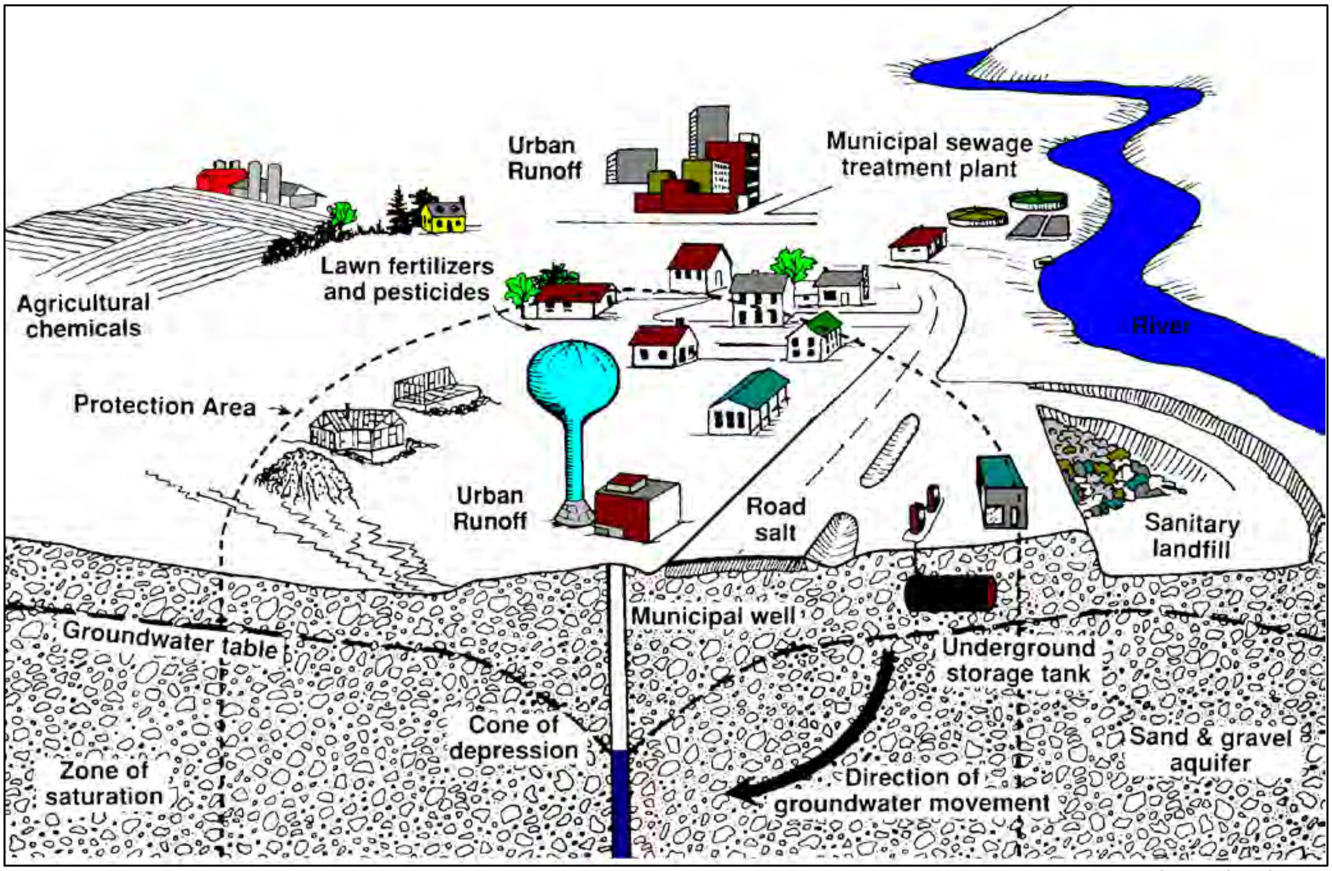
Dane County Groundwater Protection Planning Framework



Source: Wisconsin DNR

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

January 2017

Capital Area Regional Planning Commission

CAPITAL AREA REGIONAL PLANNING COMMISSION

210 Martin Luther King Jr. Blvd. Room 362 Madison, WI 53703 Phone: 608-266-4137 Fax: 608-266-9117 www.CapitalAreaRPC.org info@CapitalAreaRPC.org

CARPC Resolution No. 2017-02

Recommending to the WDNR Amendment of the *Dane County Water Quality Plan* by Adopting the Update of Appendix G: *Dane County Groundwater Protection Planning Framework*

WHEREAS, In March 1975, Dane County was designated by the Governor of Wisconsin as an area having substantial and complex water quality control problems, and certified such designation to the federal Environmental Protection Agency; and

WHEREAS, the Capital Area Regional Planning Commission is a duly created regional planning commission under Wis. Stats. § 66.0309; and

WHEREAS, the CARPC has an agreement with the Wisconsin Department of Natural Resources (WDNR) to provide water quality management planning assistance to the WDNR; and

WHEREAS, the *Dane County Water Quality Plan* is the approved areawide water quality management plan for the Dane County region; and

WHEREAS, the Capital Area Regional Planning Commission has adopted, reaffirmed, and recommended amendment of the *Dane County Water Quality Plan*; and

WHEREAS, the Capital Area Regional Planning Commission has prepared an updated Appendix G to the *Dane County Water Quality Plan*, entitled "*Dane County Groundwater Protection Planning Framework*," and has made the document available to all local units of government in Dane County; and

WHEREAS, the public hearing was deferred during the Regional Planning Commission meeting on August 11, 2016, to allow more time for public comment on the Appendix; and

WHEREAS, a public hearing was held during the Regional Planning Commission meeting on January 12, 2017, to take testimony on the Appendix including revisions to the report based on public comments received.

NOW, THEREFORE, BE IT RESOLVED that in accordance with Wis. Stats. § 66.0309, and Sec. 208 of Public Law 92–500, the Capital Area Regional Planning Commission recommends the amendment of the *Dane County Water Quality Plan* by adopting the updated Appendix G: *Dane County Groundwater Protection Planning Framework.*

January 12, 2017
Date Adopted

Larry Palm, Chairperson

Kris Hampton, Secretary

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- Michael Mucha, Chief Engineer and Director – Madison Metropolitan Sewerage District
- Michael Parsen, Hydrogeologist – Wisconsin Geological and Natural History Survey
- Stan Senger, Environmental Quality Section Chief – DATCP
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Thanks also to WDNR for pre-publication review and comment:

- Tim Asplund, Water Quality Monitoring Section Chief -- WDNR
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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, the Capital Area Regional Planning Commission recommends that its staff:

  a. Support the conduct of water supply service area planning required by Wis. Stats. 281.348 and also comprehensive (master) planning under Wis. Stats. 66.0309(9).

  b. Assist municipalities and resource management agencies incorporate and utilize the information, tools, and guidelines in this planning framework to develop processes and standards to address potential groundwater impacts. 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 the Capital Area Regional Planning Commission 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.

[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**.

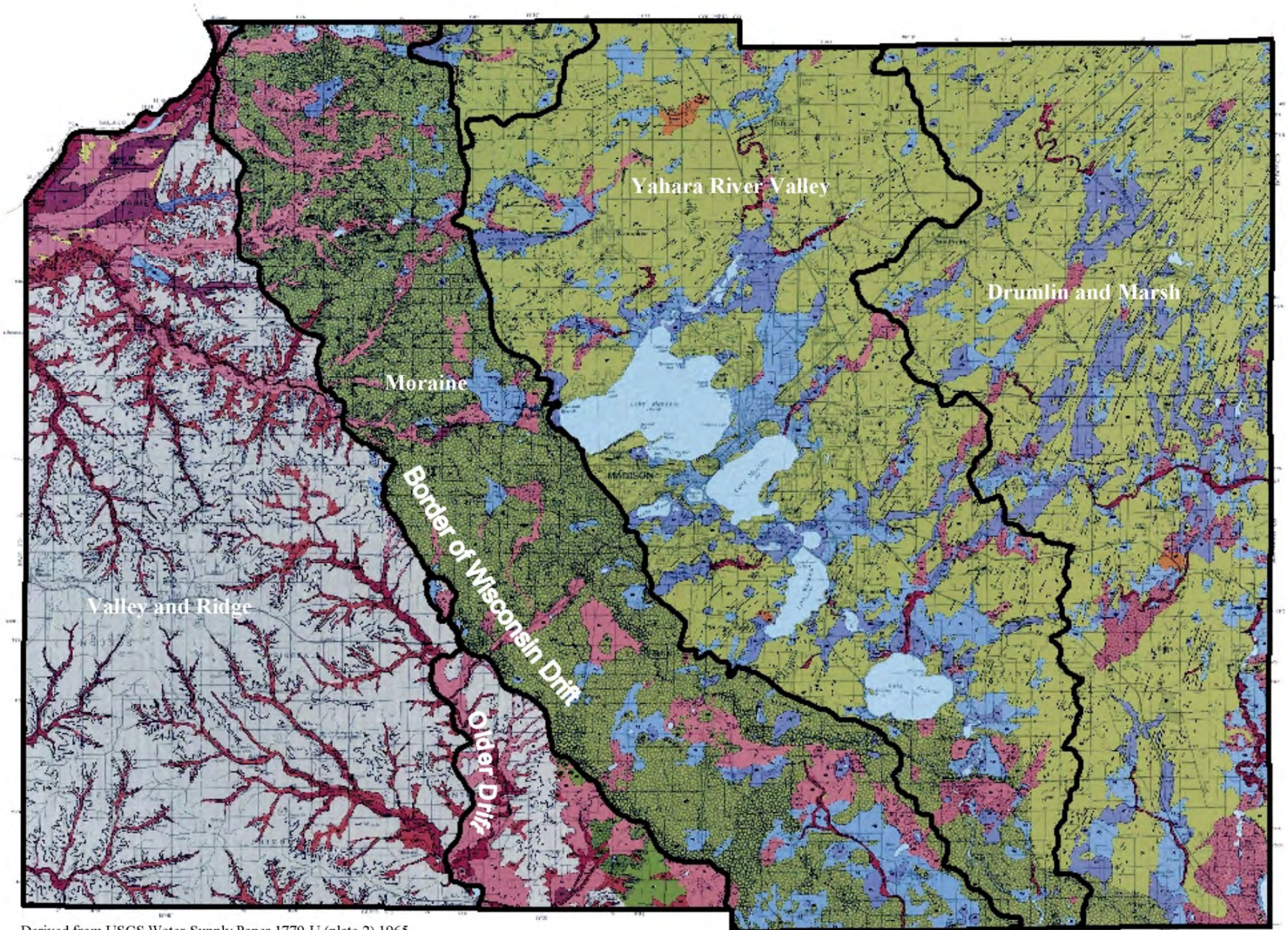
The bedrock in the county is comprised of many layers of sandstone and dolomite (up to 1,700 feet thick) formed from sediments deposited by an ancient sea 420 to 600 million years ago. Under these layers of sedimentary rock is an even older crystalline rock, mostly rhyolite, granite, and basalt. The 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.

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)

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. 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
[2]), 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**).

[2] 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

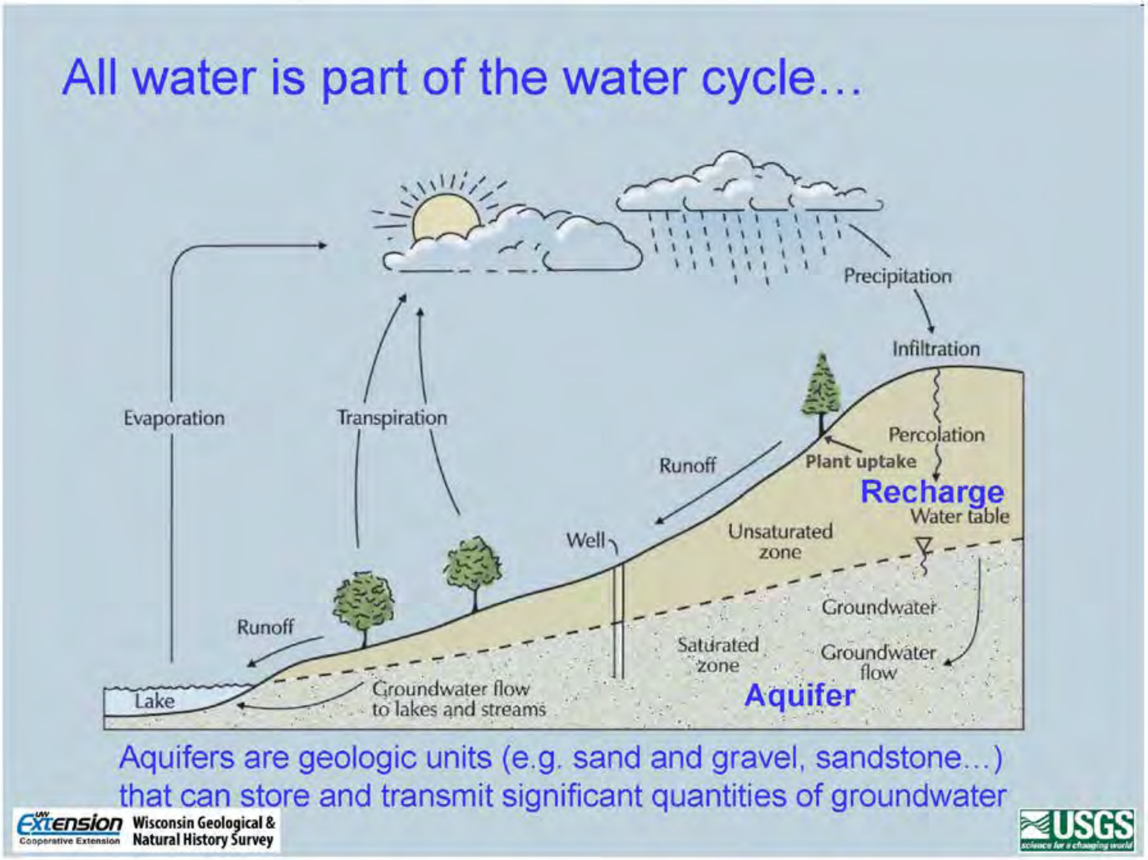
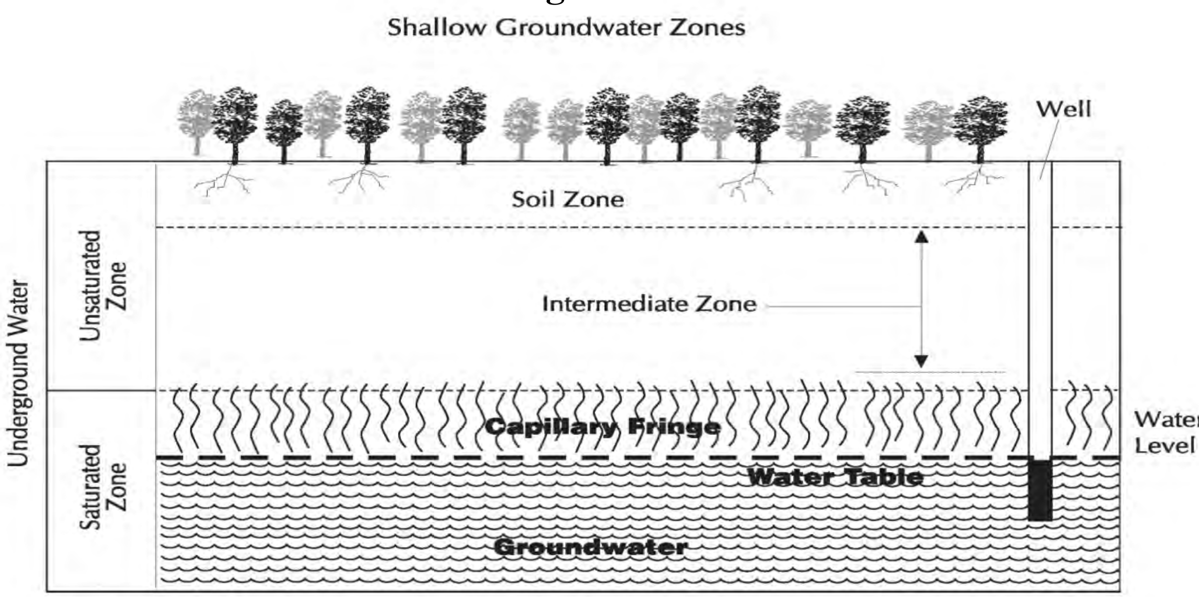


Figure 2



Source: Heath, 1983.

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.
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.[3] **Figure 3** shows the general arrangement and approximate relative thicknesses of bedrock geologic units across Dane County.[4]

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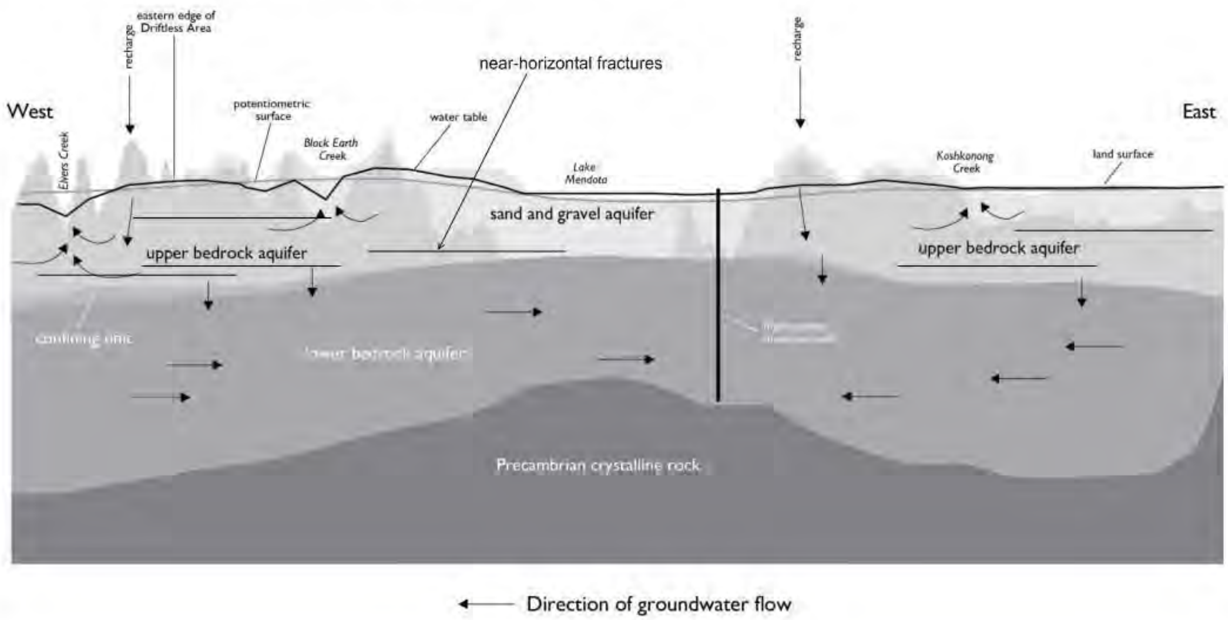
[3] Bradbury, et al. 1999. *Hydrogeology of Dane County, Wisconsin*. WGNHS Open File Report 1999-2004,

[4] 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

Age		Stratigraphic name			Model layers, names				
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)	
							2	Unlithified II (till and meltwater stream deposits)	
Paleozoic	Ordovician		Maquoketa		2	Upper bedrock	3	Upper bedrock	aquifers
		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.

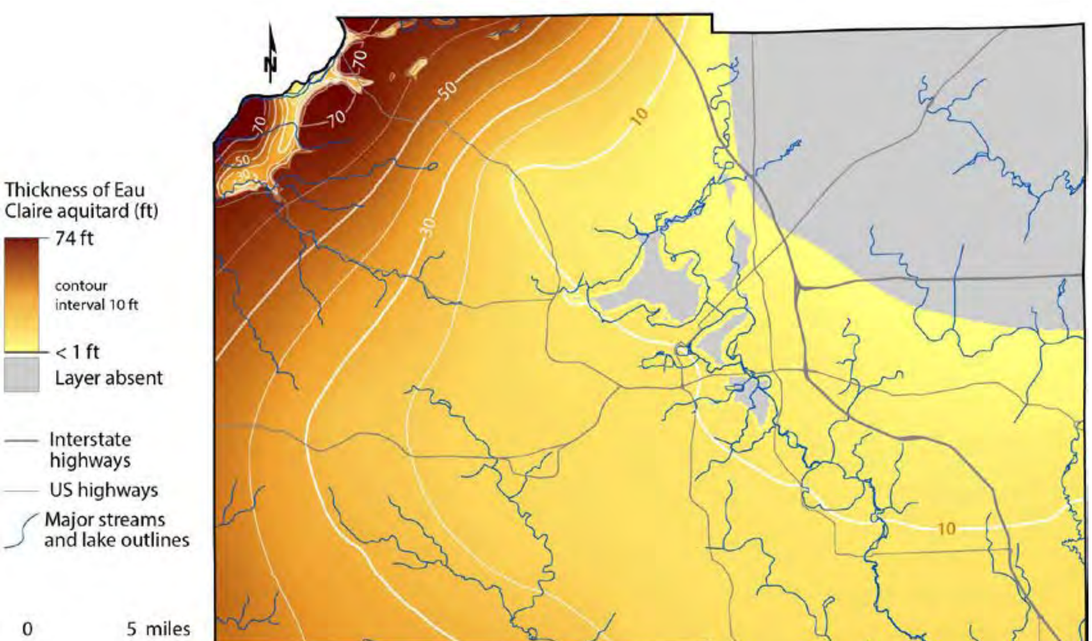
The Mt. Simon aquifer is the most important aquifer in Dane County for the purposes of water supply to high-capacity wells. This aquifer consists of sandstones of the Mt. Simon and lower Eau Claire Formations. The lower boundary of the aquifer is the Precambrian granite surface. The upper boundary is 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.

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.

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



Source: Wisconsin Geological and Natural History Survey, 2016

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.[5] 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.

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.[6] 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.** The Capital Area Regional Planning Commission 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.

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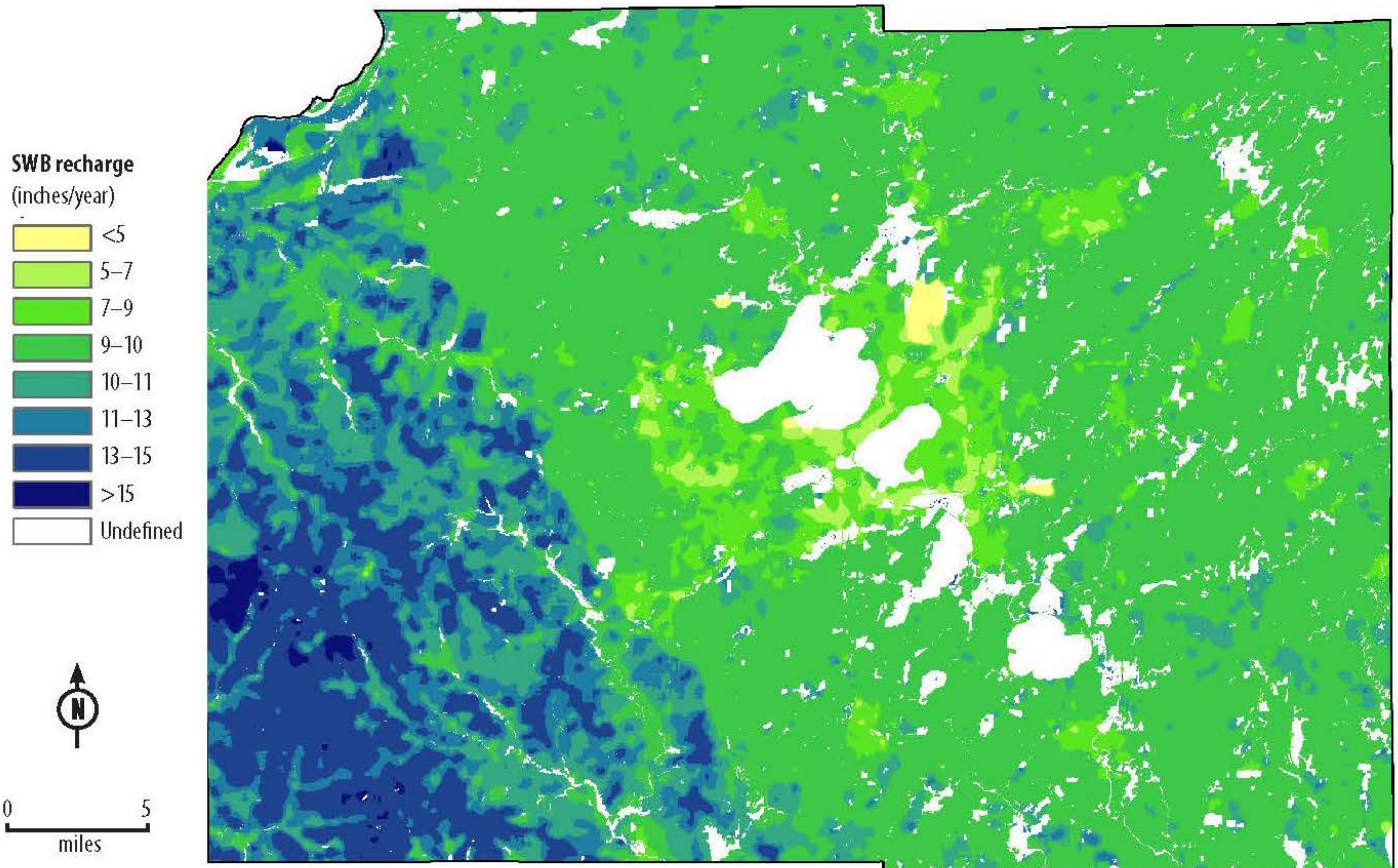
[5] Fritz, A. 1996. *Aquifer Contamination Susceptibility of Dane County, Wisconsin.* Master's thesis. University of Wisconsin, Madison.

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

Map 3. Groundwater Recharge Map for Dane County.



Source: Wisconsin Geological and Natural History Survey, 2012.

In 2006 the Capital Area Regional Planning Commission developed relative infiltration maps for Dane County. **Maps 20, 21, and 22** (**see 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 Capital Area Regional Planning Commission's 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.

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

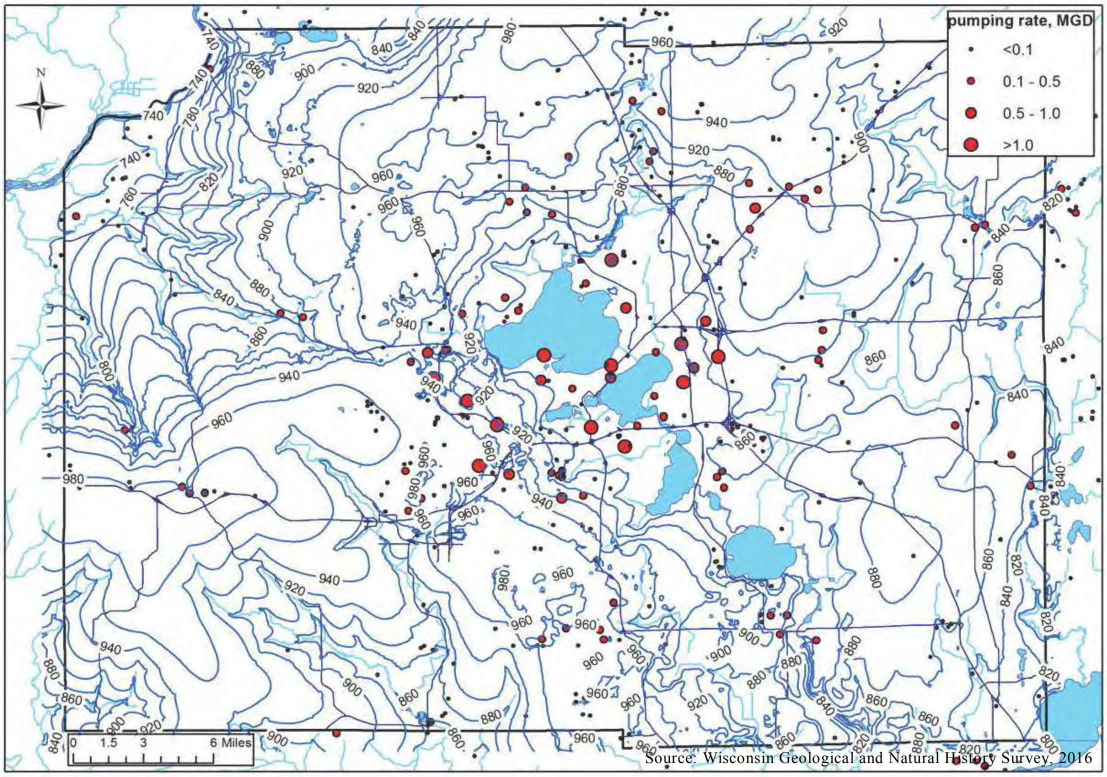
Surface water, shallow groundwater, and deep groundwater are intimately connected in Dane County. Almost all groundwater in Dane County originates as recharge occurring within the County. Most lakes and streams in the county are discharge points for groundwater where the water table intersects the land's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

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.

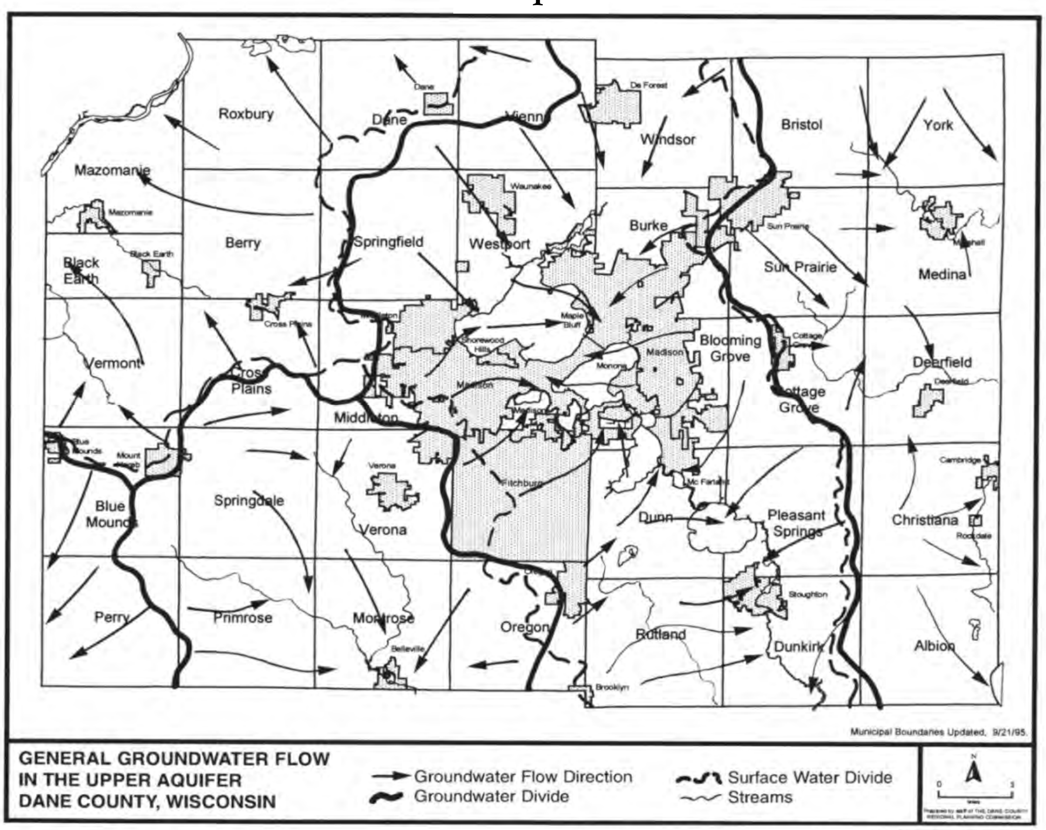
Map 5 superimposes the two types of divides, and shows that they differ significantly in several areas, notably between Madison and Verona and just west of Middleton. In these areas, groundwater passes beneath surface topographic divides. For example, just east of Verona surface water drains to the southwest 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.

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



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

Map 5

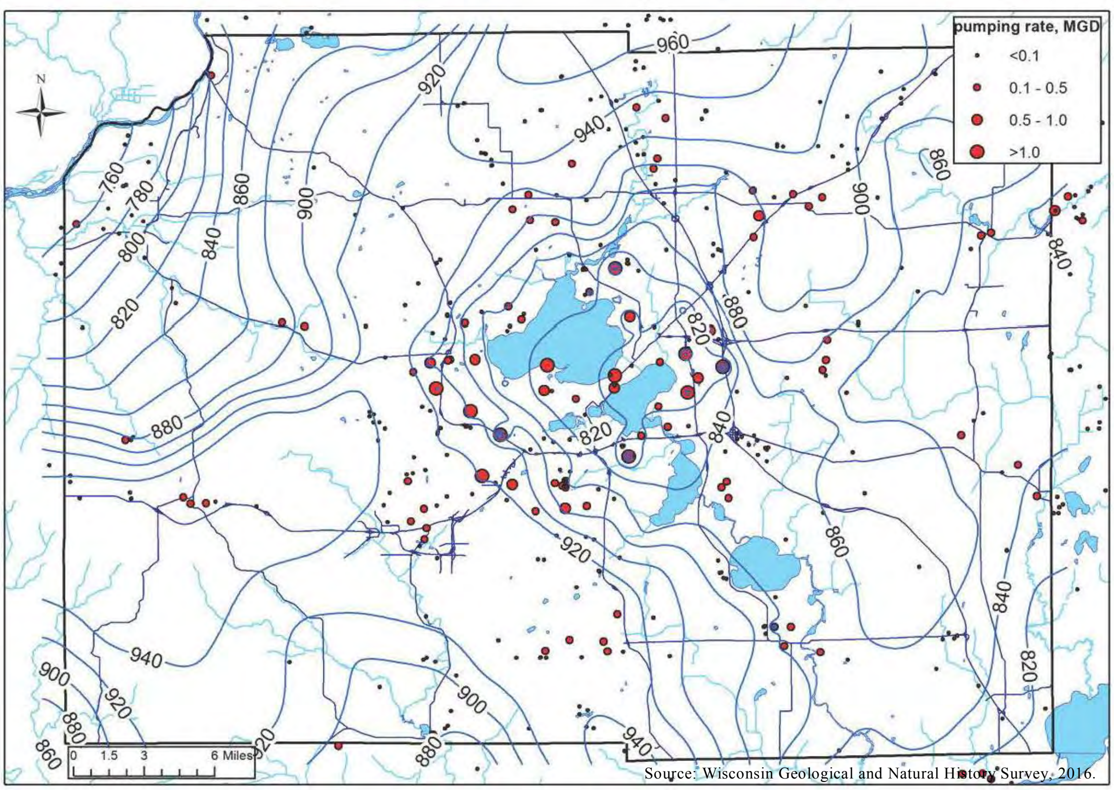


Source: Wisconsin Geological and Natural History Survey, 1995.

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.

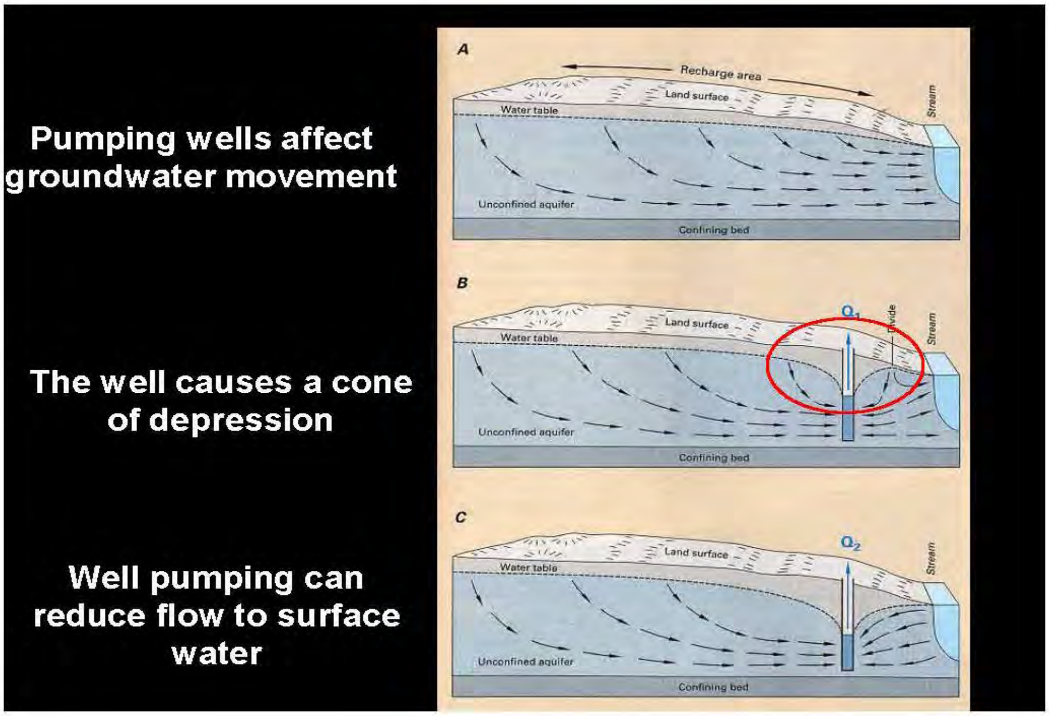
Figure 4 shows these ground-surface water relationships. Groundwater withdrawals by pumping from high-capacity wells in the Madison metropolitan area since the turn of the century have lowered hydraulic heads in the deep sandstone aquifer. These head declines have propagated upward to the surface and 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.

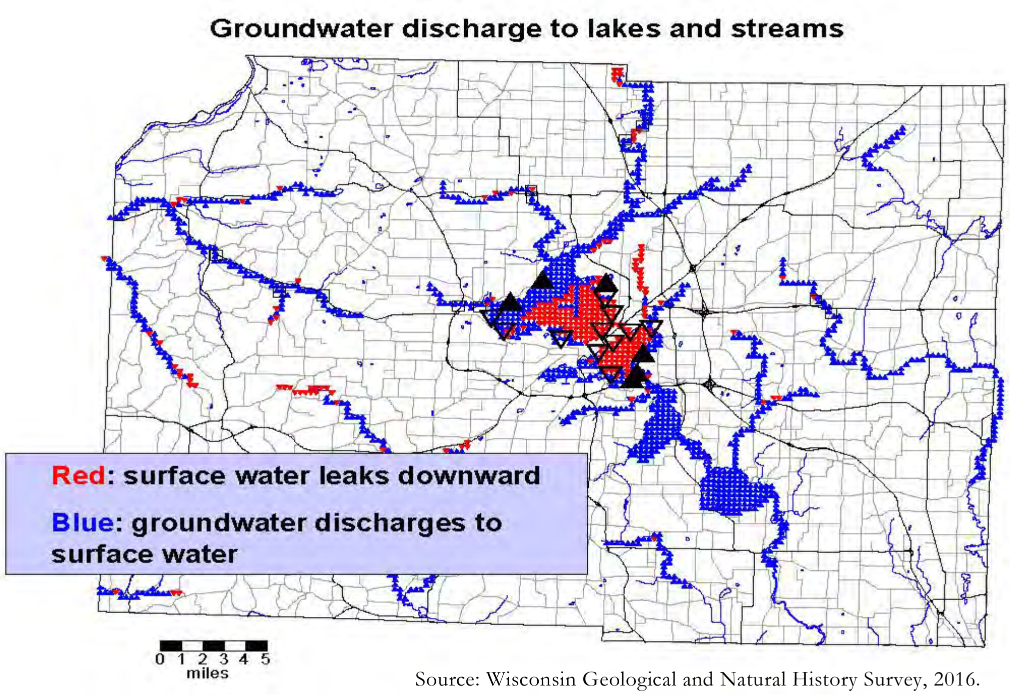
Conversely, the presence of the Eau Claire aquitard can help mitigate the localized impact of high capacity well water withdrawals on surface water features. The presence or absence of the Eau Claire aquitard is an important control on vertical groundwater movement between shallow and deep bedrock aquifers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



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. The Effect of Well Withdrawals on Area Waters





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.

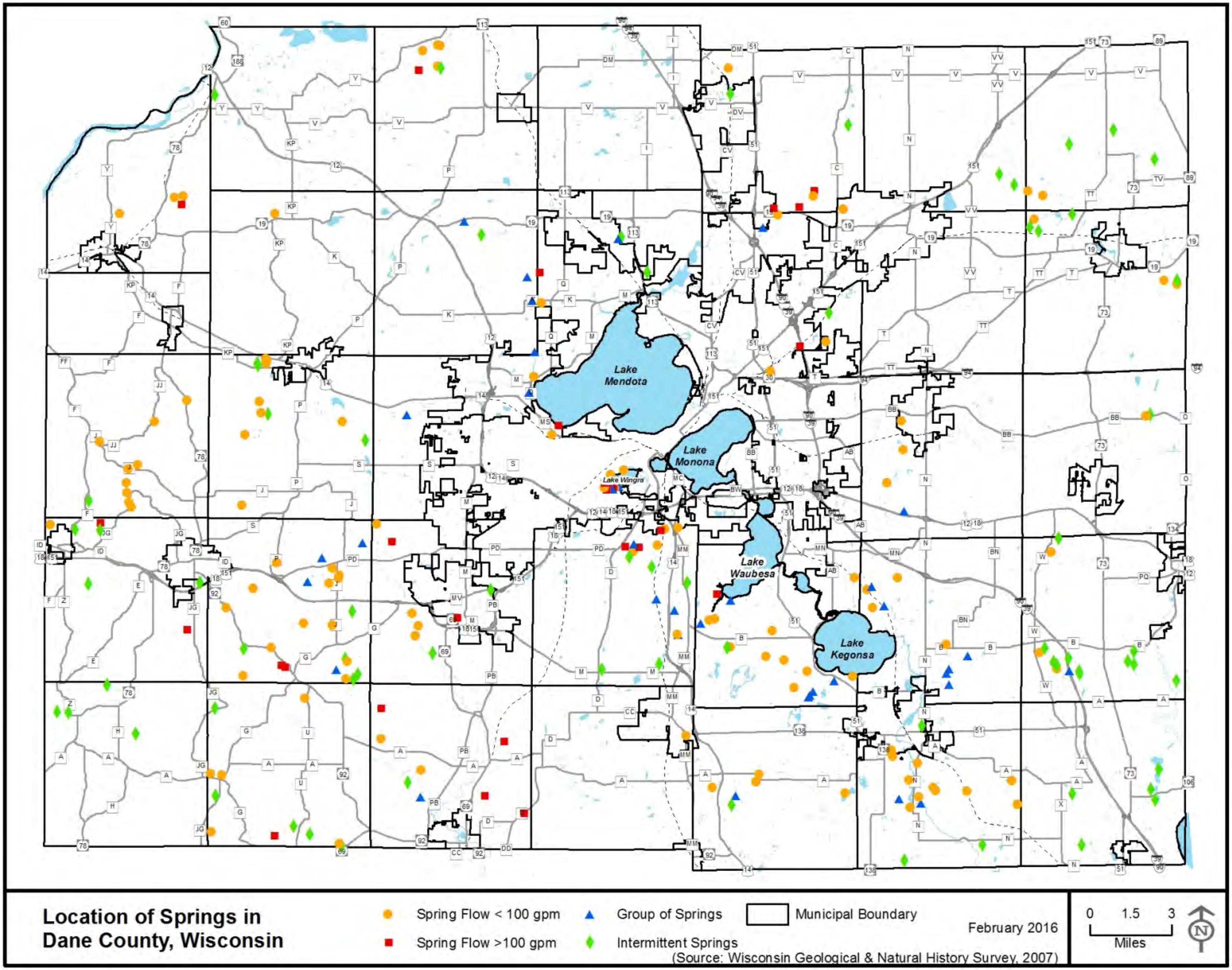
[8] Swanson, S. 2004. *Analytical and Numerical Models to Explain Steady Rates of Spring Flow.* Groundwater Vol. 42, No. 5: 747-759.

[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

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).

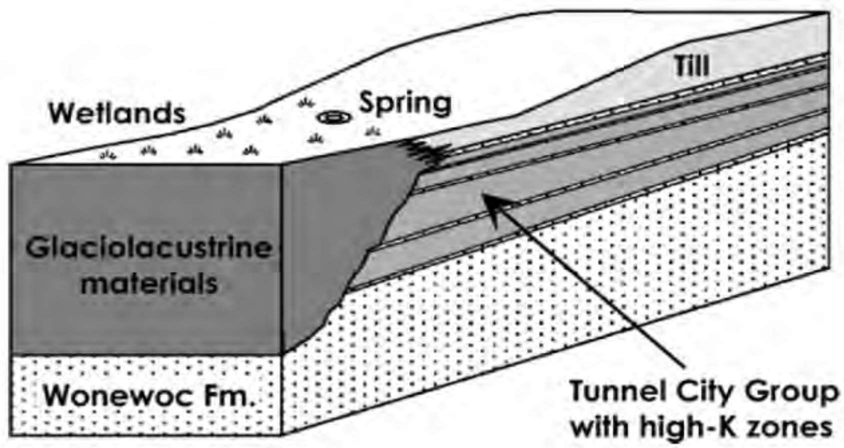


Figure 5. Conceptual model used in the design of the Nine Springs Inset Model. Springs form where high permeability zones in a shallow sandstone aquifer are truncated by a bedrock valley (the Yahara River in this case).

Source: Swanson 2006

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 conducted 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 9.** 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

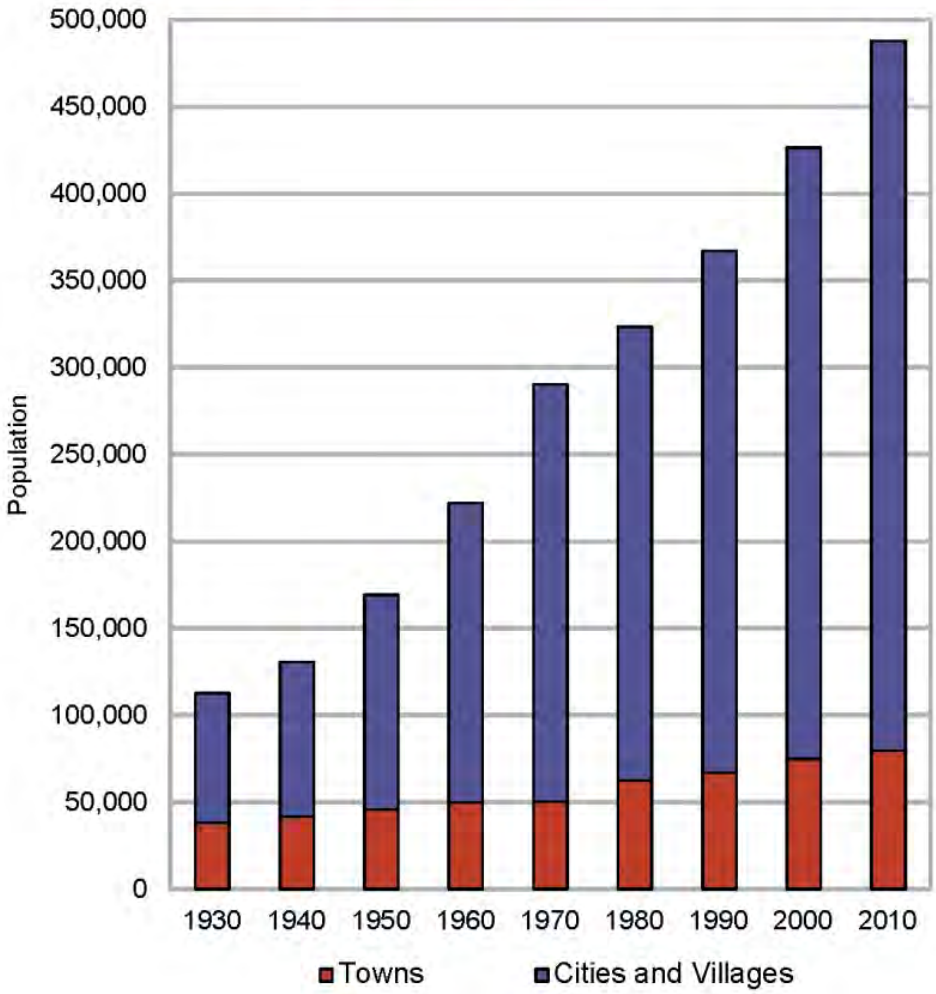


Table 1: Dane County Population Growth

Category	1980		1990		2000		2010	
	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)

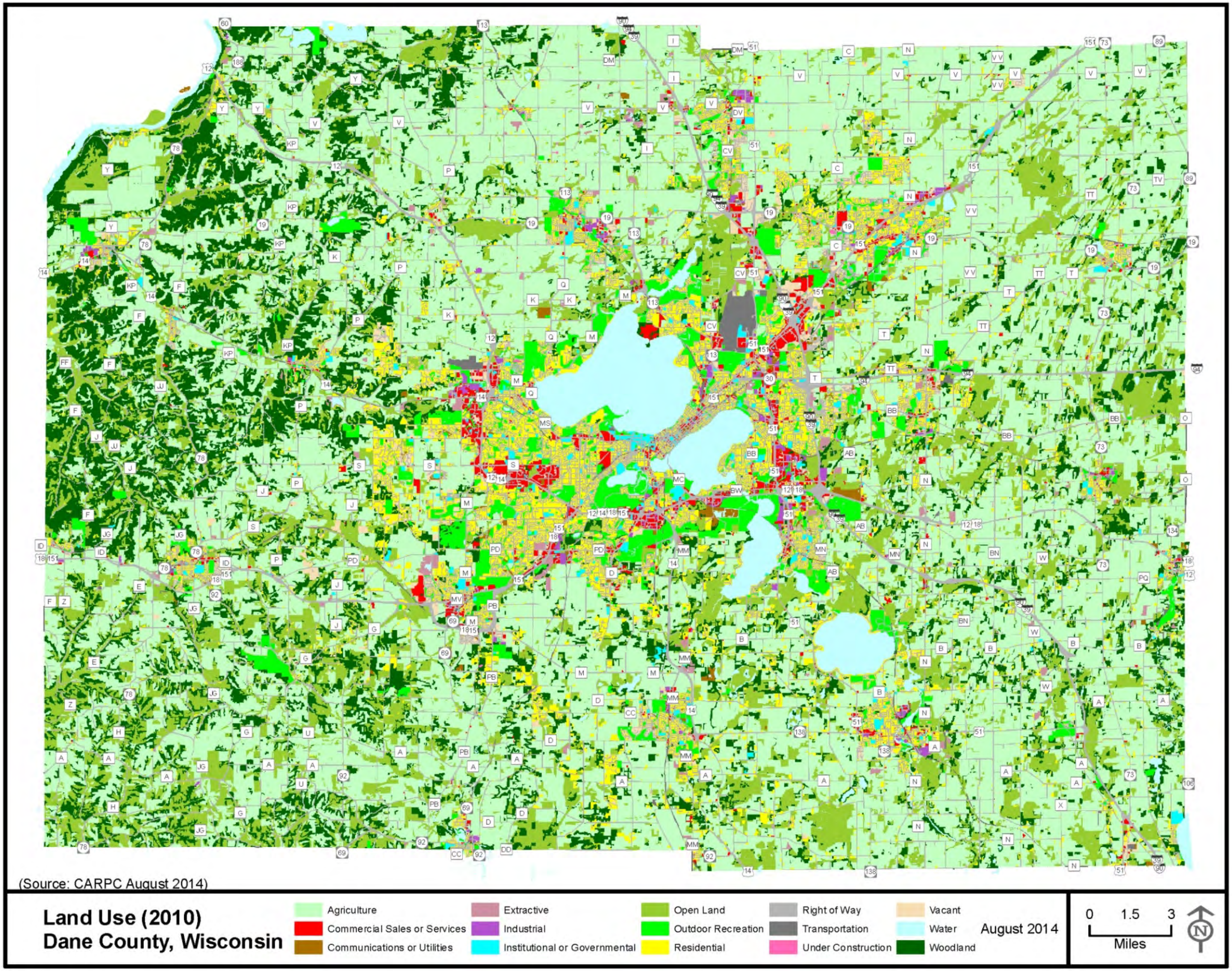
Table 2. Population Forecasts for Urban Service Areas (USAs) Dane County, WI.

USA	Census 2010	Urban Service Area Forecasts 2020	2030	2040	Change 2010-2040
Belleville*	1,885	2,041	2,255	2,369	484
Black Earth	1,346	1,378	1,409	1,404	58
Blue Mounds	855	965	1,090	1,185	330
Brooklyn*	936	1,120	1,350	1,510	574
Cambridge*	1,348	1,476	1,651	1,771	423
Central	302,935	327,042	352,548	367,749	64,814
Cottage Grove	6,230	7,228	8,504	9,509	3,279
Cross Plains	3,541	3,798	4,128	4,323	782
Dane	995	1,135	1,285	1,400	405
Deerfield	2,397	2,642	2,917	3,103	706
Edgerton*	97	294	519	640	543
Koshkonong	620	657	695	732	112
Marshall	3,862	4,100	4,440	4,635	773
Mazomanie	1,657	1,735	1,830	1,870	213
Mount Horeb	7,023	7,640	8,431	8,962	1,939
Northern	13,022	14,922	17,139	18,892	5,870
Oregon	9,234	10,303	11,623	12,583	3,349
Stoughton	12,921	13,434	14,098	14,364	1,443
Sun Prairie	29,403	34,812	40,876	45,629	16,226
Verona	10,645	12,827	15,098	16,878	6,233
Waunakee	12,159	13,916	16,011	17,604	5,445
Urban Total	423,111	463,465	507,897	537,112	114,001
Rural Total	64,962	67,155	69,403	69,508	4,546
Dane County	488,073	530,620	577,300	606,620	118,547

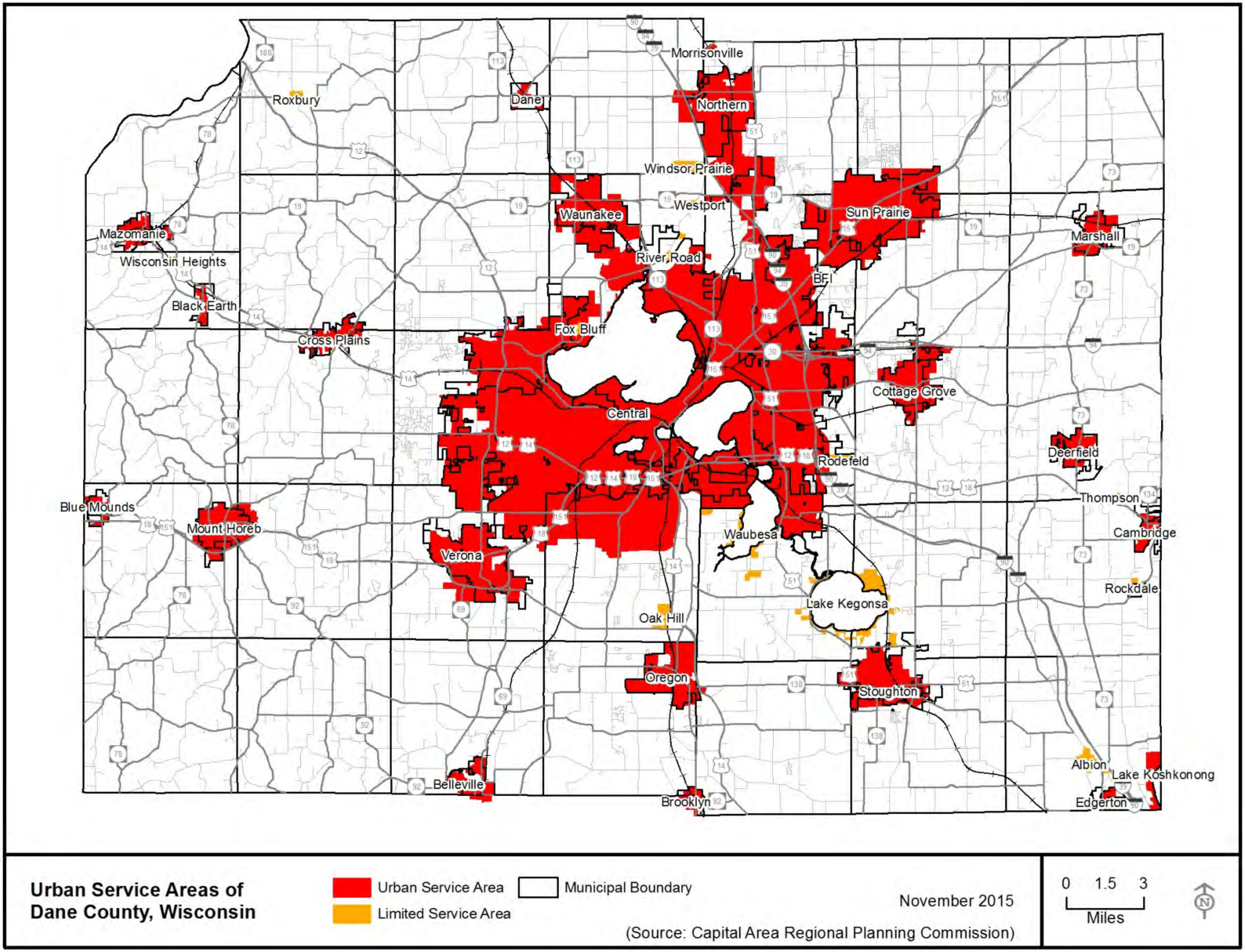
*Dane County portion

Source: Capital Area Regional Planning Commission 12/16

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
Mazomanie
Marshall
Wisconsin Heights
River Road
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.

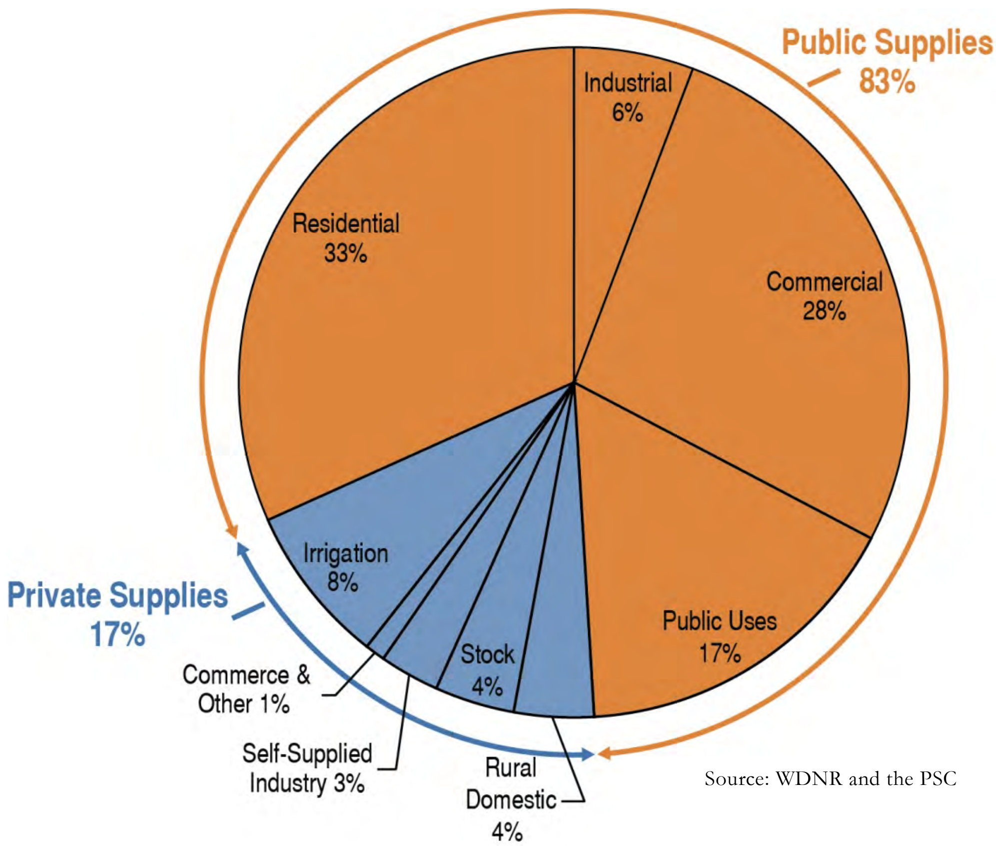
The City of Madison is the largest single consumer, withdrawing over 27 mgd and accounts for over half of the total use in the county (**Table 3 and Map 10**). Most of this water is returned to surface water after use, most often in a location different from where it was withdrawn. In the Madison Metropolitan 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 Dance 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

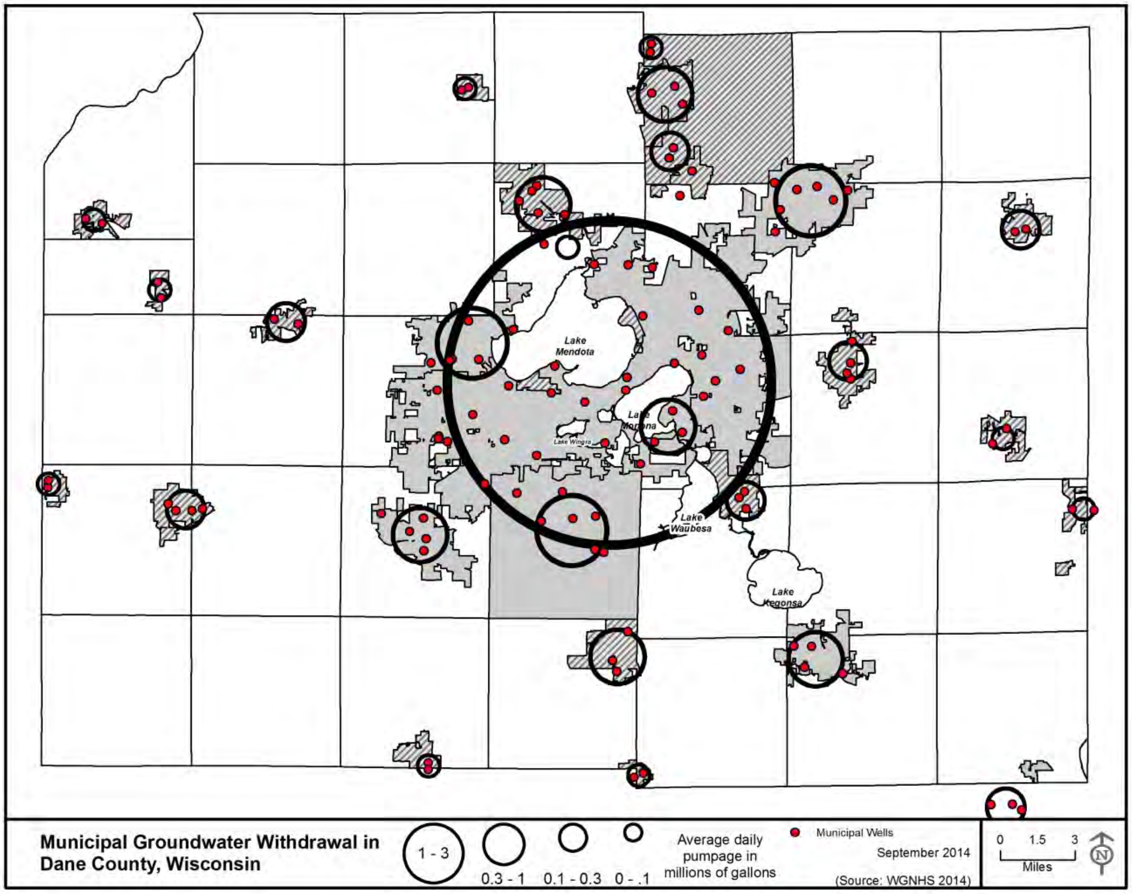
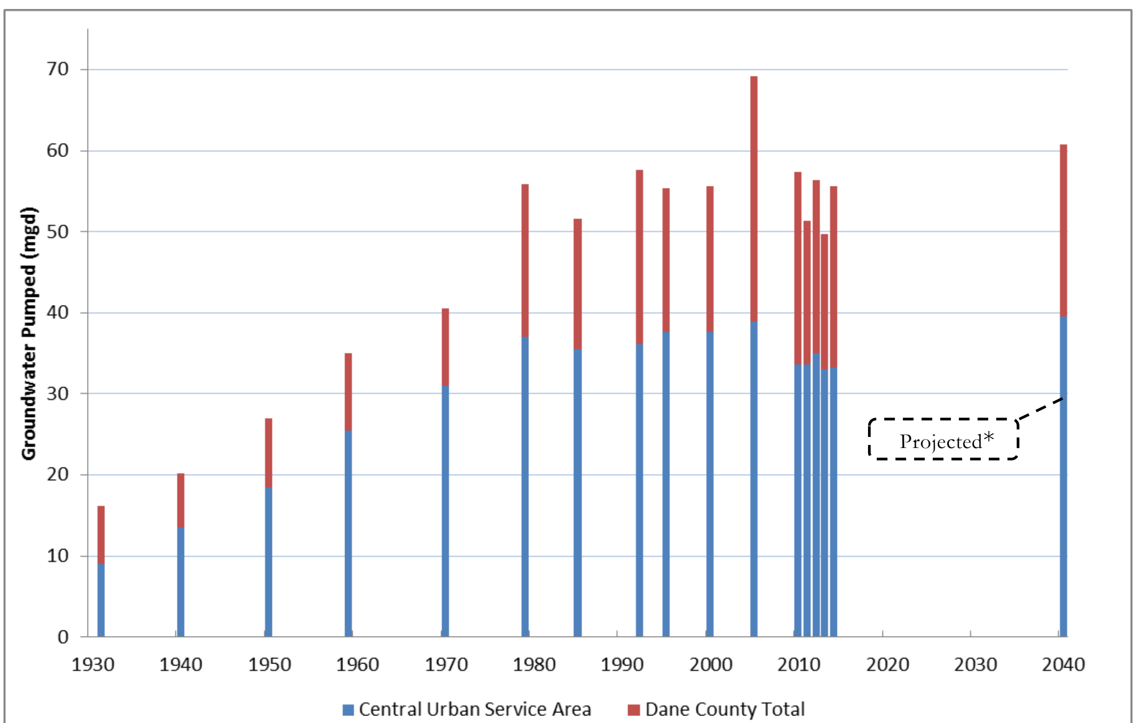


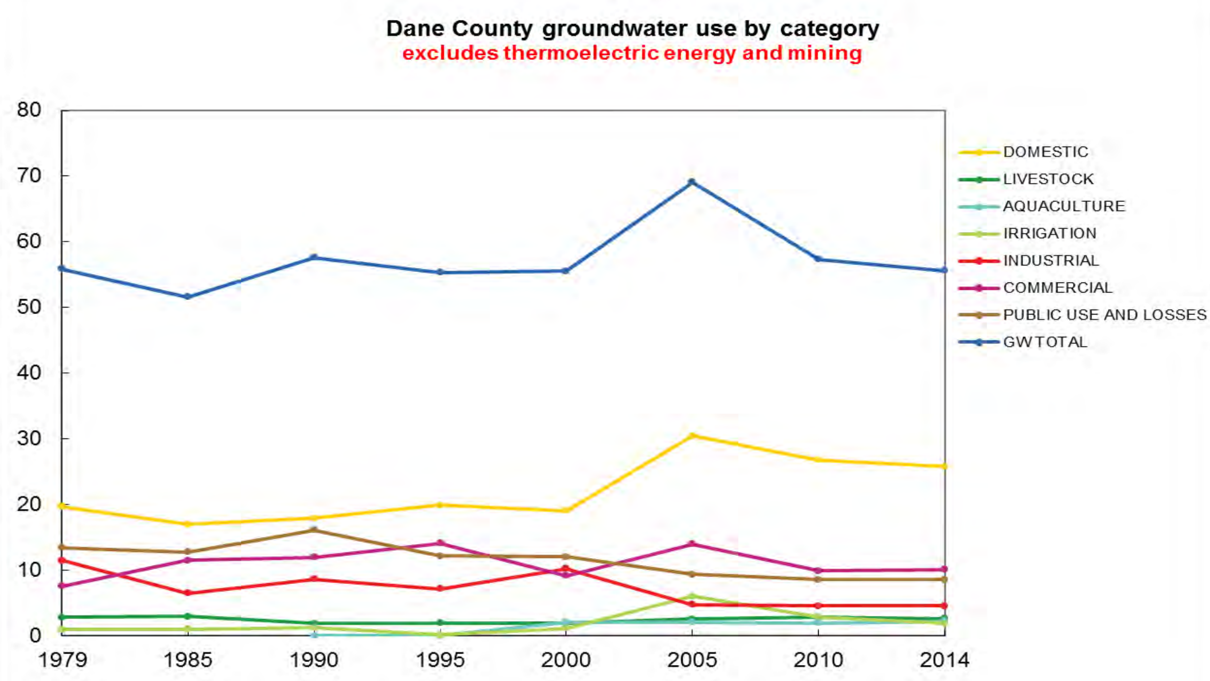
Fig. 8. Reported and Projected Groundwater Withdrawals in Dane County.



* 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

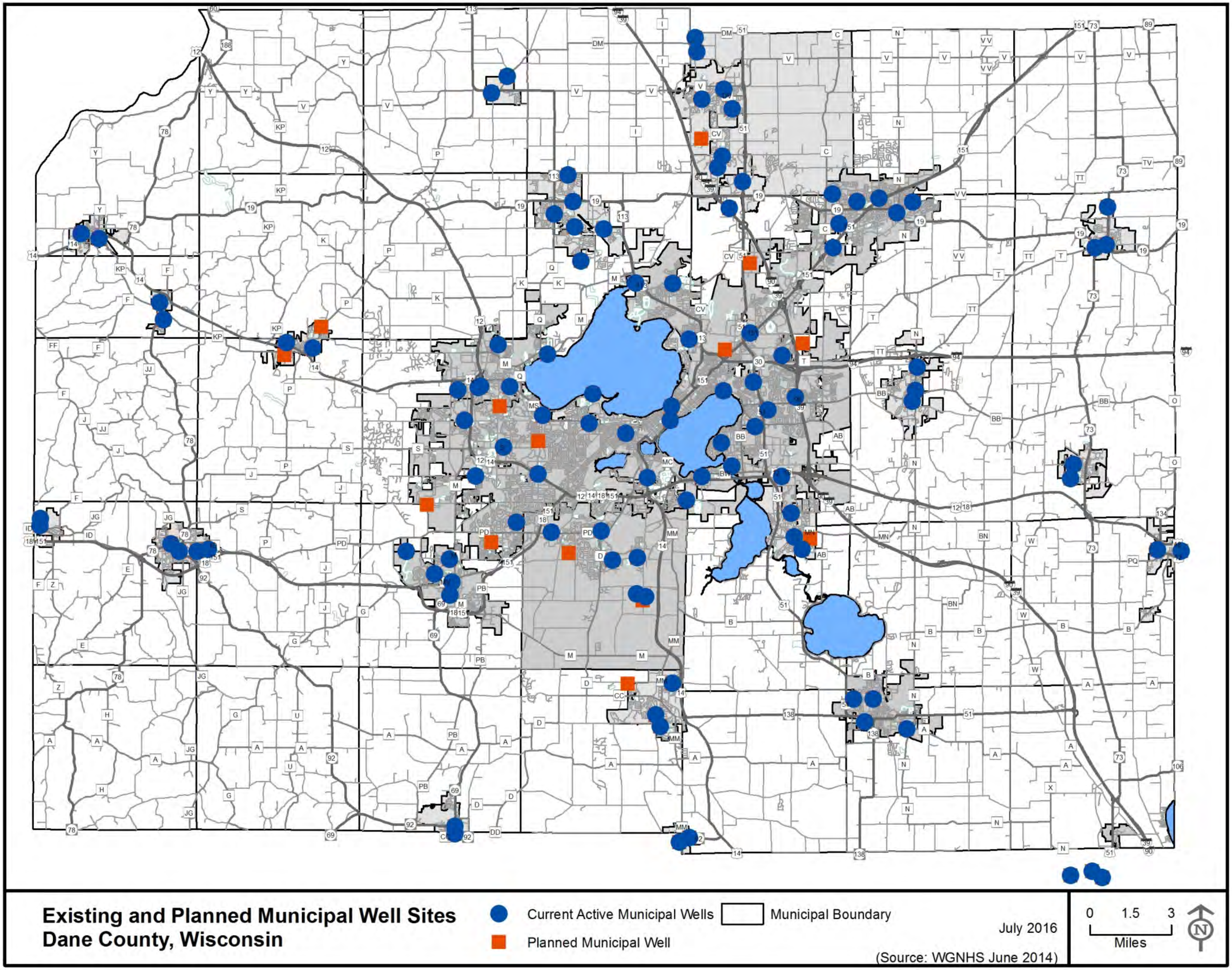
Table 3 summarizes reported 2014 and projected 2040 water use. **Map 11** shows the locations of existing and proposed wells for each community in central Dane County. Note, specific locations of existing and planned wells may change. Municipal water supply agencies can provide more recent and detailed 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 base-flows 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 ground-water 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 the Capital Area Regional Planning Commission), 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.

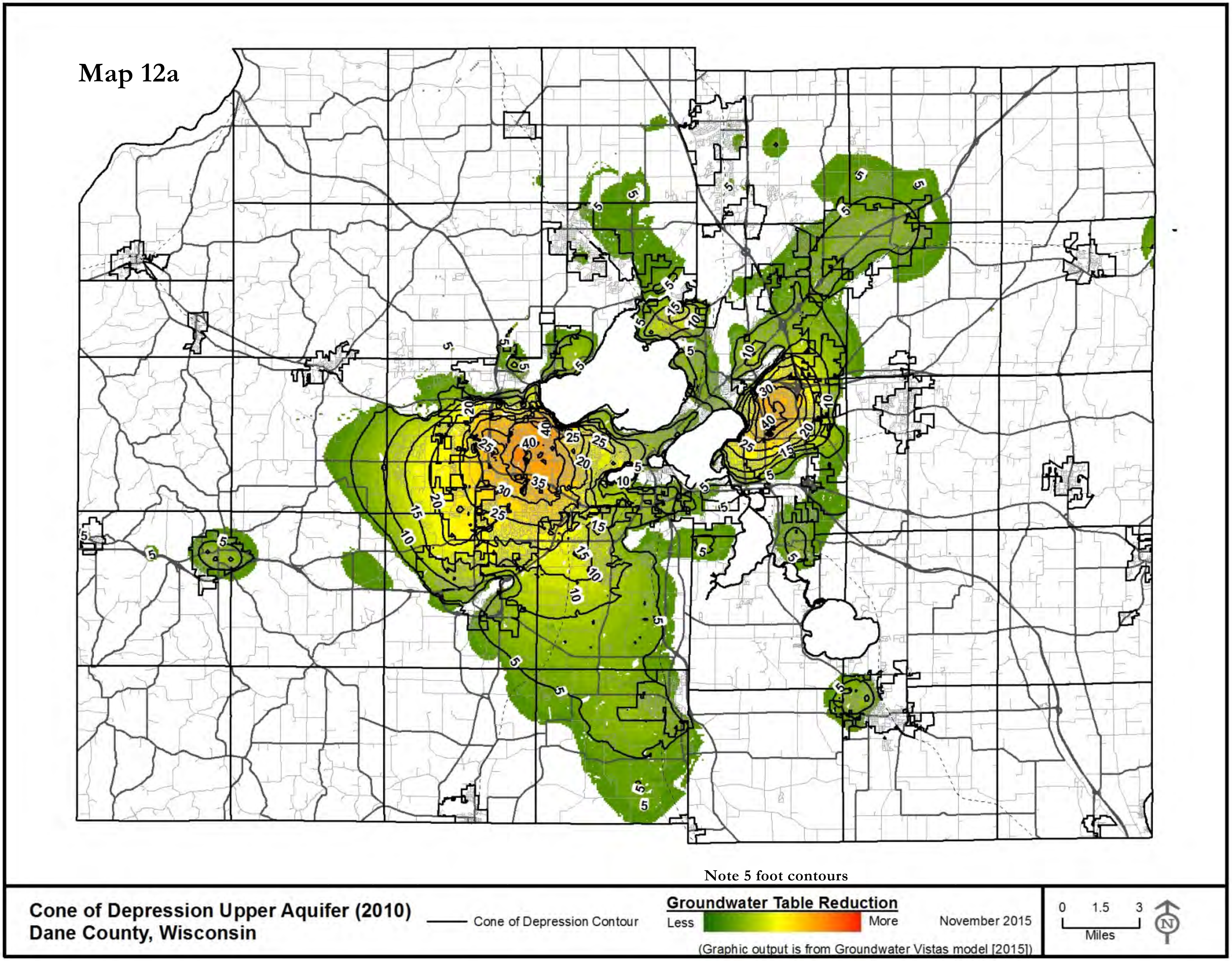
Effects of Pumping and Wastewater Diversion

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.

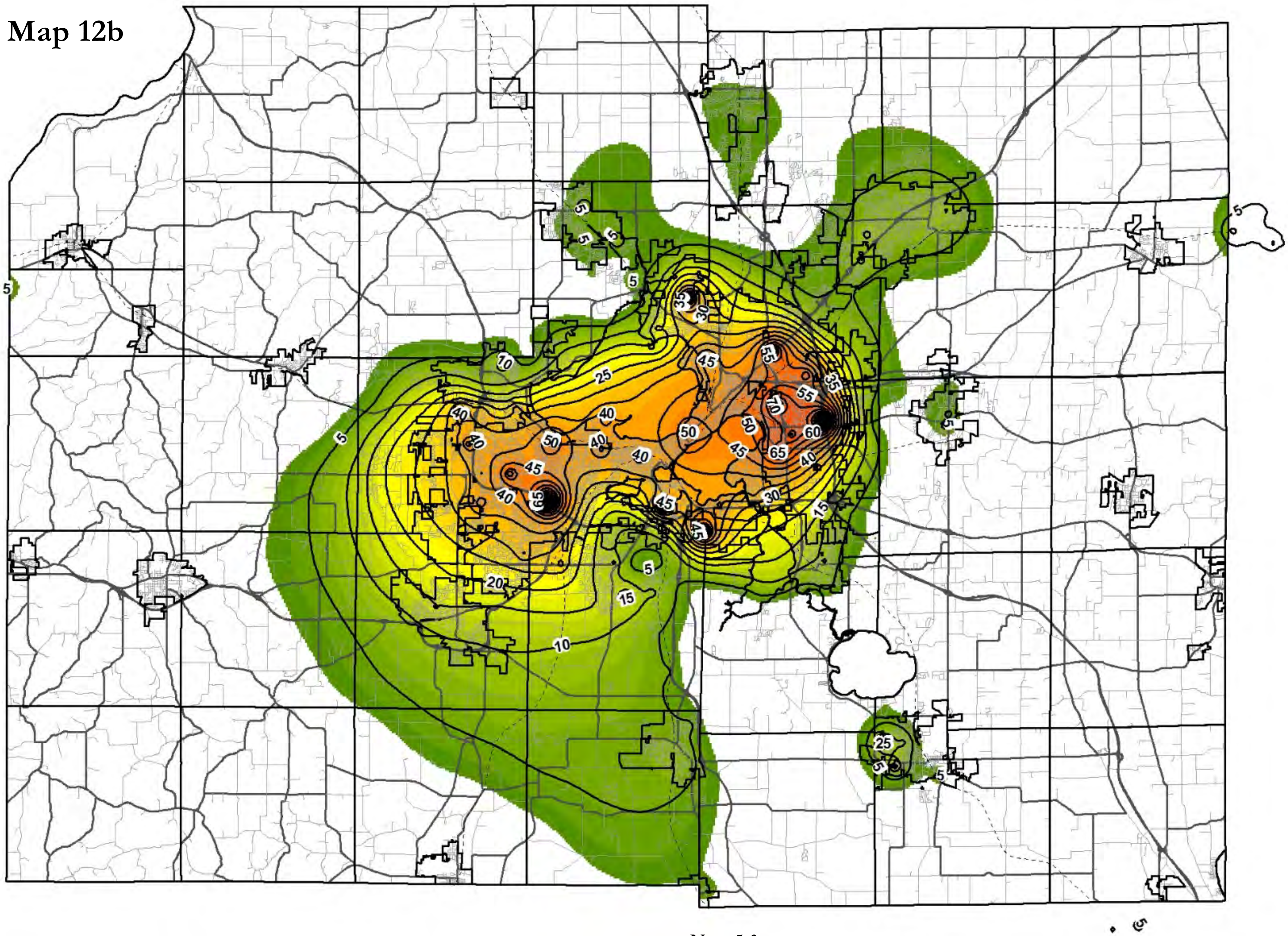
Pumping or withdrawal of groundwater, and its eventual return to surface waters in a different watershed, can have indirect but serious impacts on local hydrology and water quality conditions. The most serious impacts are evident in the urban and urbanizing areas surrounding the Yahara Lakes. Although 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
5
10
15
20
25
30
35
40
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

Potentiometric Level Reduction*

Less — More

— Cone of Depression Contour

November 2015

0 1.5 3 Miles

N

Cone of Depression Mt Simon Aquifer (2010) Dane County, Wisconsin

* Equivalent groundwater level in a confined [i.e. pressurized] aquifer

(Graphic output is from Groundwater Vistas model [2015])

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

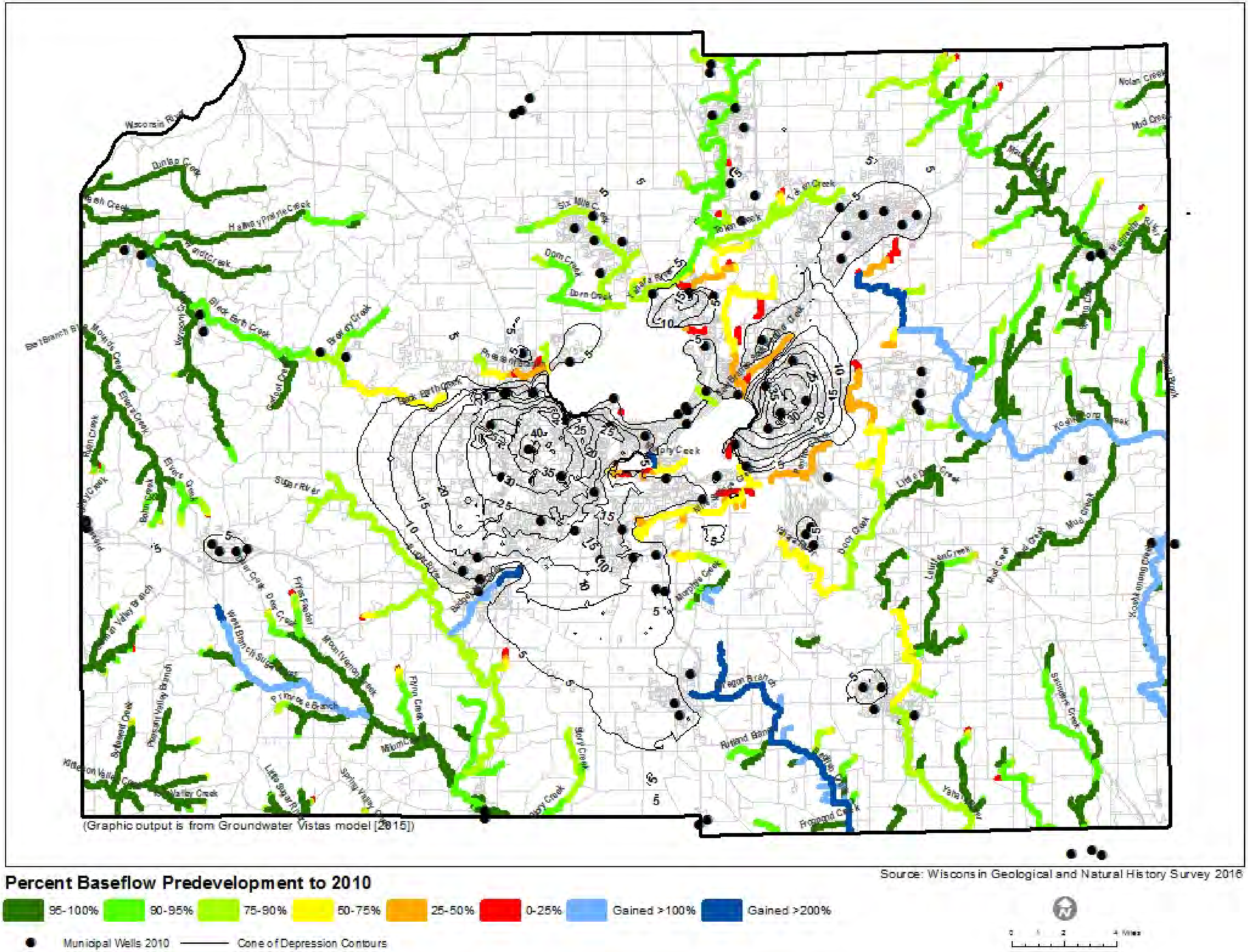
[1] Simulated predevelopment results were estimated by removing all well pumping from the regional groundwater model resulting in a subsequent rebound in water table levels and stream baseflows. Predevelopment flows do not include wastewater treatment plant discharges present in 2010. Asterisks (*) indicate 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.[12] 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.[13]

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 (**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 (**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[14]

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

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

[13] 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.

[14] Assumes no mitigating actions being taken.

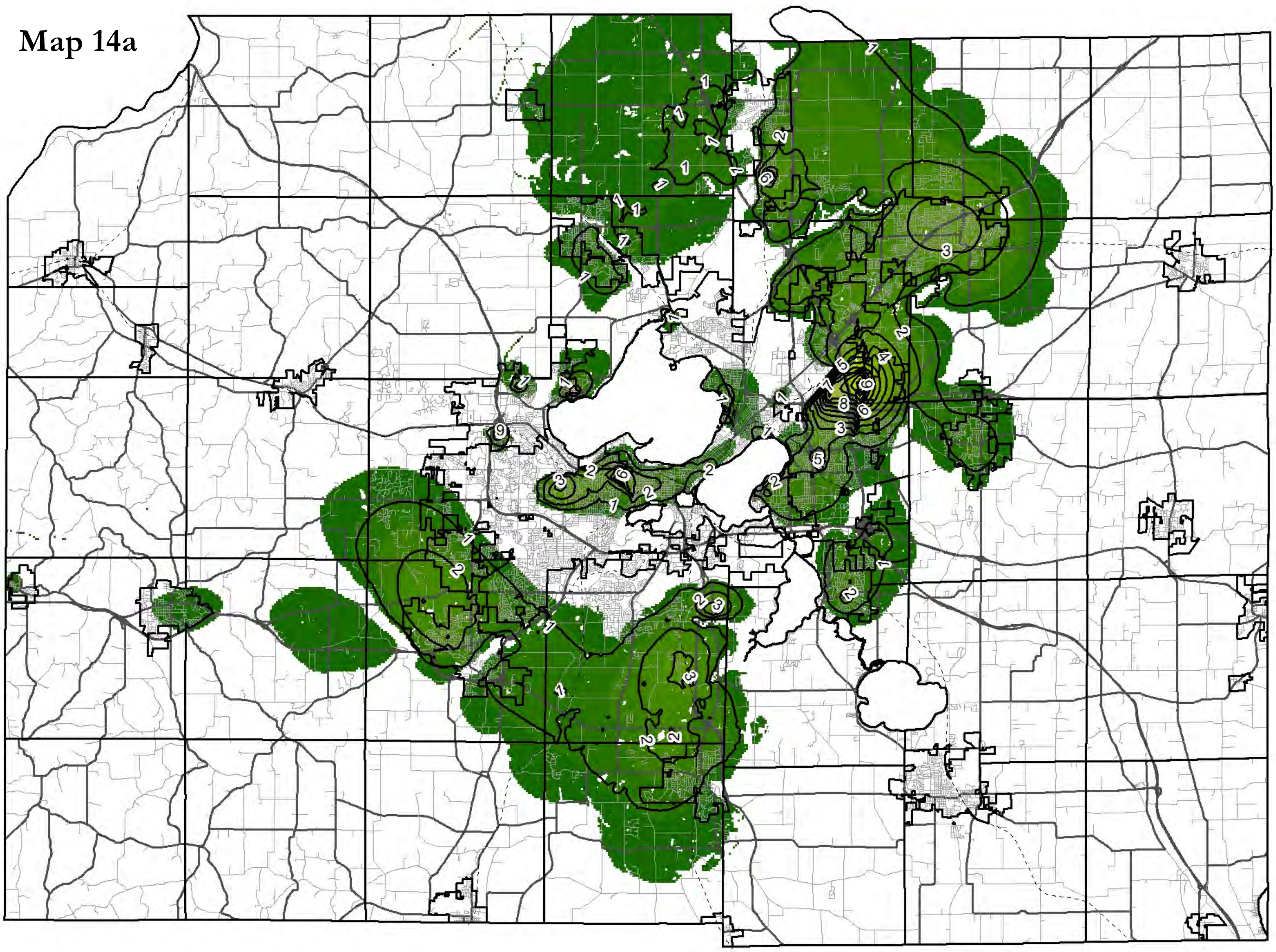
likelihood of withdrawal among existing and planned municipal wells. That is usually not the case under actually conditions, which can change year to year and community to community. The modeling indicates the kinds of analyses that can be conducted for individual communities depending on different well 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 (**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 (**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 **Table 7** below).

Map 14a



(Graphic output is from Groundwater Vistas model [2015])

Note 1 foot contours

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

Groundwater Table Reduction

Less — More

Cone of Depression Contours

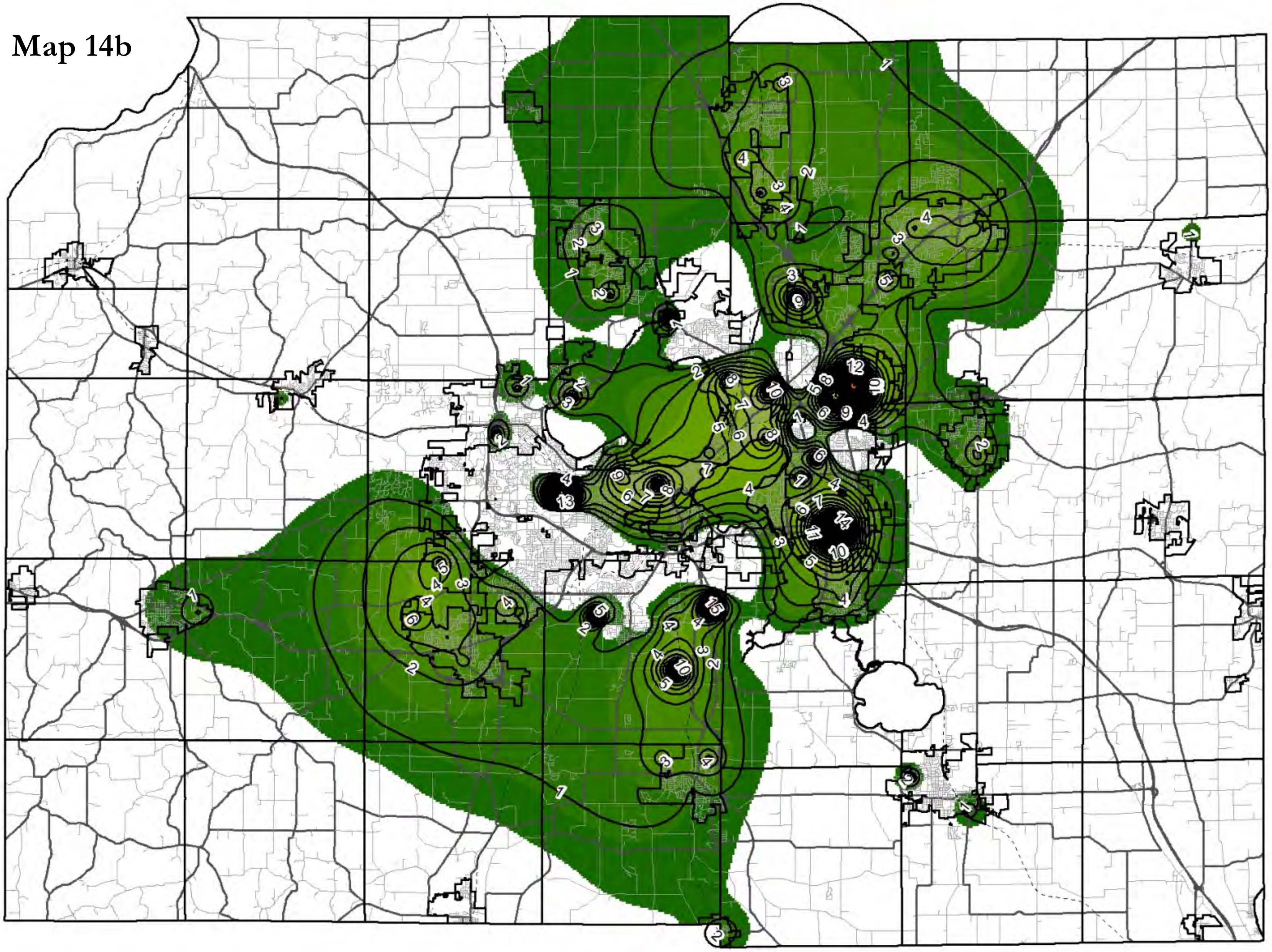
November 2015

(Source: WGNHS 2015)

0 1.5 3

Miles

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	$\mathbf{SW_{in}}$ = flow from surface waters to groundwater	$\mathbf{SW_{out}}$ = discharge to surface waters from groundwater	Volume of water in the aquifer below the water table and above the Eau Claire shale formation
	$\mathbf{Sh_{in}}$ = lateral inflow through the aquifer	$\mathbf{Sh_{out}}$ = lateral outflow through the aquifer	
	$\mathbf{L_{up}}$ = leakage up from the deep aquifer	$\mathbf{L_{down}}$ = leakage down to the deep aquifer	
	$\mathbf{H_r}$ = human inputs (e.g., artificial or enhanced recharge)	$\mathbf{Well_{sh}}$ = pumpage from the shallow aquifer	
Eau Claire Shale – semi-confining unit			
	Inflows	**Outflows**	**Storage**
Deep Aquifer – lower Mt. Simon sandstone formation	$\mathbf{D_{in}}$ = lateral inflow through the deep aquifer	$\mathbf{D_{out}}$ = 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
	$\mathbf{L_{down}}$ = leakage down from the shallow aquifer	$\mathbf{L_{up}}$ = leakage up to the shallow aquifer	
	$\mathbf{H_{dp}}$ = human inputs = 0	$\mathbf{Well_{dp}}$ = 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 **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 15a 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.

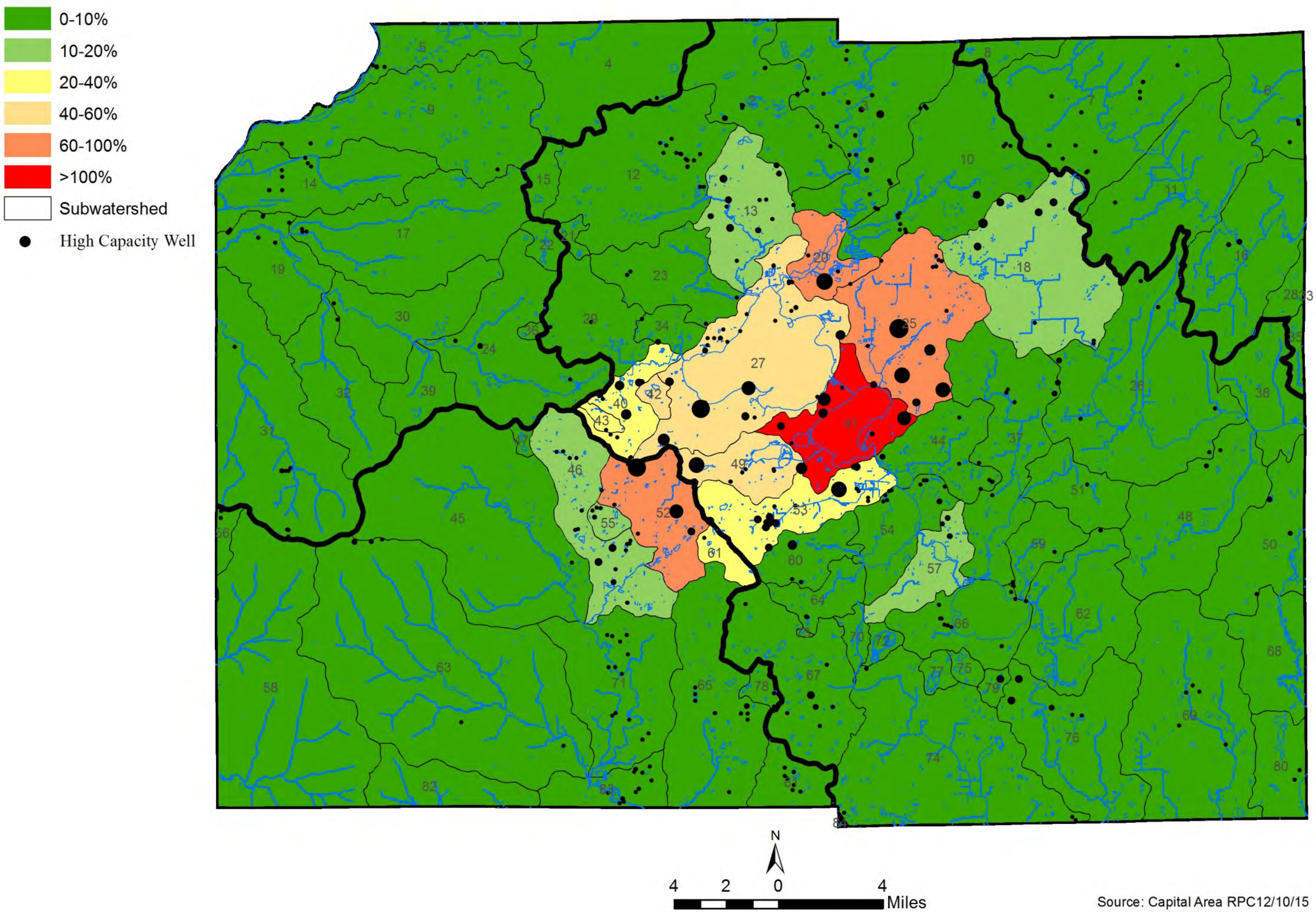
The highest DSRs are in the Madison Metropolitan Area, with the Lake Monona value being in excess of 100 percent (demand greater than supply). The result is that water is being induced from the Yahara Chain of Lakes. Whereas groundwater discharged to Lakes Monona and Mendota during pre-development conditions, 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 the Capital Area Regional Planning Commission 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

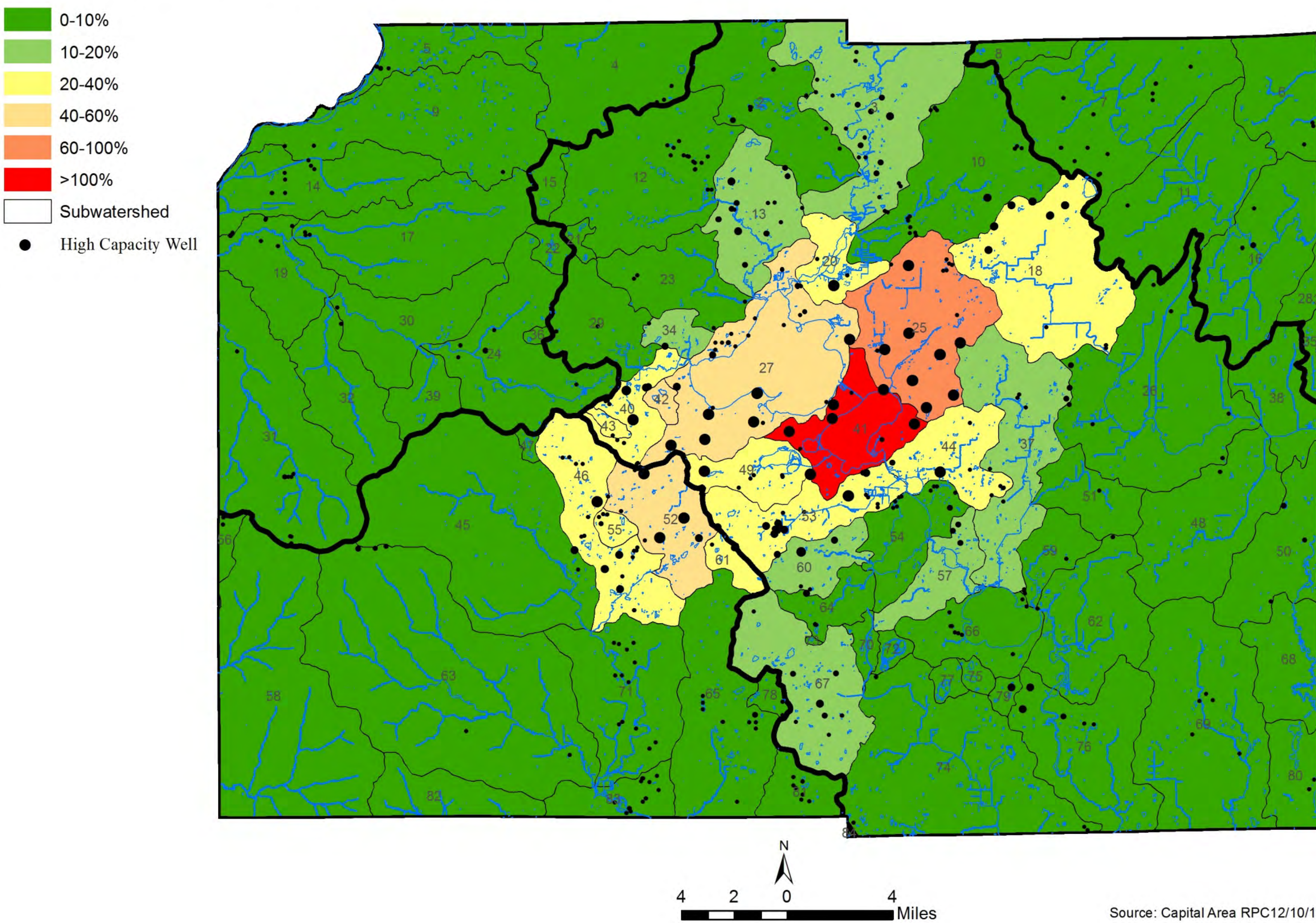
[4] See the Stormwater Performance Standards contained in Dane County Chapter 14.51(2)(e)(3). https://pdf.countyofdane.com/ordinances/ord014.pdf

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 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 $SW_{out} - SW_{in}$ (**Table 6**).

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

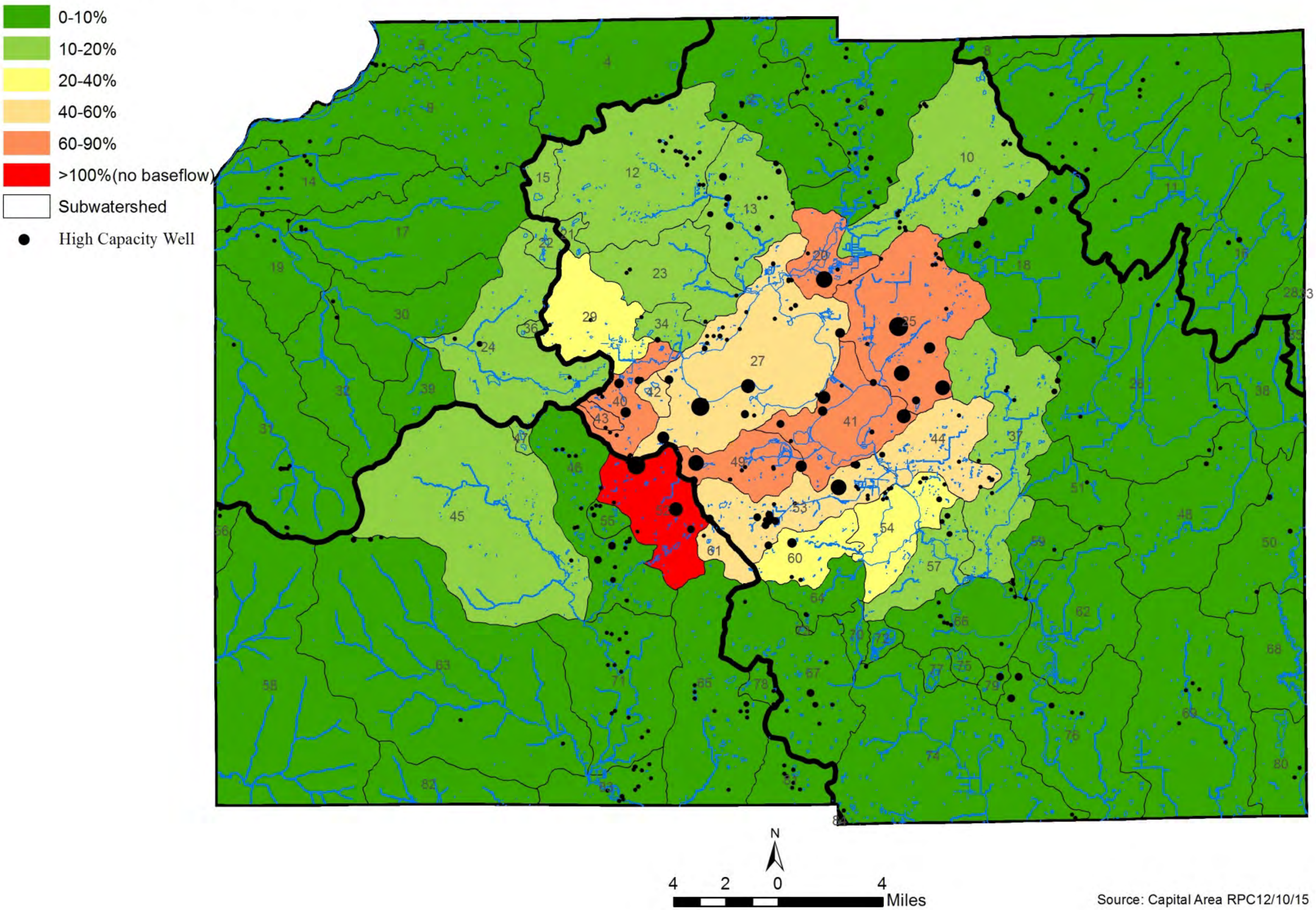
The values, expressed as percent, are presented in **Maps 16a and b.** There has been a baseflow reduction of 20 percent or greater throughout much of the central region (shown in yellow, orange, and red). This shows a strong parallel to DSR, **Maps 15a and b.** Also, BRIs generally increase in developing 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.

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.

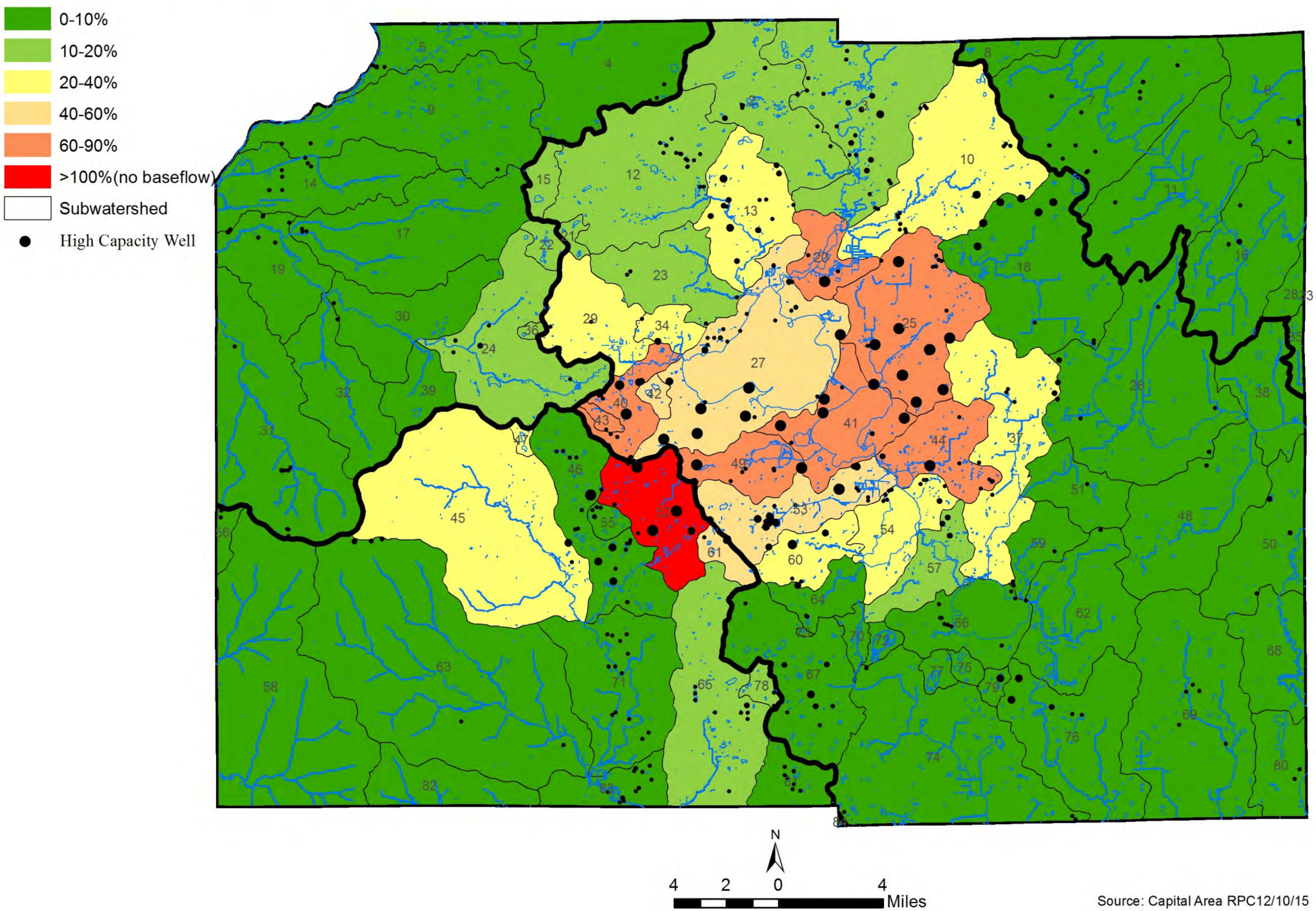
Similar to the DSR above, the utility of this index is that it is possible to test different configurations of wells and withdrawals to evaluate alternative pumping patterns and management strategies. More specifically, the index provides useful information and methodology for testing alternative growth 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 **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

Map 16a. 2010 Baseflow Reduction Index (BRI)



Map 16b. 2040 Baseflow Reduction Index (BRI)



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.

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

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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/

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**).

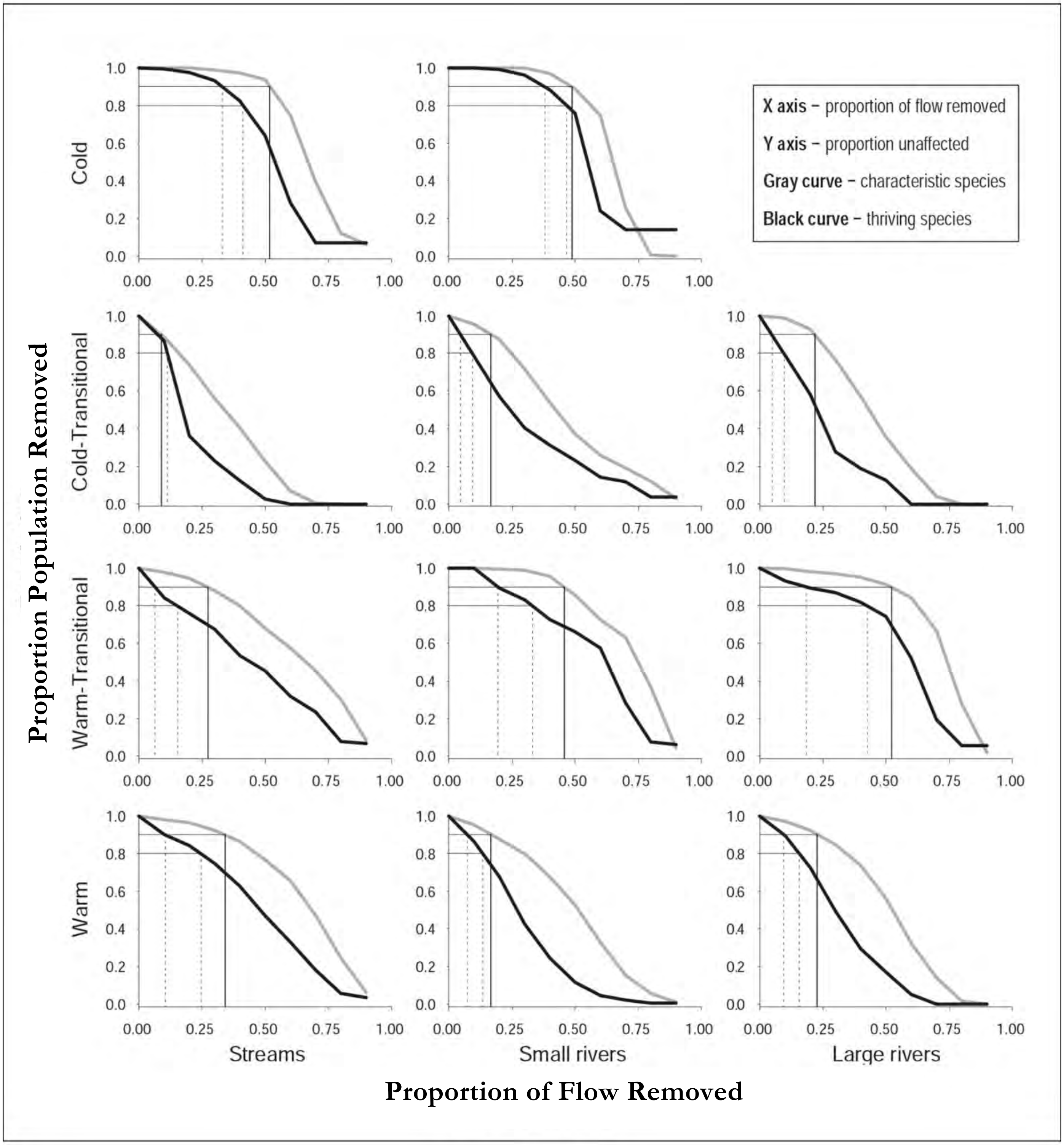
A diverse stakeholder committee proposed a ten percent decline in the thriving (sensitive) fish population as a socially acceptable or sustainable resource impact (Region A). A ten percent decline in the characteristic (tolerant) fish population was deemed to be an unacceptable adverse impact (Region 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]

The Capital Area Regional Planning Commission 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 (**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.

[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.

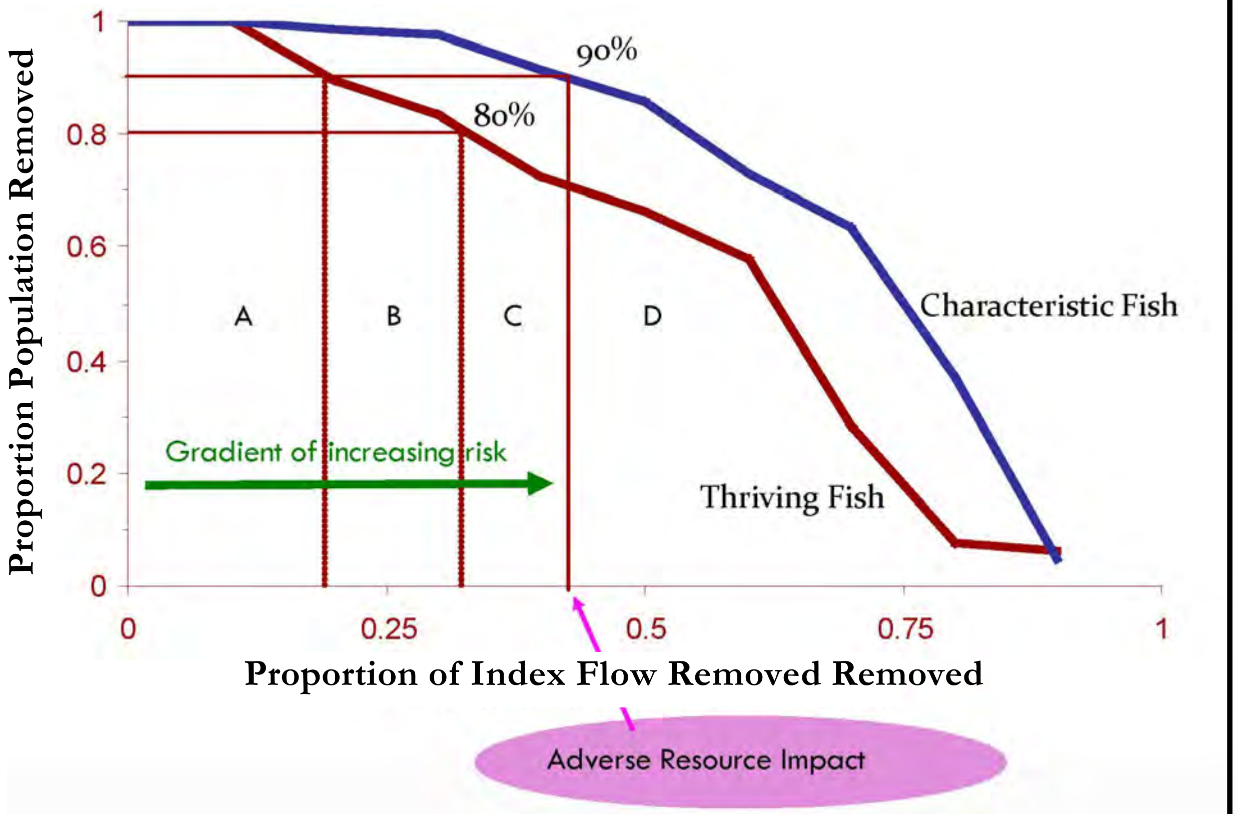


Curves describing fish community responses to water withdrawal for Michigan's 11 river types, as defined by size and July temperature characteristics. Axes are identical to those in Figure 12. The black curve describes the proportion of more sensitive "Thriving Species" at each increment of flow reduction. 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.

Source: *A Regional-scale habitat Suitability Model to Assess the Effects of Flow Reduction on Fish Assemblages in Michigan Streams*. 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.

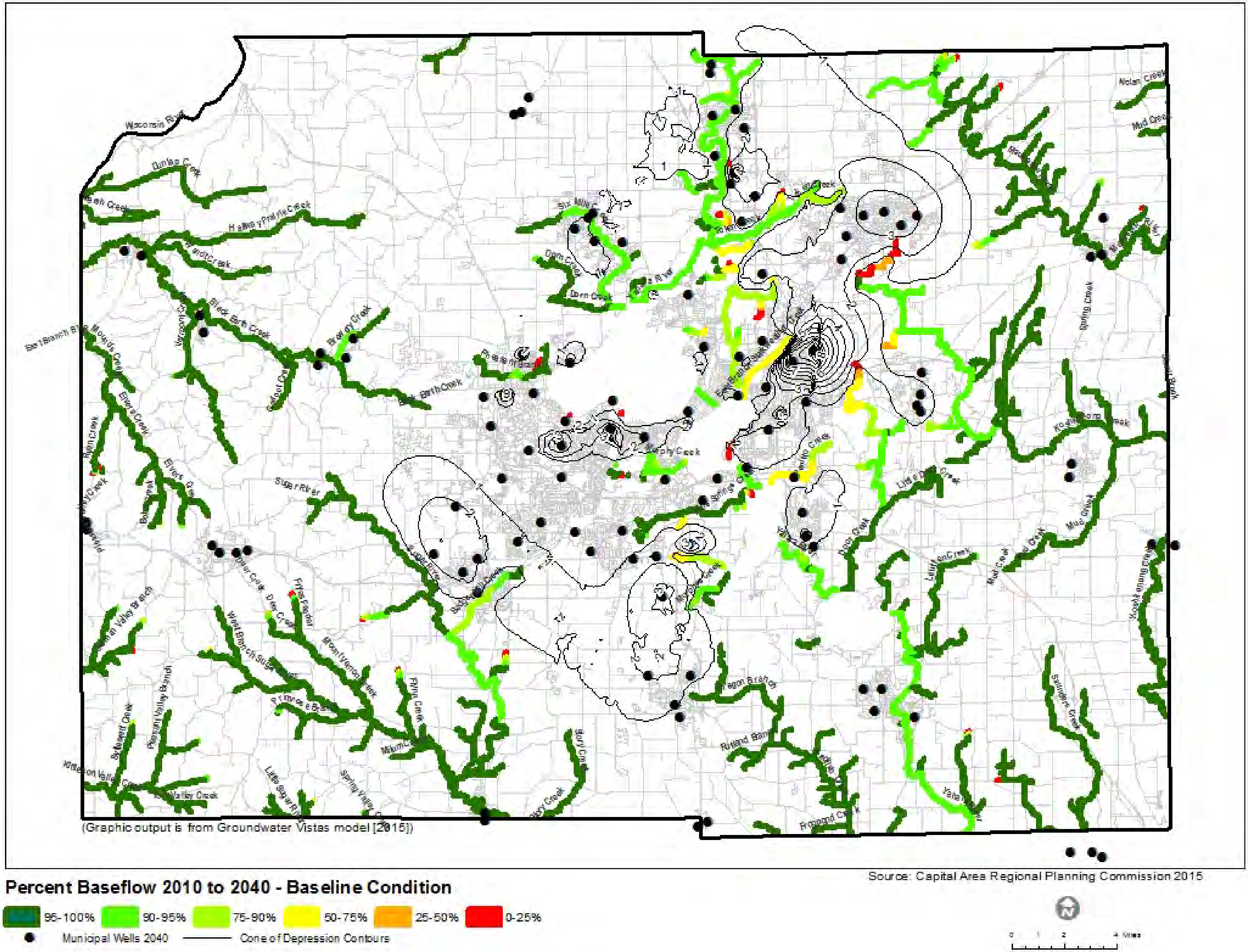
Source: Michigan Groundwater Conservation Advisory Council, 2007.

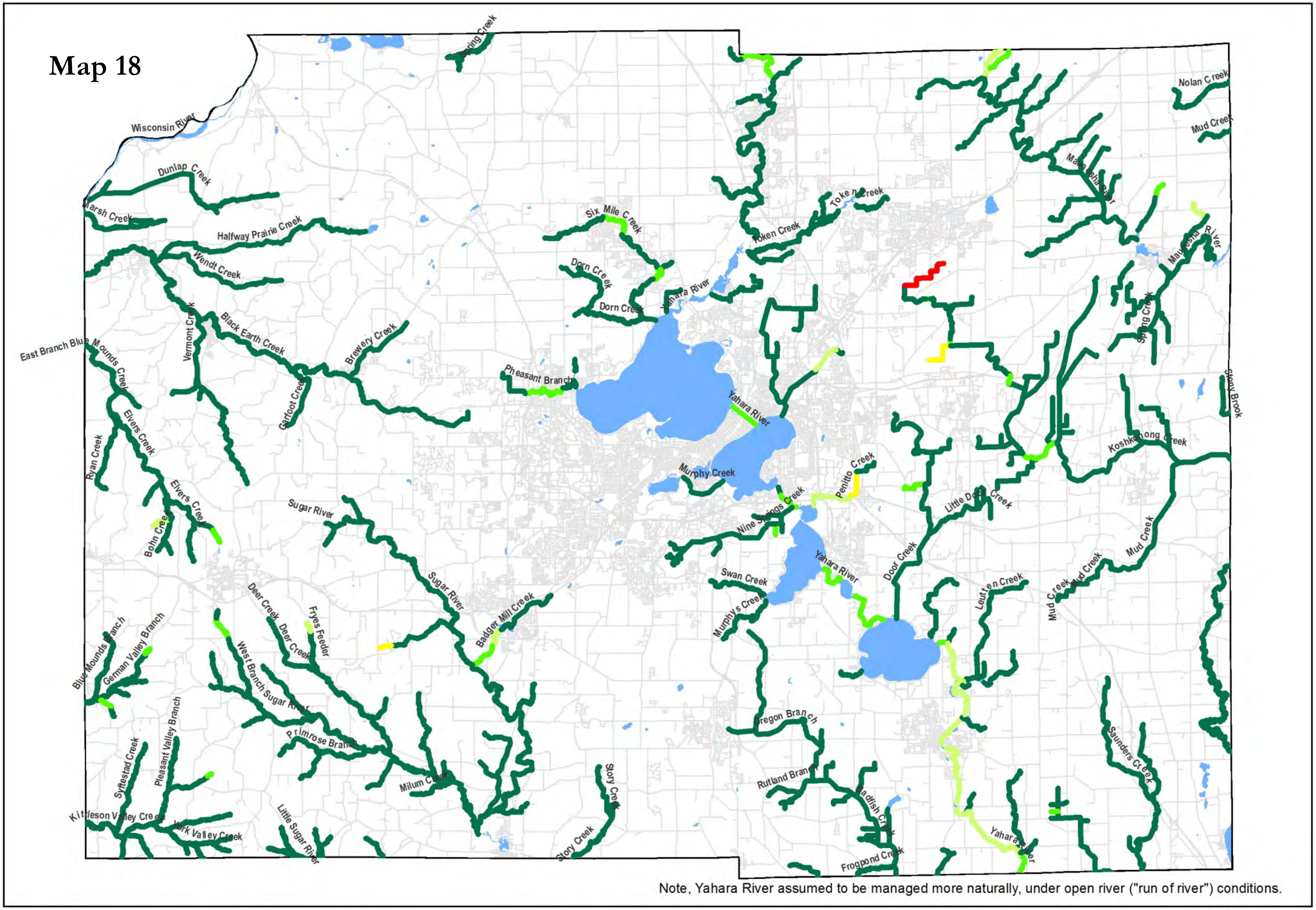
The ecological models use fish species composition as a surrogate for overall biological integrity. The objective of this analysis was to predict the response of stream fishes to changes in stream flow that are expected to occur by 2040 due to changes in land use and groundwater use in Dane County. The 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 **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 17. Comparison of changes in streamflow between 2010 and 2040, assuming current wastewater discharges from existing treatment facilities.





Percent Fish Community Status 2010 to 2040

95-100% | 90-95% | 75-90% | 50-75% | 25-50% | 0-25%

Map created by the Capital Area Regional Planning Commission
Source: M. Diebel, WDNR. 2015. Ecologic Limits of Hydrologic Alteration.

Date: 8/30/2016

Miles
0 2.5 5

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 **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 (**Figure 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.

[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.*

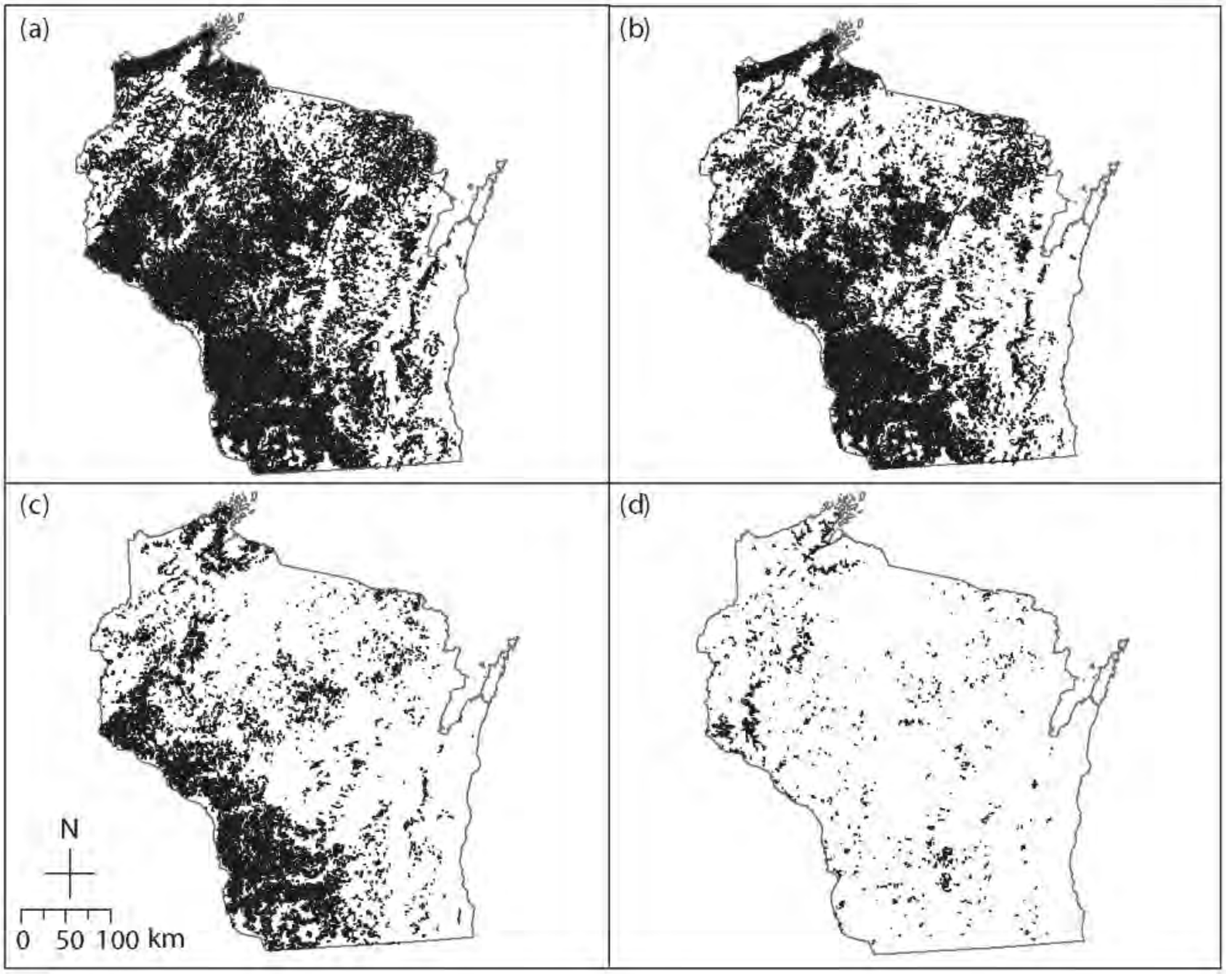


Figure 12. Predicted distribution of Mottled Sculpin, a cold-water species, under four climate warming scenarios: (a) Current conditions, (b) Limited warming, (c) Moderate warming, and (d) Major warming. Only stream segments where the species is predicted to occur are shown.

Source: Lyons, 2010

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 **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.

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[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 (**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 (**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

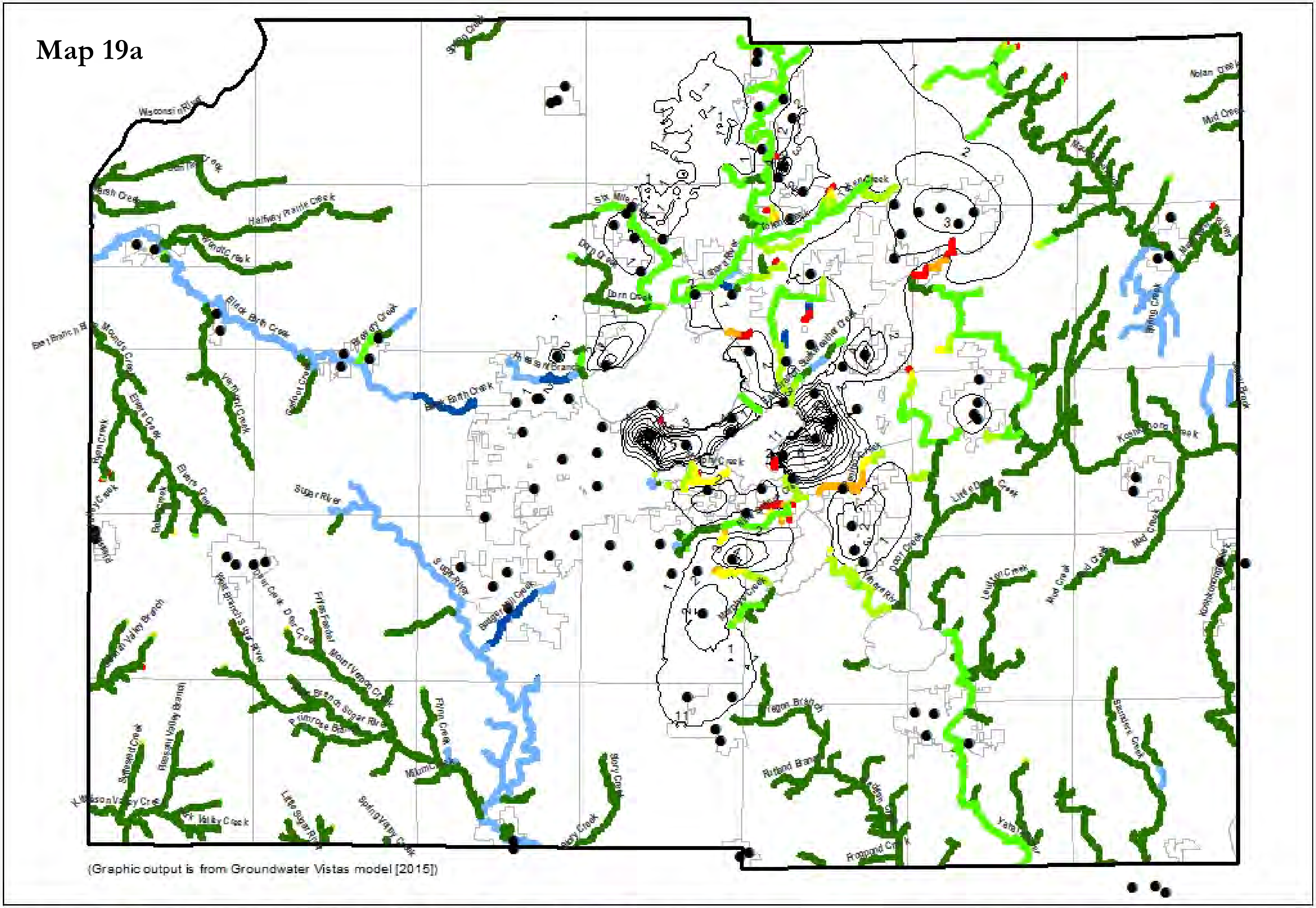
[20] Madison Water Utility. 2000. *Report on Task 10 – Well Pumpage Optimization*. Water System Master Planning Study.

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).

[21] Al Larson, Principle Engineer Madison Water Utility, communication January, 2016.

Map 19a



(Graphic output is from Groundwater Vistas model [2015])

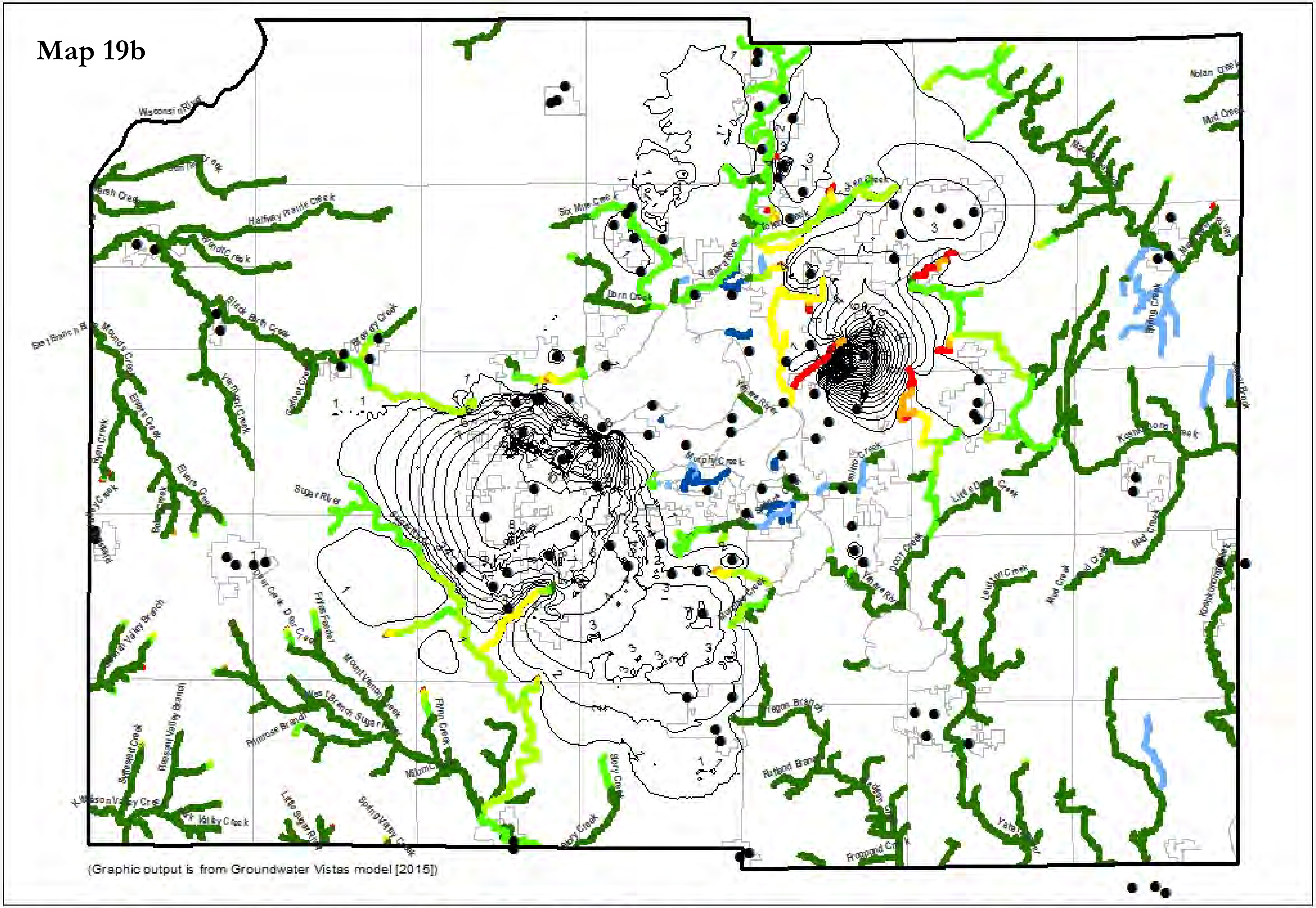
Percent Baseflow 2010 to 2040 (75%Inner/25%Outer Wells Pumping Scenario)

(Source: Capital Area Regional Planning Commission 2016)

95-100% | 90-95% | 75-90% | 50-75% | 25-50% | 0-25% | 100-110% | 110-120%

Municipal Wells 2040 | Cone of Depression Contours

0 1 2 4 Miles



Percent Baseflow 2010 to 2040 (75%Outer/25%Inner Wells Pumping Scenario)

(Source: Capital Area Regional Planning Commission 2016)

95-100% | 90-95% | 75-90% | 50-75% | 25-50% | 0-25% | 100-110% | >110%

● Municipal Wells 2040 —— Cone of Depression Contours

0 1 2 4 Miles

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 (**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.

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., **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.

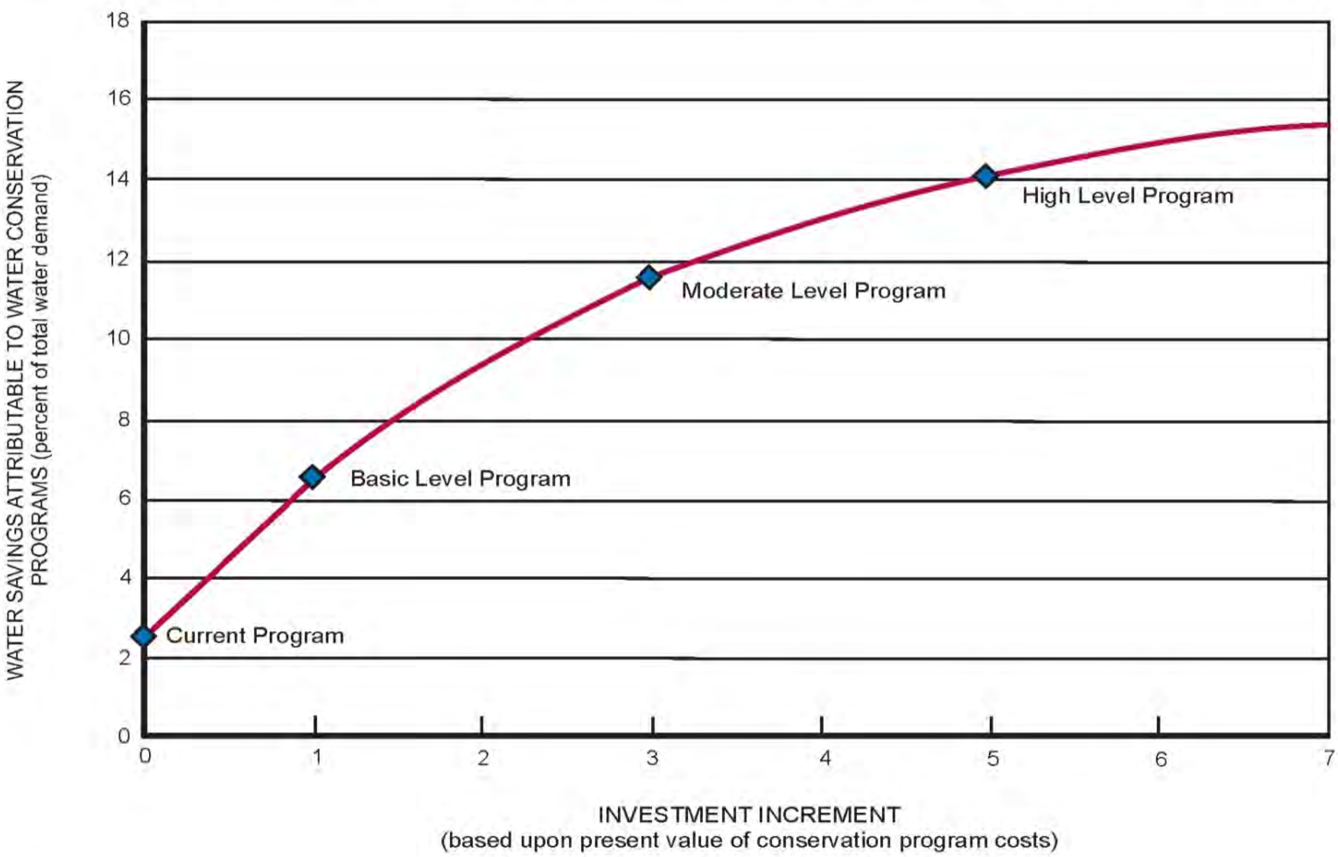
Each community should develop its own Water Conservation and Sustainability plan tailored to its unique opportunities and circumstances using the most cost-effective mix of practices and programs. *State of the Art Water Supply Practices* SEWRPC Technical Report 43 provides useful information including 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.

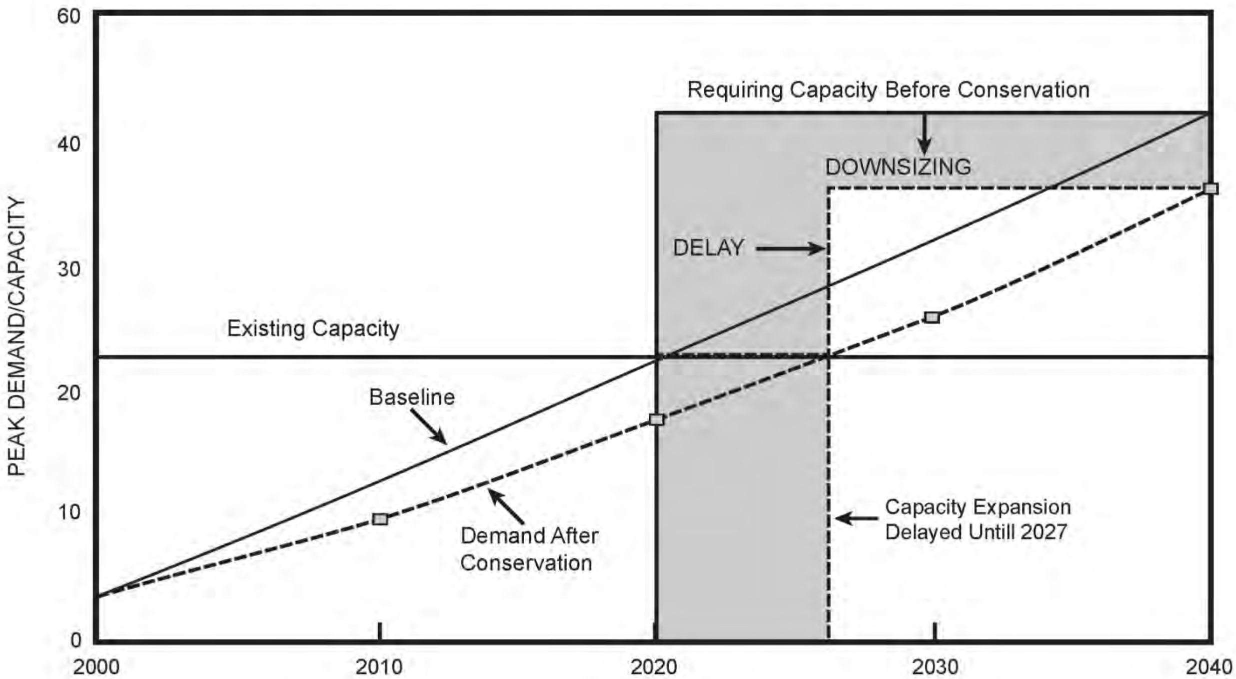
[a]*Annual savings are based on avoided chemical and energy costs associated with pumping and treating water less the cost of the conservation plan.*

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



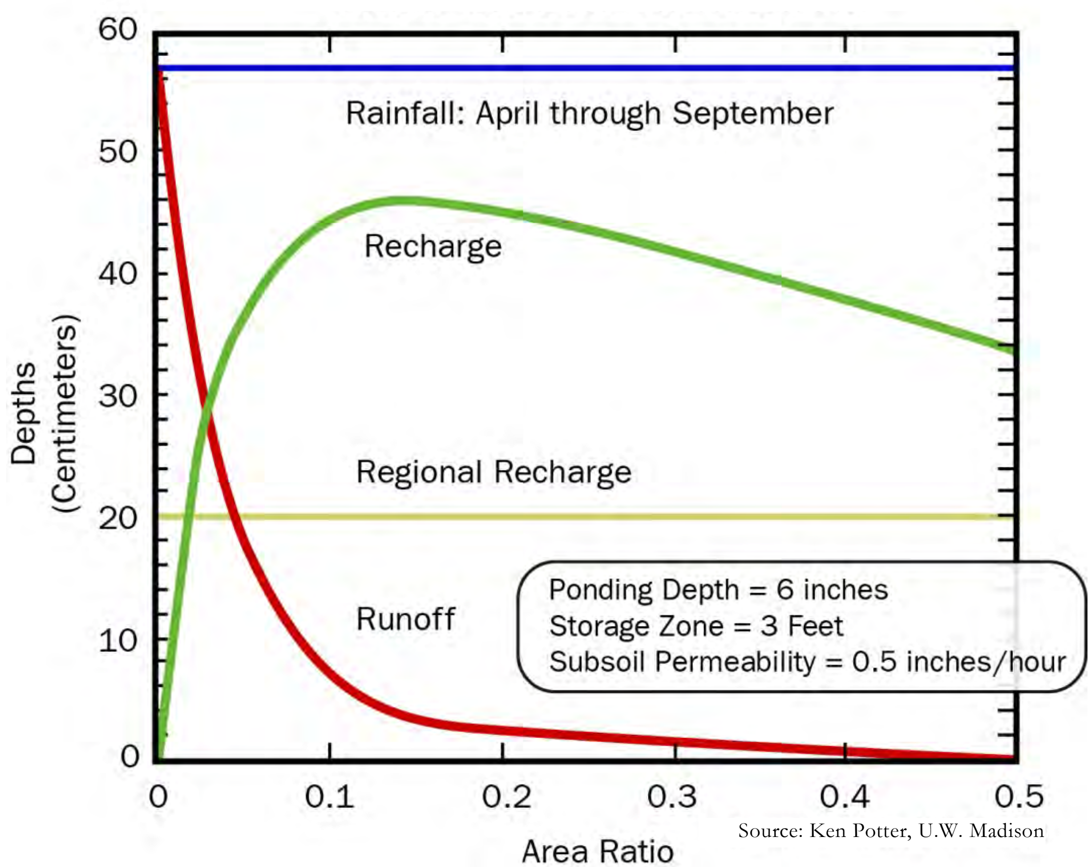
Source: Maddaus, W. et al. 1996. *Integrating Conservation into Water Supply Planning.*

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 the Capital Area Regional Planning Commission. 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.

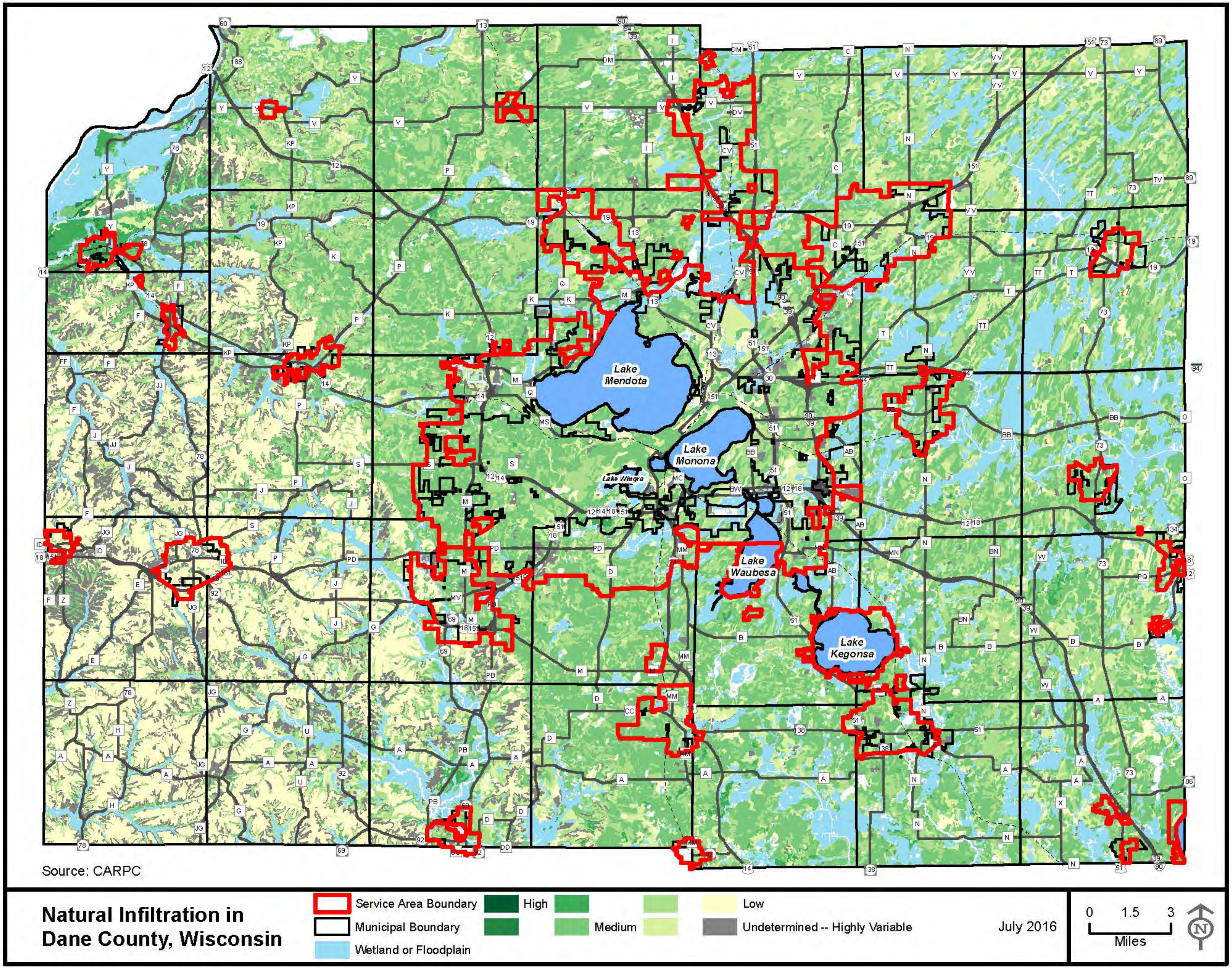
Map 21 presents enhanced infiltration that could result through removal of shallow layers of soils with low permeability and tapping into deeper sand and gravel deposits. The use of engineered soils (e.g., mixtures of sand, clay, and compost, along with native prairie plants) can enhance natural infiltration 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.

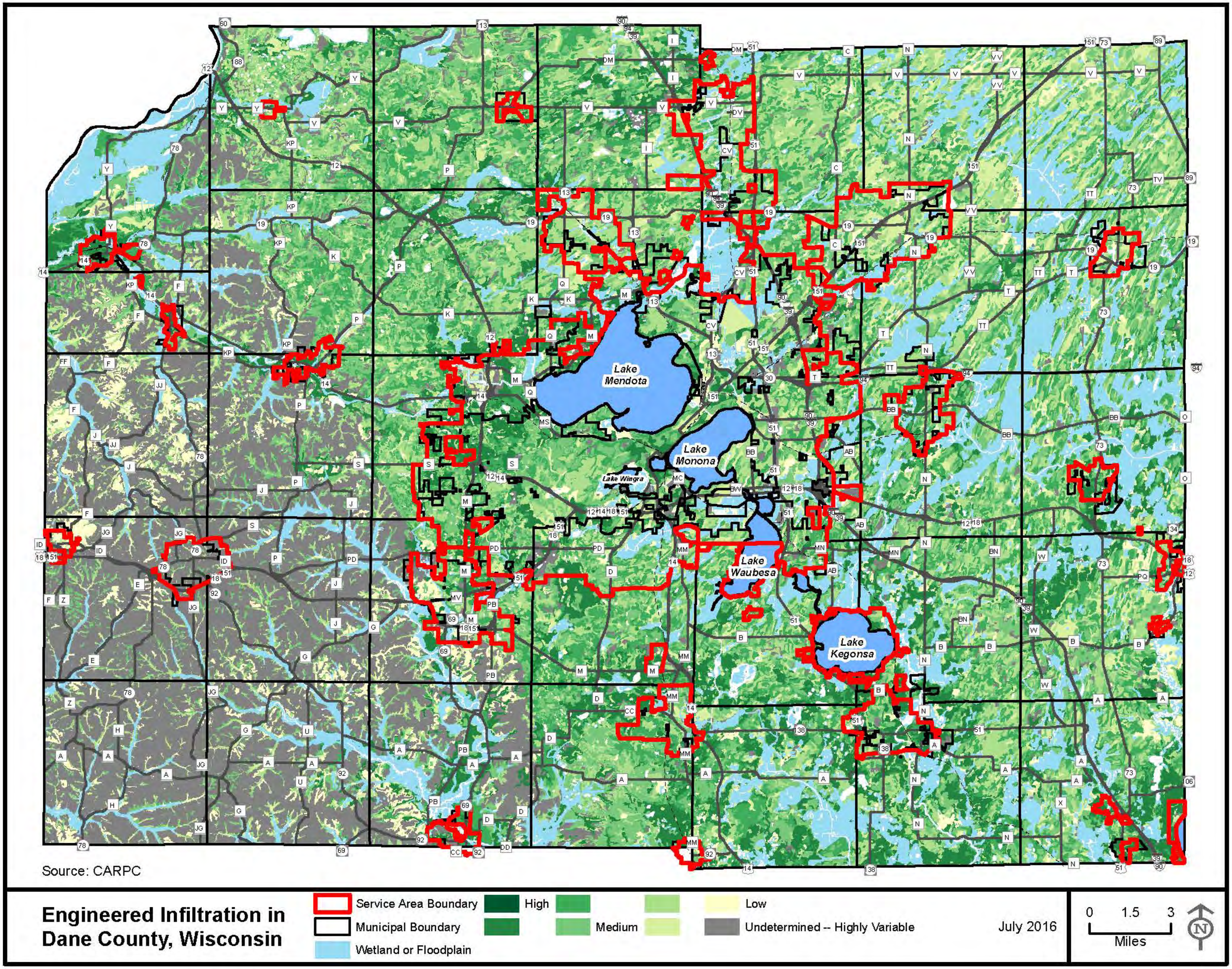
A distinction between infiltration and recharge should be made. Whereas all precipitation that reaches groundwater is infiltrated into the soil, not all infiltrated precipitation actually makes it all the way to recharging groundwater supplies. Some of it may be captured by plants and evaporated or transpired 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.

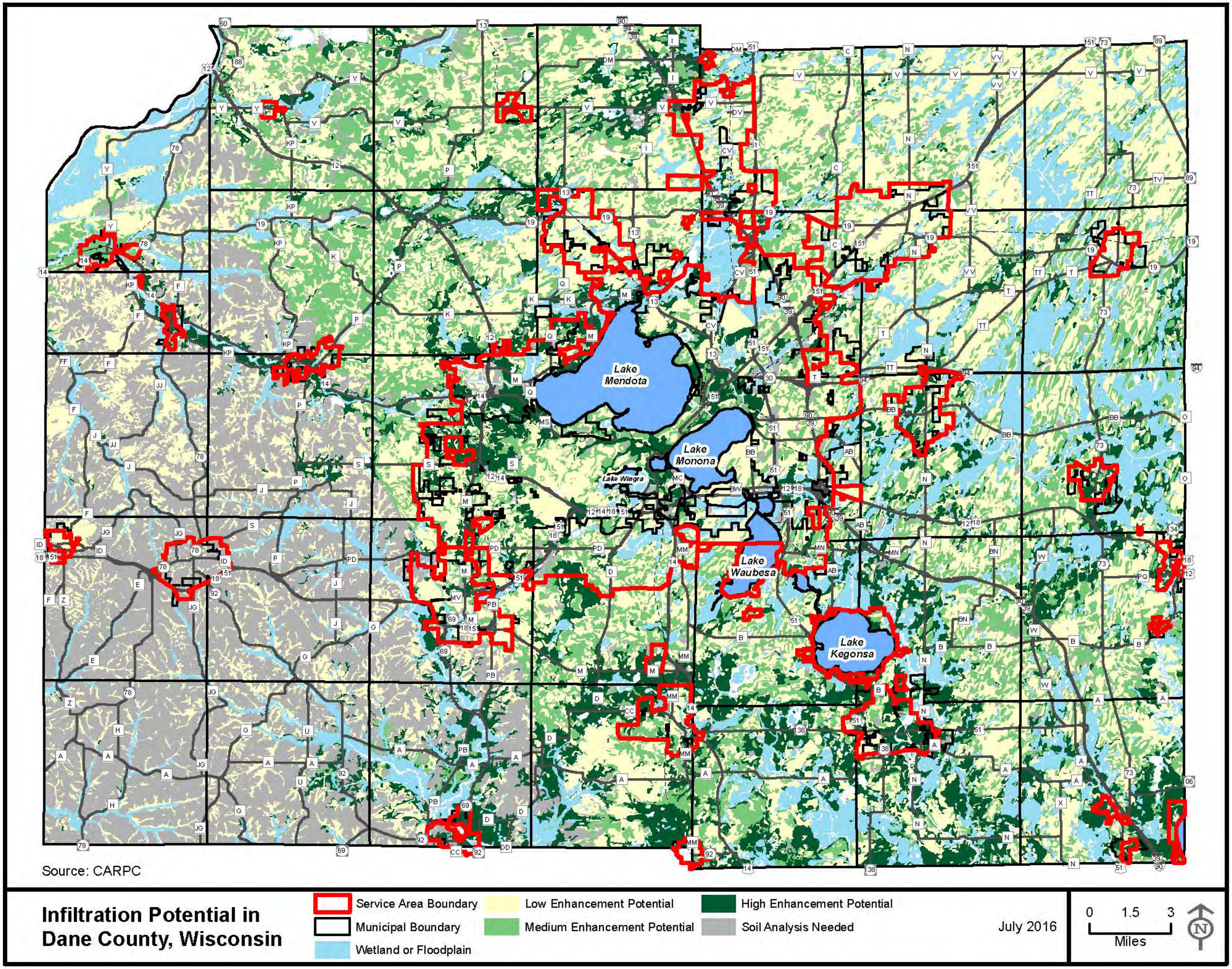
Map 20


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
July 2016
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 or Floodplain
High
Medium
Low
Undetermined -- Highly Variable
July 2016
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 or Floodplain
Low Enhancement Potential
Medium Enhancement Potential
High Enhancement Potential
Soil Analysis Needed
July 2016
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.

[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.*