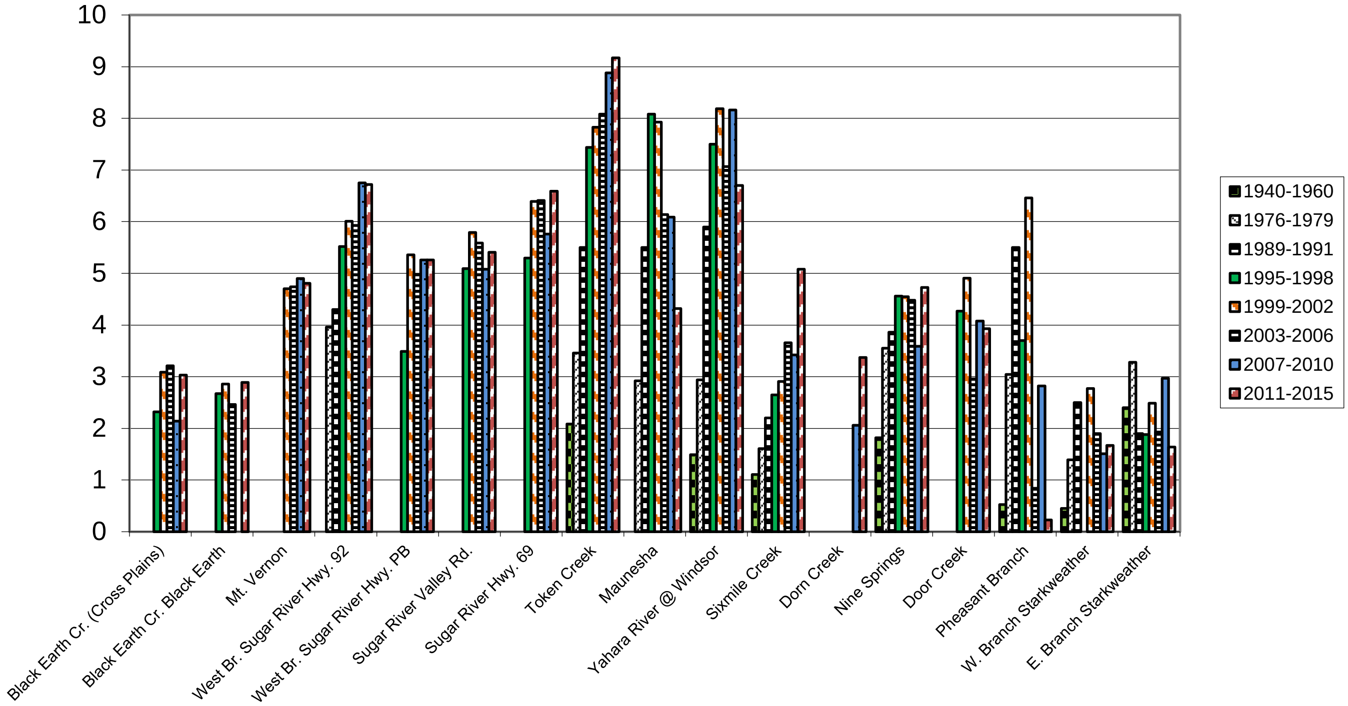

Map 28b
(Source: WDNR Drinking Water System Database)
Nitrate Concentration Rates in High Capacity Municipal Wells (mg/L) 1993 to 2014 Dane County, Wisconsin
>2
1-2
0-1
0
0--1
-1--2
>-2
Cone of Depression Contour
September 2014
0 1.5 3
Miles

Figure 19. Baseflow Nitrate and Nitrite Nitrogen in Representative Dane County Streams (mg/L)



Note: Baseflow results indicate dry weather groundwater contributions and do not include wastewater discharge streams having greater than 15% effluent volume.
Source: CARPC Cooperative Water Resources Monitoring Program and the U.S. Geologic Survey.

Sources of Elevated Nitrate in Dane County

A recent study by area researchers evaluating tens of thousands of nitrate test results in wells across the region have discovered that nitrate levels are improving slightly, attributed to improvements in agricultural nutrient management practices (**Figure 20**.).[6] However, while areas with high nitrate concentrations appear to be decreasing (typically shallow domestic wells), results also indicate that wells with low nitrate concentrations (typically deeper public wells) are increasing. This suggests that the groundwater system is equalizing and that it may take some time for the reductions to become evident in deeper water sources, attributed to slow groundwater movement and an associated lag effect. Also, lower nitrate concentrations were generally observed nearer to major surface water features such as lakes, rivers, and streams and farther from groundwater divides seen in **Figure 21**. This supports the notion that nitrate concentrations and spatial patterns are a reflection of groundwater age. In other words, groundwater discharge to streams is typically older and more diluted in nitrates than more recent groundwater percolating into the ground in upland areas.

Fertilizer Use

Estimates of historical nitrogen loading to shallow groundwater correspond remarkably well with historical nitrogen fertilizer use, evident in **Reference Figure 20**. In contrast, according to the study, areas of intensive residential development do not appear to exert a significant influence on regional nitrate concentrations. This does not imply that septic systems or other sources cannot be significant sources of nitrate to individual wells, but that the background fertilizer use is primarily responsible for high nitrate levels across the area.

Based on past surveys, approximately 25% of the county's tested wells exceeded the state and federal drinking water standard for nitrate of 10 mg/L, which is more than double the statewide exceedance level of 12%. Unfortunately, only about one-third of the county's private wells have ever been tested for nitrate. Since 2014, nitrate testing is now required by state law when a new well is constructed, or when repair or maintenance on a well is conducted. Some reasons for homeowners not testing their well water include: the water looks, tastes, and smells fine, perceptions that water testing is expensive, and fears of declining property values in the event of elevated nitrate levels.

So, while we seem to have turned the corner on historical increases in nitrates levels in the region, reductions in rural drinking water supplies will take time. Public health officials recommend private well owners test their water for nitrates every year or so – especially in households with pregnant women, infants, or young children if there are any changes in taste, color or odor, or if they are located in an intensive agricultural area. The WDNR also publishes brochures[7] on this and other tests for private wells, which are more shallow and vulnerable than deep municipal wells that are tested routinely and more frequently.

[6] McDonald, C,, J. Parsen, R. Lathrop, K Sorsa, K. Bradbury, and M. Kakuska. 2015. *Characterizing the Sources of Elevated Groundwater Nitrate in Dane County, WI.*

[7] http://dnr.wi.gov/topic/DrinkingWater/documents/pubs/TestsForWell.pdf

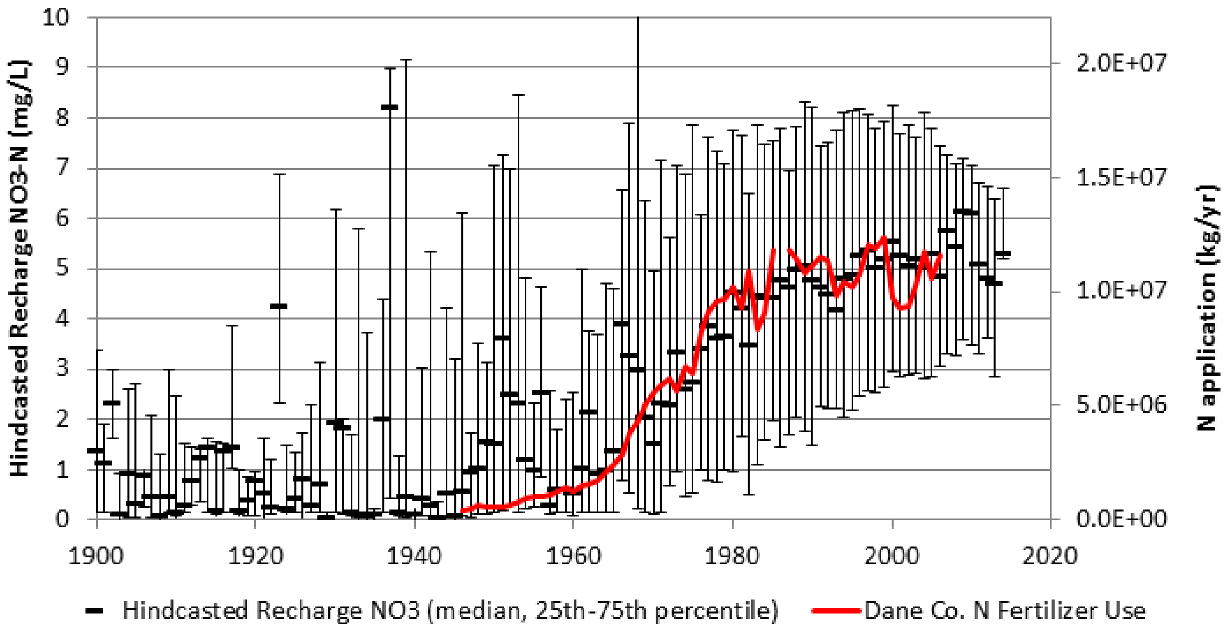


Figure 20. Median recharge nitrate concentrations overlaid with the total application of inorganic nitrogen fertilizer in Dane County.

Source: McDonald, et. al. 2015.

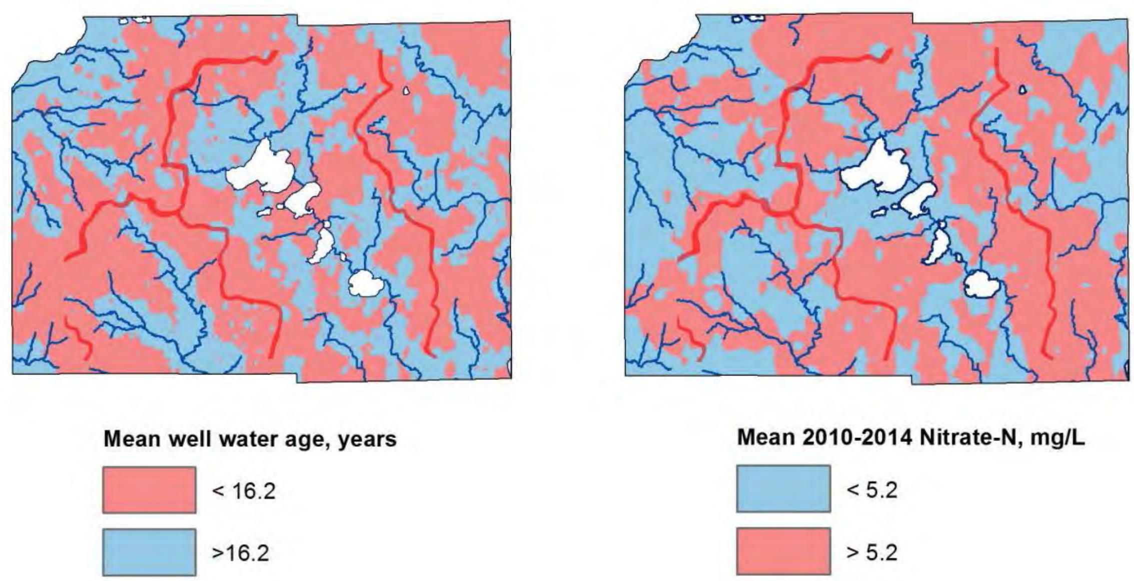


Figure 21. Dichotomous representation of mean modeled well water age (a) and interpolated mean nitrate concentrations for the 2010-2014 period (b). The breakpoints (16.2 years and 5.2 mg/L) are the spatially averaged median values, with the result that each figure is 50% red and 50% blue. The solid red lines indicate major groundwater divides.

Source: McDonald, et. al. 2015.

<u>On-Site Septic Systems</u>

Although not a significant source of nitrates at a regional level, on-site systems can cause increased levels of groundwater nitrate in localized areas if many systems are concentrated in a relatively small area. In such circumstances, the close proximity of systems surpasses the ability of the groundwater to dilute the nitrate concentrations released by the systems.

The limited national and state/local information suggests that it is unlikely that localized groundwater nitrate contamination will be caused by on-site systems at a density lower than one system per two acres, but that there is a greater potential for groundwater contamination where systems exceed a density of one per acre.[8] Based on this information, the following recommendation was included in the 2013 *Private On-Site Wastewater Treatment Systems Management* report, a technical appendix of the *Dane County Water Quality Plan:*

> *Large on-site wastewater systems and clusters of systems should be planned and evaluated to ensure that wells and water supplies can be protected from excessive nitrate levels. The planning of rural subdivisions or developments that include large on-site systems or clusters (more than 20) of on-site systems with an average density of one house per 1-1.5 acres, based on the gross acreage of the development, should include an evaluation to ensure that drinking water supplies are protected. If the evaluation indicates a risk for nitrate levels above 10 mg/L, alternatives such as protected water supplies (well location and depth), utilizing nitrogen-reducing wastewater treatment systems, or community scale water supply and wastewater treatment systems should be explored.*

This recommendation is intended to serve as screening criteria to direct attention and further evaluation to instances where there is a significant possibility that the added nitrogen load from on-site systems might result in violation of groundwater quality standards.

Several types of treatment processes are capable of removing nitrogen in wastewater. Nitrogen removal systems are used in onsite treatment trains to ensure protection of ground water as well as surface waters recharged by ground water. Biological nitrogen removal requires aerobic conditions to first nitrify the wastewater, then anaerobic conditions to denitrify nitrate-nitrogen to nitrogen gas. The successful removal of nitrogen from wastewater requires that environments conducive to nitrification and denitrification be induced and positioned properly. The limited ability of conventional on-site wastewater treatment systems to achieve enhanced nitrate reductions and the difficulty in predicting soil nitrogen removal rates means that systems sited in drinking water aquifers or near sensitive aquatic areas should incorporate additional nitrogen removal technologies prior to final soil discharge.[9] However, the Wisconsin Administrative Code currently exempts private sewage systems from having to meet groundwater nitrate standards.

Testing

The only way to know if a drinking water supply contains excessive nitrate is to have a water sample analyzed by a certified laboratory. Shallow private wells are typically more susceptible to contamination than deep municipal wells, which are tested regularly. A nitrate test is recommended for all newly constructed private wells and wells that have not been tested during the past 5 years. Testing is also recommended for well water used by pregnant women and is essential for a well that serves infants under 6 months of age. Wells with nitrate concentrations between 5 and 10 milligrams per liter should be tested annually. Additional testing may also be useful if there are any known sources of nitrate or if high nitrate concentrations are found in neighboring wells.

Several other areas can be checked to determine the vulnerability of a well to nitrate contamination:

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[8] CARPC. 2013. *Private On-Site Wastewater Treatment Systems Management.*
[9] U.S. Environmental Protection Agency. 2002. *Onsite Wastewater Treatment Systems Manual.*

- **Well location.** Nitrate-contaminated wells are often located near farm fields, barnyards, feedlots, septic tanks, municipal wastewater treatment systems or "sludge" spreading sites.
- **Well casing depth and construction.** Since nitrate enters the aquifer from the ground surface, wells that have shallow casing are more likely to be affected than deeper cased wells.
- **Geology.** Areas with highly porous, sandy soils, fractured bedrock, natural caves and sinkholes, and shallow depths to bedrock or groundwater are especially vulnerable to contamination.

If the nitrate-nitrogen concentration exceeds the 10-milligram per liter standard, the following actions are recommended:

- Avoid drinking the water during pregnancy and do not give the water to infants less than 6 months of age or use the water to prepare infant formula.
- The Wisconsin Division of Public Health recommends that people of all ages avoid long-term consumption of water that has a nitrate level greater than 10 ppm.
- Do not attempt to remove the nitrate by boiling the water. This will only increase the nitrate concentration.
- Seek medical help immediately if the skin color of an infant appears bluish or gray. Sometimes color change is first noticed around the mouth, or on the hands and feet.
- Protect your water supply from nitrate contamination by reducing fertilizer use, improving manure-handling methods, maintaining septic systems and pumping septic tanks regularly to prevent overflow.
- A safer, longer-term remedy may be to drill a new well.
- Install treatment devices approved by the Department of Commerce

Management Strategies

The Groundwater Law (1983, Wis. Act 410) is the overriding statute establishing authority for groundwater protection and numerical enforcement standards applicable to all Wisconsin agencies and programs. The enforcement standard is the health-based concentration of a substance at which a facility regulated by state agencies must take action to reduce the level of the substance in groundwater. Once enforcement standards are established, all state agencies must manage their regulatory programs to comply. Private wells are regulated under Chapter 160, Wis. Stats. However, nitrate is handled differently than other substances. Under sec. 160.25(3), Wis. Stats., a regulatory agency is not required to impose a prohibition or close a facility when nitrate-nitrogen levels attain or exceed the enforcement standard if the agency determines that this occurred in whole or in part because (a) high background levels of nitrate or (b) the additional concentration does not represent a public welfare concern.

State and local agencies are working on multiple initiatives to reduce nitrate inputs to groundwater and drinking water. It is important to note that farms cannot be required to have a nutrient management plan (NMP) unless they are offered cost share at the rate of $28/ac. or if the farm:

1) is required by local manure storage or livestock siting ordinances;
2) participates in the Farmland Preservation Program/Working Lands programs;
3) is regulated by a WPDES permit;
4) accepts cost share for manure storage; or
5) causes a discharge.

In 2015 about 31 percent of the state's cropland was covered by a NMP. NMPs can help reduce the risk of nitrogen reaching groundwater by identifying where on specific farms soils most susceptible to nitrogen leaching exist. The NMP includes restrictions on the amount, timing, and/or application method of nitrogen sources on those sensitive soils types. The UW-Extension publishes a guide to help farmers regarding the appropriate amounts of nutrients to apply to maximize yield and profitability.[10] It sets N and P application limits based on crop need, soil yield, and the economic optimum application rate. WDNR and DATCP, with USDA-NRCS, reference this document in several nutrient management codes and rules. **SnapPlus** is a Nutrient Management Planning software program designed for the preparation of nutrient management plans in accordance with Wisconsin's Nutrient Management Standard Code 590. The 590 nutrient management standard contains criteria for surface and groundwater protection that manages the amount and timing of all nutrient sources. These plans are annual and based on soil tests and UW soil fertility recommendations. The program helps farmers make the best use of their on-farm nutrients, as well as make informed and justified commercial fertilizer purchases. By calculating potential soil and phosphorus runoff losses on a field-by-field basis, while assisting in the economic planning of manure and fertilizer applications, SnapPlus provides farmers with a tool for protecting soil and water quality.

It is difficult to assess the impact and effectiveness of nutrient management planning on groundwater nitrate levels without full coverage and implementation of NM across the state. **Figure 22 and Map 29** track the development of nutrient management plans. While progress has been made, more work is needed to address increasing nitrate concentrations in groundwater. Additional point and nonpoint sources are addressed through UW-Madison, WDNR, DATCP, NRCS, DSPS, and County Land Conservation Departments in cooperation with local landowners, operators, and waste dischargers. More specifically:

- The University of Wisconsin-Madison and the University of Wisconsin-Extension provide research information and educational programs on nutrient management largely through the Department of Soil Science in College of Agriculture and Life Sciences. The University of Wisconsin's Nutrient and Pest Management program is an educational effort based on soil testing programs and University of Wisconsin Extension Soil fertility recommendations by soil type and crop.

- The Nonpoint Source Water Pollution Abatement Program cost shares the use of best management practices to protect water quality by reducing the amount of nutrients from urban and rural sources.

- The Agricultural Conservation Program is a federal program administered to restore and protect land and water resources and preserve the environment. This program uses cost sharing of best management practices and outreach efforts to reduce nutrient loads from agriculture.

- County land conservation departments provide cost-share funding to farmers for nutrient management planning through DATCP's Land and Water Resource Management grants.

- DATCP awards funds to groups who wish to assist farmers in writing their own NMPs through the Nutrient Management Farmer Education Grant Program

- The newly established Producer Led Watershed Protection Grant Program administered through DATCP funds projects developed by producers to address nonpoint pollution issues in their watershed through innovative partnerships and strategies.

- The WDNR wastewater program regulates the discharge of nitrogen containing wastewater and biosolids to the land surface and potentially to groundwater. The wastewater program regulates:

    - Discharge of municipal and industrial wastewater to land treatment systems such as spray irrigation systems, seepage cells and ridge and furrow systems.

[10] Laboski, C. and J. Peters. 2012. *Nutrient Application Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin.* UW-Extension Publ. A2809.

- Discharge of municipal and industrial sludges, biosolids and industrial liquid wastes through land application.

- Discharge of septage through land application.

- Impacts on groundwater from wastewater treatment and storage lagoons leaking in excess of groundwater standards.

- Disposal of animal waste (manure) from concentrated animal facilities is also regulated. Facilities with over one thousand animal units must have a Wisconsin Pollutant Discharge Elimination permit as required under NR 243.

- The Department of Safety and Professional Services under SPS 383 Wis. Stats regulates private septic systems. The private septic system program does the following:

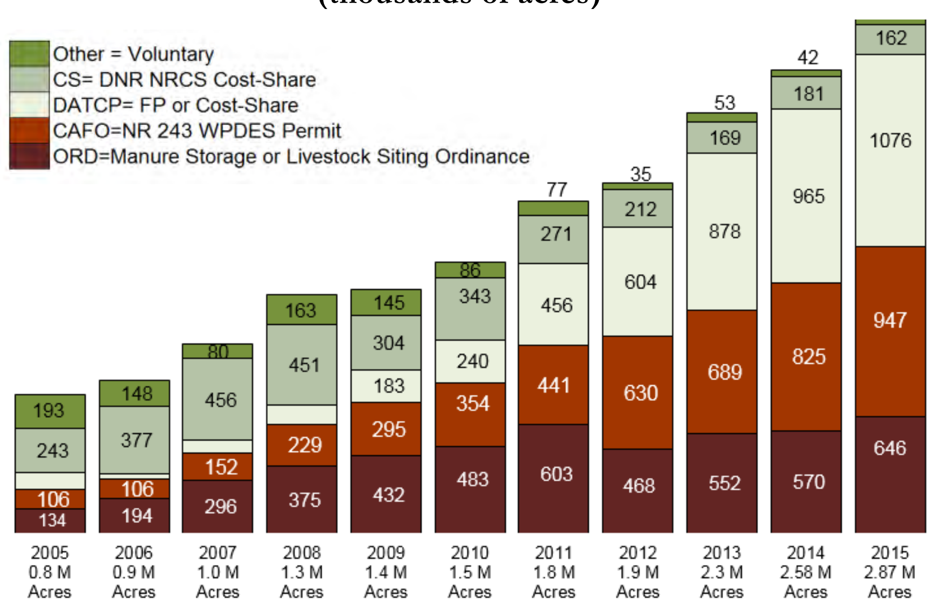
  - Establishes design standards and accepted waste management practices for private septic systems.

  - Establishes the criteria under which sanitary permits are issued to build private septic systems, which discharge pollutants to waters of the state.

  - Establishes soil site evaluation standards for placement of septic systems.

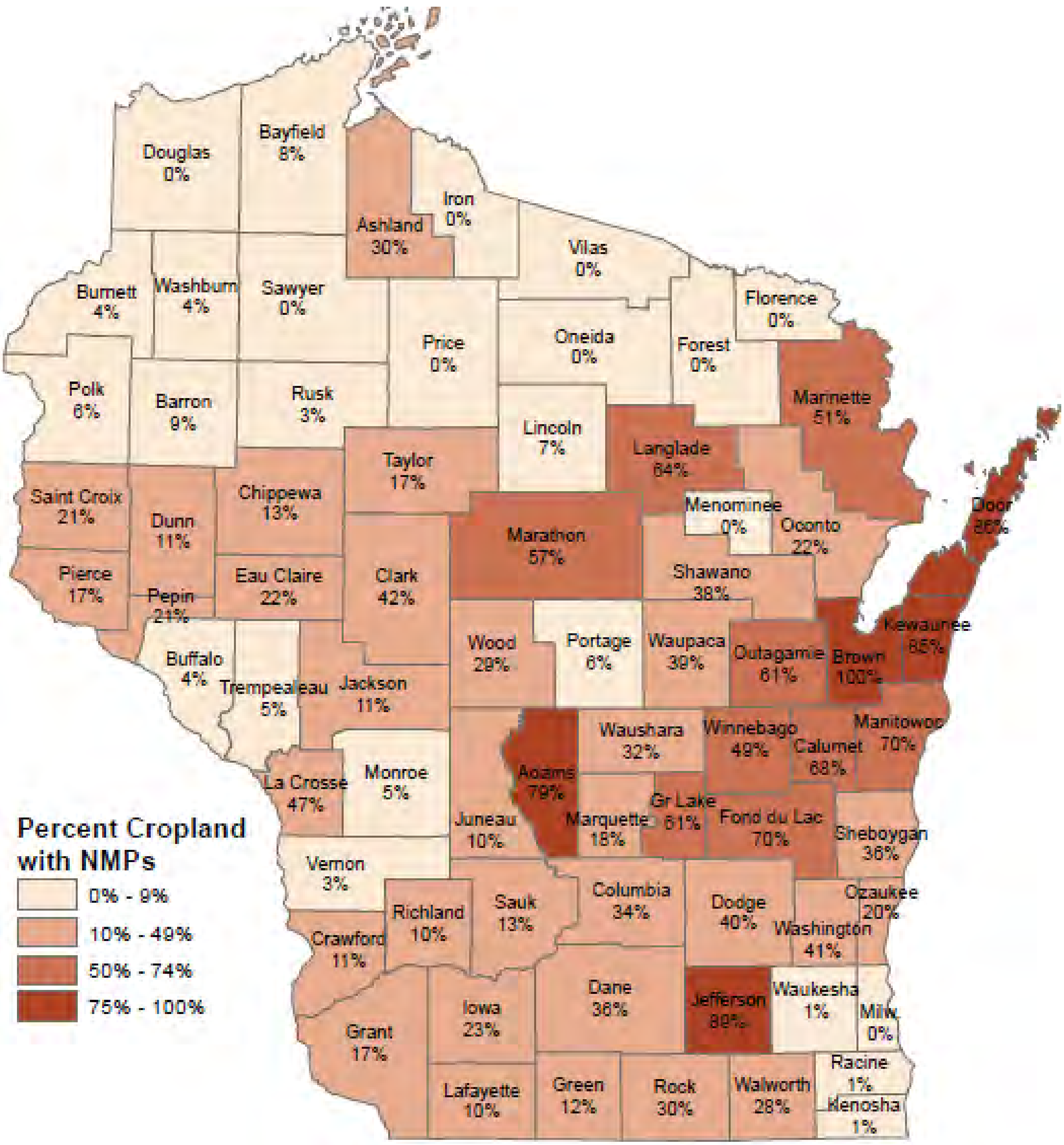
It is important to point out that DSPS does not regulate nitrate in septic systems. This should not be a problem as long as septic systems are not concentrated. Groundwater dilution prevents elevated hot spots, unless groundwater has high background nitrate concentrations from agricultural land uses adjacent to or up gradient.

Figure 22
2005-2015 Nutrient Management Plan Acres
Reported by Program
(thousands of acres)



Source: Acreage Trends in Nutrient Management as Reported to DATCP.

Map 29. Percent of County Cropland with 2015 Nutrient Management Plans Reported to DATCP



Pesticides

A pesticide is any substance used to kill, control or repel pests or to prevent the damage that they may cause. Included in the broad term "pesticide" are herbicides to control weeds, insecticides to control insects, and fungicides to control fungi and molds. Pesticides are used by businesses and homeowners as well as by farmers, but figures for the amounts and specific types of pesticides used are not generally available on a county-by-county basis.

A 2005 DATCP report indicates that approximately 13 million pounds of pesticides are applied to major agricultural crops in Wisconsin each year, including over 8.5 million pounds of herbicides, 315,000 pounds of insecticides, one million pounds of fungicides, and 3 million pounds of other chemicals (this last category applied mainly to potatoes). The number of pounds of pesticide applied per acre in Wisconsin varies greatly by crop, from 28 pounds/acre for apples to less than one pound/acre for oats and barley (**Table 15**). The principle commodities in Dane County include corn (214,600 ac.), soybeans (80,700 ac.), and wheat (25,000 ac.).

Once a pesticide is applied, ideally it will harm only the target pest and then break down through natural processes into harmless substances. However, the actual fate of pesticides in the environment may include evaporation into the air; runoff into surface water; plant uptake; breakdown by sunlight, soil microorganisms or chemical reactions; attachment to soil particles; leaching into groundwater; or remaining on the plant surface and removal at harvest. When pesticides are spilled, disposed of, or applied on the soil, some amount can be carried into the surrounding surface water or groundwater. These products move with the water, and can eventually enter nearby drinking water wells.

Table 15. Total Pounds of Pesticides Applied to Major Crops in Wisconsin, 2004-2005

Crop	Acres	Total pounds of pesticides applied	Pounds of pesticides applied per acre
Apples	5,800	163,300	28
Potatoes	68,000	950,000	14
Tart cherries	1,800	14,700	8
Carrots for processing	4,200	29,400	7
Snap beans	76,000	251,600	3
Sweet corn	88,400	198,000	2
Field corn	3,800,000	6,503,000	2
Green peas for processing	30,200	33,500	1
Soybeans	1,610,000	1,770,000	1
Cucumbers for processing	4,600	3,800	1
Cabbage, fresh	4,400	2,700	1
Barley	55,000	5,000	1
Oats	400,000	25,000	<1

Wisconsin Agricultural Statistics Service. 2006. *Wisconsin Pesticide Use.*

How much of a pesticide application will leach to groundwater depends upon four factors:

- **Pesticide properties** such as high water solubility, low adsorption (the ability of a pesticide to attach to soil particles), and high persistence (how long it takes for the chemical to degrade)
- **Soil characteristics** such as high permeability and porosity, low soil compaction, low amounts of organic material, and high amounts of sand and gravel content
- **Site conditions** such as shallow depth to groundwater, high amount of precipitation, and excessive irrigation
- **Management practices** such as poor timing of pesticide application, not incorporating the pesticide into the soil, poor handling of the chemical, and solely relying on chemicals for pest control

Determining which pesticides are in groundwater at a given location and time is difficult and can be expensive. A pesticide test generally looks for a single chemical, or more commonly, a broad group of chemicals, but not all pesticides are detected by any one test. Pesticides also break down over time into metabolites which may not have the same testing method as the parent compound. Further, some pesticides do not have approved testing methods, so they cannot be measured in water.

Health Effects

In Wisconsin about 30 pesticides currently have health-based drinking water limits and groundwater standards in Chap. NR 140, Wis. Adm. Code. These advisory levels are calculated from available toxicological studies and are set to protect average exposed populations. Potential health effects in people consuming pesticides above the health advisory levels depend upon the kind and amount of pesticide, how long the person has been consuming the water, as well as the person's overall health. The pesticides with standards are a fraction of the 90 different pesticides Wisconsin farmers reported using on major crops.[11] Occasionally, pesticides and pesticide metabolites that do not have groundwater standards are detected in drinking water in which case the health effects cannot be properly evaluated.

Acute pesticide poisoning is extremely rare in the state. Long-term or chronic effects of pesticides in humans are not completely understood. The health effects of pesticide exposure vary by pesticide. For example, atrazine, a common corn herbicide, has been linked to weight loss, cardiovascular damage, retinal and some muscle degeneration, and cancer when consumed at levels over the drinking water limit for long periods of time. Long-term exposure to alachlor, another herbicide, is associated with damage to the liver, kidney, spleen, and the lining of the nose and eyelids, and cancer.[12] The local public health department or family doctor are the best resources for determining if an individual may have an illness related to pesticide exposure. Since only about 30 pesticides currently have health-based drinking water limits in Wisconsin, occasionally they are detected in drinking water but their harmful levels or health effects are unknown.

Also unknown are the health effects of a combination of pesticides in drinking water, even at levels below the drinking water limit for any one of the pesticides. The health effects of multiple pesticides in drinking water are not well understood. Some studies have found that pesticide mixtures at equal or less than the EPA drinking water standard can produce effects that are not found upon exposure to a single pesticide at the same concentrations. Tests of mixtures of the insecticide aldicarb, the herbicide atrazine, and nitrate in rats show endocrine, immune and behavioral effects including decrease in speed of learning, change in aggression intensity and frequency, change and reduction in memory and motor coordination in the brain, change in growth hormone, and reduction in antibodies formation capability.[13] Frogs exposed to pesticide mixtures

[11] Wisconsin Agricultural Statistics Service. 2006. *Wisconsin Pesticide Use.*
[12] U.S Environmental Protection Agency. 2007. *Consumer Factsheet on Alachlor.*
[13] Porter, W., et al. 1999. *Endocrine, Immune, and Behavioral Effects of Aldicarb (carbamate), Atrazine (triazine) and Nitrate (fertilizer) Mixtures at Groundwater Concentrations.*

used on a corn field (with each pesticide at 0.1 ppb) had retarded larval growth and development and induced damage to the thymus, resulting in immunosuppression.[14]

All public water systems are required to notify consumers if any contaminant, including pesticides, is detected at concentrations above the maximum contaminant level (MCL). In addition, public water systems that serve residential populations are required to complete a Consumer Confidence Report (CCR) each year. If a community well is contaminated with pesticides, consumers will be notified of the problem by the water system owner and given instructions on what to do. Typically, the water system will be required to drill a new well in an uncontaminated area. Communities can also opt to treat the water, however the cost of equipment, operation, and maintenance can be very high.

Private well owners are responsible for the safety of their own water supply. As always, if residents notice a change in taste, color, or odor, they may want to use an alternative safe drinking water source until the water can be tested. Private well owners should also have their well tested if they suspect pesticide contamination. Owners whose wells have pesticides above the MCL should contact the regional office of WDNR for assistance. In most cases owners will be advised to replace the well with a new, safe water supply. Depending on the specific pesticide and the amount of contamination, the well owner may be able to purchase a home treatment system.

Several factors can affect the vulnerability of a well to pesticide contamination. These include:

- **Location.** Wells located on or near agricultural areas, or near pesticide-related industries.
- **Quantity.** Larger spills or applications tend to affect a wider geographic region and can result in higher levels of contamination than smaller spills.
- **Well depth and construction.** Since contaminants are seeping from the ground surface, shallow wells are more likely to be affected than deep wells
- **Soil type or geology.** Areas with thin, highly porous or sandy soils, and have shallow groundwater aquifers or fractured bedrock (karst topography), are most vulnerable to contamination. Clay soils can absorb and significantly slow down the movement of some contaminants.
- **Time.** Groundwater usually moves very slowly. It can take years for pesticides to reach a well. Wells that are safe today may eventually become contaminated by a spill that happened in the past. This is why it is important to test water supplies regularly.

Serious concerns about pesticide contamination in Wisconsin were raised in 1980 when aldicarb, a pesticide used on potatoes, was detected in groundwater near Stevens Point. The WDNR, DATCP, and other agencies responded by implementing monitoring programs and conducting groundwater surveys. In 1983 WDNR and DATCP expanded sampling programs to include analysis of pesticides commonly used in Wisconsin. These programs now include sampling for pesticide metabolites (breakdown products) in the soil and groundwater. Based on DATCP monitoring surveys, the most frequently detected pesticides in Wisconsin are:

- Chemical breakdown products of alachlor (*Lasso*).
- Chemcial breakdown products of meolachlor (*Dual*).
- *Atrazine* and its chemical breakdown products.
- Metribuzin (*Sencor*).
- Chemical breakdown products of Cyanazine (*Bladex*). Note, Cyanazine is no longer manufactured.

From 2000-2001 DATCP conducted a private well water study looking for some of the most commonly used herbicides in Wisconsin. From that study, the statewide estimate of the proportion of private drinking water wells that contained a detectable level of a herbicide or herbicide metabolite was 37.7 percent. **Map 30** shows

[14] Hayes, T., et al. 2006. *Pesticide Mixtures, Endocrine Disruption, and Amphibian Declines: Are We Underestimating the Impact?*

the estimated percentage of wells containing herbicide or herbicide metabolites by region. The study did not look at less commonly used herbicides or any insecticides or fungicides.

In 2007 DATCP conducted a statewide statistically designed survey of agricultural chemicals in Wisconsin groundwater. The purpose of the survey was to obtain a current picture of agricultural chemicals in groundwater, relate findings to land use, and compare results to previous surveys conducted in 1994, 1996, and 2001. Three hundred and ninety-eight private drinking water wells were sampled as part of this survey. Each well sample was analyzed for 32 compounds including 17 pesticide parent compounds, 14 pesticide metabolites and nitrate-nitrogen. Health standards have been established for 11 of the parent compounds and 4 of the metabolites. Based on the statistical analysis, it was estimated that the proportion of wells in Wisconsin that contained a pesticide or pesticide metabolite was 33.5 percent. The average number of pesticide or pesticide metabolite detects for wells with detects was 2.3. Areas of the state with a higher intensity of agriculture generally had higher frequencies of detections of pesticides and nitrate, as shown in **Figure 23.** Limited pesticide monitoring of private wells was taken from the GRN database (**Table 16 and Map 31a**). Most pesticide concentrations tested below the detection limit, except for atrazine, alachlor, cyanazine and metolachlor. Atrazine was by far the most common compound. Pesticides levels found in municipal wells in Dane County are typically below the PAL (**Map 31b)**

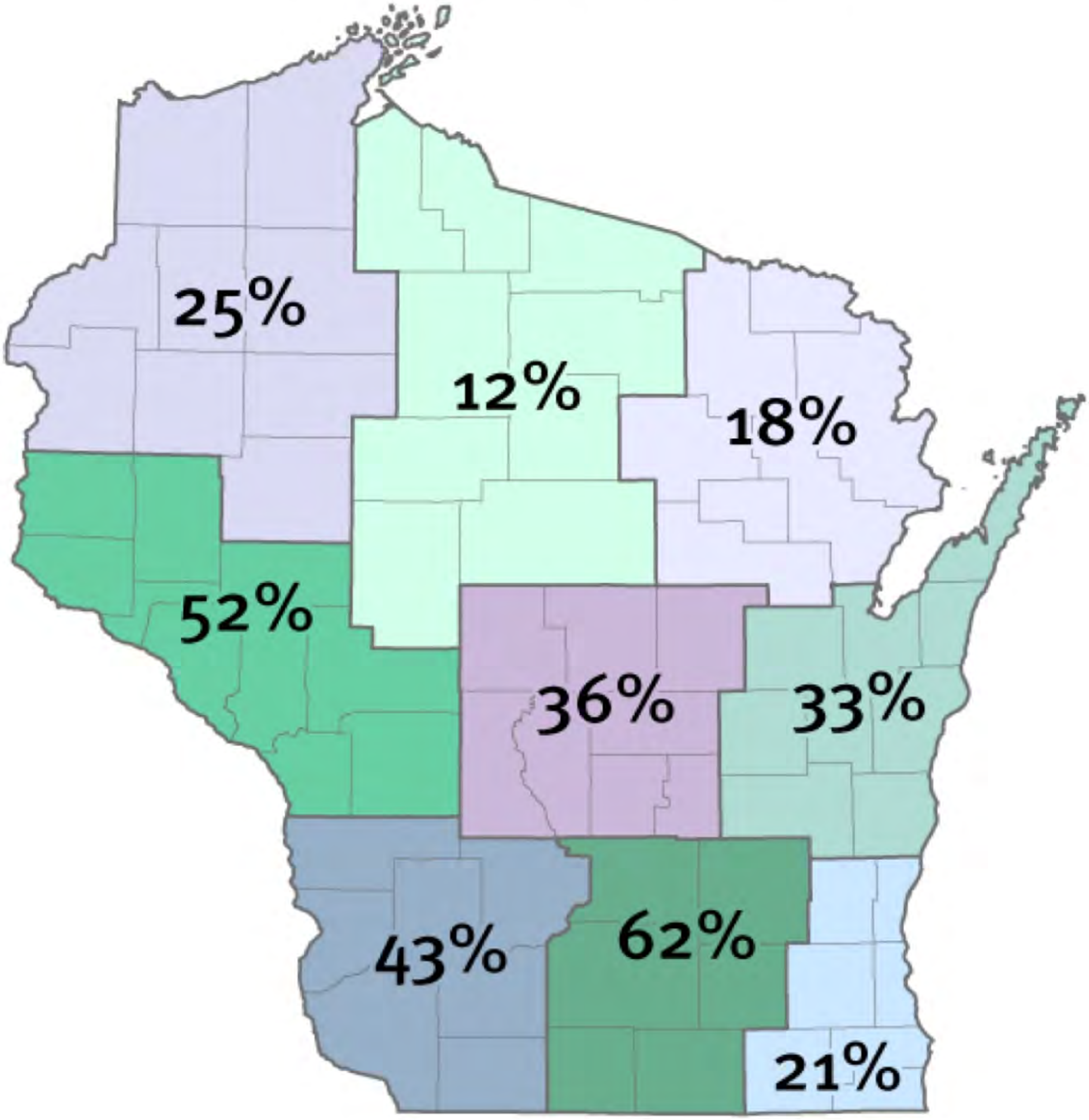
Table 16
Groundwater Pesticide Detection in Private Wells in Dane County

Chemical Name	Total No. of Wells	Wells With Detects	NR 140 Enforcement Standard (UG/L)	Wells Exceeding Enforcement Standard	NR 140 Preventive Action Limit (UG/L)	Wells Exceeding PAL	Highest Detection Level (UG/L)
Aatrex (atrazine)	185	107	3	10	0.3	76	12
Bladex (cyanazine)	143	3	1	2	0.1	3	14
Dual (metolachlor)	152	2	15	0	1.5	0	1.1
Lasso (alachlor)	153	11	2	0	0.2	5	0.5

Source: Wisconsin Department of Natural Resources, Bureau of Drinking Water and Groundwater, 2013.

Map 30

Percentage of Private Wells with Detectable Herbicides or Herbicide Metabolites (2001)



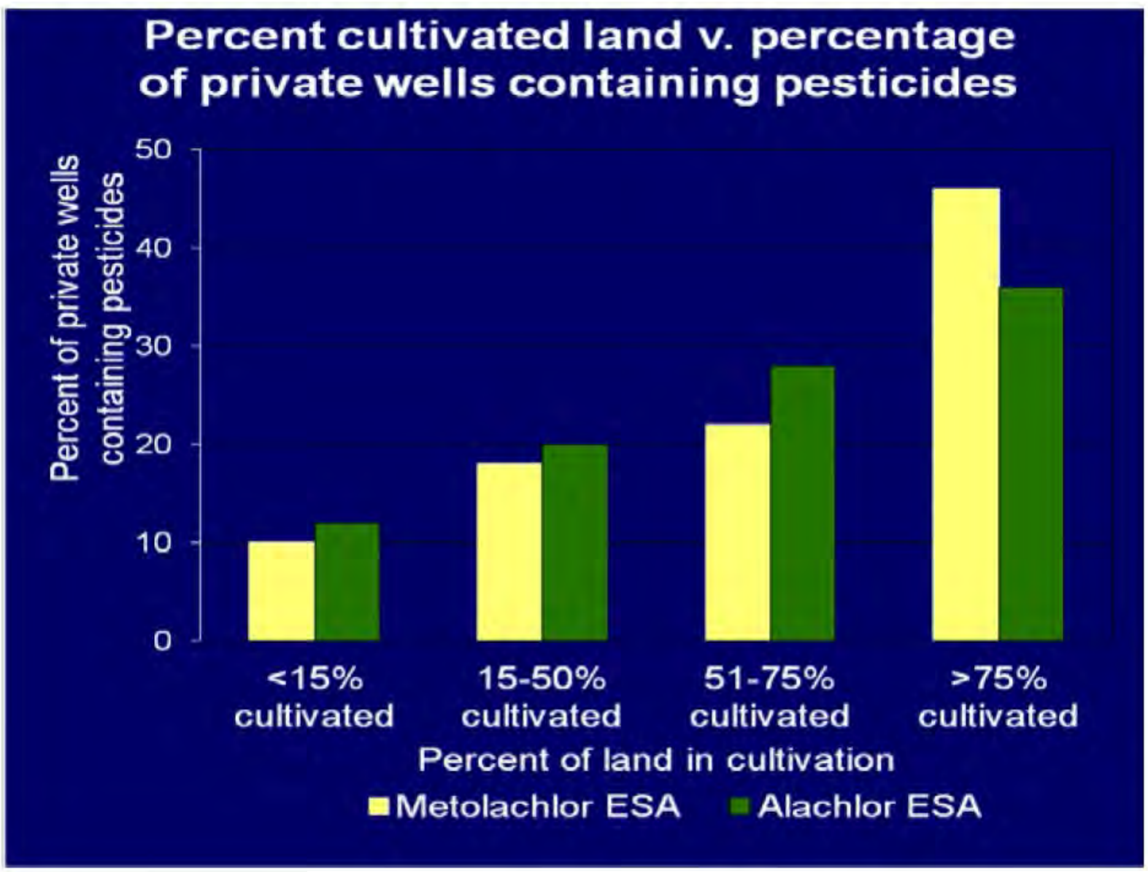
Herbicide data: Wisconsin Department of Agriculture, Trade and Consumer Protection, 2002, Agricultural chemicals in Wisconsin groundwater: final report, *http://www.datcp.state.wi.us/arm/agriculture/land-water/environ_quality/pdf/arm-pub-98.pdf*

Figure created for the "Protecting Wisconsin's Groundwater Through Comprehensive Planning" web site, 2007, *http://wi.water.usgs.gov/gwcomp/*

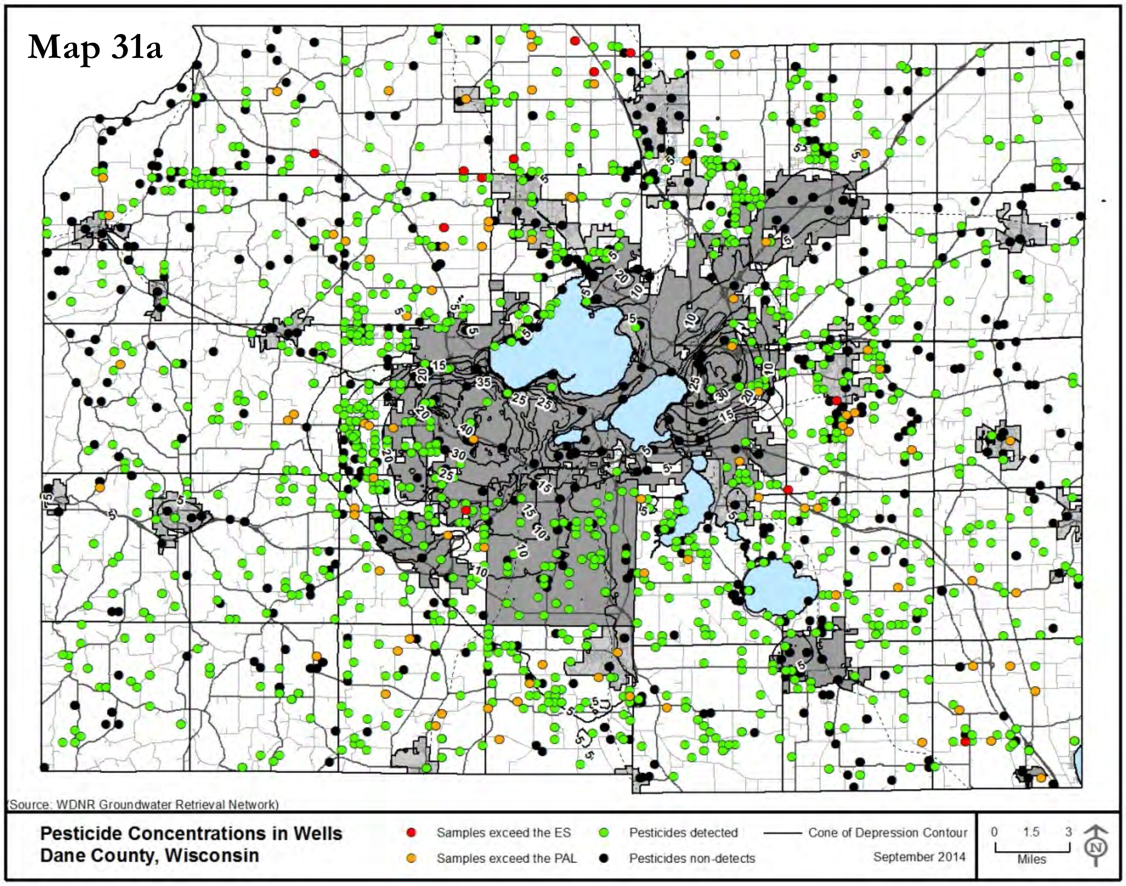
Atrazine

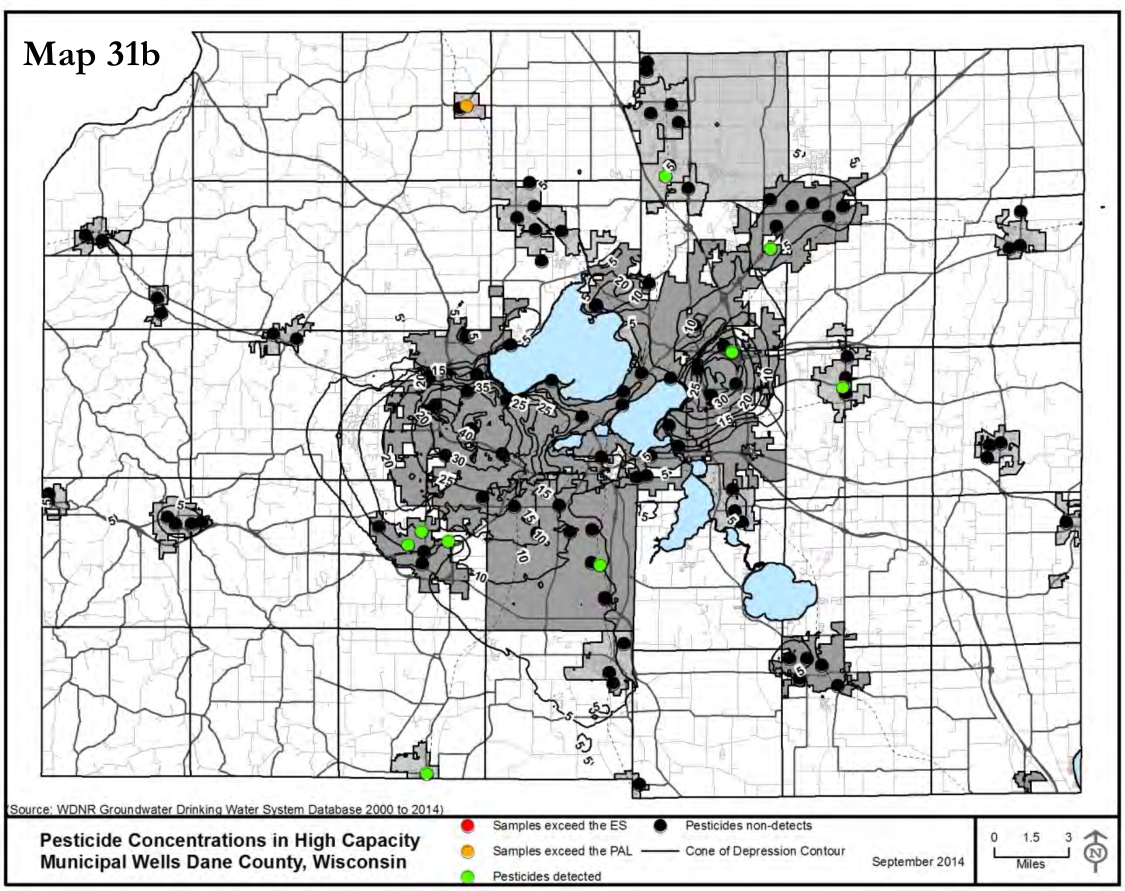
Atrazine, a herbicide used on corn, is one of the pesticides most often found in private drinking water wells in Wisconsin. The DATCP pesticide database contains test results from nearly 13,000 wells tested with the immunoassay screen for atrazine, and over 5,500 wells tested by the full gas chromatography method. In June 2013, DATCP produced a map showing locations and atrazine levels of private drinking water wells tested for atrazine in the state (**Map 32**). The immunoassay screen results showed that about 40 percent of private wells tested have atrazine detections, while about 1 percent of wells contained atrazine over the groundwater enforcement standard of 3 μg/l. The approximately 5,500 wells tested by full gas chromatography showed detectable levels of atrazine in about 38 percent of the wells and 8 percent of wells over the enforcement standard. The enforcement standard for atrazine includes parent atrazine and three of its breakdown metabolites.

Figure 23

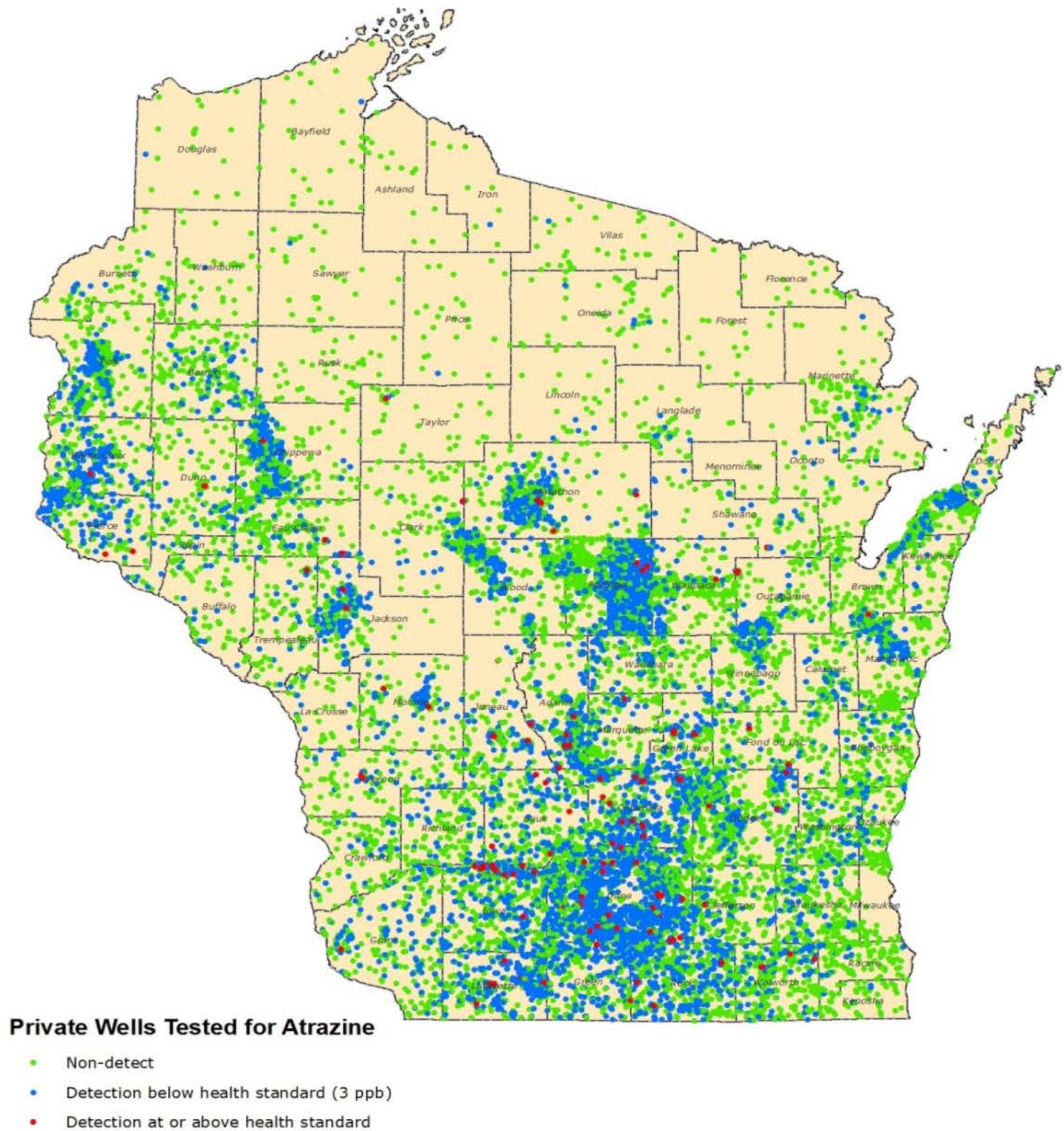


(Source: Wisconsin Groundwater Coordinating Council, 2014, with 2007 DATCP data)


Map 31a
(Source: WDNR Groundwater Retrieval Network)
Pesticide Concentrations in Wells
Dane County, Wisconsin
Samples exceed the ES
Samples exceed the PAL
Pesticides detected
Pesticides non-detects
Cone of Depression Contour
September 2014
0 1.5 3
Miles
N


Map 31b
(Source: WDNR Groundwater Drinking Water System Database 2000 to 2014)
Pesticide Concentrations in High Capacity
Municipal Wells Dane County, Wisconsin
Samples exceed the ES
Samples exceed the PAL
Pesticides detected
Pesticides non-detects
Cone of Depression Contour
September 2014
0 1.5 3
Miles
N

Map 32
Private Wells Tested for Atrazine in Wisconsin as of June 2013



This map was created June 4, 2013 and depicts the most recent atrazine results for private wells in Wisconsin.

Source: DATCP

Pesticides like atrazine get into groundwater mostly through general use, while others are only found in groundwater if they have been spilled or mishandled. A combination of factors is most likely responsible for the widespread atrazine contamination shown on the map:

Atrazine was the most widely used herbicide in Wisconsin for more than 40 years because it is effective and inexpensive. Glyphosate use has now passed atrazine use in Wisconsin due to Roundup-ready soybeans and corn, but fortunately glyphosate is not a groundwater threat because it is tightly bound to the soil. Atrazine leaches through the soil into groundwater more readily than many other herbicides Atrazine was commonly used at much higher rates and applied more often before DATCP's Atrazine rule (ATCP 30) began in 1991. As of 2011, there were 101 atrazine prohibition areas in Wisconsin, covering about 1.2 million acres where all uses of atrazine are prohibited. In Dane County 531,830 acres of land are within an atrazine prohibition area (**Maps 33a and b**).

In 1997, DATCP conducted an *Atrazine Rule Evaluation Survey* to evaluate the restrictions on the use of atrazine in Wisconsin. The purpose of the survey was to determine how levels of atrazine and its metabolites in groundwater were changing three and five years after the atrazine rule was put into effect. The results show a significant decline in atrazine concentrations in Wisconsin between 1994 and 1996. The average atrazine plus metabolite concentration in wells with detections declined from 0.96 to 0.54 in the two-year period, a 44 percent decrease. The percent of contaminated wells, however, did not show a significant decline.

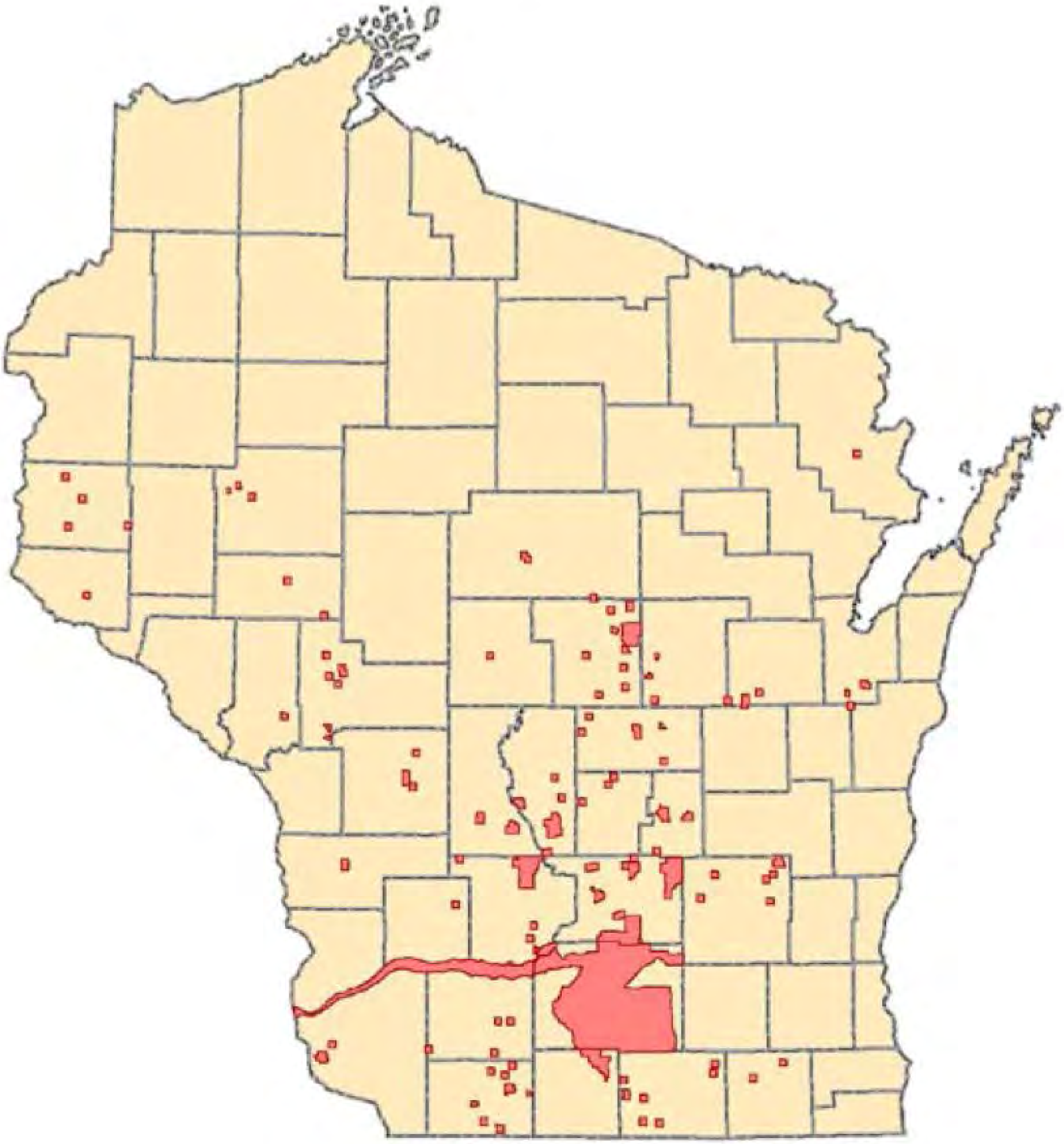
In 2011 DATCP completed a *Survey of Weed Management Practices in Wisconsin's Atrazine Prohibition Areas*. The main purpose of the survey was to evaluate differences in herbicide use and other weed control practices inside and outside of Wisconsin's atrazine prohibition areas. A specific objective was to determine whether simazine, a triazine herbicide that is similar to atrazine, is used more extensively inside prohibition areas since atrazine is prohibited and if this could become a bigger water quality problem. Information was also collected on how prohibiting the use of atrazine affects the ability to grow corn.

The results of this survey suggest that although many corn growers would like the option to use atrazine in a prohibition area, they have adapted well to growing corn without it. Half of the respondents indicated that they do not find it more difficult to control weeds in a prohibition area without atrazine. Only about eight percent of respondents indicated that it is much more difficult to control weeds in a prohibition area and another 32 percent said it is somewhat more difficult.

Corn growers appear to be split on the question of whether it costs more to control weeds in a prohibition area with 39 percent responding "yes" and 39 percent "no." The 39 percent that said it costs more reported an average cost increase of $13.60 per acre. Only 5 percent of the corn growers surveyed indicated that they had experienced a yield reduction in a prohibition area.

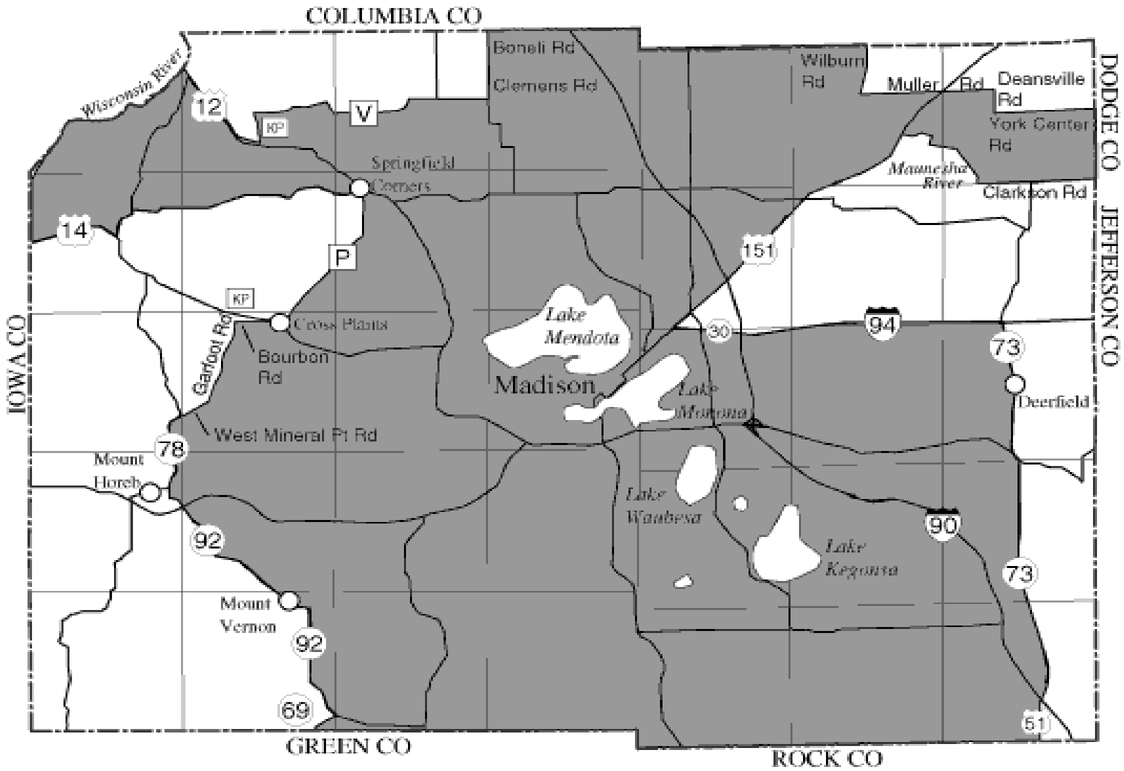
By far the most common alternative to atrazine in prohibition areas was glyphosate-containing products such as Roundup. A comparison of the use of six commonly-used herbicides inside versus outside of prohibition areas showed only minor differences. It was not possible to determine if simazine is used more inside prohibition areas due to low reported use both inside and outside of prohibition areas. A full report on this survey can be found at *http://datcp.wi.gov/uploads/Environment/pdf/WeedMgtAtrazinePAs.pdf*.

Map 33a
Atrazine Prohibition Areas in Wisconsin.



Source: Wisconsin Department of Agriculture and Consumer Protection

Map 33b
Atrazine Prohibition Area in Dane County (in gray)



Management Actions

Organic Farming

Wisconsin has seen a dramatic growth in certified organic farms (which do not use synthetic pesticides), from 422 in 2002 to 1,202 in 2007, an increase of 285 percent. Likewise, organic acreage in Wisconsin increased from 81,026 acres to 195,603 acres from 2002 to 2011, a 241 percent increase. Though the percentage of farms and farm acreage in Wisconsin that are organic remains below 2 percent, organic markets continue to expand due to increased consumer interest in organic food, and reports of increased profits by organic producers.[15] Another benefit of organic farming is the significantly decreased potential for pesticides in groundwater (drinking water in rural areas) where organic practices are followed.

Planning and Implementation

Goals for groundwater protection from pesticides include:

- Determine what pesticides are being used and where. Test wells in these areas for these pesticides and their metabolites.
- For pesticides with established drinking water limits, keep concentrations below the drinking water limit.
- Encourage and support the use of organic farming methods in the county.
- Limit use of lawn pesticides.

[15] Wisconsin Department of Agriculture, Trade, and Consumer Protection. 2011. *The Economic Impact of the Organic Sector in Wisconsin and Beyond.*

Because of differences in pesticides, soils, and management practices, knowing which crops are grown in an area alone does not accurately indicate the risk to human health. However, knowing where pesticide use is likely to be heaviest may be useful in minimizing human exposure to potential contaminants in the environment. Implementation strategies that can be used to protect the groundwater from agricultural chemical contamination include the following:

Education – Education and citizens taking private actions aimed at limiting pesticide contamination of groundwater, for example:

- Private well water testing and education programs offered by the University of Wisconsin – Extension can increase public awareness of pesticide contamination in groundwater and local government officials' interest in taking proactive planning steps to protect groundwater.

- The University of Wisconsin – Madison and UW - Extension have many educational programs to help farmers limit the use of pesticides and pesticide losses to the environment, such as the Integrated Crop and Pest Management (ICPM) program, which can be accessed and implemented locally through the county Extension office.

Environmental Assessment – Environmental assessment requirements within zoning or subdivision ordinances to ensure that suitable sources of water for private wells are available on a proposed development site.

Facility Planning – More detailed facility plans for potential contamination sources, such as spill containment plans for potential pesticide sources.

Funding – For example, WDNR grant or loan programs to help communities assess and meet their needs in areas involving sensitive natural resources such as groundwater.

Incentives – Incentives from local governments to grow groundwater-friendly crops including, for example:

- Identifying agricultural lands in the recharge area for its wells and providing various incentives for farmers to enter into cropping agreements to limit pesticide inputs.
- Hiring a specialist to evaluate areas of high pesticide use and develop possible pesticide management strategies or promote low-pesticide agricultural systems or organic farming systems which forbid the use of synthetic pesticides.
- Encouraging food processors that purchase organic or groundwater friendly foods to locate or form in the area.

Volatile Organic Compounds

Volatile Organic Compounds (VOCs) refers to a group of chemicals that are used as solvents in many industrial and household products that evaporate, or volatilize, when exposed to air. The most abundant source of VOCs are fossil fuel products such as gasoline and fuel oil. Since they also make excellent solvents, VOCs are used as cleaning and liquefying agents in fuels, degreasers, solvents, polishes, cosmetics, and dry cleaning solutions. Potential sources of VOCs in Wisconsin's groundwater include landfills, underground storage tanks, and hazardous substance spills.

When VOCs are spilled or disposed of on or below the land surface a portion evaporates, but some can be carried deep into the soil by rainwater or melting snow. Once they enter groundwater, VOCs can remain there for years decomposing slowly because of the cool, dark, environment. These chemical move with the groundwater and pose a threat to nearby drinking water wells.

Several factors can affect a well's vulnerability to VOC contamination. These include:

- **Location**. Typically VOC-contaminated wells are located near industrial or commercial areas, gas stations, landfills, or railroad tracks.
- **Quantity**. Larger spills tend to affect a wider geographic region and can result in higher levels of contamination than small spills.
- **Well depth and construction**. Since contaminants are seeping from the ground surface, shallow wells are more likely to be affected than deep wells.
- **Soil type**. Areas with thin, highly porous or sandy soils, and shallow depths to groundwater, are most vulnerable to contamination. Clay soils can absorb and significantly slow down the movement of some contaminants. This is helpful because slow groundwater movement can allow soil bacteria to break down harmful organic chemicals.
- **Time**. Groundwater usually moves very slowly. It can take years for VOCs to reach a well. Wells that are safe today may eventually become contaminated by a spill that happened in the past. This is why it is very important to test water supplies regularly.

The presence of VOCs in groundwater is cause for concern. Improper handling or disposal of VOCs can affect the quality of our drinking water for generations to come. VOCs include hundreds of different chemicals. Some VOCs are quite toxic, while others pose little risk. The most commonly detected VOCs have been used for many years and have been studied in both biological and occupational settings. Health risks vary depending on the type of VOC. Generally, effects of short-term exposure include symptoms of intoxication (dizziness, headache, confusion, nausea), anemia, and fatigue. Effects of long-term exposure can include cancer, liver damage, spasms, and impaired speech, hearing, and vision.

State and federal agencies are responsible for ensuring the safety of our drinking water. To do this, they set limits of how much of a contaminant can be in drinking water These limits are called "Maximum Contaminant Levels" (MCLs) and groundwater "Enforcement Standards" (ESs) specified in NR 890 and NR 140, respectively. Limits are set at levels that protect against short-term and long-term exposures and are cost effective to implement.

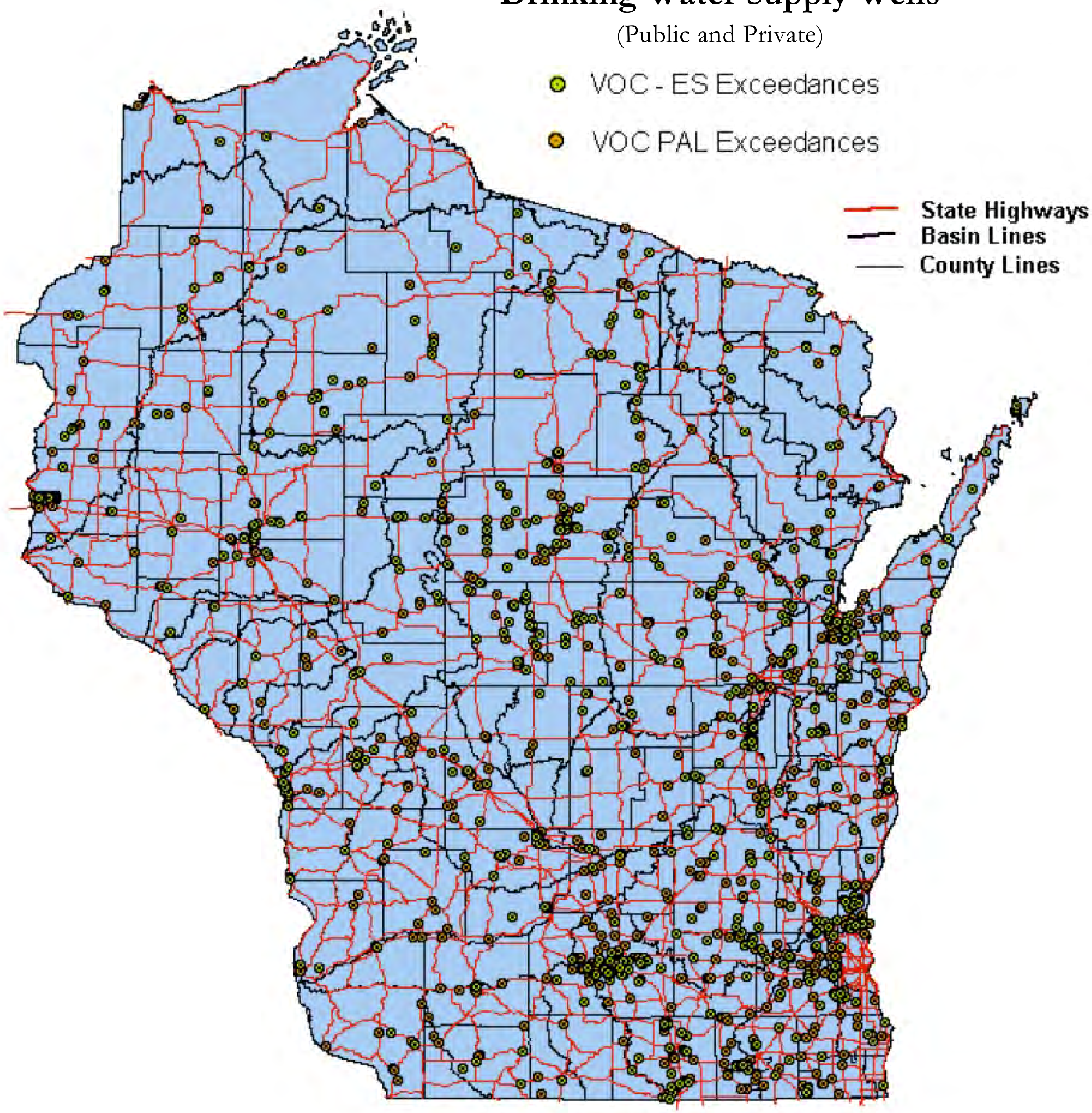
Thousands of wells have been sampled for VOC analysis across the state. Fifty-nine different VOCs have been found in Wisconsin groundwater, although only 34 of those have health based standards. Trichloroethylene, used as a solvent and degreaser and a common ingredient in many household products like paints, adhesives and spot removers, is the VOC found most often in Wisconsin's groundwater. **Map 34** shows the location of drinking water wells with past enforcement standards (ES) and preventive actions limits (PAL) exceedances based on data from 6,399 unique wells recorded in the WDNR's Groundwater Retrieval Network (GRN) database. **Maps 35a and b** indicate VOC results for Dane County and municipal wells, respectively.

The Madison water utility annually tests its wells for over 50 different VOCs including carbon tetrachloride, tetrachloroethylene (PCE), trichloroethylene (TCE), and methyl t-butyl ether (MTBE). Further monitoring is triggered if the level of one VOC exceeds a threshold, typically one tenth of the maximum contaminant level (MCL).

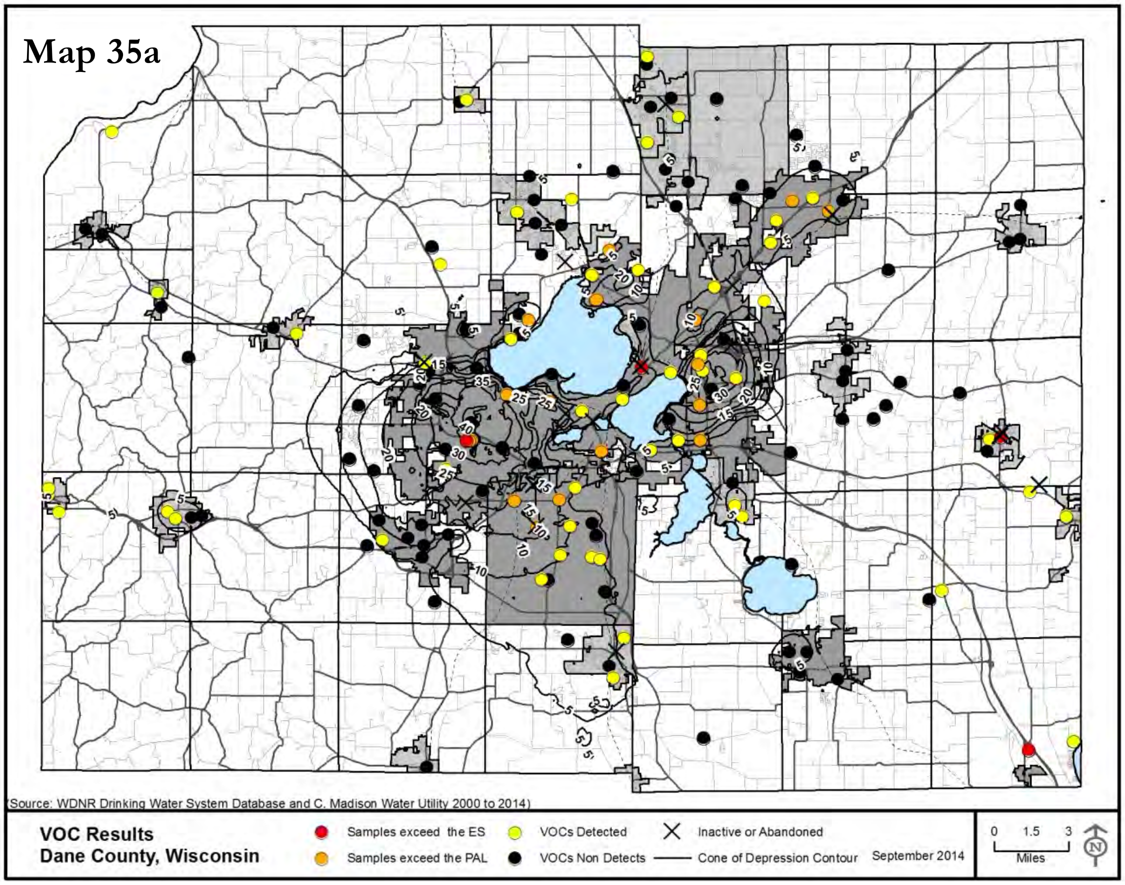
The most frequently encountered VOC in Madison water is tetrachloroethylene (PCE) widely used in dry-cleaning and metal degreasing operations. In 2012, as in previous years, PCE was detected at seven wells (**Table 17**). Although the amount found at most wells was below 1 μg/L, the average at Well 9 was 1.4 μg/L while at Well 15 it averaged 3.3 μg/L and measured as high as 3.9 μg/L. These levels compare to an MCL of 5 μg/L. The amount at Well 15 has been gradually increasing over several years and ultimately led to the decision to install an air stripper to remove VOCs from the pumped water. The treatment facility is expected to begin operation in summer 2013.

A limited number of other VOCs have been found in some Madison municipal wells. Except for trichloroethylene (TCE), these contaminants are found in only one or two wells and are generally detected at trace levels (<0.5 µg/L). **Reference Table 17** identifies the chemical, maximum amount detected, and the well in which each was found.

Map 34
Drinking Water Supply Wells
(Public and Private)



Source: Wisconsin Groundwater Coordinating Council., 2014. *Fiscal Year 2014 Report to the Legislature.*


Map 35a
(Source: WDNR Drinking Water System Database and C. Madison Water Utility 2000 to 2014)
VOC Results
Dane County, Wisconsin
Samples exceed the ES
Samples exceed the PAL
VOCs Detected
VOCs Non Detects
Inactive or Abandoned
Cone of Depression Contour
September 2014
0 1.5 3
Miles

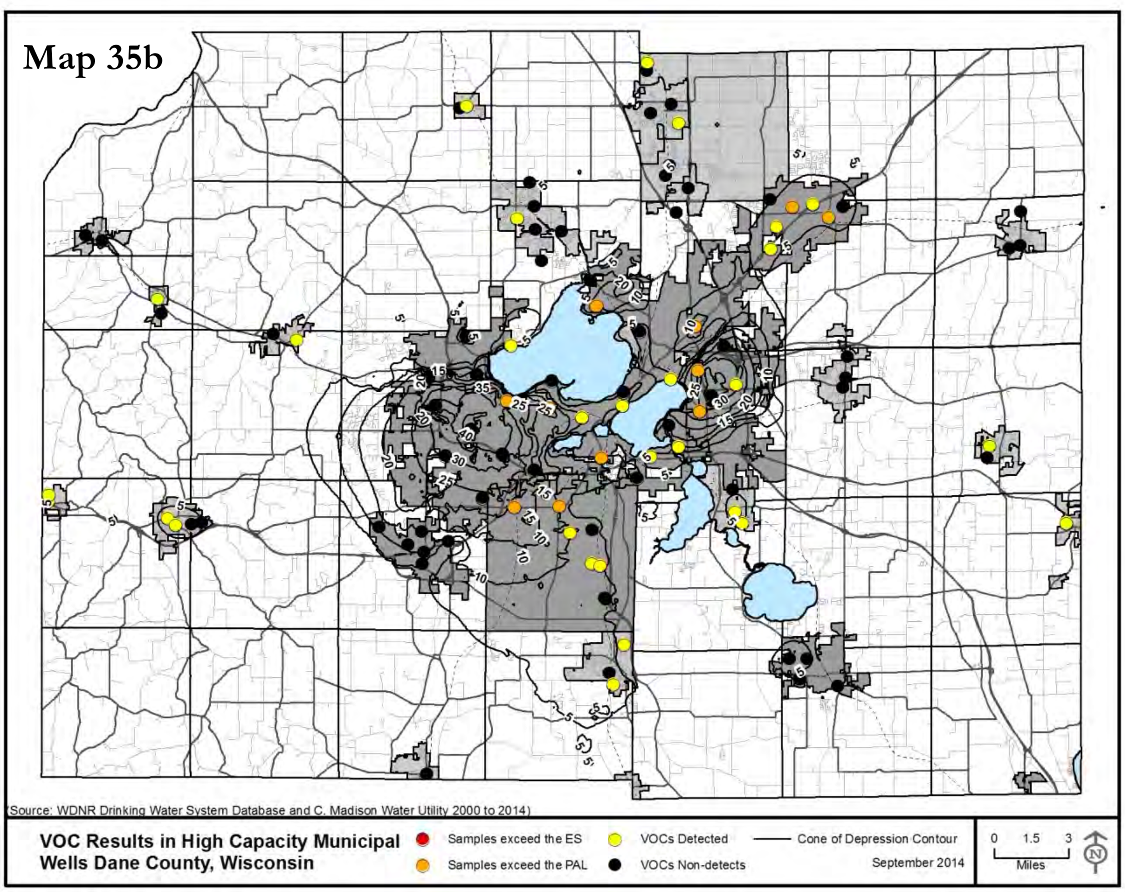

Map 35b
(Source: WDNR Drinking Water System Database and C. Madison Water Utility 2000 to 2014)
VOC Results in High Capacity Municipal
Wells Dane County, Wisconsin
Samples exceed the ES
Samples exceed the PAL
VOCs Detected
VOCs Non-detects
Cone of Depression Contour
September 2014
0 1.5 3
Miles

Table 17. Summary of 2012 VOC Detections in Madison Wells					
Volatile Organic Compound	Maximum	Units	Well(s) Present	MCL[1]	MCLG[2]
Dichlorodifluoromethane	[0.20][3]	µg/L	14	--	--
1,2-Dichloroethylene (cis)	[0.34]	µg/L	8, 11	70	70
Tetrachloroethylene [PCE]	3.9	µg/L	6, 9, 11, 14, 15, 18, 27	5	zero
Trichloroethylene [TCE]	0.43	µg/L	11, 14, 15, 18, 27	5	zero
Trichlorofluoromethane	0.92	µg/L	11	--	--
Xylene, Total	[1.5]	µg/L	225	10000	10000

[1] Maximum Contaminant Level (MCL) - the maximum amount allowed in drinking water
[2] Maximum Contaminant Level Goal (MCLG) - the level below which there is no known or expected risk to health
[3] Bracketed numbers correspond to measurements above the detection limit but below the limit of quantification (LOQ)

Wisconsin has 66 active and 600 closed, licensed solid waste landfills, which are required to monitor groundwater. In addition, the WDNR currently tracks about 20,000 leaking underground storage tanks (LUSTs) and about 8,000 reported releases at a variety of facilities including gas stations, bulk petroleum and pipeline facilities, plating, dry cleaning, industrial facilities, and abandoned non-approved unlicensed landfills. Many of these sites have been identified as sources of VOCs. The WDNR also tracks approximately 33,000 spills, some of which are also sources of VOCs. The WDNR Bureau of Remediation and Redevelopment Tracking System (BRRTS) is a searchable database containing information on the investigation and cleanup of potential and confirmed contamination to soil and groundwater in Wisconsin. **Map 36** indicates the contaminated and cleaned up sites in Dane County. Properties that are or were contaminated with hazardous substances can be found using the WDNR's Bureau for Remediation and Redevelopment Tracking System (BRRTS). Types of hazardous substance occurrences or discharges that are documented in the BRRTS database include:

- Abandoned Container (AC) – an abandoned container with potentially hazardous contents has been inspected and recovered, but discharge to the environment has not occurred.
- Leaking Underground Storage Tank (LUST) – a leaking underground storage tank has contaminated soil and/or groundwater with petroleum. Petroleum products contain cancer-causing and toxic substances, but may biodegrade, or break down naturally in the environment, over time.
- Environmental Repair (ERP) – sites other than LUSTs that have contaminated soil and/or groundwater. Industrial spills or dumping, buried containers of hazardous substances, closed landfills, and leaking above-ground petroleum storage tanks are potential ERPs.
- Voluntary Party Liability Exemption (VPLE) - an elective process in which a property owner conducts an environmental investigation and cleanup of an entire property and then receives limits on future liability for that contamination.
- Spills – discharges of hazardous substances, usually cleaned up quickly.

Currently, there are 189 open-status sites in Dane County that have contaminated groundwater and/or soil These sites include 3 Spills (2278 closed sites) 80 Leaking Underground Storage Tanks (1239 closed), 99 ERP sites (336 closed), and 7 VPLE sites (8 closed).

Map 36. WDNR Bureau of Remediation and Redevelopment Sites, Dane County, WI.

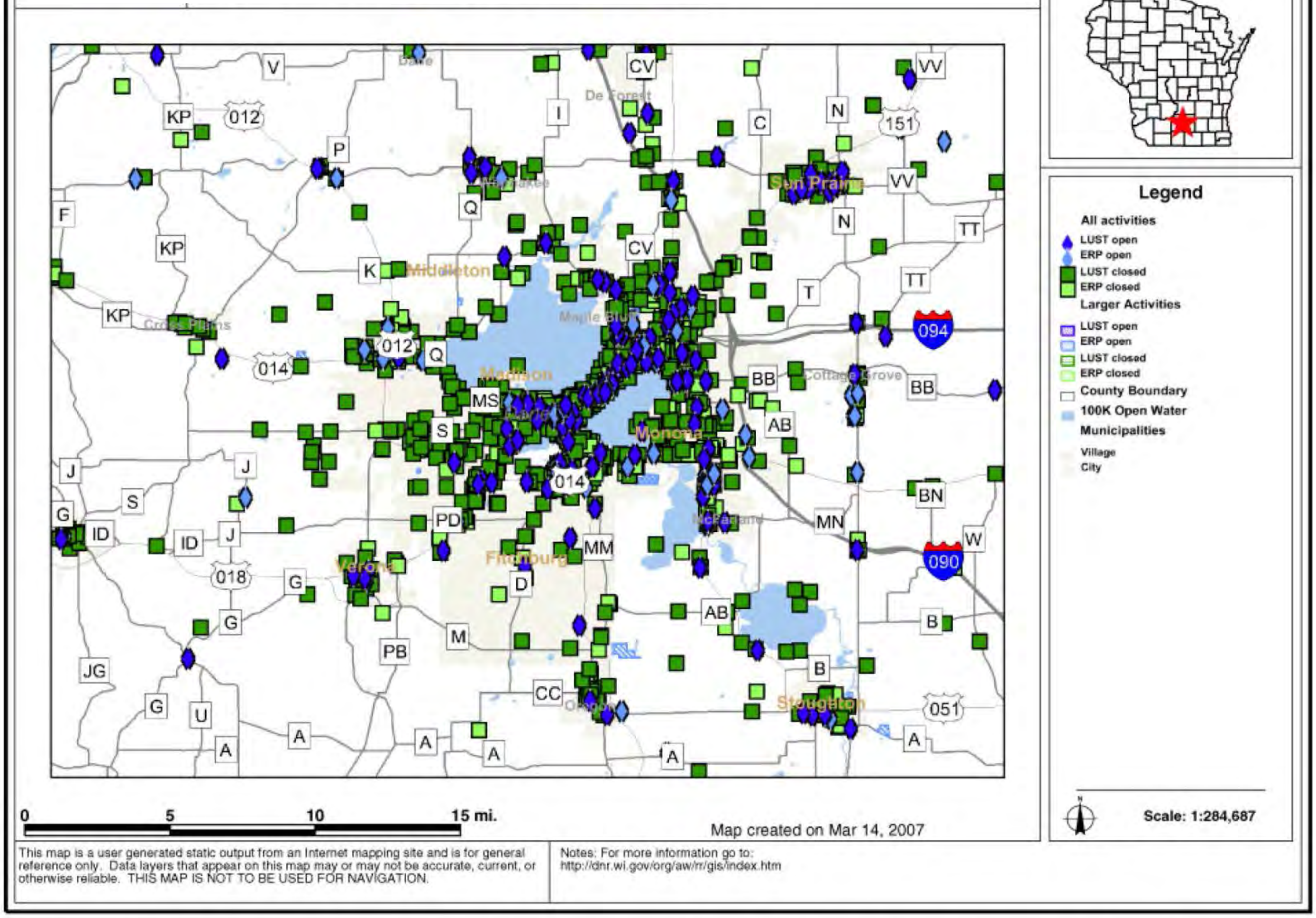


Figure created for the "Protecting Wisconsin's Groundwater Through Comprehensive Planning" web site, 2007, *http://wi.water.usgs.gov/gwcomp/*

Landfills

Two studies conducted over four years revealed that VOCs were significant contributors to groundwater contamination at unlined Wisconsin landfills.[16] Out of a total of 45 unlined municipal and industrial landfills tested, 27 (60 percent) had VOC contamination in groundwater. All of these landfills are currently closed. Of 26 unlined municipal solid waste landfills tested, VOCs contaminated groundwater at 21 (81 percent). No VOCs were confirmed present at any of the six engineered (liner and leachate collection) landfills included in the studies. While 20 different VOCs were detected overall, 1,1 – Dichloroethane was the most commonly occurring VOC at all of the solid waste landfills.

In a follow-up VOC study conducted from July 1992 through July 1994, the WDNR reviewed historical data and sampled groundwater at 11 closed, unlined landfills and at six lined landfills. VOC levels had decreased after closure at all but two of the unlined landfills, although at many sites VOC levels did not show continued improvement. Also, the level of contamination, while below initial concentrations, remained high at many closed sites. No VOC contamination attributable to leachate migration was found at any of the six lined landfills investigated.

[16] Wisconsin Groundwater Coordinating Council., 2014. *Fiscal Year 2014 Report to the Legislature*.

Underground storage tanks

Wisconsin requires underground storage tanks (USTs) with a capacity of 60 gallons or greater to be registered with the Department of Safety and Professional Services. Since 1991, this registration program has identified over 180,000 USTs of which 82,260 are federally regulated. About 11,978 federally regulated tanks are in use, with a total of 51,337 USTs in use total (federally regulated and state regulated). A federally regulated tank is any tank, excluding exempt tanks that is over 1,100 gallons in size, has at least 10 percent of its volume underground, and is used to store a regulated substance. Wisconsin regulates USTs down to 60 gallon capacity. Exempt tanks include: farm or residential tanks of 1,100 gallons or less; tanks storing heating oil for consumptive use on the premises where stored; septic tanks; and storage tanks situated on or above the floor of underground areas, such as basements and cellars.

Hazardous waste

Hazardous waste treatment storage and disposal facilities are another VOC source. There are approximately 140 sites statewide subject to corrective action authorities, and WDNR's Bureau for Remediation and Redevelopment is overseeing investigation or remediation at approximately half of these sites. Generators improperly managing hazardous waste are another source of VOC contamination. The majority of hazardous waste projects are being addressed in accordance with the NR 700 Wis. Adm. Code series.

Hazardous Substance Spills

The Hazardous Substance Spill Law, ch. NR 292.11 Wis. Stats., requires immediate notification when hazardous substances are discharged, as well as taking actions necessary to restore the environment to the extent practicable. In FY 13 approximately 870 hazardous substance discharges were reported to WDNR. Approximately 550 were spills, 310 were Environmental Repair Program sites or LUSTs, and 13 were agrichemical discharges reported to DATCP.

The NR 700 Wis. Adm. Code series, specifically ch. NR 706, contains the requirements for notification when a discharge or spill occurs. Chapter NR 708 contains requirements for taking immediate and/or interim actions when releases occur. Groundwater monitoring is performed when necessary to delineate the extent of contamination. The spills program develops outreach materials to help reduce the number and magnitude of spills and provide guidance for responding to spills. Topics addressed include spills from home fuel oil tanks, responses to illegal methamphetamine labs, and mercury spills, all of which can lead to significant environmental impacts, if not properly addressed.

What solutions are available for citizens?

Public water supplies are tested regularly to ensure that they meet the safe drinking water standards. If a community well is contaminated with VOCs, consumers will be notified of the problem by the water system owner and given instruction what to do. Typically, the water system will be required to drill a new well in an uncontaminated area. Communities can also opt to treat the water by aeration or filtration. These methods are highly effective in reducing VOC levels. However, the cost of equipment, operation and maintenance can be very high. Water quality must also be monitored regularly to assure that the treatment continues to work.

Private well owners are responsible for the safety of their own water supply and should have their water tested if they suspect contamination. All wells located near a potential source of VOCs, such as a landfill, airport, industrial site, or service station, should be tested periodically. If well owners notice a solvent-like or gasoline taste or odor in their water, they should use an alternate, safe source until it can be tested for VOCs. Owners whose wells have VOCs above health advisory levels should contact the WDNR for assistance. In most cases, they will be advised to replace the well with a new, safe water supply. Sometimes, a temporary solution can be used. These typically involve the use of bottled water, connecting to a neighboring well, or installing a home treatment system.

The most important action citizens can take is to prevent contamination. Pouring dirty or spent solvents or paint thinners onto the ground does not really get rid of them – they pollute the air and can contaminate drinking water supplies.

- Dispose of solvents properly. Waste VOCs should be taken to a hazardous waste collection facility.
- Use less toxic alternatives like borax, ammonia, vinegar, and baking soda whenever possible.
- Never flush solvents into a septic system. That actually releases them directly into the ground.
- Report spills immediately.
- Participate in "Clean Sweep" hazardous waste collection/exchanges in your community.[17]

For more information contact the WDNR Bureau of Water and Drinking Water.[18]

Pharmaceuticals, Personal Care Products, and Endocrine Disrupters

Pharmaceuticals, personal care products (PCPs) and endocrine disrupting compounds (EDCs) are a large group of substances present in human generated waste streams that could potentially contaminate groundwater resources. These substances are recognized by U.S EPA, along with other chemicals, as contaminants of emerging concern (CECs), emerging contaminants (ECs) or trace organic contaminants (TOCs).

The list of pharmaceuticals is long and includes such medications as tranquilizers, pain killers, antibiotics, birth control, hormone replacement, lipid regulators, beta blockers, anti-inflammatories, chemotherapy, antidiabetics, seizure control, veterinary drugs, antidepressants, and other psychiatric drugs. There is a related category of chemicals referred to as "personal care products" that includes over-the-counter non-prescription medication, cosmetics, perfumes, soaps, sunscreens, insect repellants, etc. The volume of pharmaceuticals and personal care products entering the environment each year is about equal to the amount of pesticides used.[19] New analytical methods, allowing detection of very small quantities of a substance, have helped improve investigations into the occurrence of emerging contaminants such as pharmaceuticals, PCPs, and EDCs in the environment. In 2000 the U.S Geological Survey conducted a nationwide assessment of drugs in streams and groundwater. They picked locations likely to be contaminated and found pharmaceuticals in about 60 percent of groundwater samples. Potential sources of discharge of pharmaceuticals to the environment include wastewater treatment plants, onsite wastewater treatment systems, landfills, sludge and manure spreading, and livestock feedlots.

Why be concerned about traces of chemicals that were designed to be consumed? We are only beginning to understand the health effects. Because of the low concentrations, any effects are likely to appear only after years of exposure. A real concern is that some of the drugs are endocrine disruptors. Endocrine glands, such as the thyroid, pituitary, or thymus send hormones, such as adrenaline, estrogen or testosterone to specific cells stimulating certain responses. There are hundreds of different hormones, and they are messengers that regulate a multitude of normal biological functions, such as growth, reproduction, brain development, and behavior. The delivery of hormones to various organs is vital, and when the delivery, timing, or amount of hormone is upset, the results can be devastating and permanent. Chemicals that are similar to hormones ("hormone mimics") can fit onto the receptor sites on the target cells and either block the real hormones or trigger abnormal responses in the cells. Scientific studies have indicated links between endocrine disruptors

[17] http://www.danecountycleansweep.com/
[18] http://dnr.wi.gov/regulations/labcert/documents/testsforwell.pdf
[19] USGS Protecting Wisconsin's Groundwater Through Comprehensive Planning website. http://wi.water.usgs.gov/gwcomp/find/dane/index_full.html

and reproductive disorders, immune system dysfunction, certain types of cancer, congenital birth defects, neurological effects, attention deficit, low IQ, low sperm counts, and early onset of puberty in girls.[20] The mobility and fate of discharged/released substances in the subsurface is a function of a variety of factors including the substance's adsorption and biodegradability properties and the amount and characteristics of any soil through which the substance percolates before reaching groundwater. Recent studies in other states have shown that pharmaceuticals, PCPs, and EDCs can be present at sites where treated wastewater is used to recharge groundwater. In Wisconsin, research has been done evaluating the occurrence and movement in the subsurface of some pharmaceuticals, PCPs, and EDCs.

The WDNR is using the results of pharmaceutical, PCP, and EDC research studies to evaluate whether current state groundwater protection regulations are adequate to address potential adverse impacts from the discharge of these substances. Studies comparing the levels of pharmaceuticals, PCPs, and EDCs present in wastewater influent with treatment system effluent levels are providing information on the removal effectiveness of wastewater treatment processes. Research into the behavior of pharmaceutical, PCP, and EDC substances in soil and groundwater is helping the WDNR develop effective monitoring strategies. Studies evaluating new sampling techniques and analytical test methods have helped assure that the WDNR is utilizing the best available tools to assess the occurrence of these substances in the environment.

In the meantime, the WDNR recommends that household pharmaceuticals be managed as follows:

1. REDUCE pharmaceutical waste whenever possible.

- Use all antibiotics as prescribed by your doctor.
- Buy only as much as can reasonably be used before the expiration date.
- When your doctor prescribes a new medication, ask the doctor to prescribe only enough to see if the medication will work for you and in the lowest dose advisable. That way, if the medication doesn't suit you, less goes to waste. Do the same for your pet's medications.
- Reconsider the use of products that claim to be antimicrobial or antibacterial. Plain soap and water is as effective as antibacterial soaps. The Centers for Disease Control recommends plain soap in its hand washing procedure.
- For more ideas, see UW-Extension’s pharmaceutical waste reduction information http://www4.uwm.edu/shwec/pharmaceuticalwaste/reduceHome.cfm

2. REUSE/RECYCLE drugs when possible.

- Wisconsin allows certain pharmacies to take back unit doses of drugs for cancer and chronic diseases. Certain drugs can be returned for re-issuance through the Cancer Drug Repository.
- Citizens may be able to donate other items; however, the circumstances where this is possible are limited. While it is a noble intention, it is very unlikely that medications from households would be acceptable for use overseas. If you see an opportunity to do this, approach with caution and research the program well.

3. DISPOSE of the remainder properly.

- If you have narcotics or other controlled substances, contact your local police department to find out if the police will accept them. Some police departments accept non-controlled substances too, but you should find out exactly what yours will accept before dropping off the items.

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[20] Morse, E. 2005. *Drugs in Our Water?*

- Whenever possible, take your unused pharmaceuticals to a pharmaceutical collection program or event.[21]
- **Note:** If you choose to store your waste for a pharmaceutical collection, please minimize the risk of accidental poisoning, overdose or diversion (illegal use by someone other than the intended person) by storing medications out of reach of children or in a locked cabinet.

Microbial agents

Microbial agents include bacteria, viruses, and parasites. These agents can cause acute illness and result in life-threatening conditions for young children, the elderly, and those with chronic illnesses or depressed immune systems. Some of the more familiar organisms include *Cryptosporidium*, *E. coli*, and *Salmonella*. Common symptoms include diarrhea, nausea, vomiting, cramps, or fever. When people bathe or shower in this contaminated water, it is less likely that they become ill. However, they can still get sick with ear and respiratory infections, skin rashes, or infections in open wounds.

Bacteria

In one assessment,[22] approximately 23 percent of private well water samples statewide tested positive for total coliform bacteria, an indicator species of other biological agents. In Dane County between 15-20 percent of private wells tested positive for total coliform bacterial over the last 25 years.[23] The reason is often a construction defect (e.g., loose or cracked well cap, poor grout, corroded casing, improper backflow prevention, etc.). A percentage of bacterial contamination much higher than 15 percent is often an indication of geologic or aquifer susceptibility in an area.

A survey of WDNR's GRN database in Dane County indicates bacterial pollution of shallow wells is widespread (**Map 37).** Shallow private wells are typically more vulnerable than deep municipal wells, which are also disinfected. Increased frequency of results observed near subdivisions may be the result of many factors including greater numbers and frequency of tests, higher concentrations of homes resulting in greater potential for contamination, older homes, as well as surrounding land uses. WDNR recommends private well owners test water for total coliform bacteria annually, especially when there is a change in taste, odor, or appearance. Municipal water suppliers typically disinfect their water supplies and sample quarterly.

Bacterial contamination is likely from a local source and is often associated with poorly constructed or located wells. Problems may be solved on-site and future problems minimized if wells are constructed according to the Wisconsin well construction code (NR 112) and located at appropriate distances and direction from pollution sources. Bacterial pollution can be treated by chlorination and other methods, although this does not always solve the problem. If bacteria persist, the source of pollution should be identified and corrected.

WDNR responds to homeowners regarding private well contamination, many of which correspond to manure spreading. Until 2007 there were no readily available methods for testing for manure in these wells. Standard methods for testing for bacteria do not indicate whether the source is human or non-human sources. Recently developed laboratory techniques have made it possible to discern whether bacteria are from human, animal, or other sources.[24] Since 2007 groundwater analyses by WDNR indicate that the majority of well water samples were contaminated with grazing animal waste (i.e., manure). Less than ten percent of samples collected indicate microbial contamination from human sources.[25] The manner in which manure is spread on the landscape does make it more likely to result in sudden or widespread contamination of a

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[21] http://www.safercommunity.net/meddrop.php

[22] Warzecha, C. et al. 1995. *Wisconsin Private Well Water Quality Survey.*

[23] UW-Stevens Point Well Water Quality Viewer. http://gissrv2.uwsp.edu/cnr/gwc/pw_web/.

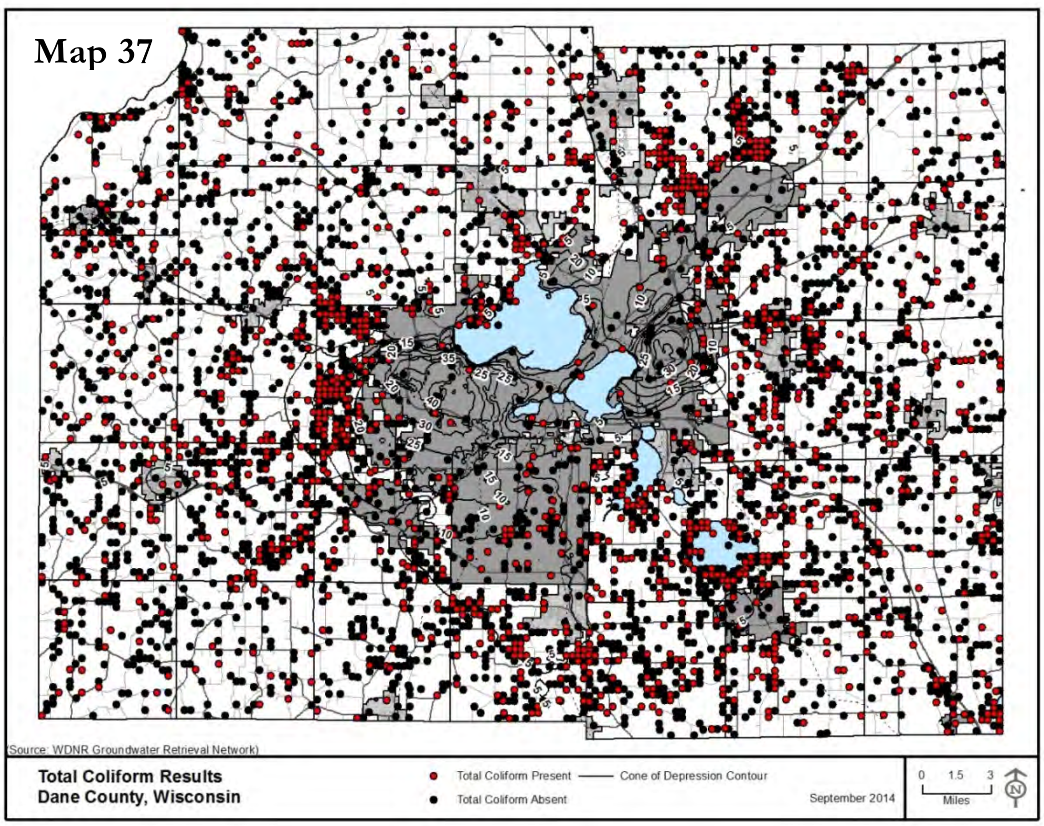
[24] These microbial source tracking (MST) tools include tests for *Rhodococcus coprophilus* (indicative of grazing animal manure) and *Bifidobacteria* (indicative of human waste).

[25] Groundwater Coordinating Council. 2014. *Report to the Legislature.*

groundwater aquifer. Whatever is taking place within a quarter to half mile of the well is likely influencing well water. WDNR and DATCP oversee liquid manure spreading, particularly during late winter and early spring, when manure should not be tilled and cannot be absorbed by soil.

Some common factors that can lead to contamination of residential wells include:

- Thin or sandy soils above fractured bedrock,
- Groundwater near the surface,
- Depressions where runoff water stands (or drains into the ground),
- Sink holes,
- Winter or early spring spreading of manure nearby (especially liquid manure),
- Winter and early spring rains or snow melt causing runoff from nearby fields,
- Nearby unused or improperly abandoned wells,
- Residential wells with shallow or cracked casings, and
- Poorly constructed wells.



Runoff risks can be substantially reduced if manure spreading is done according to an approved nutrient management plan, which includes a number of restrictions on manure applications. Currently, 36 percent of Dane County's cropland is covered by a state-approved nutrient management plan.

The State Well Code requires all new wells to be tested for bacteriological quality. Wells must also be tested following the installation or reinstallation of a pump, or anytime a well is entered for repairing or reinstalling equipment within the well. The Wisconsin Department of Health and Family Services recommends that all wells be sampled for bacteria at least once a year, or whenever there is any change in the taste, odor, or appearance of the water. Even if none of these factors are present, activities or circumstances that put well water at risk cannot always be seen by well owners. The best times of the year to test well water are when it is most likely to be unsafe. Statistically these times occur following a period of heavy snowmelt in early spring or during the hot stagnant time of late summer and early fall. If the water is found to be unsafe then the area surrounding the well should be checked for possible sources of contamination including animal yards, septic systems, sewers, improperly abandoned wells, landfills, sinkholes, quarries, bedrock outcroppings, etc.

Other possible causes of an unsafe water condition include inappropriate openings in the well head, a damaged or corroded casing, an inadequate casing depth, faulty installation of an adapter or any other component of the pump installation. If any of these items seems to be a likely cause of the well contamination, the necessary repairs should be made to the water system. A licensed Well Driller, or Pump Installer can assist in inspecting the well and water system and to recommend whether or not the system should be modified, upgraded, or replaced.

Viruses

Viruses in groundwater are becoming an increasing concern as new analytical techniques have detected viral material in private wells and public water supplies. Research conducted at the Marshfield Clinic indicates that 4-12 percent of private wells contain detectible viruses. Another study, conducted in conjunction with the USGS, found that 50 percent of water samples collected from four La Crosse municipal wells were positive for intestinal viruses.[26]

Public and private water samples are not regularly analyzed for viruses due to the high cost of the tests. The presence of coliform bacteria has historically been used to indicate the water supply is not safe for human consumption. However, recent findings show that coliform bacteria do not always correlate with the presence of enteric viruses. For example, municipal water sampled by Borchardt and others (2004) showed that, even though 50 percent of the samples were positive for viruses, none of the same samples tested positive for coliform or other indicators.[27] Indicators have a high positive predictive value but a low negative predictive value for pathogen occurrence. In other words, when an indicator is present in drinking water there is a high probability that particular water source will be contaminated with a pathogen at some time. However, if an indicator is absent, no inferences can be made about pathogen occurrence. Additional study is needed to determine what virus results mean to human health.

Microbial contamination of groundwater is also not restricted to aquifers typically regarded as vulnerable or shallow aquifers. In a novel study, researchers discovered human viruses in the confined aquifer supplying Madison's drinking water .[28] This finding was completely unexpected because it was believed the 3 to 9 meter shale confining layer protected the aquifer from microbial contamination. Additional research by the Marshfield Clinic, WGNHS, and USGS on the Madison wells has shown virus transport from leaking sanitary sewers to the wells is very rapid, on the order of weeks to months instead of years.[29] The virus transport and contamination levels were particularly high after extreme rainfall events or rapid snowmelt. From a public health perspective, the lesson learned is that *all* aquifers are potentially vulnerable to microbial contamination. Public water supply systems in cities, towns, or villages that supply groundwater are particularly vulnerable to pathogen contamination from leaky sanitary sewer systems. While there is no federal or state requirement for such systems to disinfect their drinking water, the vast majority of Wisconsin's municipal water utilities do, killing viruses and bacteria that can unexpectedly occur in groundwater.

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[26] Wisconsin Groundwater Coordinating Council., 2014. *Fiscal Year 2014 Report to the Legislature.*

[27] Borchardt M. et al. 2004. *Vulnerability of Municipal Wells in La Crosse, Wisconsin, to Enteric Virus Contamination from Surface Water Contributions.*

[28] Borchardt, M. et al. 2007 *Human Enteric Viruses in Groundwater from a Confined Bedrock Aquifer.*

[29] Bradbury, K. 2013. *Source and Transport of Human Enteric Viruses in Deep Municipal Water Supply Wells.*

Inorganic Elements of Concern

Inorganic compounds are rather simple chemicals. They can be described as mineral in nature and usually exist as ions – substances with a positive or negative charge – when dissolved in water. Familiar examples include calcium, chloride, sodium, iron, magnesium, manganese, nitrate, sulfate, and zinc. Many inorganics are naturally occurring minerals that are dissolved from the rock which makes up the aquifer. However, some of these compounds may be introduced to surface and groundwater by human activities – nitrate (a component of fertilizer) and sodium chloride (road salt) are two examples. Municipal water utilities in Dane County routinely test their wells for different inorganic compounds including those named above plus arsenic, barium, cadmium, chromium, lead, mercury, selenium, thallium, among others.

For example, **Table 18** summarizes the annual inorganic test results for Madison well samples collected in 2013. With few exceptions, notably nitrate, the regulated inorganic contaminants that were detected are found at levels near the detection limit, generally <1 μg/L, and well below the maximum contaminant level (MCL). The ranges of results are similar to those observed in previous years. Representative test results for municipal wells in Dane County can be found in **Attachment A**. In addition, annual Consumer Confidence Reports (CCRs) required by U.S. EPA and the federal Safe Drinking Water Act can be obtained from individual water utilities, which detail the quality of their drinking water supplies.

Table 18
Summary of Annual Inorganic Test Results After Chemical Treatment for Madison Wells

Parameter	Units	MCL	Minimum	Median	Maximum
Alkalinity (CaCO3)	mg/l	-	270	313	343
Aluminum	µg/l	50-200*	0.3	0.4	2.6
Antimony	µg/l	6	<0.206	<0.206	<0.206
Arsenic	µg/l	10	<0.206	<0.206	1.2
Barium	µg/l	2000	7.8	19	53
Beryllium	µg/l	4	<0.206	<0.206	<0.206
Cadmium	µg/l	5	<0.103	<0.103	<0.103
Calcium	mg/l	-	56	70	100
Chloride	mg/l	250*	2.1	20	109
Chromium	µg/l	100	0.4	1.1	2.8
Conductivity	umhos / cm	-	507	667	1040
Copper	µg/l	1300	1.0	3.1	58
Fluoride	mg/l	4	0.6	0.8	0.9
Hardness (CaCO3)	mg/l	-	278	340	464
Iron	mg/l	0.3*	<0.0013	0.06	0.58
Lead	µg/l	15	<0.103	0.12	9.2
Magnesium	mg/l	-	33	42	52
Manganese	µg/l	50*	<0.206	9.6	90
Mercury	µg/l	2	<0.0206	<0.0206	<0.0206
Nickel	µg/l	100	0.4	0.9	3.7
Nitrogen-Nitrate	mg/l	10	<0.12	0.7	3.9
Nitrogen-Nitrite	mg/l	1	<0.04	<0.04	0.08
pH (Lab)	s.u.	6.5-8.5*	7.5	7.6	7.9
Potassium	mg/l	-	1.0	1.4	1.7
Selenium	µg/l	50	<0.412	0.4	1.1
Silver	µg/l	100*	<0.206	<0.206	<0.206
Sodium	mg/l	20*	2.1	8.8	37
Sulfate	mg/l	250*	7.0	18	55
Thallium	µg/l	2	<0.103	<0.103	0.32
Total Solids	mg/l	500*	296	417	784
Zinc	µg/l	500*	4.3	11	194

Shaded boxes correspond to regulated contaminants

*U.S. EPA Secondary Drinking Water Regulations – non-enforceable Federal guidelines regarding cosmetic effects (such as tooth or skin discoloration) or aesthetic effects (such as taste, odor, or color).

Source: Madison Water Utility 2013.

Chloride

The issue of chloride in ground and surface waters warrants particular mention. Chloride is very soluble and therefore mobile in the environment. Chloride at levels greater than 10 mg/L usually indicate contamination by de-icers, onsite wastewater treatment systems, fertilizer, animal waste, or other wastes. Chloride is not toxic in concentrations typically found in groundwater, but some people can detect a salty taste at 250 mg/L. Levels of chloride that are above what is typical under natural conditions indicate that groundwater is being affected by human activities, and extra care should be taken to ensure that those activities do not degrade water quality further.[F42] Since there are no cost effective treatment options currently available at the landscape scale (reverse osmosis or microfiltration being prohibitively expensive), reduction in usage appears to be the best and most effective salt management strategy to-date.

Increasing chloride (salt) concentrations in the Yahara Lakes, area streams, and some municipal wells have been well documented (**Figures 24, 25, and 26,** respectively). **Figure 26** compares past chloride concentrations with deeply cased wells, which draw water from the lower Mt. Simon aquifer, and wells with short casings which draw water from both the upper and lower aquifers. The bisecting line represents the median concentration. Generally the deeper wells show lower chloride levels because of their distances from the land surface, dilution, and a protective shale layer (the Eau Claire formation) between aquifers in some areas. While these levels have been found to be generally below the secondary (aesthetic) drinking water standard of 250 mg/L, they do indicate an increasing trend. **Figure 27** shows historic salt use in Madison and Dane County, the two largest salt users. The increase indicates road building has been increasing faster than salt reduction efforts can offset. Salt applied to sidewalks and parking lots is believed to equal or exceed City use.[30]

Map 38a shows chloride concentrations in wells tested in Dane County. Two factors that influence the sodium and chloride levels at a well are length of the steel casing and proximity to major roadways (salt routes). A well with a short casing draws proportionally more water from the upper aquifer and water quality is more impacted by surface activities such as road salt application. Note that reductions in water table levels represented by the cones of depression northeast and southwest of the Yahara Lake chain do not indicate a significant relationship or cause of higher chloride levels. Also, research indicates that salt concentrations in northern U.S. streams are more associated with deicer application than other sources (e.g., water softeners).[31]While these concentrations are all below drinking water standards (maximum 146 mg/L west of Madison), increasing levels in some wells is certainly cause for concern. **Map 38b** shows the rate of increase in municipal high capacity wells over the last 20 years (shown as warm colors in the map) along with some decreases (shown as cool colors in the map).

The use of sodium chloride for street deicing is the norm throughout much of the northern United States and Canada for a reason: it is cheap and effective. Although some communities augment their deicing capabilities with alternative deicers, there is currently nothing available to adequately replace sodium chloride. Substitute deicers are usually either a different salt, which still contributes to the chloride issue, or an organic compound. Organic compounds contribute nutrients, oxygen demand, and/or metals instead of chloride. So, replacement of sodium chloride with an organic deicer would trade chloride toxicity for increases of already problematic algal blooms, lake dead zones (maybe fish kills), and/or metals toxicity, as well as a substantial increase in cost.

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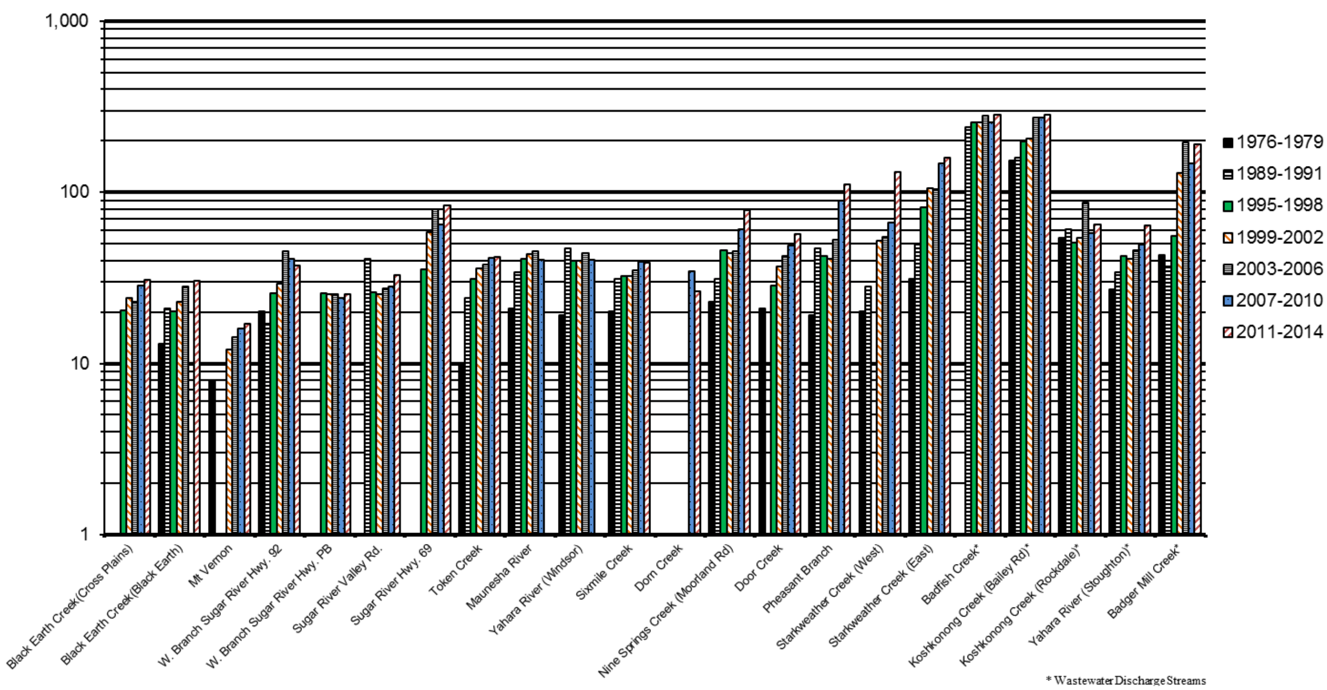
[30] City of Madison 2012 Road Salt Report

[31] Corsi, S. et. al., 2010. *A Fresh Look at Road Salt: Aquatic Toxicity and Water Quality Impacts on Local, Regional, and National Scales.*

Figure 24. Average Annual Chloride Levels in the Yahara Lakes, 1915 to present.

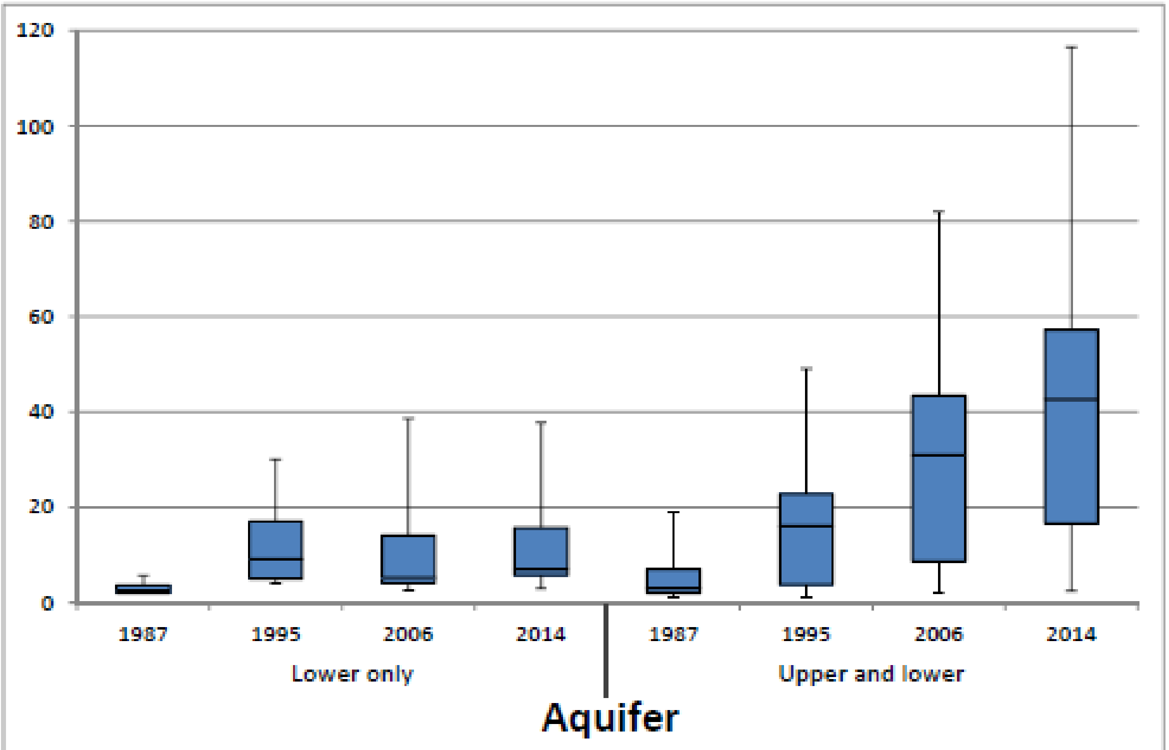
Source: *2014 Road Salt Report*. Public Health Madison and Dane County.

Figure 25. Historical Comparison of Mean Baseflow Chloride Concentrations in Area Streams (mg/L).



Source: CARPC Cooperative Water Resources Monitoring Program and U.S. Geological Survey

Figure 26. Chloride Trends in Madison Wells.



Lower aquifer only

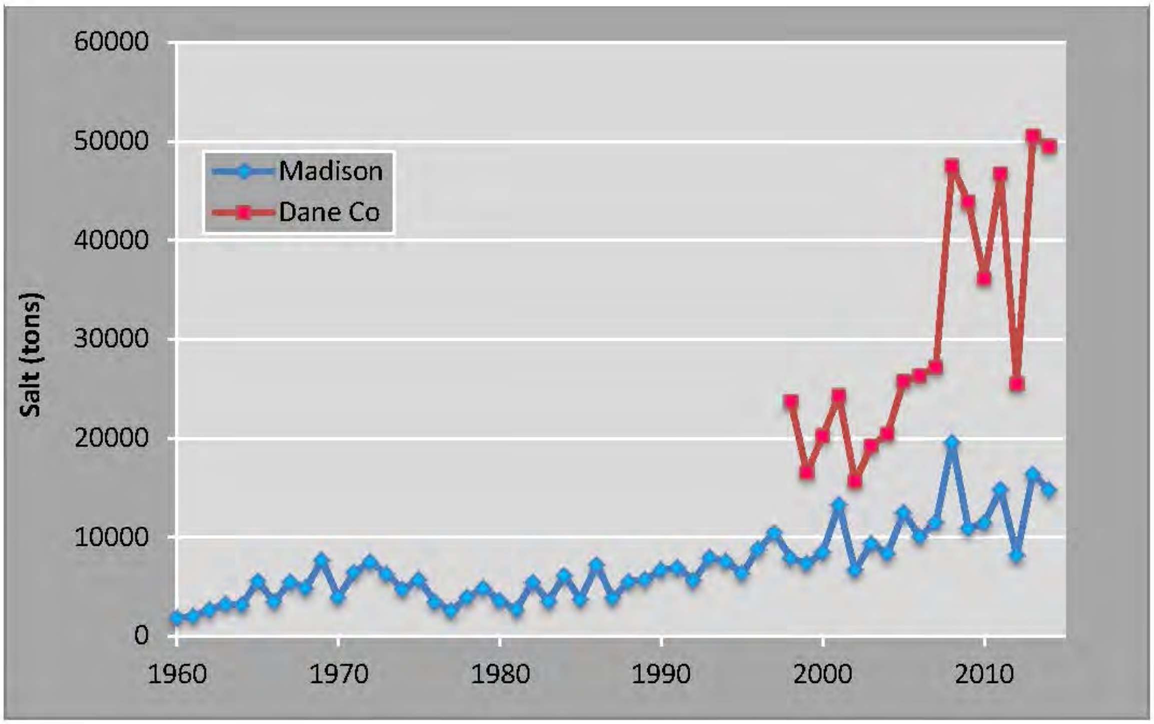
Year	#7	#8	#19	#24	#27	#28	#29	#30
1987	2.0	5.6	2.0	3.0				
1995	9.0	17.0	4.0	5.0	30.0			
2006	13.4	16.0	5.4	5.1	38.6	2.5	2.6	4.6
2014	15.1	17.6	7.6	6.3	37.7	2.9	5.3	5.8

Upper and lower aquifer

Year	#6	#9	#11	#12	#13	#14	#15	#16	#17	#18	#20	#23	#25	#26
1987	7.0	16.0	2.9	1.0	6.0	8.0	3.0	1.0	19.0	2.0	2.0	5.0	1.1	
1995	23.0	35.0	18.0	1.0	6.0	41.0	22.0	14.0	21.0	7.0	1.0	49.0	1.0	3.0
2006	28.9	33.0	47.3	2.5	8.3	76.8	41.6	34.2	43.9	9.5	2.1	82.0	2.6	11.4
2014	59.2	45.7	57.1	3.5	39.6	116.6	53.6	57.3	34.9	13.2	2.4	71.7	3.6	26.7

Source: Madison and Dane County Public Health 2014 Road Salt Report

Figure 27. Annual Road Salt Use: Madison and Dane County.



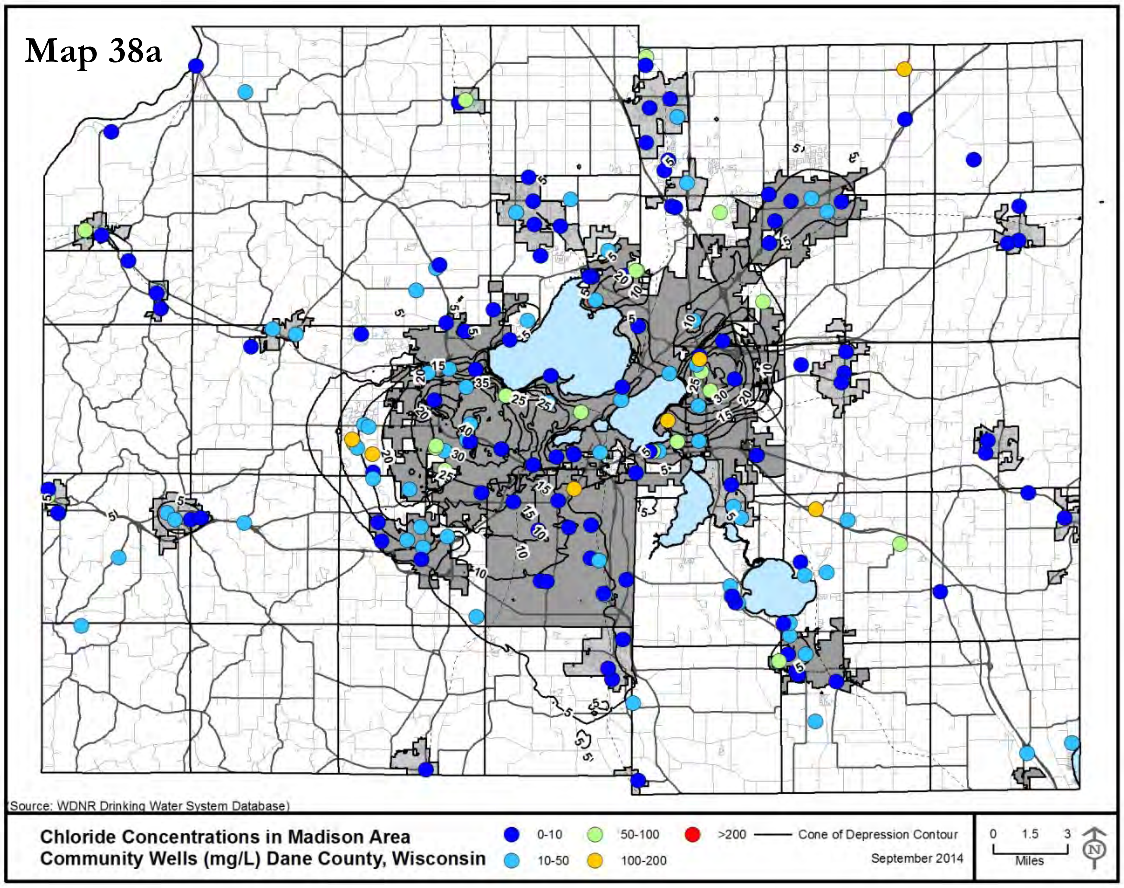
Source: Public Health Madison and Dane County Road 2014 Salt Report.

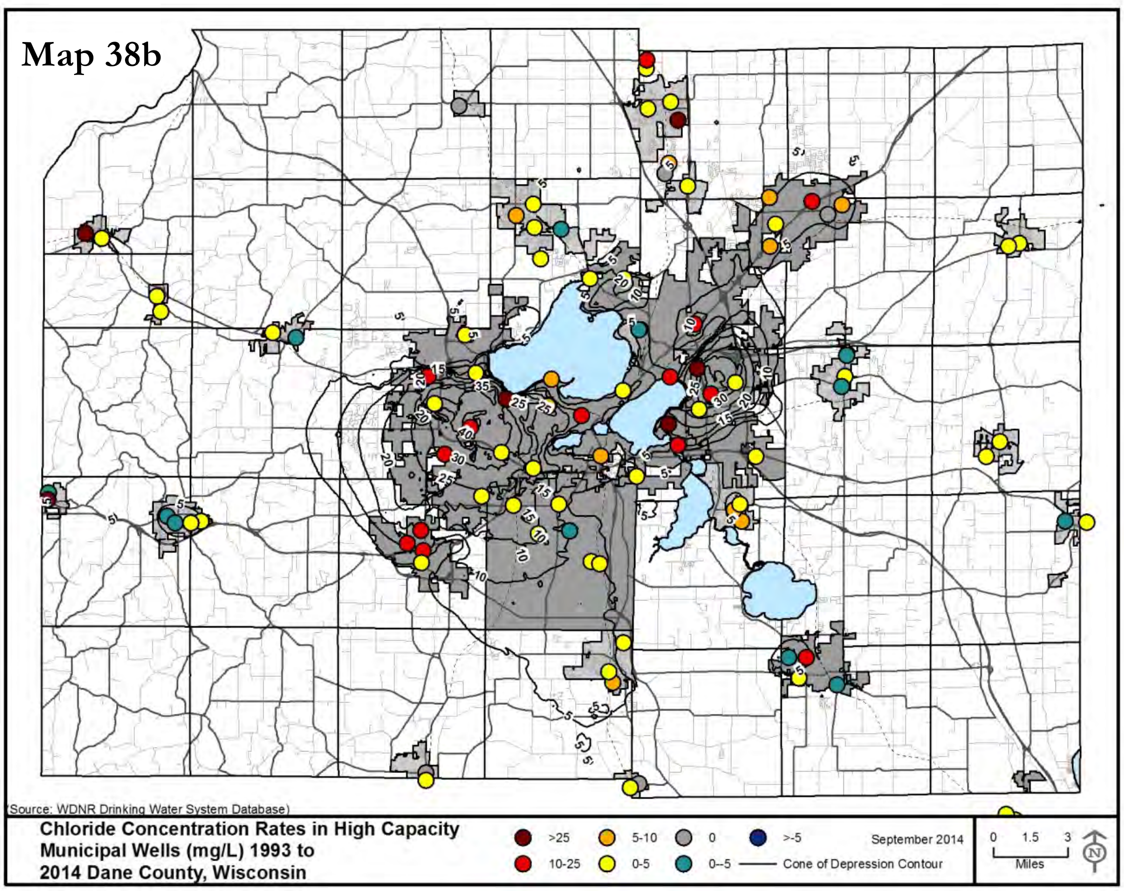
Sodium chloride appears to be the best choice at this time, however, once it is applied road salt cannot be recovered. The only remediation currently available is the dilution and flushing provided by precipitation. So communities must use less to minimize its detrimental effects. Reductions through judicious and efficient application won't be enough, and may have already reached their potential. A shift in maintenance goals from "bare pavement" to "safely passable" is required, and other reduction efforts will be necessary too. Salt application in capture zones around drinking water wells should be restricted. Salt use on parking lots and sidewalks should be substantially reduced. Lastly, and just as important, every community within the Yahara Lakes watershed (as elsewhere) should be engaged in a collaborative, basin-wide salt reduction effort. There is little satisfaction for one community to forego the convenience of bare pavement if upstream communities are not similarly self-constrained.

Forty years ago, Madison had the foresight to recognize the fate and effects of wholesale road salt application. Since then, a commendable effort has been made to maintaining a balance between safe roadways and judicious deicing. However, steadily increasing chloride levels indicate more reductions are necessary in this as well as in other communities. Homeowners can also assist in reducing the amount of salt in our ground and surface waters:

- Keep walkways shoveled as snow quickly becomes ice when walked upon
- Pre-treat walkways before the storm, less deicer will be need in the long run
- Mix sand with salt to gain additional traction
- Consider not using a water softener
- Use a portable exchange-type softener, which contains a replaceable cartridge and does not release used brine into the wastewater stream
- Place self-regenerating softeners "On-Demand" to regenerate itself as needed and not automatically on a timer
- Set water softener for the correct water hardness level, many are installed at the highest setting

The Wisconsin Salt Wise Partnership provides useful information for reducing salt usage across the spectrum of public and private groups https://www.wisaltwise.com/


Map 38a
(Source: WDNR Drinking Water System Database)
Chloride Concentrations in Madison Area Community Wells (mg/L) Dane County, Wisconsin
0-10
10-50
50-100
100-200
>200
Cone of Depression Contour
September 2014
0 1.5 3
Miles


Map 38b
(Source: WDNR Drinking Water System Database)
Chloride Concentration Rates in High Capacity Municipal Wells (mg/L) 1993 to 2014 Dane County, Wisconsin
>25
10-25
5-10
0-5
0
0--5
>-5
Cone of Depression Contour
September 2014
0 1.5 3
Miles

Sodium

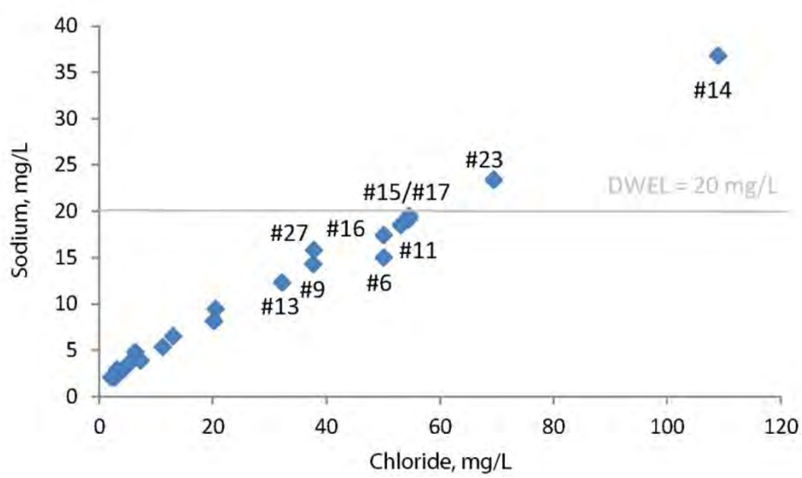
Sodium is the sixth most abundant element on earth and is widely distributed in soils, plants, water, and foods. It is essential to human life. When salt such as sodium chloride dissolves in water it breaks up into positively- and negatively-charge sodium and chloride ions, respectively. Every water supply contains some sodium and chloride from the natural weathering of rocks and soils. The total concentration of sodium in groundwater is dependent on the local geologic conditions as well as contamination from other sources. Salt used in de-icing can elevate sodium concentrations in groundwater and drinking water supplies. Domestic water softeners can also contribute additional sodium to household drinking water by replacing the calcium and magnesium that make the water hard.

The U.S. EPA recommends that sodium concentrations in drinking water not exceed 20 mg/L for higher-risk individuals on low-sodium diets.[32] This is the same level recommended by the American Heart Association. A diet high in sodium has been identified as a risk factor and in health complications due to high blood pressure. Currently, the EPA requires that all public water systems monitor sodium levels and report levels greater than 20 mg/L to local health authorities so that physicians treating people on sodium-restricted diets can advise patients accordingly. A review of City of Madison wells found wells #14 and #23 have sodium levels in excess of 20 mg/L (**Figure 28)**, as do other wells around the county (**Maps 39a and b**).

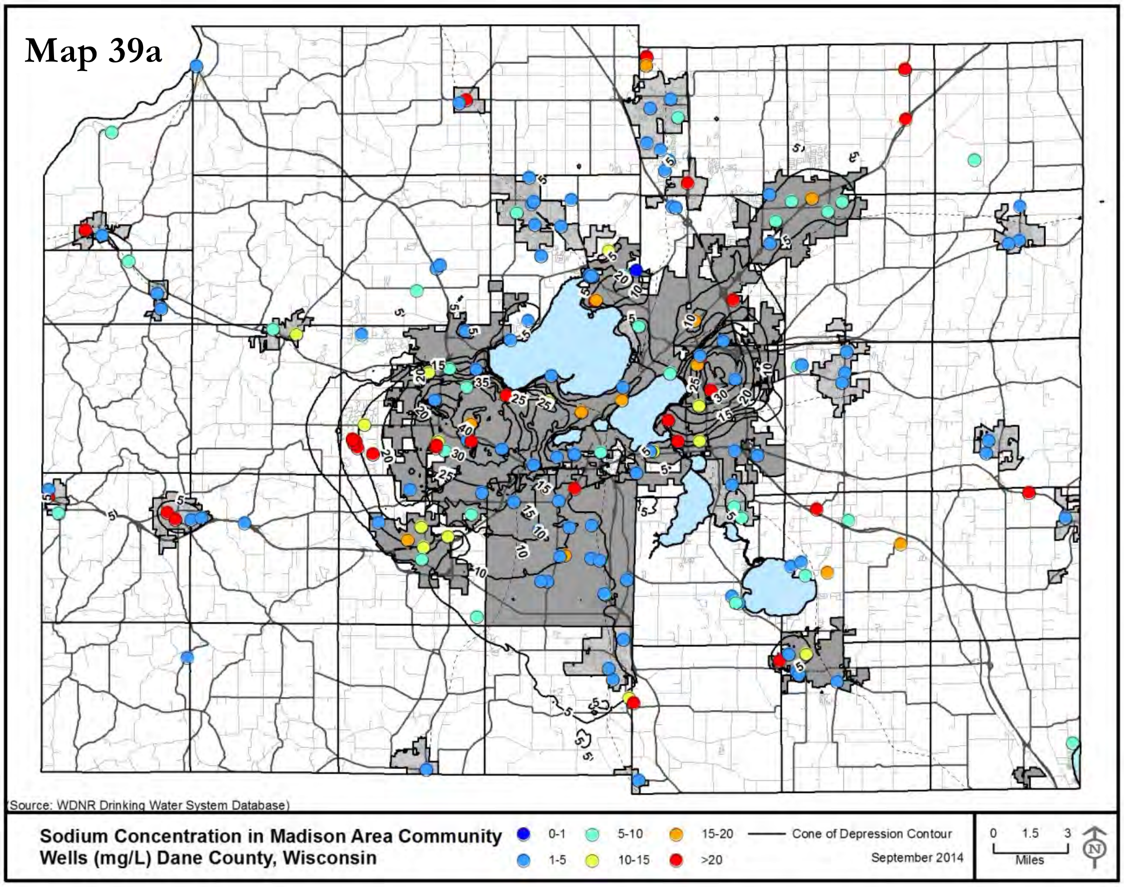
It should be noted that this is a very stringent level. For comparison purposes, regular milk has a sodium concentration of approximately 500 mg/L. A review of scientific data from U.S. EPA shows that the vast majority of sodium ingestion is from food rather than drinking water. Sodium levels in drinking water from most public water systems are unlikely to be a significant contributor to adverse health effects. Drinking water contributes only a small fraction to a person's overall sodium intake. When considering the health importance of sodium, EPA assumed that water users consume two liters of water per day and found that 10 percent or less of a person's daily sodium intake comes from drinking water. The rest is usually from food. While persons on a sodium-restricted diet should evaluate all sources of sodium when attempting to reduce their sodium intake, it is often much easier (and less expensive) to make a dietary change than to purify drinking water.

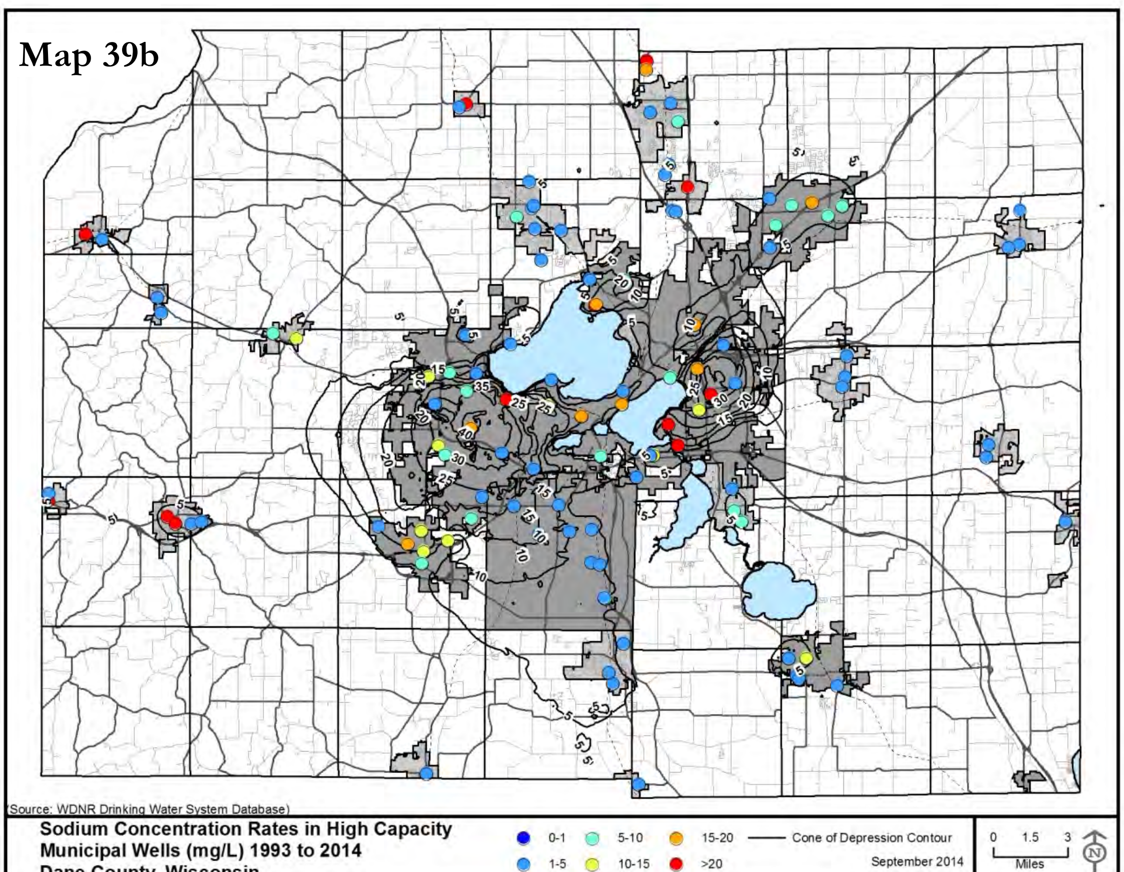
Several years ago the water conditioning industry was pleased to announce the advent of sodium free salt – potassium chloride. Potassium salt works in the same way as sodium salt in the ion exchange softener, but instead of exchanging the hardness minerals for sodium it exchanges them for potassium. Not only does this new product contain no sodium but in fact contains a mineral which is useful and beneficial to the body, potassium. The drainage from softeners using potassium salt during regeneration is also more environmentally friendly than sodium because potassium is an important plant nutrient.

Figure 28. Sodium and Chloride Levels at Madison Municipal Wells



[32] The Drinking Water Equivalent Level (DWEL) for sodium of 20 mg/L is a lifetime exposure level at which adverse, non-carcinogenic health effects would not be expected to occur.


Map 39a
(Source: WDNR Drinking Water System Database)
Sodium Concentration in Madison Area Community Wells (mg/L) Dane County, Wisconsin
0-1
1-5
5-10
10-15
15-20
>20
Cone of Depression Contour
September 2014
0 1.5 3
Miles
N


Map 39b
(Source: WDNR Drinking Water System Database)
Sodium Concentration Rates in High Capacity Municipal Wells (mg/L) 1993 to 2014 Dane County, Wisconsin
0-1
1-5
5-10
10-15
15-20
>20
Cone of Depression Contour
September 2014
0 1.5 3
Miles
N

Iron and Manganese

Iron and manganese are common elements found in minerals, rocks, and soil. Iron is one of the earth's most plentiful resources, making up at least five percent of the earth's crust. When rainfall seeps through the soil, the iron in the earth's surface dissolves, causing it to seep into almost every natural water supply, including well water. While present in drinking water, iron is seldom greater than 10 mg/L. Iron is not considered hazardous to health. In fact, iron is essential for good health because it transports oxygen in our blood. In the United States, most tap water supplies less than 5 percent of the dietary requirement for iron.

Under WDNR drinking water standards (NR 809.60), iron is considered a secondary or "aesthetic" contaminant. The recommended limit for iron in water is 0.3 mg/L, based on taste and appearance rather than on any detrimental health effect. Concentrations of iron as low as 0.3 mg/L can cause water to turn a reddish brown color and leave stains on plumbing fixtures, tableware, and laundry that are very hard to remove. The water may also have a metallic taste and an offensive odor. Water system piping and fixtures can also become restricted or clogged with iron bacteria.

Manganese is another common element found in drinking water. It is also part of a healthy diet, but can be harmful if consumed in excess. The U.S. EPA has established a drinking water health advisory for manganese of 300 μg/L. Many years of exposure to high levels of manganese can cause harm to the nervous system. A disorder similar to Parkinson's disease can result. This type of effect is most likely to occur in the elderly. The federal health advisory for manganese is intended to protect against this effect.

Manganese is also a concern for infants and young children, especially for bottle-fed infants. Certain baby formulas contain manganese as a nutrient, and if prepared with water that also contains manganese, the infant may get a higher dose than the rest of the family. In addition, young children appear to absorb more but excrete less manganese than older age groups. This adds up to a greater potential for exposure in the very young. Some studies suggest that early childhood and prenatal exposures to manganese can have effects on learning and behavior. Thus, it is very important to know what the manganese levels in drinking water are when using it to make baby formula.

Otherwise, manganese is found in small amounts in meat and vegetables. A normal diet provides 2000 to 5000 μg manganese per day. Mineral supplements may contain as much as 5000 μg of manganese. As a comparison, drinking 8 cups of water at 300 μg/L would contribute 600 μg manganese – about a quarter of one's diet.

While manganese levels are not regulated in public water supplies, the U.S. EPA and WDNR have established an aesthetic water quality standard of 50 μg/L. Manganese levels below 50 μg/L should prevent the staining of bathroom fixtures and laundry. This standard is considerably lower than the health advisory established to protect public health.

Accumulation and later re-suspension of iron and manganese sediment in water mains is the primary cause of discolored water at the tap. Periodic flushing of hydrants helps remove the accumulated sediment where it is a problem; however, the groundwater source continually introduces new iron and manganese into the distribution system building the levels up again.

In Madison, monthly samples are collected at wells that consistently have iron and manganese above 0.15 mg/L and 20 μg/L, respectively. Four wells produce water with iron ranging from 0.15 to 0.25 mg/L, while two exceed the secondary drinking water standard of 0.3 mg/L, see **Table 19.** Eight wells have manganese levels above 20 μg/L but below the secondary standard of 50 μg/L. Due to aesthetic concerns by residents, such as staining of laundry or unpleasant taste, the Madison water utility is planning to add treatment at four wells to remove the iron and manganese from the source water.

Table 19. Summary Statistics for Wells with Higher Levels of Iron and Manganese					
Well	Samples	Manganese (μg/L)		Iron (mg/L)	
		Mean	St Dev	Mean	St Dev
7	11	27	0.7	0.37	0.02
8*	3	45	8.0	0.52	0.13
17*	7	34	6.2	0.13	0.04
19	11	44	3.6	0.19	0.01
23*	7	34	25	0.10	0.12
24	8	27	3.4	0.17	0.04
27*	5	31	1.2	0.14	0.02
28*	7	21	1.9	0.18	0.01
30	11	14	0.5	0.20	0.01

* Seasonal well, typically operating between April and September

Private Water Supplies

Shallow private wells are typically more susceptible to contamination than deep municipal wells. Also, unlike public water supplies, private wells are largely unregulated when it comes to regular or routine water quality monitoring. Private well owners are therefore responsible for the monitoring and safety of their own water supplies. Several factors can affect a well's vulnerability to contamination. These include:

<u>Well location</u> Contaminated wells are often located near farm fields, barnyards, feedlots, septic tanks, or industrial facilities.

<u>Well casing depth and construction</u> Since contaminants can enter the aquifer from the ground surface, wells that have shallow casing are more likely to be affected than deeper cased wells.

<u>Soil type or geology</u> Areas with thin, highly porous or sandy soils, and have shallow groundwater aquifers or fractured bedrock (karst topography), are most vulnerable to contamination. Alternatively, loamy soils can help absorb and significantly slow down the movement of some contaminants (like pesticides) but not others (like nitrates).

While construction codes and standards exist for the proper location, installation, and initial testing of private wells, this does not necessarily guarantee protection from the effect of surrounding land uses and practices, especially in an area with as productive of an agricultural industry as is found here. Since the situation and circumstances surrounding each well are different, it is usually a good idea for rural landowners to periodically test their wells.

Nitrates and Pesticides

A nitrate test is recommended for all newly constructed private wells and wells that have not been tested during the past 5 years. Testing is also recommended for well water used by pregnant women and is essential for a well that serves infants under 6 months of age. Wells with nitrate concentrations between 5 and 10 mg/L should be tested annually. Additional testing may also be useful if there are any known sources of nitrate or if high nitrate concentrations are found in neighboring wells.

Private well owners should also have their well tested if the suspect pesticide contamination. Wells contaminated with high nitrate levels are also more likely to be contaminated with agricultural pesticides. Owners whose wells have pesticides above the MCL should contact the regional office of WDNR for assistance. In most cases owners will be advised to replace the well with a new, safe water supply. Depending on the specific pesticide and the amount of contamination, the well owner may be able to purchase a home treatment system.

VOCs

All wells located near a source of VOCs, such as a landfill, airport, industrial site, or service station, should be tested periodically. If well owners notice a solvent-like or gasoline taste or odor in their water, they should use an alternate, safe source until it can be tested for VOCs. Owners whose wells have VOCs above health advisory levels should contact the WDNR for assistance. In most cases, they will be advised to replace the well with a new, safe water supply. Sometimes, a temporary solution can be used. These typically involve the use of bottled water, connecting to a neighboring well, or installing a home treatment system.

The most important action citizens can take is to prevent contamination. Pouring dirty or spent solvents or paint thinners onto the ground does not really get rid of them – they pollute the air and can contaminate drinking water supplies.

For people using private wells:

- Have your well system professionally inspected and water sampled annually (this is relatively inexpensive health insurance for you and your family)
- Identify and remove possible contamination sources away from your wellhead
- Be current on the cleaning and inspection of your septic system
- Properly decommission any abandoned wells using a licensed professional
- Never flush solvents into a septic system. This actually releases them directly into the ground

For those on public wells:

- Be informed about your Public Water Supply and regularly read its Consumer Confidence Reports
- Dispose of solvents properly. Waste VOCs should be taken to a hazardous waste collection facility

Things everyone can do:

- Use hazardous household substances and solvents according to manufacturer's recommendation and dispose of them properly after use
- Participate in "Clean Sweep" hazardous waste collection/exchanges in your community.[33]
- Report spills immediately
- Use less toxic alternatives like borax, ammonia, vinegar, and baking soda whenever possible
- Install water-saving devices
- Modify water use to conserve water

Bacteria

The Wisconsin Department of Health and Family Services recommends that all wells be sampled for bacteria at least once a year, or whenever there is any change in the taste, odor, or appearance of the water. Even if none of these factors are present, activities or circumstances that put well water at risk cannot always be seen by well owners. The best times of the year to test well water are when it is most likely to be unsafe.

[33] http://www.danecountycleansweep.com/

Statistically these times occur following a period of heavy snowmelt in early spring or during the hot stagnant time of late summer and early fall. If the water is found to be unsafe then the area surrounding the well should be checked for possible sources of contamination including animal yards, septic systems, sewers, improperly abandoned wells, landfills, sinkholes, quarries, bedrock outcroppings, etc.

Public Water Supplies

Public water supplies in Dane County are regularly sampled and tested by local municipalities and the WDNR to ensure compliance with federal and state drinking water regulations. The quality is generally quite high and safe for use. A listing of recent water analyses for Dane County municipal supply systems is provided in **Attachment A**. Passed in 1974, the Safe Drinking Water Act requires any water system serving 25 or more people to regularly test its water and comply with contamination limits. Since then, the number of contaminants regulated by the Act has grown from 13 to 87 primary contaminants, plus 15 secondary (aesthetic) substances.

Beginning in 1999, customers of all public water systems receive an annual Consumer Confidence Report from their water supplier. The report is mandated by the federal Safe Drinking Water Act and Environmental Protection Agency Rules. The annual water quality report includes information about the source of the drinking water supply, a list of any contaminants detected in the water and their concentrations, the potential sources and health effects of contaminants, and special health effects language for immuno-compromised individuals or other sensitive subpopulations if appropriate. The objective of the report is to provide consumers with clear, concise and accurate information about the quality of their drinking water in a readable, easily understandable format.

The recent analyses indicate that most water quality parameters are within federal safe drinking water standards (Ch. NR 809). Some municipal wells, though, have total residue, iron and manganese concentrations above secondary drinking water standards (representing objectionable water quality, such as taste or odor, rather than public health risks). The concentration of these constituents is often reduced by chemical or physical treatment. In more extreme cases, such as contamination by VOCs, wells have been abandoned and new wells drilled.

A water source exceeding a primary MCL may not serve a public water system until treatment is provided which brings the concentration below the MCL prior to entering the distribution system. Under the Consumer Confidence Report Rule, contaminants must be reported if detected at any level, but health effects information must be provided only if the level exceeds the MCL. It should be noted that drinking water contaminants are not necessarily related to the water source. Most drinking water samples are taken at customers' taps and could contain substances that contaminate the water in the distribution system or in the home. Several communities in Dane County, for example, have experienced elevated levels of copper and lead in drinking water and have taken measures to reduce concentrations of these metals. Lead and copper are not found in the groundwater in Dane County. Rather, high concentrations in tap water are the result of corrosion in lead and copper pipes and fixtures in water service lines and home plumbing systems.

Groundwater Contamination Risk Maps

Because residents of the county rely so heavily on groundwater, preventing contamination from occurring is the easiest and most efficient way of maintaining a clean and usable groundwater supply. Once groundwater becomes contaminated it is sometimes physically impossible or technically unfeasible to clean it up. Groundwater remediation costs are also very expensive. Therefore, prevention of groundwater contamination is essential. One way to do this is to identify those areas where the groundwater is most vulnerable to contamination.

Aquifer Vulnerability

As part of the Dane County Hydrologic Study, Fritz (1996) constructed and tested an aquifer contamination susceptibility Map for Dane County. This Map rates the relative risk (extreme, high, moderate, low) of groundwater aquifers to contamination from surface pollution sources (**Map 40**). The Map represents a combined overlay of the effects of soil properties, the hydrogeologic setting, and the distribution of groundwater recharge and discharge areas, described in **Attachment B**. By removing the attenuating soil layer, using this same methodology, a groundwater contamination risk Map from subsurface pollution sources was also created (**Map 41**).

By removing the soil layer, as was done in creating the subsurface map, all of the low, many of the moderate, while only a few of the high risk areas shift to the next lower risk classification (see **Table B-4 in Attachment B**). This shifts some areas with fair or good soils to the next lower susceptibility classification, emphasizing the importance of soil attenuation for reducing pollutants.

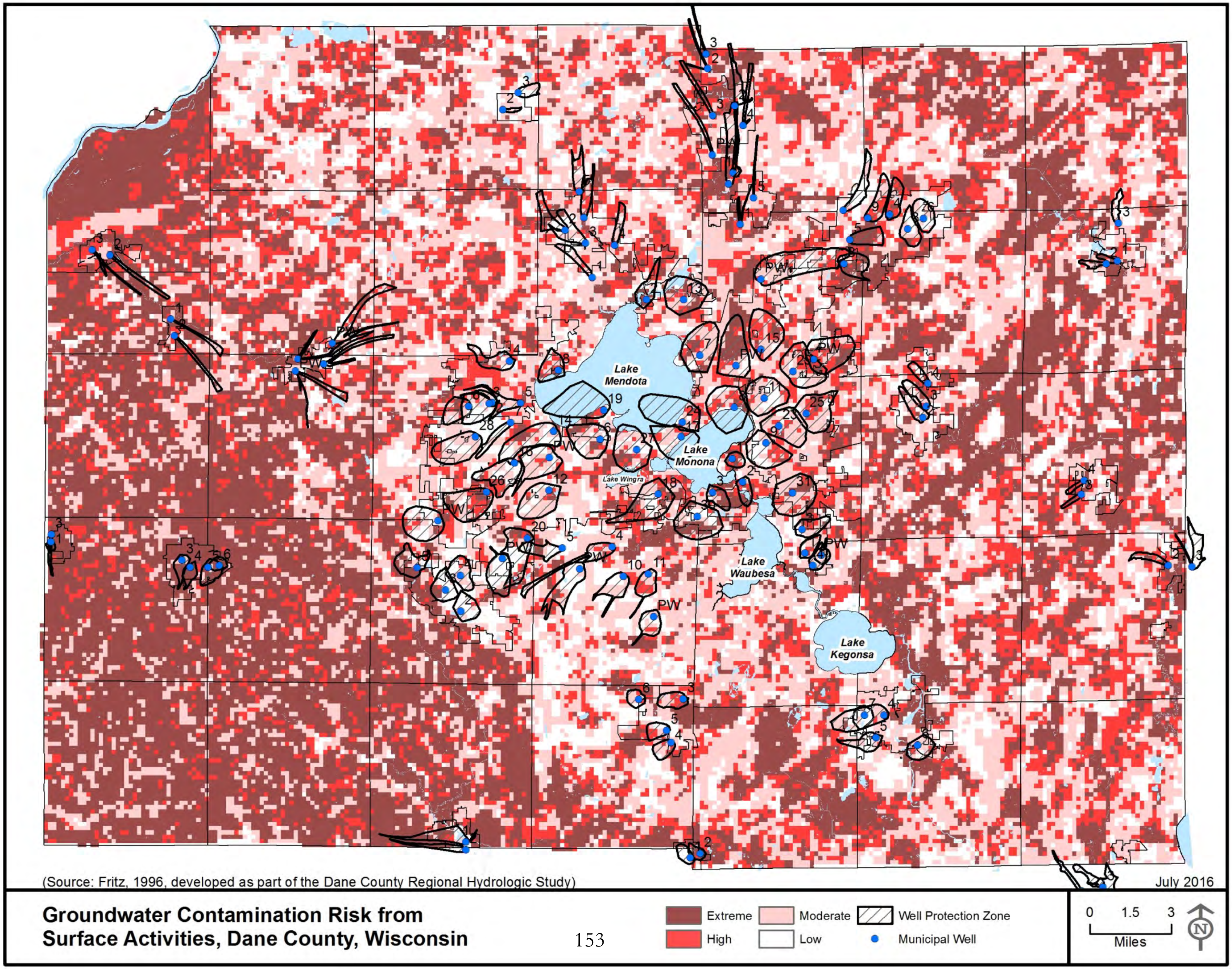
There are four final risk classifications shown on the maps: extreme; high; moderate; and low. Areas considered to be of extreme risk to contamination are areas of shallow bedrock or shallow groundwater, such as in the Driftless Area and the Wisconsin River Valley in the western part of the county, and the alluvial valleys in the eastern part of Dane County. Areas considered to be of low or moderate risk are located throughout the glaciated portion of Dane County, along the hummocky moraine zone and the Yahara lowlands.

Because of attribute variability within a single cell (one cell is 62,500 m^2—15.44 acres), it is recommended that the maps be used at the township level or larger. At this level, differences in topography and meaningful differences between risk classifications can be distinguished. Areas within 250 meters of the county boundary are likely to contain cells with no data; consequently, there is no risk classification for these areas.

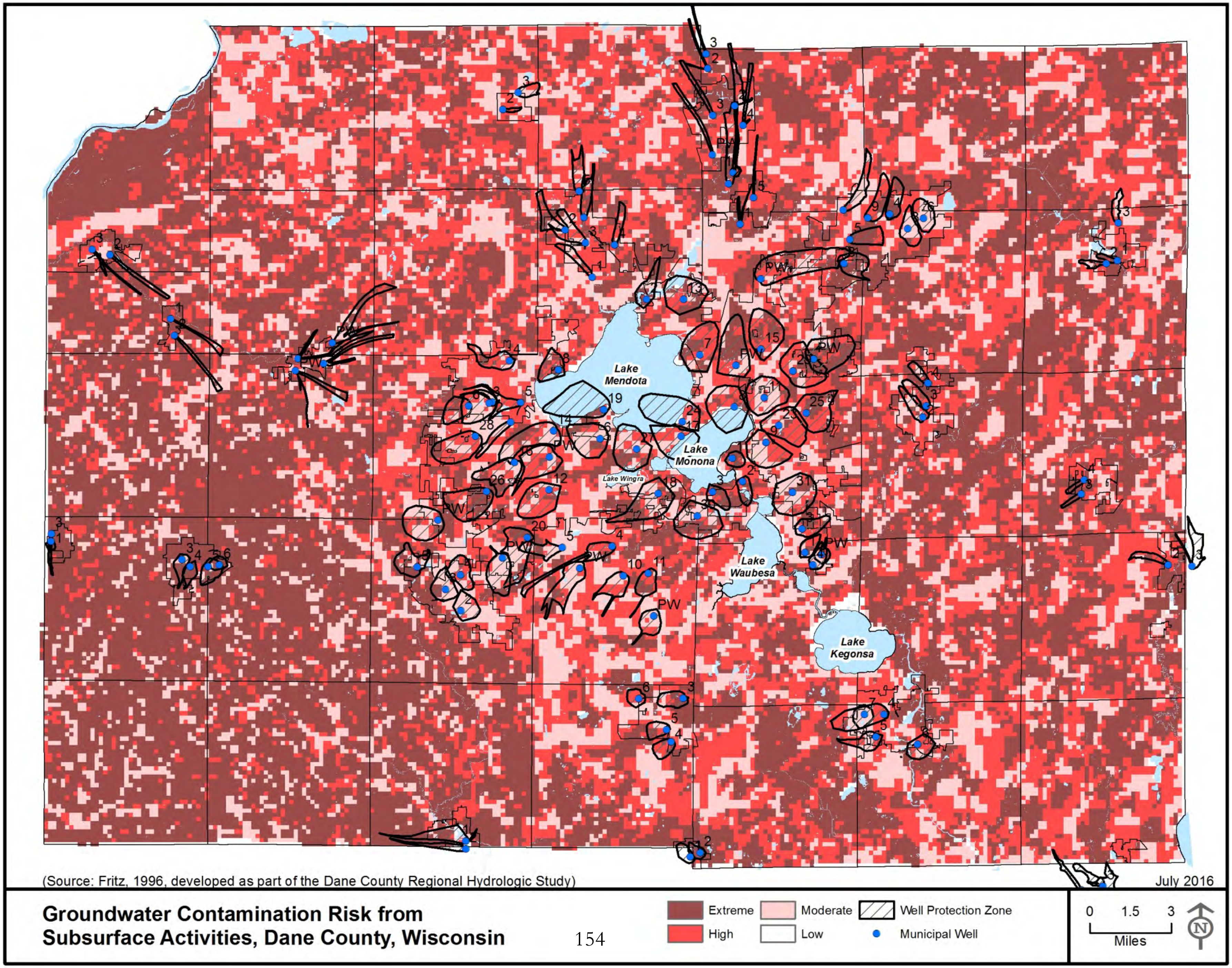
Groundwater Contamination Risk Maps are also very useful for cities, villages and towns to assess the threat of groundwater contamination posed by an actual contaminant source, such as a pesticide mixing area or leaking underground storage tanks. Suggested guidelines and criteria for using the Surface and Subsurface Groundwater Contamination Risk Maps are shown in **Table 20 and** presented in **Chapter 5.**

The Groundwater Contamination Risk Maps, together with the individual data layers, can be used as a screening tool for land and water planning and decision making, and for informing the public about the attributes of the environment that can protect groundwater.

Map 40


Lake Mendota
Lake Monona
Lake Wingra
Lake Waubesa
Lake Kegonsa
(Source: Fritz, 1996, developed as part of the Dane County Regional Hydrologic Study)
July 2016
Groundwater Contamination Risk from Surface Activities, Dane County, Wisconsin
Extreme
High
Moderate
Low
Well Protection Zone
Municipal Well
0 1.5 3
Miles
N

Map 41


Lake Mendota
Lake Monona
Lake Wingra
Lake Waubesa
Lake Kegonsa
(Source: Fritz, 1996, developed as part of the Dane County Regional Hydrologic Study)
July 2016
Groundwater Contamination Risk from Subsurface Activities, Dane County, Wisconsin
Extreme
High
Moderate
Low
Well Protection Zone
Municipal Well
0 1.5 3
Miles

Wellhead Protection

The Zone of Contribution (ZOC) of a well is the land surface area over which recharging precipitation enters a groundwater system and eventually flows to the well (**Fig. 29**). The ZOC is distinctly different from the zone of influence (ZOI) of a well, which is the area within the cone of depression created by the withdrawal of water from the well.

Delineating ZOCs for municipal wells is a critical step in establishing wellhead protection areas for the wells. A wellhead protection area (WHPA) is defined by the federal Safe Drinking Water Act as the "surface and subsurface area surrounding a water well or well field, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water or well field." In practical terms, the ZOC is a technically defined area based on groundwater hydraulics, while the WHPA is a legally defined area including all or part of the ZOC within which management practices or land-use controls can be implemented to help protect groundwater from contamination.

The Wisconsin Department of Natural Resources (WDNR) has the responsibility and authority to delineate wellhead protection areas for all public water supplies in Wisconsin. In 1992, the WDNR prepared the Wisconsin Wellhead Protection Program Plan, which required WDNR to perform initial ZOC delineations for all existing municipal wells in the state. At the same time, the Wisconsin Administrative Code, Ch. NR 811, was revised to require that a wellhead protection plan be submitted for each new municipal well constructed after April 1, 1992.

The technical methodologies for ZOC delineation range from simple to complex, and are described in a number of publications.[34] Most of these authors suggest simple techniques, such as the fixed-radius methods, as a first approach, but most also recommend the use of numerical groundwater flow models as more sophisticated and reliable methods for ZOC delineation. The Dane County Groundwater Flow Model is ideally suited for delineating ZOCs for high-capacity wells. As such, Bradbury (1998) used the model to delineate ZOCs for high capacity municipal wells throughout Dane County. These maps were subsequently revised using the updated groundwater model in 2014.

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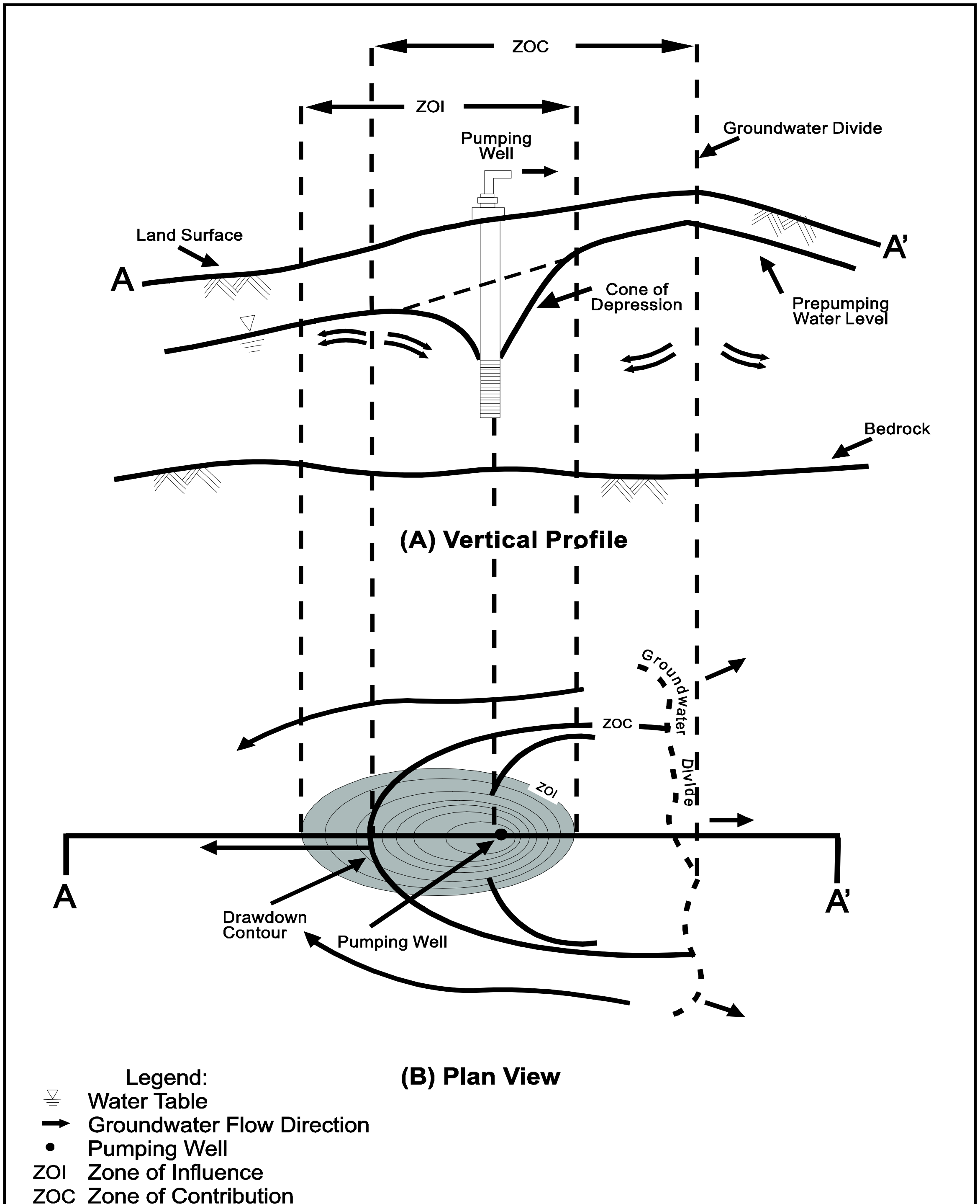
[34] U.S. EPA 1997, Born 1998, Bradbury 1991, Kreitler 1991, and Muldoon 1993, among others identified in Bradbury, K. 1998. *Zones of Contribution for Municipal Wells in Dane County, Wisconsin: Results of Delineations from the 1997 Regional Hydrologic Modeling and Management Program.*

Figure 29.
Diagram and Terminology for Wellhead Protection in a Simple Hypothetical Groundwater Flow System.



Source: U.S. EPA, 1987.

Delineation of ZOCs

One of the primary goals of the Regional Hydrologic Modeling and Management Program in 1997 was to delineate zones of contribution (ZOCs) as the basis for each municipality's wellhead protection strategy.[35] Various pumping rates and travel times were modeled as the basis for delineating ZOCs, offering each community a range of protection alternatives. Alternative ZOCs were delineated based on 5-, 50- and 100-year travel times for each of three different pumping rates:

1. 2020 Pumping – projected 2020 average daily water use distributed evenly among existing and future wells for each community;
2. Maximum Sustained Pumping – 50 percent of the pumping capacity for both existing and proposed new wells; and
3. Maximum Pumping Limit – full capacity pumping, indicating the worst-case scenario for individual wells under extreme water demand conditions. (It is unlikely that this could actually occur under sustained conditions, so it represents an extreme assumption.)

In 2014 the 5-, 50-, and 100-year ZOCs for both existing and planned wells were delineated using the upgraded groundwater model and average 2040 pumping rates (**Map 42**). The ZOCs indicate the area contributing groundwater to the well for an assumed pumping rate and travel time. These ZOCs can be used as a basis for delineating wellhead protection areas or zones which are used to evaluate or regulate land use or waste disposal activities which could have an adverse impact on the well.

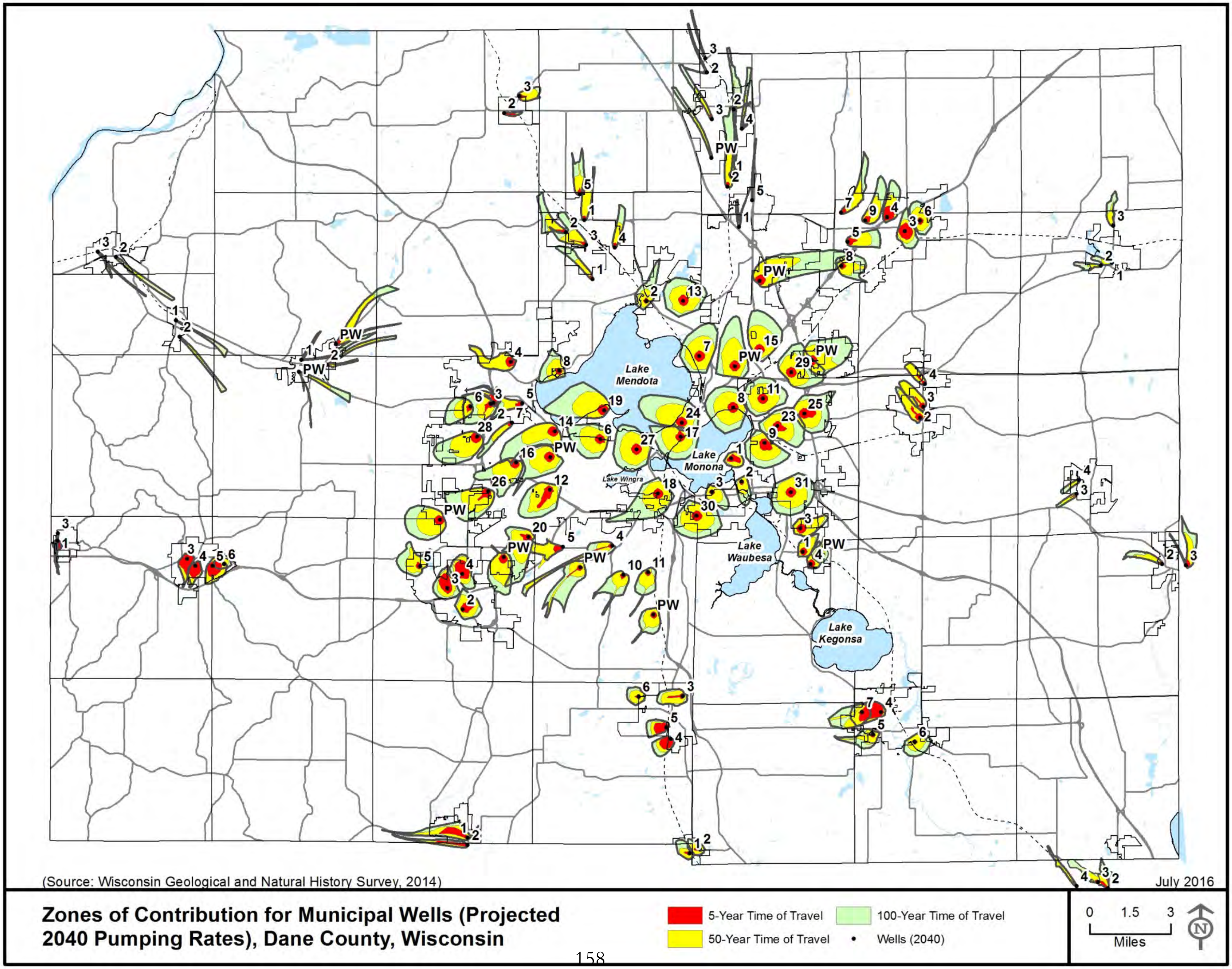
Accuracy of the ZOC Delineations

The accuracy of the locations of the ZOCs depends on the accuracy of the groundwater flow model and of the field data and data interpretations used to construct it. The MODFLOW and PATH3D codes themselves are mathematically very precise, and numerical errors associated with these codes are probably insignificant. However, the calibration of the groundwater flow model (the "fit" of the model to observed field data) is not perfect, although it is considered good from a groundwater modeling standpoint. In general, the model results are probably most precise in areas where hydrogeologic data are abundant, such as in the Madison metropolitan area. The model is less accurate in areas where hydrogeologic data are sparse, such as in western Dane County, where very few deep wells exist.

Also, all ZOCs assume steady-state conditions, meaning that groundwater levels and recharge rates do not change over short time periods. In areas where this assumption is not met the ZOCs may differ slightly from those shown here.

[35] Bradbury, K. 1998. *Zones of Contribution for Municipal Wells in Dane County, Wisconsin: Results of Delineations from the 1997 Regional Hydrologic Modeling and Management Program.*

Map 42



Lake Mendota
Lake Monona
Lake Wingra
Lake Waubesa
Lake Kegonsa
(Source: Wisconsin Geological and Natural History Survey, 2014)
July 2016
Zones of Contribution for Municipal Wells (Projected 2040 Pumping Rates), Dane County, Wisconsin
5-Year Time of Travel
50-Year Time of Travel
100-Year Time of Travel
Wells (2040)
0 1.5 3
Miles

In two municipalities, the Village of Brooklyn and City of Verona, the potential for error in the ZOC delineations is larger than in other areas. In both these municipalities the wells are located on or very near the regional groundwater divide between the Yahara River basin and the Sugar River basin. At these locations, the position of the divide is critical in controlling the direction of groundwater flow and thus the configuration of the zones of contribution. Field data in these areas are too sparse to allow a precise delineation of the position of the divide or to confirm the groundwater flow model. Therefore, the ZOCs for wells in these municipalities, while consistent with the groundwater flow model, are currently unconfirmed by field data, and should be used with caution. There is significant interference between wells, particularly in the Madison metropolitan area, that results in complex ZOCs. Simpler ZOC delineation methods, such as the fixed-radius techniques or even simple two-dimensional numerical models would fail to capture these interference effects and so would probably give inaccurate ZOC estimates. Even the more accurate ZOCs that have been developed could be substantially altered by removing a single interfering well from service.

Well Protection Zones

Previously developed well protection zones, delineated in the 1999 Dane County *Groundwater Protection Plan* as areas of special concern, were originally used to identify land areas where contaminants could potentially migrate to a municipal well. The zones were generalized and based on simplifying assumptions. They were used primarily as a screening device to evaluate the pollution risk from potentially harmful waste disposal or land use practices.

The modeled ZOCs are more precise and accurate than the previously developed (1999) well protection zones, which completely encompass the modeled 100-year travel time ZOCs for each municipality. However, the modeled ZOCs are still based on somewhat generalized assumptions, which do not reflect local variability in climatic and geologic conditions, seasonal variations or variations in pumping patterns or rates at nearby wells. It may be prudent, therefore, to define wellhead protection zones or areas which are larger than the modeled ZOCs to reflect and include the effects of uncertainties and local and seasonal variations.

WDNR requires wellhead protection plans for all new wells constructed after 1992, but requires only a 5-year time of travel. For most Dane County wells, the 5-year ZOC—typically less than 1,000 feet across—is probably too small to offer much protection. At the other end of the scale, the ZOC based on the maximum well pumping capacity is probably too severe an assumption, as this condition is unlikely to occur over a sustained period of time. The 50- and 100-year ZOCs— generally several thousand feet to a mile in length—probably represent more appropriate areas for groundwater protection efforts.

Well Protection Zones (**indicated on Maps 43 through 52**) were delineated for both existing and planned municipal wells throughout Dane County using the length of the ZOC for the 100-year, 2040 pumping rate. Well Protection Zones can thus serve as a useful technical basis for a community's wellhead protection program, or for legally defined Wellhead Protection Areas developed by a community, which may include land use controls, contingency planning or other drinking water safeguards.

Areas of Special Concern

Naturally Vulnerable Areas

The areas classified as Extreme on the Groundwater Contamination Risk Maps represent the most vulnerable areas in the county. Due to a combination of limiting physical factors (e.g., poor attenuating soils, shallow depth to bedrock and high groundwater table), these areas can be expected to provide a minimal amount of pollutant attenuation. Thus, siting of potential pollution sources or practices should be made with extreme caution or, if possible, avoided at these locations. Siting for a particular land use practice may require special conditions or provisions which establish groundwater safeguards, such as stricter maintenance, operating or monitoring requirements than are normally expected.

Potential Problem Areas

Potential problem areas are sites where existing pollution sources are located in vulnerable resource areas or which potentially threaten public drinking water supplies. These areas are a particular concern due to poor environmental attenuation conditions, or location of a nearby well and the existence of a pollution source. Consequently, many of these areas should receive a high priority for careful land use management, facility maintenance, or groundwater quality monitoring. Although these areas are primary concern, inferences should not be made that groundwater is already polluted at these sites.

Potential problem areas can be determined by overlaying pollution source locations with the Surface and Subsurface Groundwater Contamination Risk Maps. This has been done for many of the potential pollution sources in **Chapter 5** of this report.

Local Groundwater Quality Protection

Since groundwater represents the source of all water supplies in Dane County, protection and management of the groundwater resource is a high priority. The discussion of groundwater quality conditions and problems in Chapter 3 indicated that groundwater in Dane County is of generally good quality, but that there have been localized instances of contamination from nearby pollution sources, particularly in the upper or shallow aquifer affecting most individual private water supply wells. Areawide water supply concerns relate primarily to potential increases in nitrates, dissolved salts, and volatile organic compounds, which could affect the deep aquifers, from which most municipal water supplies are drawn.

The basic approach to groundwater protection and management is founded on two major considerations:

1. Siting and Land Use Decisions
   - Locating potential pollution sources in areas which minimize the risk of contaminating groundwater supplies
   - Locating groundwater supply sources in areas where they will be protected from potential pollution sources
2. Employing management practices and programs designed to reduce the risk of groundwater contamination from existing and potential pollution sources.

Siting and Land Use Decisions

Siting and land use decisions based on an evaluation of potential groundwater impacts are the most effective defense against groundwater contamination problems, which may otherwise be irreversible or very costly to remediate. All land use and siting decisions in Dane County should include evaluation of potential groundwater and hydrologic impacts. Applicants for any land use or siting approvals should be required to provide sufficient information so that regulatory agencies can evaluate the potential groundwater and hydrologic impacts of the proposed activity; such as for zoning or subdivision approvals, site or development plans, urban service area additions, and state, federal or local land disturbance or discharge permits. Unaddressed or unmitigated groundwater or hydrologic impacts would provide the basis for withholding approval for the requested activity, or require additional information to be submitted by the applicant before approval is granted. Compliance with state surface and groundwater quality standards should be included in the evaluation along with hydrologic impacts.

The groundwater contamination risk maps have been developed as a tool to assist in initial screening and evaluation of the relative groundwater contamination risk from potential pollution sources. One of the maps indicates the relative contamination risk from subsurface activities such as landfills, underground storage tanks and other pollution sources which are located below the soil zone. The other Map indicates the relative contamination risk from those activities conducted on the land surface, such as pesticide, fertilizer, biosolids and septage application. The guidelines and criteria listed in **Table 20** should be used in conjunction with the groundwater contamination risk maps for preliminary screening and evaluation of proposed impacts, and determination of whether more in-depth evaluation is needed.

Using the Groundwater Contamination Risk Maps

Reference Table 20 suggests guidelines and criteria for using the Surface and Subsurface Groundwater Contamination Risk Maps in setting priories and making groundwater management decisions for various pollution sources. These maps can also be used to establish priorities for monitoring and more detailed investigations, as well as focusing attention on problems or decisions involving greater risk of groundwater contamination. While the contamination risk maps are useful for these purposes, it must be emphasized that the generalized nature of these maps makes them insufficient for important decisions on specific sites, and that more detailed site-specific investigations will often be needed.

Water Supply Protection

Another aspect of groundwater protection and management includes programs and practices designed to ensure that water supplies are protected from potential contamination sources. The groundwater contamination risk maps also indicate well protection zones where pollutants have a greater likelihood of reaching municipal water supplies.

Protecting drinking water supplied by groundwater ultimately comes down to managing land uses and human activities in areas contributing groundwater to existing or planned wells. Protecting these source areas requires a regional approach, in that groundwater flow systems do not recognize local governmental boundaries. The state, under the direction of the federal Safe Drinking Water Act and acting through the WDNR, currently has a program by which local units of government can protect their "wellheads" – areas influencing the groundwater quality of their water supply wells. This program is required for all new high-capacity municipal wells. As indicated earlier, sufficient information and technical capacity exists in Dane County, through the federal, state, and local agencies participating in the Regional Hydrologic Modeling and Management Program, to delineate zones of contribution for wells and wellhead protection areas for special management strategies.

Land use regulatory agencies in Dane County should develop wellhead protection programs to protect municipal water supplies, including adopting more stringent siting and land use regulations for potentially polluting activities in wellhead protection zones. CARPC staff can provide review and comment as part of the permitting. Along these line, the guidelines and criteria contained in **Reference Table 20** can provide a basis for these more stringent land use and siting criteria in well protection zones. Practices might also include locating wells away from potential pollution sources, utilizing water from the lower and more protected Mt. Simon sandstone aquifer to reduce the risk and exposure for large resident populations, and employing adequate construction standards to ensure that water supply wells are protected from direct and inadvertent contamination. In addition, proper procedures for sealing and abandoning wells, as well as restrictions on using wells for disposal of waste directly to groundwater are also important management tools.

Information and Education Needs

In some cases, there is a lack of information on potential groundwater contamination problems, and additional monitoring is needed to determine the extent and seriousness of these problems. Problem areas which should receive priority for additional monitoring include monitoring of existing and abandoned landfills in municipal well protection zones; monitoring of agricultural pesticides in groundwater, particularly in areas most susceptible to contamination; and more frequent sampling and testing of shallow private wells for bacterial, nitrate, and pesticide contamination.

An expanded public information and education program on groundwater is also needed. It should be directed at those households most vulnerable to potential groundwater contamination—rural households depending on shallow, individual water supply wells. The information and education program should include guidance on proper siting, construction and (especially) maintenance and servicing of on-site wastewater disposal systems; proper siting, construction and testing needs for wells and water supplies; and information and recommendations on proper use, storage, and disposal of potentially hazardous or toxic materials such as pesticides, cleaning agents, and other potential household hazards or pollutants. Education efforts should emphasize the vulnerability of groundwater to contamination and that once it is contaminated it is very difficult, if not impossible, to restore.

The application of regulations and management practices designed to reduce the risk of groundwater contamination from potential pollution sources are treated separately in the following chapter on groundwater management controls for the major potential sources of groundwater contamination. Programs have been developed to address these areas of groundwater protection, which need to be expanded in some cases. The issue of cumulative impacts of well withdrawals on ground and surface water features and overall sustainability is another area of growing concern.

Table 20: Groundwater Contamination Risk Maps, Guidelines and Criteria

	Pollution Source	Contamination Risk Map to Use	Guidelines and Criteria
1.	Sanitary Landfill	Subsurface	Proposed landfills should be located outside of municipal well protection zones and areas of high or extreme contamination risk, or meet protective design standards. High priority for monitoring active and abandoned landfills should be for those landfills in areas of high or extreme risk in municipal well protection zones.
2.	On-Site Wastewater Systems	Subsurface	The planning of rural subdivisions or developments that include large on-site systems or clusters (more than 20) of on-site systems with an average density of one house per 1-1.5 acres (based on the gross acreage of the development) should include an evaluation to ensure that drinking water supplies are protected. If the evaluation indicates a risk for nitrate levels above 10 mg/L, alternatives such as protected water supplies (well location and depth), utilizing nitrogen-reducing wastewater treatment systems, or community scale water supply and wastewater treatment systems should be explored.
3.	Wastewater Lagoons and Infiltration Ponds	Subsurface	Proposed wastewater lagoons and infiltration areas should be located outside of municipal well protection zones and areas of high or extreme contamination risk, or meet protective design standards. Existing lagoons and ponds in municipal well protection zones should be monitored.
4.	Underground Storage Tanks	Subsurface	Stringent design and periodic testing for corrosion protection and leak containment should be required of all existing and proposed underground tanks storing hazardous or flammable materials within municipal well protection zones and in areas of high or extreme contamination risk outside of well protection zones. Existing tanks in these areas not providing adequate corrosion protection or leak containment should be immediately replaced or properly abandoned.
5.	Above-ground Storage Tanks	Surface	Strict design criteria should be required for spill or leak containment for all above-ground tanks storing hazardous or flammable materials within municipal well protection zones and in areas of extreme contamination risk outside of well protection zones. Existing tanks in these areas without adequate spill or leak containment should be replaced or properly abandoned.
6.	Land Application of Sludge (Biosolids) and Septage	Surface	Application sites should not be located in areas of extreme contamination risk. Sites in areas of high or moderate risk should receive highest priority in enforcement of existing siting guidelines, and should receive increased surveillance to ensure applications adhere to state guidelines and criteria.
7.	Wastewater Irrigation and Landspreading Sites	Surface	Proposed wastewater irrigation and landspreading sites should not be located in areas of extreme contamination risk. Existing and future sites in municipal well protection zones should be monitored and subject to stringent design and operating requirements.
8.	Large Feedlots and Manure Storage Lagoons	Surface	Proposed large feedlots and manure storage lagoons should not be located in areas of high or extreme contamination risk. Strict design criteria and monitoring of storage lagoons should be required for all large lagoons in areas of moderate contamination risk.