Appendix A: Five-year Assessment of Water Quality Trends and Prevention Efforts

Minnesota Pollution Control Agency and Minnesota Department of Agriculture

September 2015

Table of Contents

Prepared by:
Dave Tollefson, Mike MacDonald, Jeff Berg (Minnesota Department of Agriculture, Pesticide and Fertilizer Management Division) and Byron Adams, David Duffey, Sharon Kroening (Minnesota Pollution Control Agency, Environmental Outcomes and Analysis Division) for the Minnesota Environmental Quality Board.

Minnesota Pollution Control Agency
520 Lafayette Road North, Saint Paul, MN
55155-4194
http://www.pca.state.mn.us
651-296-6300 or
800-657-3864 toll free
TTY 651-282-5332 or
800-657-3864 toll free
Available in alternative formats

Minnesota Department of Agriculture
625 Robert Street North, Saint Paul, MN
55155-2538
http://www.mda.state.mn.us
651-201-6141 or
800-967-2474 toll free
TDD 800-627-3529 toll free
Available in alternative formats

List of Figures

List of Tables

Introduction and Executive Summary

This Minnesota Pollution Control Agency (MPCA) and the Minnesota Department of Agriculture (MDA) water quality assessment provides an overview of relevant monitoring data and efforts to reduce, prevent, minimize, and eliminate sources of water pollution to Minnesota's groundwater and surface water resources. This report consolidates information from a number of the most recent reports on the status and trends of Minnesota's water resources. Because of the large amount of information available on this subject, this report is summary in nature and directs the reader to additional information provided through web-based links.

The report was last published in August of 2010 as the *Biennial Assessment of Water Quality Degradation Trends and Prevention Efforts* (2010 Biennial Report) and can be found at the following link: https://www.eqb.state.mn.us/sites/default/files/documents/WaterPlan2010AppendixA-BiennialAssessmentofWaterQualityDegradationTrendsandPreventionEfforts.pdf.

In contrast to the 2010 Biennial Report, this report includes much of the work completed as part of the Clean Water, Land and Legacy Amendment (Clean Water Fund) investment, which includes the *Minnesota's Clean Water Roadmap* and the 2014 *Clean Water Fund Performance Report*. These two reports represent the efforts of six state agencies and the Metropolitan Council, receiving Clean Water Funding, to set long range goals to protect, enhance, and restore the state's water resources. http://www.legacy.leg.mn/funds/clean-water-fund.

Information on groundwater quality is presented first, highlighting: nitrates, pesticides, arsenic, chlorides, and contaminants of emerging concern. The groundwater information is followed by descriptions of the efforts to prevent and eliminate groundwater degradation through program activities conducted by the MPCA and MDA.

Surface water quality information is presented next by water resources (lakes, streams, and wetlands) and emphasizes the status and trends of Minnesota's surface water quality. Lake transparency data, pesticide detections, trends in water quality indicator parameters, and impaired waters listings are presented to highlight Minnesota's surface water quality condition.

For both groundwater and surface water, efforts to reduce and minimize resource degradation involve multiple program activities conducted by the MPCA and MDA. Efforts summarized in this report include the Pesticide and Fertilizer Registration and Outreach Programs, Agricultural and Pesticide Best Management Plan Programs, Clean Water Partnership Program, regulation of wastewater discharges and subsurface sewage treatment systems (SSTS), Animal Feedlot Program, Stormwater Program, and MDA and MPCA monitoring and assessments efforts.

Within the last 20 to 30 years, most of the pollution originating from point sources (municipal and industrial facilities discharging to state waters) has been controlled; in large part due to remediation programs, pollution prevention activities, and permit regulations. Water quality is mainly degraded by the pollutants entering surface waters from non-point sources derived from runoff from land, particularly from watersheds dominated by agricultural and urban land use. This report will focus primarily on non-point sources of pollution of anthropogenic (human) origin that require our continued efforts to realize our state's water quality goals.

It is important to remember that groundwater and surface waters are part of a single, interconnected hydrological system. So while monitoring assessment and reporting techniques may vary between groundwater, lakes, streams and wetlands, these water resources should not be viewed in isolation from each other.

Overview: Water Resources – Benefits of Information

The MPCA and MDA conduct water quality assessments to protect the environment; but more specifically, to provide decision makers with good information about the status of water resources, to prevent and address problems, and to evaluate how effective management actions have been. Water quality assessments are also useful in planning and implementing prevention and mitigation efforts to protect water resources, and as a means of tracking the impacts of human activity.

This report provides access to a variety of water quality reports, documents and agency plans, and highlights the status of our water quality resources, in addition to efforts to reduce and minimize water resource degradation.

Now, five-year water assessments will be prepared directly by the agencies and integrated by the Environmental Quality Board (EQB) every five years. The frequency of reports was changed from two-years to five-years because groundwater and surface water trends typically do not change within shorter periods of time, thus frequent reporting is not effective or useful. In addition, the five-year cycle will tie monitoring results to planning and management efforts via state water planning and be in accordance with Minn. Stat. 103A.43.

Groundwater Basics

Groundwater provides nearly 75% of Minnesotan's with their primary source of drinking water and nearly 90% of the water used for agricultural irrigation, as estimated by the MDH and the Minnesota Department of Natural Resources (MDNR). For these reasons alone it is important that we protect, monitor and report on the quality of this valuable natural resource.

The MPCA and MDA collect large amounts of groundwater quality data. Much of this is collected through contamination cleanup or landfill programs, and is considered investigation and compliance monitoring. However, data is also collected through ambient or "condition" groundwater monitoring efforts. Ambient monitoring has two primary objectives: to determine the status and quality of the groundwater resources, and to identify trends in water quality over time.

To understand groundwater quality it is important to recognize that groundwater occurs everywhere in Minnesota within water-bearing soil or rock formations called aquifers (Figure 1). These aquifers create a complex matrix of groundwater resources in many areas of the state that may yield either abundant or very limited water supplies. The water quality in these aquifers is influenced by both natural processes and anthropogenic (human) influences. This report focuses on reporting the ambient condition of groundwater quality in Minnesota as influenced by anthropogenic effects, with less emphasis on natural processes which affect groundwater quality.

Monitoring of Minnesota's groundwater has identified contamination from non-point sources from agricultural fertilizers and pesticides, urban runoff, manure applications, septic systems, road salt and stormwater infiltration, in many vulnerable aquifers. The most common contaminants detected include nitrates, pesticides, and road salt in urban areas. In addition, chemicals that are not commonly monitored or regulated are being identified at low concentrations in groundwater that include: antibiotics, fire retardants, detergents, and plasticizers. This group of chemicals is referred to as contaminants of emerging concern (CECs) and includes endocrine active chemicals (EACs).

Surface Water Basics

With more than 10,000 lakes, 100,000 river and stream miles, and about 9.3 million wetland acres, water is a major part of Minnesota's culture, economy, and natural ecosystems. Streams, rivers, lakes, wetlands, they are all "surface waters" in Minnesota. Their assessment for contaminants and the documentation of surface water quality trends are important functions of state agencies and their cooperators.

The MPCA follows a 10-year rotation for assessing waters of the state in Minnesota's 80 major watersheds (Figure 2). This is supplemented by annual monitoring at the outlets of the major watersheds to identify trends and statewide quality. Today, about half of Minnesota's surface waters have been assessed; of those, about 40% do not meet basic water quality standards. The MDA focuses on agricultural and urban areas where agricultural chemicals, like pesticides, are used and may impact surface water resources. The major watershed approach provides an important unifying focus for all stakeholders. For more detail on the watershed approach see http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/basins-and-watersheds/watershed-approach.html.

Minnesota's surface water monitoring has identified that for many vulnerable hydrogeologic settings the source of contamination within a watershed can be attributed to several of the same non-point sources affecting groundwater, e.g., agricultural fertilizers and pesticides, urban runoff, and septic systems, as well as to municipal and industrial wastewater. Some of the most common impacts to surface water come from sediment, phosphorus (agricultural, industrial and residential), coliform bacteria, nitrate, mercury and pesticides. As with groundwater, an emerging concern to surface water quality is the potential effects of endocrine disrupting compounds that affect aquatic life and reproduction.

Figure 1. Minnesota groundwater provinces.

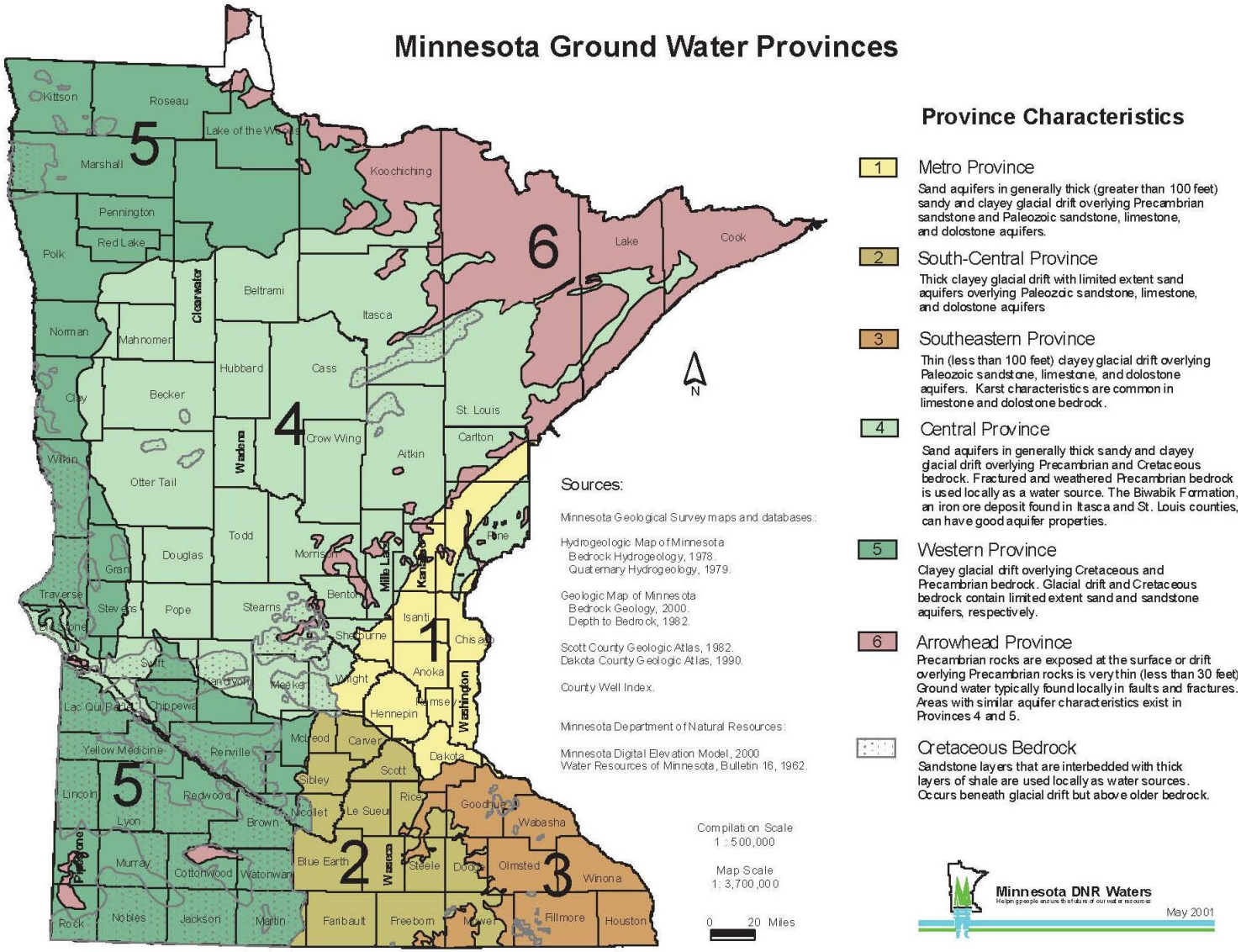
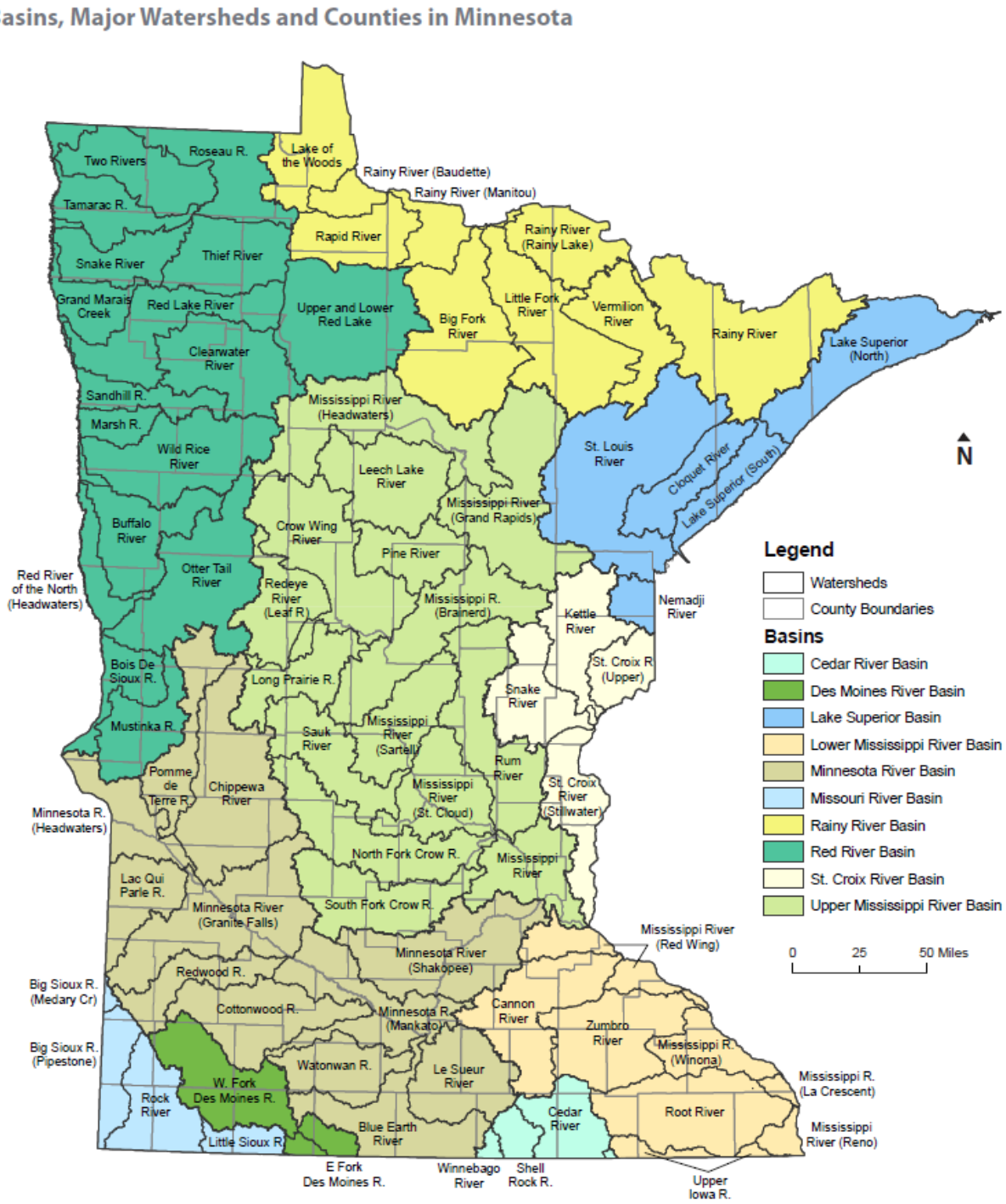


Figure 2. Basins, major watersheds and counties in Minnesota.



Water Quality Concerns

Water resource contaminants can come from human or natural sources. Some contaminants, like arsenic are naturally occurring due to geologic materials dissolved in aquifers. Arsenic can also come from human sources like industrial processes and products. Some contaminants are primarily a concern for groundwater (e.g., nitrate, arsenic and chloride) while others are primarily a concern for surface water (e.g., phosphorus and sediments).

The MPCA and MDA have tracked several key contaminants for years, while other contaminants of emerging concern have recently been discovered in part due to new analytical capabilities and are just beginning to be studied. The water quality analyses contained in this summary include both historical key contaminants and those of emerging concern.

Important water resource contaminants reviewed in this summary, include: nitrate/nitrogen, chloride, arsenic, pesticides, perfluorochemicals (PFCs), and CECs in groundwater aquifers. The status of surface water quality is reported by water resource (lakes, wetlands, streams,) and includes summaries of impairment status and surface water quality trends for several contaminants. Additional information about these and other contaminants can be found in the source documents cited throughout this summary.

The distinction between various groundwater and surface water resources – and their contaminants – can at times be difficult to make due the many interactions between lakes, wetlands, streams, and aquifers. However, the statutes that guide MPCA and MDA monitoring and reporting requirements are often aligned along specific water resources and related terms. Thus, while a contaminant may principally be assessed in one water resource (e.g., lakes and wetlands), that same contaminant may also move to groundwater resources via infiltration from the surface water body to the aquifer. Complicating matters, the impacts to groundwater (rate of contaminant degradation in the aquifer, drinking water concerns, etc.) may be evaluated differently from those associated with surface water resources, and are subject to unique monitoring methods, spatial and temporal considerations, and risk evaluation.

This report then provides an overall picture of quality with respect to several contaminants, while recognizing statutory requirements for different agencies to monitor and protect specific water resources from specific contaminants.

Groundwater Quality: Assessment and Analysis

Presented below is information on groundwater quality and trends for select contaminants of known or emerging concern. Additional detail and data for various groundwater monitoring projects and other contaminants in state aquifers and watersheds can be found in MPCA publications at http://www.pca.state.mn.us/index.php/water/water-types-and-programs/groundwater/groundwater.html and in the MDA publications at http://www.mda.state.mn.us/chemicals/pesticides/maace.aspx.

Nitrate/Nitrogen

Nitrogen in groundwater is primarily present in the form of nitrate (represented chemically as NO_3^-) and occurs naturally at low concentrations of less than 1.0 mg/L. Studies of groundwater quality in Minnesota over the last two decades have linked elevated nitrate concentrations to land uses where there are anthropogenic (human-caused) sources of nitrate in combination with vulnerable geology.

Most nitrate which enters groundwater comes from anthropogenic sources such as animal manure, fertilizers used on agricultural crops, failing SSTS, fertilizers used at residences and commercially, and nitrous oxides from the combustion of coal and gas. With this array of sources, it is not surprising that nitrate is one of the most common contaminants of groundwater in Minnesota.

Nitrate concentrations in groundwater are monitored by the MPCA and MDA, in urban and rural settings, as a part of their ambient groundwater monitoring programs. The MDA, MPCA and the Minnesota Department of Health (MDH) work collaboratively on a number of fronts to address nitrate contamination and assist state and local efforts aimed at protecting drinking water supplies and preventing further groundwater contamination. Other state and federal agencies such as the MDNR and United States Geological Survey (USGS) have also generated groundwater nitrate data through regional studies of the groundwater.

The MPCA's involvement with nitrate contamination includes providing a framework for local administration of SSTS programs, and administration of the feedlot and storm water programs. The MPCA has also conducted several studies of nitrate concentrations in groundwater relative to non-agricultural land uses. The MPCA report on groundwater quality (Kroening, Ferrey 2013) found that nitrate contamination in Minnesota, generally, has not changed in the past 15 years, but concentrations remain high in certain areas. http://www.pca.state.mn.us/index.php/view-document.html?gid=19743. For agricultural uses, nitrate is included as an analyte in MDA ambient monitoring efforts described and reported at www.mda.state.mn.us/monitoring.

Nitrate sampling from the MDA's 2014 annual monitoring showed that 86% of the shallow groundwater samples collected had detectable levels of nitrates. The Central Sands and East Central portions of Minnesota had the highest percent detection at concentrations exceeding the MDH health risk limit (59 and 44 percent, respectively). These conditions represent the most sensitive possible and may not be representative of local aquifer systems used for drinking water.

Private Well Nitrate Monitoring

To evaluate nitrate concentrations and trends in groundwater, MDA and local partners have established regional networks that monitor nitrate in private wells. Currently there are regional networks established in southeast karst and the central sands areas. These areas of the state are the most vulnerable to groundwater contamination. Sampling of private wells within these areas provides a

systematic basis to evaluate nitrate concentrations using the same private wells over several years. The data collected from private well owners is useful for evaluating long term trends and indicates whether nitrate in groundwater is a concern in these vulnerable aquifers. Participation by homeowners is voluntary. One of the current challenges in this design occurs when homeowners may decide to drop out. This tends to be most prevalent with either no detectable or very high nitrate levels, therefore creating inconsistent data collected. Nevertheless regional monitoring of private wells provides a logical way to monitor groundwater contamination by monitoring the same wells over multiple years.

Southeast Volunteer Nitrate Monitoring Network Results

Drinking water quality is a concern across southeastern Minnesota due to highly variable hydrogeologic conditions that allow for rapid movement of water and contaminants in groundwater. In 2008, the Southeast Minnesota Water Resources Board (SEMNWRB), and several partners (MPCA, MDA, MDH) began collecting data from the "volunteer nitrate monitoring network" (VNMN). This region was selected as a pilot because of its vulnerable and complex geology. The network was developed to assess the practicality of establishing a cost-effective, locally driven means of obtaining long-term data on nitrate concentrations in private drinking water supplies. Nitrate concentrations were tested in approximately 600 private drinking water wells across nine counties in southeastern Minnesota. The wells were monitored to determine the impact that well construction and local land use have on drinking water quality, and to describe the regional distribution of nitrate concentrations and any temporal trends.

Before data collection began, well network coordinators (county staff) enrolled volunteers (well owners) into the program by collecting detailed information about well location, well construction, and nearby nitrate sources. Well owners collected six rounds of samples, between February 2008 and August 2012.

Based on the 3,245 samples collected and analyzed, the percentage of wells exceeding the Health Risk Limit (HRL – the EPA drinking water standard)) for nitrate-N of 10 mg/liter for each sampling round ranged between approximately 7.6 and 14.6% (Table 1) (MDH 2012; Aug. 2012- unpublished data from MDA).

Table 1. Median nitrate-N and wells exceeding the Health Risk Limit (HRL)

	February 2008	August 2008	February 2009	August 2009	August 2010	August 2011	August 2012
Median Nitrate-N (mg/L)	0.3	0.3	0.2	0.3	0.7	0.5	0.4
Exceed HRL (%)	14.6	11.4	11.1	11.0	9.3	10.4	7.6

The study evaluated several factors related to well construction and hydrogeology, and found them to influence groundwater quality. Well construction (the documented presence or absence of casing grout) and overlying geologic protection (shale or at least ten feet of clay above the open interval of the well) had the strongest influence on groundwater quality. Low nitrate concentrations were measured in 97.7% of wells with the most-desirable construction and hydrogeologic characteristics. The results are only applicable to the nine counties in the study area. The initial well selection grid consisted of 675 uniformly spaced search areas; no participant was identified for some search areas. The sample return rate steadily dropped over time from a high of about 77 percent in Round 1 to a low of around 63 percent in Round 5 & 6 in August 2010 & 2011. See MDH report for details: http://www.health.state.mn.us/divs/eh/water/swp/nitrate/reports/methodsresults.pdf

MDA Central Sands Private Well Monitoring Network Results

Due to the success of the southeast volunteer nitrate monitoring network, as well as the availability of newly acquired funding from the Clean Water Legacy Amendment, the MDA launched a similar project in the Central Sands area of Minnesota. The MDA determined that because high levels of nitrate have been measured in Central Sands monitoring wells, it was important to expand nitrate monitoring to private drinking water wells to determine if the concentrations in them were similar to concentrations found in the monitoring wells. In the spring of 2011, the MDA began the Central Sands Private Well Monitoring Network (CSPWN). The first goal of this project was to look at current conditions across the Central Sands region and the second long term goal was to determine long term nitrate concentration trends using a subset of this monitoring data.

By July 1, 2011, the MDA had analyzed 1,555 samples for nitrate. Over 88% of the wells sampled had nitrate-N concentrations below 3 mg/L, 6.8% of the wells ranged from 3-10 mg/L of nitrate-N and 4.6% were greater than the 10 mg/L nitrate-N health risk limit (HRL) (Table 2). These results were similar to findings from a 2010 U. S. Geological Survey (USGS) report on nitrate concentrations in private wells in the glacial aquifer systems across the upper Midwest of the United States (Warner and Arnold 2010). The USGS report found that less than 5% of sampled private wells had nitrate-N concentrations greater than or equal to 10 mg/L nitrate-N. Nitrate concentrations from the 2011 CSPWN varied widely over short distances. This was also the case in the USGS report on glacial aquifer systems.

Table 2. Summary of nitrate-N concentrations for the Central Sands Private Well Network (2011)

	# of Samples	Minimum (mg/L)	Median (mg/L)	75th Percentile (mg/L)	90th Percentile (mg/L)	Maximum (mg/L)	% ≤ 3 (mg/L)	% 3-10 (mg/L)	% ≥10 (mg/L)
Average	1,555	<0.03	0.01	0.66	4.15	31.9	88.6	6.8	4.6

Starting in 2012, approximately 550 homeowners volunteered to participate in long-term annual sampling of their private wells. These 550 homeowners were a subset of the original testing population of 1555. 89% of the wells in 2012 and 2013 had less than 3 mg/L of nitrate-N concentration, similar to 2011. The 2014 results show: 89% of sampled wells were < 3 mg/L, 8% were 3-10 mg/L, and 3% were ≥10 mg/L. (Table 3). Work on this project is ongoing. For further information see http://www.mda.state.mn.us/en/protecting/cleanwaterfund/gwdwprotection/characterizingnitrates.aspx.

Table 3. Summary of nitrate-N concentration results for the Central Sands Private Well Network (2011 – 2014)

		Sample Distribution by Year			
		2011	2012	2013	2014
Nitrate-N (mg/L)	Total # of Samples	534	510	487	434
0 < 3	→	478	454	433	388
3 < 10		35	40	41	32
≥ 10		21	16	13	14
Percent of Samples ≥ 10		4%	3%	3%	3%

Township Testing Program

The revised Nitrogen Fertilizer Management Plan (NFMP) outlines a new Township Testing Program (TTP) to identify the areas of the state with the greatest nitrate contaminated groundwater. Townships with greater than 20% row crop agriculture and vulnerable groundwater will be sampled. All private wells in these townships will be offered a nitrate test at no cost to the homeowner. The results from the TTP will be summarized and will help in prioritizing for further actions. Up to 70,000 private wells may be sampled.

The MDA works with local partners such as Counties and Soil and Water Conservation Districts (SWCDs) to coordinate private well nitrate testing using Clean Water Funds. The map in Figure 3 served as a starting point for planning sample locations and was modified based on local expertise from Counties or SWCDs. The Beach Ridge townships in the Red River Valley may not have had significant nitrogen fertilizer use history and need to be assessed individually to determine whether they meet the MDA's sampling criteria.

Benton, Dakota, Morrison, Sherburne, Stearns, Olmsted, Wadena and Washington Counties were chosen for the initial sampling based on historically high nitrate results and strong local partnerships. In total, sixty townships from the eight counties participated in the TTP since 2013. Overall, 13% of the 7,342 wells exceed the Health Risk Limit (HRL) for nitrate-N. Figure 4 shows the percentage of wells over 10 milligrams per liter (mg/L) for each township. Table 4 summarizes the number of townships by nitrate concentration criteria. In roughly half of the townships, 10% or more of the wells were over the 10 mg/L HRL. See;
https://www.mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/townshiptesting.aspx

In the first year of sampling (2013) 82% percent of townships had 10% or more wells exceeding the 10 mg/L drinking water HRL for nitrate-N. In the second year of sampling (2014) 34% percent of townships had 10% or more wells exceeding the HRL. The 2014 results are preliminary and have not yet been published and are subject to change. These results have yet to be analyzed for possible nitrogen point sources, so the final percentage of wells over the HRL from a non-point source may change based on follow-up sampling.

Table 4. Townships and Nitrate-N Concentration Criteria

Concentration Criteria	Number of Townships	Approximate Number of Participating Wells*	Number of wells that exceed HRL	% of wells in each Criteria Level that exceed the HRL
Less than 5% exceeding 10 mg/L	13	1293	35	3%
5%-9.9% exceeding 10 mg/L	18	2392	163	7%
10% or more exceeding 10 mg/L	29	3657	784	21%
Total	60	7342	982	13%

* Does not include wells of known hand dug construction or wells with unverified locations.

Follow-up sampling will be offered to homeowners using trained MDA staff to resample wells that had nitrate-N concentrations over 5 mg/L. At that time, an assessment will be performed to rule out obvious well construction issues and point sources of nitrogen, such as septic systems, livestock, etc. Homeowners with nitrate detections in their water sample will also be offered a no-cost pesticide sample analysis. Results from the TTP will help guide the type of response necessary to address nitrate in groundwater through the NFMP.

Figure 3. Vulnerable townships and townships sampled in 2013 and 2014.

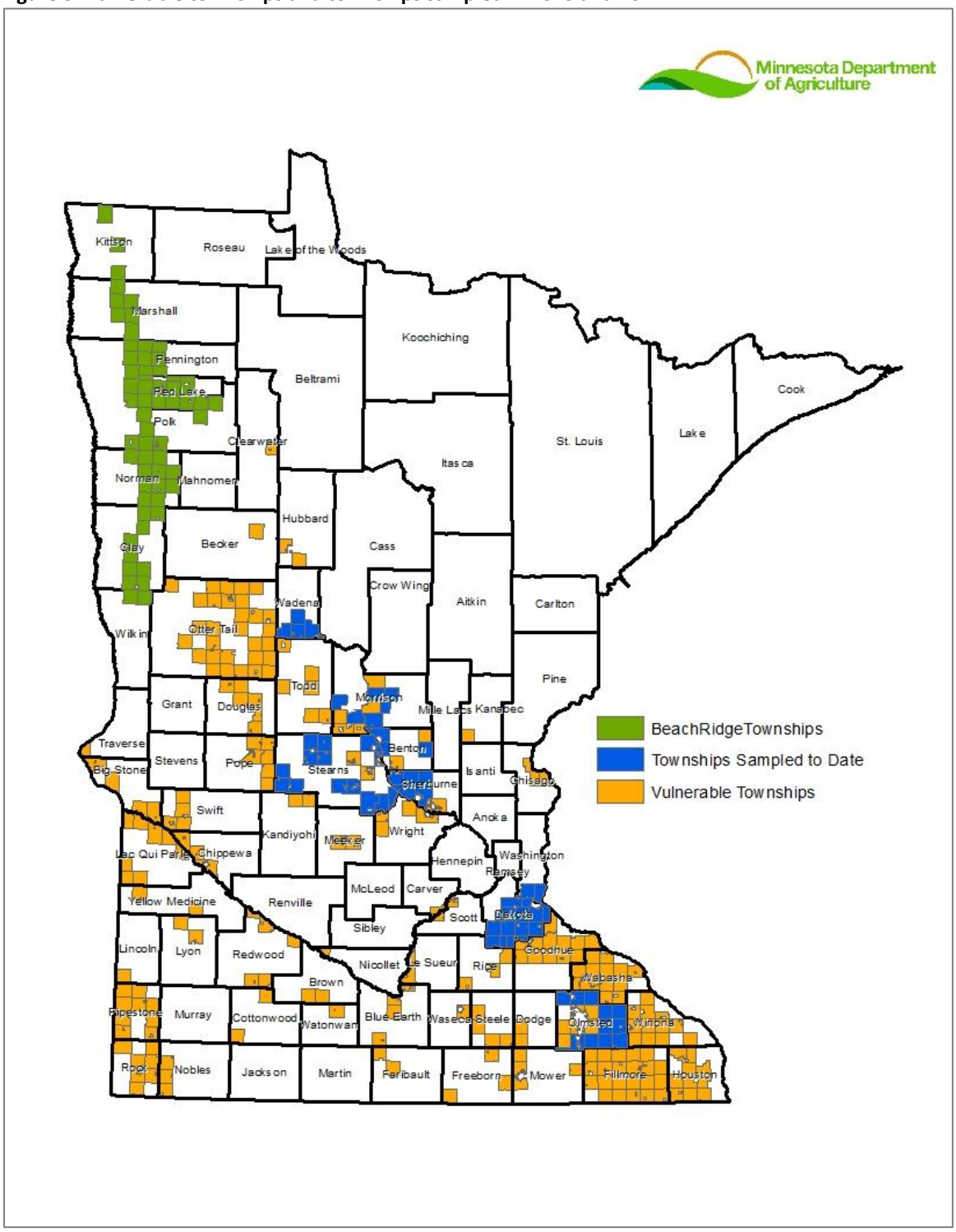
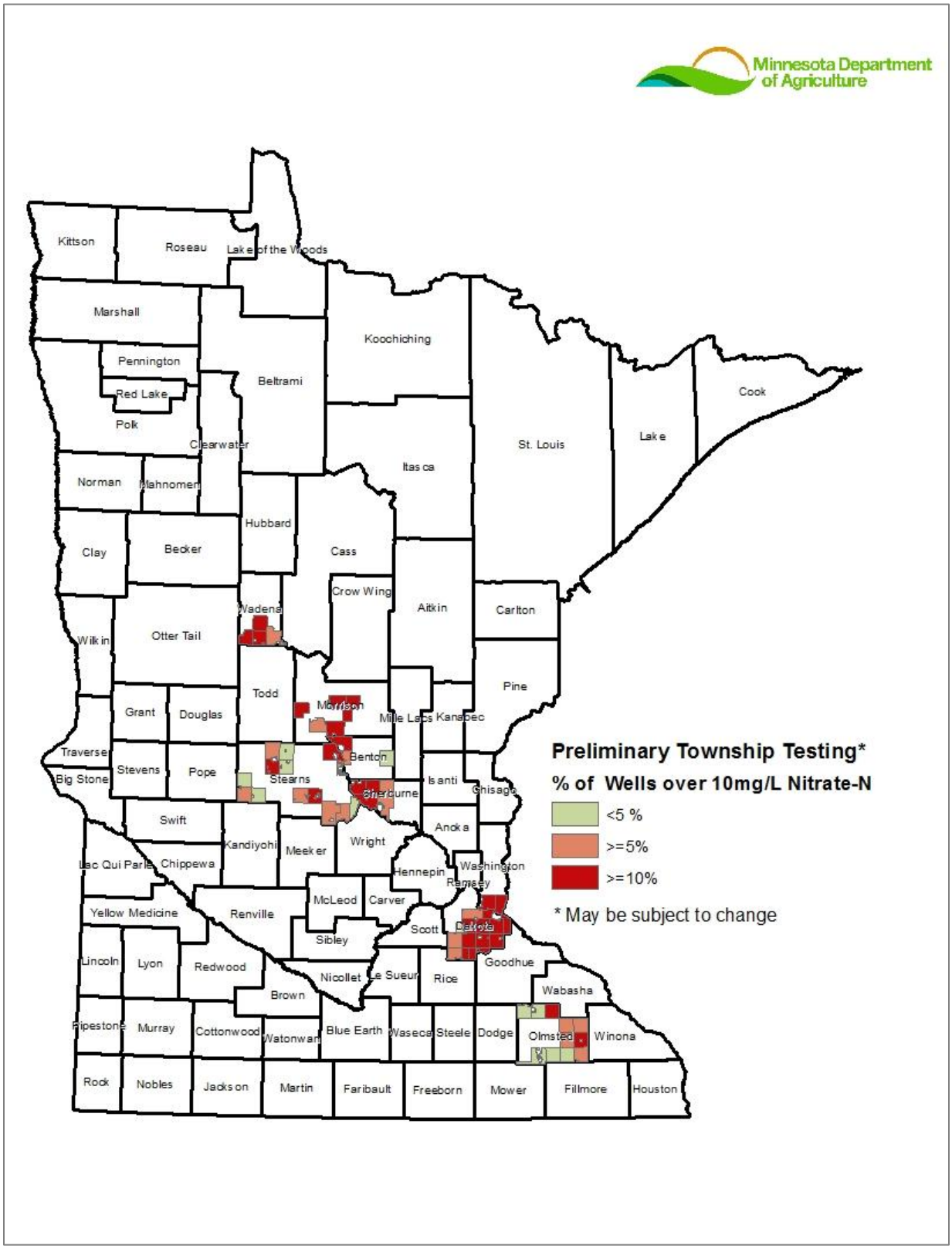


Figure 4. 2013 and 2014 Township Testing Results Summary.



Pesticides

MDA's groundwater monitoring network provides information on impacts to the state's groundwater from the routine use of agricultural chemicals. Information is made available so management decisions can be made to reduce or eliminate impacts to groundwater. The MDA began monitoring groundwater in 1985 and redesigned the program in 1998. New wells were installed in 1999, and the MDA began sampling the re-designed network wells in 2000.

Samples were collected from 167 groundwater monitoring sites in 2014 (Figure 6). Of these sites, 142 consisted of one or more specifically designed and installed monitoring or observation wells, 12 were private drinking water wells, and 13 consisted of naturally occurring springs emerging from bedrock formations of interest in the southeastern karst area of the state. All of the locations are considered sensitive to contamination from activities at the surface. Network design and sampling protocols are available in the program's groundwater design document on the MDA website at www.mda.state.mn.us/monitoring

In 2010 and 2013, improvements in laboratory equipment and techniques have increased the number of compounds that can be detected. In 2009, 44 compounds could be detected. In 2014, the number of compounds rose to 133. The MDA laboratory has also been able to lower the detection limit of some pesticides. Thirty seven different pesticides or degradates were detected in groundwater in 2014. In 2014 none of the detected pesticides exceeded their established Health Risk Levels or other drinking water benchmarks. In accordance with statutory requirements in the Groundwater Protection Act (Minn. Stat. chapter 103H), the MDA has determined that five pesticides are commonly detected in groundwater, leading to the development of Best Management Practices to prevent or reduce ongoing degradation of groundwater resources. The five "common detection" pesticides are agricultural herbicides: acetochlor, alachlor, atrazine, metolachlor and metribuzin.

Figure 5 shows the number of "common detection" pesticides detected at each sampling site. The locations showing the greatest number of pesticides per site are concentrated in the central sand plains (Pesticide Monitoring Region 4), the east central (Pesticide Monitoring Region 5), and in southeastern Minnesota (Pesticide Monitoring Region 9).

Metolachlor ESA (a Metolachlor degradate) was the most commonly detected pesticide compound within the MDA dataset in 2014. The best dataset for assessing changes in Metolachlor ESA impacts to groundwater over time is the concentration data from Pesticide Monitoring Region 4. Concentration time-trend data for Metolachlor ESA is presented in Figure 6 using the median, 75th percentile, and 90th percentile concentration values for 2002 through 2014. Time-trend analysis on median values is the most widely accepted measure on which to base decisions. The median values indicate no trend in concentrations over time. The 75th and 90th percentiles have shown a decline since 2002, but have been relatively stable since about 2005.

The trend of the frequency of detection for Metolachlor ESA in PMR 4 has risen since 2002 while the frequency of detection for Metolachlor has decreased. Figure 7 presents the data for Metolachlor and it's degradates, Metolchlor ESA and OXA. In 2014, the highest concentration measured for Metolachlor or it's degradates was 92,900 ng/L (metolachlor). The Health Risk Limit for Metolachlor is 300,000 ng/L.

Atrazine or its degradates were detected in approximately 25% of the samples collected in the fall 2014 sampling period. None of the concentrations exceeded the Health Risk Limit. The frequency of atrazine detections across the state have decreased over the past four years.

Additional information about detections, concentrations and time-trend analysis for Metolachlor, Metolachlor ESA and other pesticides can be found in the MDA's annual reports at http://www.mda.state.mn.us/chemicals/pesticides/maace.aspx

Neonicotinoids were first analyzed by the MDA in groundwater samples in 2010. Currently, MDA analyzes water samples for six neonicotinoid pesticides including: acetamiprid, imidacloprid, thiamethoxam, clothianidin (analysis began in mid-2011), dinotefuran (analysis began in 2012) and thiacloprid (analysis began in 2014). All of these insecticide compounds are analyzed utilizing the LC/MS-MS method at a method reporting limit (MRL) of 20 to 25 ng/L. To date none of these compounds have been detected in urban samples. Acetamiprid, dinotefuran, and thiacloprid have not been detected in agricultural areas. Clothianidin, imidacloprid, and thiamethoxam have been detected in agricultural areas. All detections have been below applicable reference values.

The MDA collaborated with MDH to sample approximately 100 community supply wells for pesticide analysis in 2010 and 2015. This project tested community supply wells for over 133 pesticide compounds in 2015. The 2015 data is to be published in 2016.

The MDA is conducting monitoring to assess impacts of pesticides to private and residential drinking water wells in vulnerable areas (see previous Township Testing Program section for details). In the fall of 2014, MDA began collecting samples for pesticide analysis in private wells where nitrate has been detected in previous sampling efforts. The sampling is scheduled to continue through at least the summer of 2017 and the results will be reported on a regular basis. Preliminary data has shown two low level pesticide detections from the 825 samples collected.

Figure 5. Number of common detection pesticides detected in MDA groundwater samples per site in 2014. (The MDA's 10 Pesticide Monitoring Regions are outlined in bold).

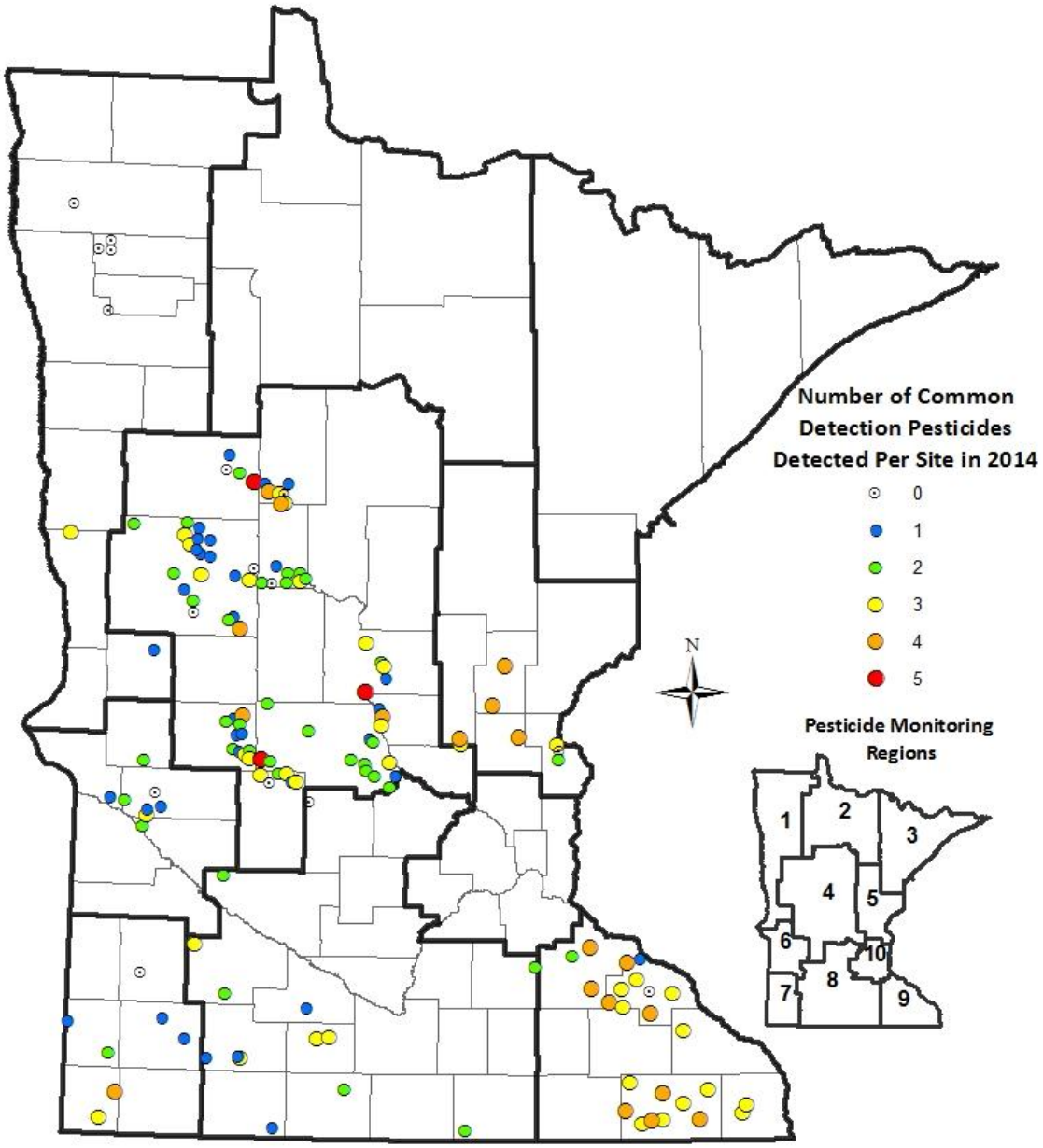


Figure 6. Metolachlor ESA, a Metolachlor degradate, groundwater sample analysis results over time for MDA PMR 4.

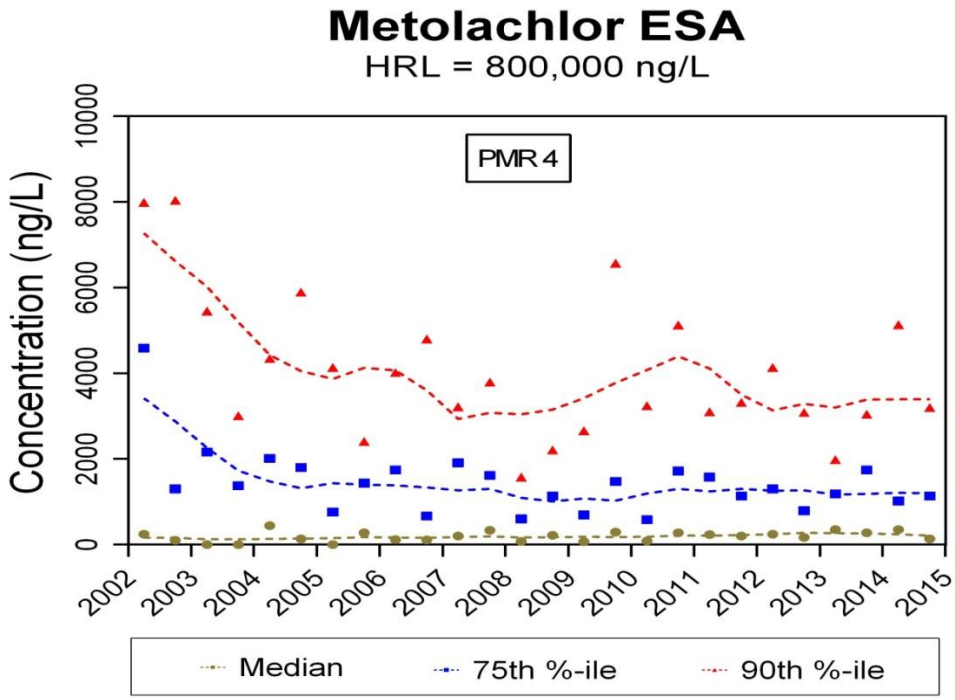
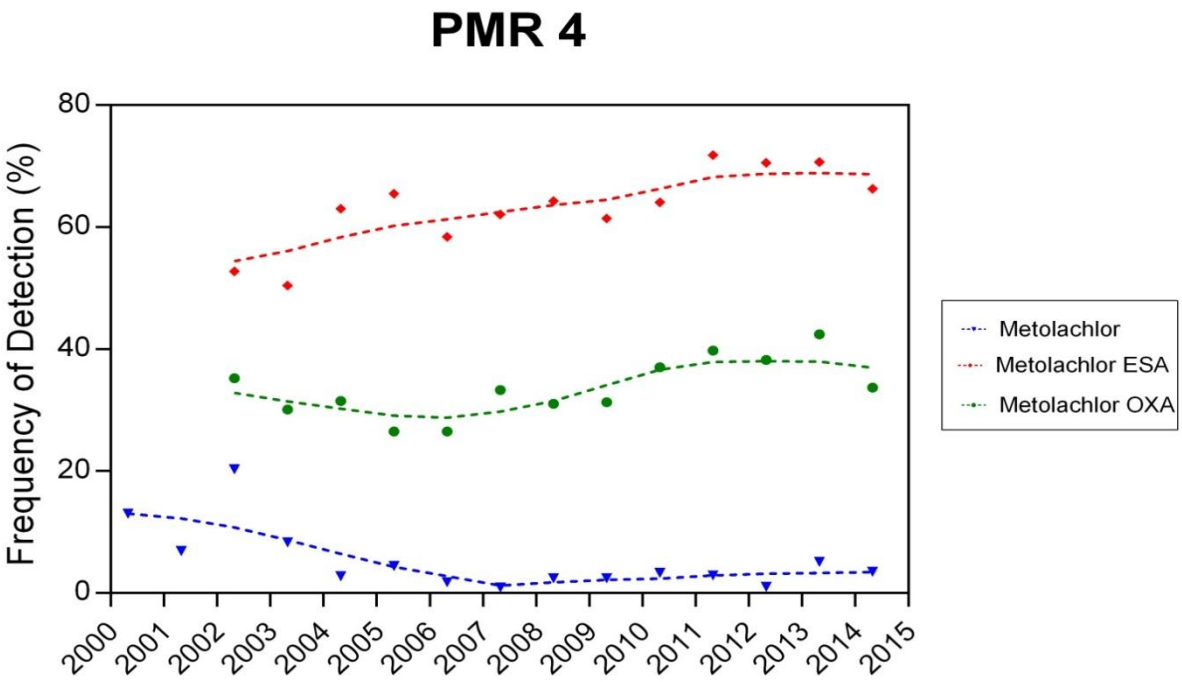


Figure 7. Frequency of Detection for Metolachlor and Metolachlor degradates ESA and OXA, over time for MDA PMR 4.



Arsenic

Arsenic is an element that occurs naturally in soil and rock and can dissolve into groundwater, the primary drinking water source for Minnesota residents. Arsenic can occur in groundwater just about anywhere in Minnesota but some areas are more susceptible to arsenic contamination than others. Long term exposure to arsenic can be detrimental to human health. The US EPA has set a Maximum Contaminant Level (MCL) of 10.0 micrograms per liter for arsenic in groundwater. The Minnesota Department of Health estimates that, based on monitoring data, about 10 percent of all wells in Minnesota have natural arsenic levels of 10.0 micrograms per liter or more. More information on arsenic in Minnesota's groundwater is available from the MDH at https://apps.health.state.mn.us/mndata/arsenic_wells.

Chloride

Excessive chloride concentrations in groundwater restrict its use for drinking and can be harmful to fish and other freshwater aquatic life if transported to surface waters. Chloride is highly mobile in the environment and once in the environment, is extremely difficult to remove. Monitoring of Minnesota's groundwater has detected elevated concentrations of chloride within specific land use settings.

The most recent MPCA report on statewide groundwater quality found chloride concentrations in the surficial sand and gravel aquifers throughout Minnesota to be higher in urban settings versus agricultural and forested parts of the State. Thirty percent of the wells tested in the Twin Cities Metropolitan Area (TCMA) exceeded Minnesota's chronic water quality standard of 230 mg/L. Halite, likely derived from road salt, was identified as the primary source of high chloride concentrations in the sand and gravel aquifers across the state, based on interpretations of chloride/bromide ratios.

Additional details of chloride in Minnesota's groundwater are presented on page 27 of the MPCA Report on groundwater at http://www.pca.state.mn.us/index.php/view-document.html?gid=19743.

Contaminants of Emerging Concern (CECs) and Perfluorochemicals (PFCs)

Contaminants of Emerging Concern (CECs) have been identified in both Minnesota's groundwater and surface water in national reconnaissance studies conducted by the MPCA and USGS. In 2009, the MPCA expanded its CEC monitoring in groundwater by adding CEC sampling to its ambient monitoring program. The monitoring has targeted shallower wells to provide an early warning of groundwater contamination, focusing on different urban land use settings. To date, the agency has sampled almost 250 wells in its monitoring network for over 200 different CECs.

CECs samples collected between 2009-2012 have detected thirty-five different chemicals, occurring in about one-third of the wells sampled. The antibiotic sulfamethoxazole was the most frequently detected in 11.3% of the samples, most of which were found in residential areas with septic systems. The plasticizer Bisphenol A was the second most frequently detected in about 5% of the samples. The highest concentrations of CECs were found in monitoring wells at a closed landfill, installed specifically to monitor contamination from the landfill. Other CECs detected include caffeine, AHTN (musk fragrance), cotinine (a nicotine metabolite), the fire retardants tris (dichloroisopropyl) phosphate and tributyl phosphate, the antibiotics azithromycin and lincomycin, and the antihistamine diphenhydramine.

The CEC concentrations measured to date have generally been low; no concentrations exceeding any established human-health guidance values. However, many of the CECs measured in groundwater do not have established human-health guidance.

The MDA collaborates with and provides assistance to the MPCA and MDH as appropriate and when agricultural chemical use and regulation overlap with interagency CEC concerns.

Additional details of CECs occurring in Minnesota's environment can be found at MPCA http://www.pca.state.mn.us/index.php/water/water-monitoring-and-reporting/water-quality-and-pollutants/endocrine-disrupting-compounds.html and at MDA www.mda.state.mn.us/monitoring.

Perfluorochemicals (PFCs) are a family of synthetic chemicals, initially developed by the 3M Company that have been used for decades to make products that resist heat, oil, stains, grease, and water. 3M phased out manufacture of some PFCs in 2002, but there are other manufacturers of PFCs around the world, and the chemicals are still used in some fire-fighting foams, lubricants, packaging, metal-plating, clothing, and other consumer and industrial products.

In late 2003, the MPCA discovered PFCs in groundwater at and near four dump sites in Oakdale and Woodbury, the 3M manufacturing facility in Cottage Grove, and the Washington County Landfill. In 2004, MPCA began sampling monitoring wells at the disposal sites and nearby private wells, and the MDH sampled city wells in Washington County to identify drinking-water supplies with PFCs.

To date, most of the drinking water supplies located away from the eastern Twin Cities suburbs that have been tested have no detectable PFCs. Although perfluorobutanoic acid (PFBA) was detected in several wells, the concentrations were below levels of health concern established by the MDH. Testing of additional drinking water sources throughout Minnesota will continue to evaluate potential exposure to PFCs through drinking water.

The MDH, MPCA, and 3M have worked with affected parties to provide safe drinking water by supplying alternative sources of water or assisting with water filtration to remove PFCs. Results over the past several years indicate the areas of groundwater contamination are not expanding and concentrations are not increasing. The MDH and MPCA continue to test wells in the area to monitor any changes in concentrations or movement of the PFC groundwater plumes.

Additional details of PFCs occurring in Minnesota's environment can be found at MPCA: http://www.pca.state.mn.us/index.php/waste/waste-and-cleanup/cleanup/superfund/perfluorochemicals-pfc/perfluorochemicals-pfcs.html.

Groundwater Quality: Reducing, Preventing, Minimizing and Eliminating Degradation

Minnesota has been a leader in addressing many sources of ground-water contamination such as Superfund sites, leaking underground storage tanks (LUST), agrichemical incident cleanup, voluntary investigation and cleanup (Brownfield) sites, landfills, and more. Additionally, examples of Minnesota's strong pollution prevention programs include effective permitting and secondary containment requirements for a variety of industrial and public activities. Minnesota has long had one of the strongest pesticide groundwater monitoring programs in the nation, dedicated to the establishment of long-term monitoring well networks in diverse agricultural regions, as well as individual studies to assess specific issues.

In the past, Minnesota has focused its limited state resources on cleanup, source control, and direct protection efforts, and required groundwater monitoring at many sites to determine individual facilities' compliance. More resources are now dedicated to monitoring for changes in local and regional groundwater quality as a result of these efforts. In recent years, Minnesota has increased its emphasis on nonpoint sources, which should result in increased implementation of Best Management Practices

(BMPs) that address nonpoint source pollution concerns such as feedlots, manure management, and agrichemical application.

Efforts to reduce, minimize, prevent and eliminate the degradation of Minnesota's groundwater resources are in almost all cases directed at the source of a specific contaminant or group of contaminants (point source or non-point source) and conducted on a programmatic level by the responsible government agency. The following discussion presents the efforts of MDA and MPCA programs to control (reduce, minimize, prevent and eliminate) specific contaminants or groups of contaminants by their source.

Nitrate/Nitrogen

The MPCA and MDA manage a number of different programs that prevent and reduce nitrate impacts to waters of the state. The MPCA and MDA also partner with the MDH in source water protection area program efforts. To prevent water quality degradation MDA, MPCA and MDH programs use a combination of regulatory tools that include: discharge limits, permit requirements, environmental and technical reviews, facility inspections, operator training, technical assistance, compliance and enforcement, guidance documents, fact sheets, BMPs, and more. Some examples of these programs are described below:

Animal Feedlots – Animal manure contains significant quantities of nitrogen which if improperly managed can lead to nitrate contamination of waters of the state. The Animal Feedlot program regulates the land application and storage of manure in accordance with Minnesota Rules Chapter 7020 for approximately 20,000 registered feedlots in Minnesota. The feedlot program requires that the land application of manure and its storage in manure storage basins is conducted in a manner that prevents nitrate contamination of waters of the state. Manure management plans, facility inspections, permitting, technical assistance and record keeping are all used to manage nitrogen impacts to water quality.

Additional information on the Feedlot Program can be found on the MPCA website link: http://www.pca.state.mn.us/index.php/topics/feedlots/feedlots.html.

Subsurface Sewage Treatment Systems (SSTS) – Of the approximate 532,000 septic systems across the state, about 80,000 fail to protect groundwater and approximately 28,000 are hydraulically failing and could be sources of pollution to our water resources. A system failing to protect groundwater is one that does not provide adequate separation between the bottom of the drainfield and seasonally saturated soil. The wastewater in SSTSs contains bacteria, viruses, parasites, nutrients and some chemicals. SSTSs discharge treated sewage into the soil for treatment, ultimately traveling to the groundwater. In some cases the sewage is pretreated before soil dispersal. Additionally, non-compliant SSTSs, located adjacent to surface waters, can discharge untreated contaminants to these surface waters and cause excessive aquatic plant growth leading to degradation in water quality. Therefore, SSTSs must be properly sited, designed, built and maintained to minimize the potential for disease transmission and contamination of groundwater and surface waters.

The SSTS program is engaged in a number of different efforts to prevent and minimize impacts to water quality degradation that can be found on the MPCA website link: http://www.pca.state.mn.us/index.php/water/water-types-and-programs/subsurface-sewage-treatment-system-ssts/index.html.

Nutrient Management – The MDA nutrient management programs help identify potential sources of nitrate contamination, and evaluate and implement practices and tools to reduce nitrate in groundwater**.** The goal of these programs is to prevent or minimize nitrate losses from nitrogen fertilizer

in accordance with the Ground Water Protection Act (Minn. Stat. chapter 103H). The Ground Water Protection Act requires that MDA work to properly manage nutrients and to adequately protect groundwater from their impacts.

In January, 2015 MDA produced a report titled "*Interim Report on Nitrate in Groundwater*" that demonstrates how Clean Water Funding has been critical in allowing the MDA to put forth steady and sequential ramping up of efforts to reduce nitrate from fertilizer in groundwater. See this report at; http://www.mda.state.mn.us/news/~/media/Files/news/govrelations/legrpt-nitrate15.pdf.

Nitrogen Fertilizer Management Plan: In March, 2015 the MDA completed the revised Nitrogen Fertilizer Management Plan (NFMP). First developed in 1990, the NFMP is the state's blueprint for prevention or minimization of the impacts of nitrogen fertilizer on groundwater. This revision process updated the plan to reflect current water protection activities and integrate new scientific information about groundwater protection. Also the revision process will better align the plan with current water resource programs. ; http://www.mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/nitrogenplan/~/media/Files/chemicals/nfmp/nfmp2015.pdf.

The Nitrogen Fertilizer Management Plan (NFMP) outlines how the MDA addresses elevated nitrate levels in groundwater. The purpose of the NFMP is to prevent, evaluate and mitigate nonpoint source pollution from nitrogen fertilizer in groundwater. The NFMP provides the blue print for the MDA's activities to address nitrate in groundwater. It outlines three major activities: 1) prevention, 2) monitoring and prioritization and 3) mitigation. See plan details at: www.mda.state.mn.us/nfmp.

Nutrient management programs occur statewide, however there is a greater focus in areas of the state that are vulnerable to groundwater contamination. Much of this effort is directed to implementation of the Nitrogen Fertilizer Management Plan (NFMP) and development of best management practices (BMPs) for nitrogen fertilizer use. The MDA works with many important partners including soil and water conservation districts, counties, farmers, agricultural dealers, the University of Minnesota and local communities.

Research and Technical Assistance: The MDA works with University of Minnesota (U of M) to develop, promote, and provide education on nitrogen fertilizer BMPs. Activities include workshops, conferences and research projects. There are two active research projects that will provide a better understanding of nitrogen fertilizer management and the associated water quality impacts on irrigated, sandy soils. One project is located in Westport, Minnesota at the Rosholt Farm and the other is located in Dakota County; see http://www.mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/rosholtfarm.aspx.

Another research project will develop computer-based modeling tools to evaluate nitrate leaching losses to groundwater under multiple agricultural production systems. These tools will be able to quantify the potential success of implementing BMPs and other changes in technology and help the MDA in implementation of the NFMP.

The MDA also supports an irrigation water quality specialist who develops guidance and provides education on irrigation and nitrogen BMPs. The position was requested by the irrigator community and is located at the University of Minnesota Extension, see http://www.mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/irrigationspecialist.aspx

The MDA works with local partners to assess groundwater in agricultural areas and works directly with farmers and agri-business in areas that are vulnerable to nitrate contamination. These activities include workshops, technical assistance, on farm programs and demonstration sites. For example, the MDA partners with East Otter Tail Soil and Water Conservation District to support activities in central Minnesota. Partners host irrigation workshops and support an on farm nitrogen management program.

The East Otter Tail SWCD also offers one-on-one training for individual farmers to schedule proper irrigation management; see http://www.mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/irrigationworkshops.aspx

A cooperative effort between the MDA and MDH has established the Source Water Protection Web Mapping Application, providing assistance to municipal drinking water authorities and members of the public in identifying where source water protection areas are located and the probability of potential contamination impacts and sources; see http://www.mda.state.mn.us/protecting/waterprotection/waterprotectionmapping.aspx

Nutrient Management Initiative: The Nutrient Management Initiative (NMI) program provides a framework for farmers to evaluate their current nutrient management practices compared with an alternative practice on their own field. Participants are required to work with a certified crop adviser, who assists with site design, and validates cropping information, and yield results. The goal is for farmers to evaluate practices that may improve nitrogen efficiency by lowering fertilizer inputs. Farmers can compare nitrogen rates, timing or use of a stabilizer product. As compensation for their time, participating farmers receive $1,000 while crop advisers receive $500 for each site enrolled. Many of the NMI sites are located in southeast Minnesota and complement the Southeast Region Grant that is supporting on farm BMP demonstrations, U of M fertilizer BMP trials, and farmer-to-farmer nitrogen management learning groups. An informational brochure is available at http://www.mda.state.mn.us/~/media/Files/protecting/nmi/nmi-brochure.pdf.

The MDA also administers the Agricultural Best Management Practices Loan Program, providing low interest loans to implement practices that improve and protect water quality. Loans are typically provided for: feedlot improvements, manure storage basins, and spreading equipment; conservation tillage equipment; terraces, waterways, sediment basins; shore and river stabilization; and septic systems. More information is available at http://www.mda.state.mn.us/en/grants/loans/agbmploan.aspx.

The most recent program status report is available at http://www.mda.state.mn.us/~/media/Files/news/govrelations/agbmpstatusrpt.ashx.

Discovery Farms Minnesota is a farmer-led effort to gather field scale water quality information from different types of farming systems, in landscapes all across Minnesota. The goal is to provide practical, credible, site-specific information to enable better farm management. Discovery Farms is a collaborative program between farmers, the Minnesota Agricultural Water Resources Center (MAWRC), the MDA, the University of Minnesota Extension, soil and water conservation districts and watershed districts throughout the state. The program began in 2010 and currently has 10 farms in 10 counties throughout Minnesota. The program is designed to collect accurate measurements of sediment, nitrogen and phosphorus movement over the soil surface and through subsurface drainage tiles. This work leads to a better understanding of the relationship between agricultural management and water quality. More information about the program can be found here: http://www.discoveryfarmsmn.org/.

Arsenic

The MPCA Ambient Groundwater Monitoring Program includes arsenic in its standard suite of analytes for network wells. Additionally, state regulations now require all newly constructed wells be tested for arsenic before being placed into service. If no arsenic is detected, further testing is not necessary. If arsenic is detected above the MCL of 10 micrograms per liter in water used for drinking and cooking, the MDH recommends installing a treatment system or finding an alternate source of drinking water and provides an instructional Q&A at the following web link: http://www.health.state.mn.us/divs/eh/wells/waterquality/arsenic.html.

Chloride

The recently completed Draft Metropolitan Area Chloride Management Plan notes that protecting all surface waters and groundwater from further degradation due to chloride is important.

Streams interact with groundwater and the causes of chloride contamination to surface waters in the seven county Twin Cities Metropolitan Area (TCMA) are in part due to contributions from groundwater with elevated chloride concentrations discharging into streams. Implementation of the BMPs in the Chloride Management Plan will help protect groundwater as a source of drinking water and its contribution to stream baseflow and other surface water bodies.

The Draft Plan is available at the website: http://www.pca.state.mn.us/index.php/view-document.html?gid=22754, in addition to the project website : http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/tmdl-projects/special-projects/metro-area-chloride-project/road-salt-and-water-quality.html.

Hazardous Waste Site Clean-ups

Efforts to prevent and reduce hazardous substance degradation of Minnesota's groundwater resources have included the cleanup of soils, groundwater and soil vapors at VOC contaminant release sites, in addition to pollution prevention (P2) programs.

Cleanup (Remediation) – Over the past 30 years, MPCA's cleanup (Remediation) programs including the petroleum remediation, Superfund, Hazardous Waste, Closed Landfill, Spills, and voluntary investigation and cleanup (Brownfields) programs have addressed the contamination of groundwater from hazardous substances at thousands of chemical release sites. The main focus of remediation activities is the cleanup of soil, groundwater and soil vapor to control human exposure to hazardous substances. This includes insuring that the quality of the groundwater we drink meets drinking water standards.

Emerging issues for the remediation programs include vapor intrusion into homes and other buildings as a result of historic releases of volatile organic compounds (VOCs) into soil and groundwater and the reduction of drinking water quality standards for a number of hazardous substances that require additional efforts at sites that previously were considered safe.

The remediation programs have worked on a cumulative total of 22,321 sites. There are 1,798 sites that remain open, where cleanup activities (remediation) have yet to be completed. The reduction in these groundwater contaminant sites has been a result of remediation efforts, preventative programs and a change in societal and business knowledge and ethics. The number of contaminant sites that are "open" compared to the cumulative number of sites on a per program basis are provided on a program by program basis in Table 2.

Several of the remaining cleanup sites have long term operation and maintenance activities such as the CLP - Closed Landfill Program, where all 112 sites are under operation and maintenance. Overall, the remediation of these sites in tandem with pollution prevention and environmental regulation have prevented and reduced most controllable causes of hazardous substance releases to the environment, however, hazardous substance releases may continue to occur as a result of spills and other accidents. Historic releases along with emerging concerns will continue to require significant effort by the remediation programs into the future to limit risk to human health and the environment.

Table 5. Number of remediation contaminant sites that are "open" compared to the cumulative number of sites on a per program basis.

Program	Open	Cumulative
Petroleum Remediation	1,108	16,971
Superfund Program	189	465
VIC (Brownfields)	437	4,385
RCRA (Haz. Waste sites)	56	388
CLP (Closed Landfills)	8	112
Total	**1,798**	**22,321**

Additional details of efforts to prevent and clean-up hazardous substances in the environment can be found on the MPCA website: http://www.pca.state.mn.us/index.php/waste/waste-and-cleanup/cleanup-programs-and-topics/topics/remediation-sites/remediation-sites.html, and in the Superfund 2013-2014 bi-annual legislative report: http://www.pca.state.mn.us/index.php/view-document.html?gid=22362.

Pollution Prevention – Pollution prevention is the best way to avoid the risk posed by contaminants to groundwater resources. Pollution prevention means eliminating or reducing at the source, the use, generation or release of toxic chemicals, hazardous substances and hazardous waste. Examples of pollution prevention include waste reduction and use of less persistent and less toxic chemicals. Some of the Best Management Practices (BMPs) to decrease the risk of contamination include: Proper storage of VOC-containing chemicals; proper disposal of VOC-containing waste; locating water supply wells upgradient of VOC sources; and locating industries in areas where aquifers are less sensitive.

The MPCA in partnership with the Minnesota Technical Assistance Program (MnTAP) and Retired Engineers Technical Assistance Program (ReTAP) provides technical assistance and financial assistance for businesses and institutions seeking ways to reduce waste to achieve pollution prevention goals. For 2008 and 2009, pollution prevention technical assistance efforts resulted in 6.8 million pounds of waste reduced, 1.3 million pounds of materials reused, 104 million gallons of water conserved, 15.5 million kWh and 780,000 therms of energy conserved for a savings of $8.7 million. By January 1, 2013, technical assistance at specific facilities is projected to reduce the amount of pollution generated by 10% from 2008 levels. Current reporting of pollution prevention efforts can be found on the MPCA webpage for Pollution Prevention activities: http://www.pca.state.mn.us/index.php/topics/preventing-waste-and-pollution/preventing-waste-and-pollution.html.

Pesticides

The MDA has developed the Minnesota Pesticide Management Plan (PMP): A Plan for the Protection of Groundwater and Surface Water (the PMP; revised in 2007) as the primary tool for preventing, evaluating and mitigating pesticide impacts to water resources. The PMP established the delineation of Pesticide Management Areas (PMAs) based on similar hydrologic, geologic, and agricultural management characteristics occurring within a region/area of the state (Figure 4). The PMAs provide the MDA with a framework for outreach and education to agricultural stakeholders, further described in the PMP (Chapter 8: Prevention) at http://www.mda.state.mn.us/protecting/waterprotection/pmp.aspx.

The PMP establishes a multi-stakeholder Pesticide Management Plan Committee to annually review pesticide water quality data and provide comment to the Commissioner of Agriculture regarding the detection and concentration of pesticides in vulnerable aquifers, as well as the need for BMP development to minimize and prevent pesticide contamination of water resources. The PMP also

establishes a Pesticide BMP Education and Promotion Team made up of state and local pesticide and water quality specialists, along with others interested in developing and delivering consistent messages to pesticide users about BMPs and water quality protection.

In 2004, the MDA developed "core" BMPs for all agricultural herbicides, and separate BMPs specific to the use of the "common detection" herbicides acetochlor, alachlor, atrazine, metolachlor and metribuzin. The acetochlor BMPs were revised in 2010 due, in part, to impairment decisions for acetochlor in two southern Minnesota watersheds. One of the ways MDA is evaluating the adoption of BMPs through biennial surveys (see http://www.mda.state.mn.us/chemicals/pesticides/pesticideuse.aspx), while BMP effectiveness is being evaluated through in-field studies and other methods (see, for example, http://www.mda.state.mn.us/chemicals/pesticides/acetochlor1/acetochlor6.aspx).

The MDA has a program of conducting special registration reviews of pesticides that might have specific concerns to use in Minnesota, including water quality protection. The scope of these special registration reviews varies depending on the potential education, outreach, and enforcement needs identified by the MDA. The MDA reviews new active ingredients recently approved by the U.S. Environmental Protection Agency along with currently registered pesticides that have significant new uses or have undergone a major label change. At times, more in-depth reviews are necessary to provide stakeholders and the MDA Commissioner with more information about specific pesticide products and issues. Neonicotinoid insecticides are currently under review. A complete list of the pesticides that have been reviewed is provided at http://www.mda.state.mn.us/chemicals/pesticides/regs/pestprodreg.aspx

Contaminants of Emerging Concern (CECs) and Perfluorochemicals (PFCs)

Currently, the MPCA ambient groundwater monitoring program is monitoring for CECs and EACs in the groundwater as part of its efforts to address the rising concerns associated with these chemicals in Minnesota's environment. This monitoring will significantly expand the existing knowledge of the occurrence of CECs in the groundwater and this information will help to evaluate the sources of any contamination found in the groundwater. The MDA shares these objectives as it coordinates with other state agencies its own pesticide-related CEC monitoring and response activities.

The Minnesota Department of Health (MDH) has a CEC program to identify contaminants in the environment for which current health-based standards do not exist or need to be updated to reflect new toxicity information. Through the CEC program, the MDH investigates the potential for human exposure to these contaminants, and develops guidance values. Information on the CEC program and a list of chemicals that have been evaluated is available at http://www.health.state.mn.us/divs/eh/risk/guidance/dwec/index.html.

PFC cleanup continues at the sites included in the 2007 Settlement Agreement and Consent Order negotiated between MPCA staff and 3M. Information on cleanup of the four sites is on the MPCA Web site at www.pca.state.mn.us/cleanup/pfc/pfcsites.html.

MDH's East Metro PFC Biomonitoring Study is measuring exposure to PFCs in adults living in selected areas of Washington County where the drinking water is contaminated with PFCs. Although public health actions to prevent or reduce people's exposure to PFCs are now in place, some PFCs stay in the body for years and can likely still be measured. Additional details and reports on PFCs in Minnesota's environment can be found on the MPCA websites at http://www.pca.state.mn.us/index.php/waste/waste-and-cleanup/cleanup-programs-and-topics/topics/perfluorochemicals-pfc/perfluorochemicals-pfcs.html .

Groundwater Summary

The MPCA and MDA continue to lead the way in addressing sources of groundwater contamination, particularly through remediation, permitting and BMP activities. It is critical, though, to maintain a continued concern for this valuable resource.

Some of the most common contaminants detected include nitrates and specific pesticides in rural settings, and chloride from road salt in urban areas. State agencies continue to monitor from the forefront, identifying new contaminants of emerging concern to groundwater quality and continuing to manage known risks.

Continued effort is needed to fully realize the state's groundwater quality goals. In particular, ongoing monitoring of vulnerable aquifers is critical to identify and track trends, and evaluate the success of management efforts.

Long term commitment to the collection and analysis of groundwater data is necessary to identify changes in water quality and quantity over time and provide information needed to effectively manage and protect this critical resource. Continued monitoring efforts by the MPCA and MDA provide the baseline from which to base critical decisions and future analyses.

Surface Water Quality: Assessment and Analysis

Presented below is information that defines the status and trends of water quality in Minnesota's streams, lakes and wetlands. Somewhat different from the groundwater quality data presented in the previous section, the surface water quality data includes a combination of water chemistry, water clarity and measures of fish and aquatic insect health (biological integrity); which are used to determine a waterbody's suitability for drinking, swimming, and fishing.

Within the last five years, a large number of reports have been published on Minnesota's surface water condition that would overwhelm all but the most diligent reader. To guide the reader, report summaries are provided, accompanied by figures, graphs and tables of some of the more relevant monitoring and assessment data contained in these reports. Web-based links are also provided for additional information on the following surface water quality topics:

- The Impaired Waters List and Watershed Approach,
- Lake and Stream Water Quality Trends - clarity, swimming & recreation, pesticides,
- Minnesota Milestone historic data - pollutants & clarity in streams and rivers,
- Stream water quality - pesticides, fish & aquatic life,
- Metro Area Surface Waters - nutrients & chlorides,
- Wetland water quality trends,
- Statewide Nitrogen Study, and
- Contaminants of Emerging Concern and Perfluorochemicals (PFCs).

Impaired Waters Listings and Watershed Approach

Impaired Waters – The Clean Water Act of 1972 requires states to adopt water quality standards to protect waters from pollution. These standards define how much of a pollutant can be in a water and still allow it to meet designated uses, such as drinking water, fishing, swimming, irrigation or industrial purposes. Impaired waters are those waters that do not meet water quality standards for one or more pollutants, thus they are "impaired" for their designated use(s).

In 2006, the passage of Minnesota's Clean Water Legacy Act and the 2008 Clean Water, Land and Legacy Constitutional Amendment provided policy framework and money for state and local governments to accelerate efforts to monitor, assess, and restore impaired waters, and to protect unimpaired waters. Starting in 2008, the MPCA began a 10 year cycle to monitor and assess about eight of Minnesota's 80 watersheds each year, to identify impaired and "unimpaired" waters. This effort is on track to monitor and assess the water quality of 100% of the state's major watersheds by 2019/2020. http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/watershed-approach/index.html (MPCA Webpage, Watershed Approach).

The MPCA assesses waters and lists the impaired waters every two years in accordance with the Clean Water Act. The table below provides the *proposed* 2014 Impaired Waters List (sent to the EPA for approval) and the number of impaired waters that need total maximum daily load (TMDL) plans to restore protection of fish and swimming uses. http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/impaired-waters-list.html (2014 Integrated Report to Congress, page 33).

Table 6. Impaired Waters and TMDL-Listed Waters for Minnesota.

2014 Inventory of Impaired Waters Summary		
Pollutant in 2014 proposed Waters List	**Total number of impairments**	**Number of impairments requiring a TMDL**
Mercury in fish tissue	1604	353
Nutrient/Eutrophication Biological Indicators	573	459
Escherichia coli/ Fecal coliform	533	388
Turbidity	368	300
Aquatic Macroinvertebrate Bioassessments	299	292
Fishes Bioassessments	277	267
PCB in fish tissue	144	144
Oxygen, Dissolved	127	107
Chloride	47	45
Mercury in water column	46	24
Nitrates	16	16
Aquatic Plant Bioassessments	12	12
Perfluorooctane Sulfonate (PFOS) in fish tissue	10	10
PCB in water column	9	9
pH	7	6
Arsenic	7	0
Ammonia (Un-ionized)	5	5
Total Suspended Solids (TSS)	5	5
DDT	5	5
Dieldrin	5	5
Lack of a coldwater assemblage	4	3
Dioxin (including 2,3,7,8-TCDD)	3	3
Toxaphene	3	3
Chlorpyrifos	3	3
Perfluorooctane Sulfonate (PFOS) in water column	1	1
Temperature, water	1	1
Total	4114	2466

Lake and Stream Water Quality Trends

One of the goals of MDA and MPCA water quality monitoring efforts is to identify and track trends in Minnesota waters. The following sections highlight available trend information for Minnesota's lakes and streams. As a part of this assessment, it is important to note that trend analysis can be very challenging, in part due to the amount of data needed over multiple years to detect a trend.

Lake Water Quality – Minnesota has about 12,200 lakes greater than 10 acres in size and another 50 lakes greater than 5,000 acres, totaling roughly 4.5 million acres. Detecting changes (trends) in water quality over time is a primary goal for many monitoring programs. Secchi transparency is a good indicator of lake water clarity and a preferred parameter for monitoring lake water quality trends as it relates to recreational use.

Data collected from 1973 through 2014, show that 375 lakes had improving trends, 168 had declining trends and 1,035 had no clear trend, for lakes with sufficient data for trend analysis as shown in the table below. A map showing the locations of these lakes is provided in the following link. http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/citizen-lake-monitoring-program/secchi-transparency-trend-lists.html.

Table 7. Secchi Disc trends in Minnesota lake water quality.

Description	Number of Lakes	% Lake Clarity Trend
Assessed for Trends	1,578	
Increasing	375	22%
Decreasing	168	10%
No Clear Trend	1,035	68%

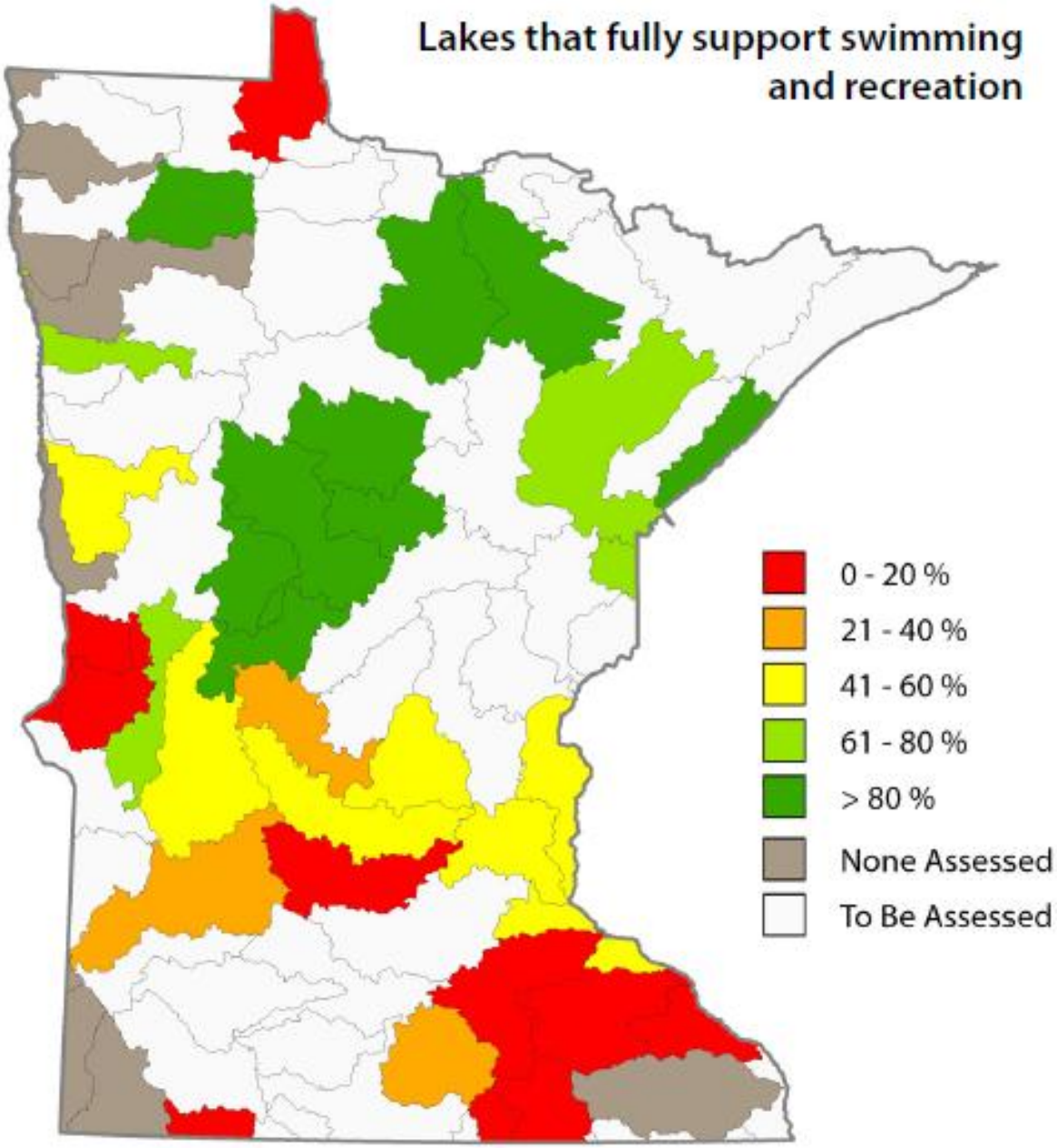
In general, water clarity is poorer in southern Minnesota, and both increasing and decreasing trends are scattered throughout north and south central Minnesota. Water clarity has stayed the same in two-thirds of the lakes, as presented on page 25 of the Clean Water Fund Performance Report http://legacy.leg.mn/sites/default/files/resources/2014_CleanWaterFund_Performance_Report.pdf.

Lakes – swimming and recreation - The MPCA and partners have assessed a total of 1,211 lakes under the watershed approach. The map below shows color shading for the percentage of lakes that fully support swimming and recreation in half of Minnesota's watersheds tested to date. The fact that a lake does not fully support swimming doesn't mean no one should ever swim there. However, during at least part of the summer, the lake is green and slimy with algae – to the point where swimming is not desirable. In some cases, the algae growth is so bad that a "bloom" forms that can release toxins harmful to pets and people.

Watersheds with just half or fewer of the lakes fully supporting swimming tend to be dominated by agricultural land that is known to contribute excessive phosphorus to water bodies. Phosphorus is the primary driver of algae in lakes.

Higher percentages of lakes fully support swimming in the more forested and wetland rich landscape of the north-central and northeastern part of the state. Natural watershed characteristics such as soil type also play a role in lake phosphorus levels. http://www.pca.state.mn.us/index.php/view-document.html?gid=22760 (Swimmable, fishable, fixable?, April, 2015, page 9).

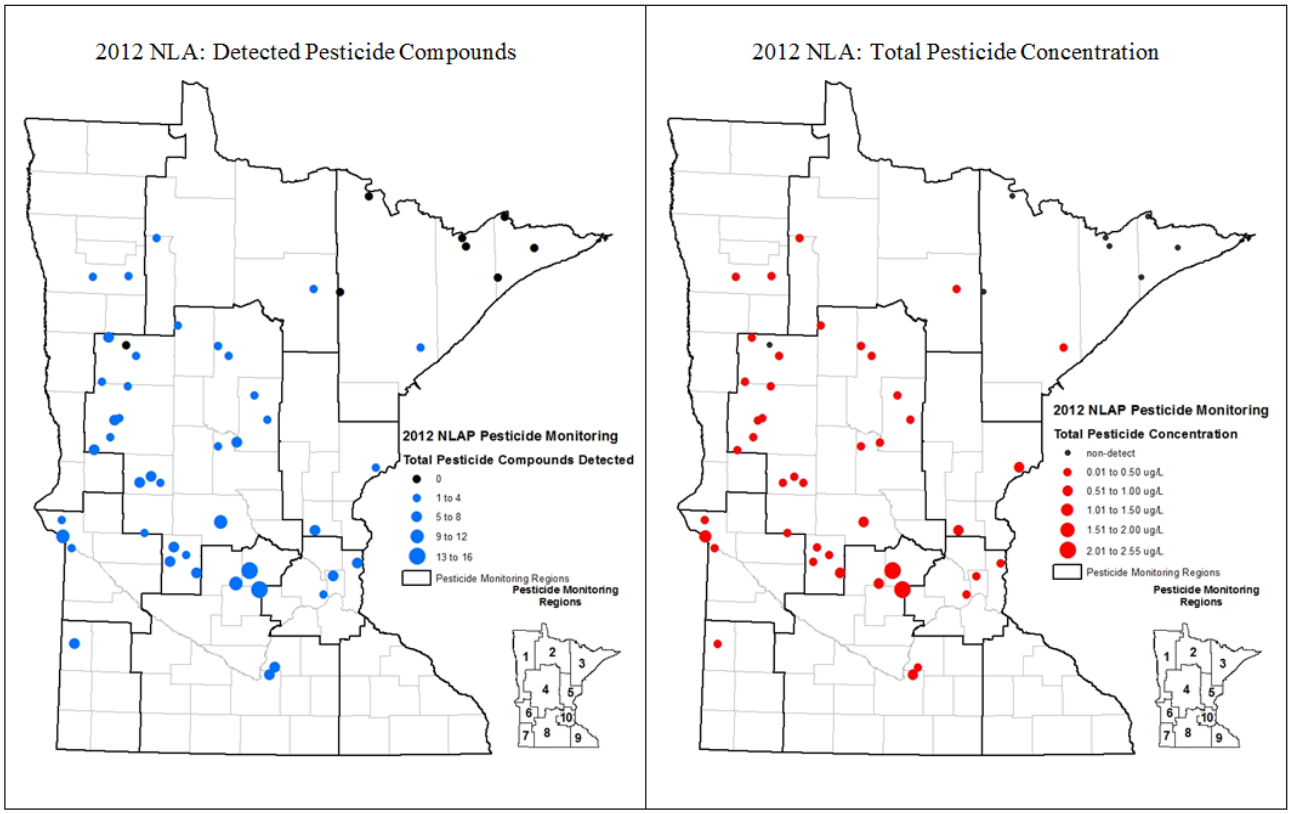
Figure 8. Percentage of Lakes by watershed that fully support swimming and recreation.



Lake Pesticide Monitoring - MDA conducted pesticide sampling nearly 300 times at 233 lakes from 2007-2012. An analysis of the data showed many low level pesticide detections occurred in lakes and the concentrations stayed relatively consistent seasonally and annually. The detections were dominated by degradates, or breakdown products, of parent pesticide products. Neonicotinoid pesticides have not been detected in Minnesota lakes. All detections were well below applicable water quality reference values and standards. MDA produced a report in 2014 titled "Minnesota National Lakes Assessment: Pesticides in Minnesota Lakes" that summarizes lake pesticide monitoring results from 2007 through 2012 (http://www.mda.state.mn.us/chemicals/pesticides/~/media/Files/chemicals/maace/2012pesticideslakes.pdf). Figure 9 provides a geographic depiction of statewide lake pesticide water quality in the 2012 National Lake Assessment.

MDA will align future lake pesticide monitoring efforts with the USEPA National Lakes Assessment that occurs every 5 years. This shift to the 5 year cycle allows MDA to look at many lakes in a single year, and to have comparable data over time for trend analysis.

Figure 9. Statewide lake pesticide water quality in the 2012 National Lake Assessment.



Minnesota Milestone Historic Data - pollutants & clarity in streams and rivers

Stream Water Quality – Some of the best available information on pollutant trends in rivers and streams comes from Minnesota Milestone sites, citizen-collected stream transparency data, MDA pesticide monitoring sites, and watershed biological conditions for fish and aquatic life.

Minnesota Milestone sites are a series of 80 monitoring sites across the state with high quality, long-term data, in some cases going back to the 1950s. In 2010, the Minnesota Milestones effort was replaced by the Watershed Pollutant Load Monitoring Network. The final report on Milestone site data

can be found at the web-link http://www.pca.state.mn.us/index.php/view-document.html?gid=21554 (Water Quality Trends for Minnesota Rivers and Streams at Milestone Sites", June, 2014).

The Milestone report shows a significant long term reduction in five pollutants (total suspended solids, phosphorus, ammonia, biochemical oxygen demand, and bacteria), often associated with human inputs. This reduction likely reflects the considerable progress made in controlling municipal and industrial point sources of pollution over the last 40 plus years. However, two pollutants (nitrite/nitrate and chloride), show significant increases; which likely reflect continuing non-point source problems.

Table 8. Pollutant long term trends in rivers and streams – Minnesota Milestone sites.

	Biochemical Oxygen Demand	Total Suspended Solids	Total Phosphorus	Nitrite/ Nitrate	Unionized Ammonia	Fecal Coliforms	Chloride
Decreasing pollutant	84%	63%	85%	0%	73%	82%	4%
Increasing pollutant	3%	4%	0%	56%	0%	0%	68%
No trend	14%	34%	15%	44%	28%	18%	28%

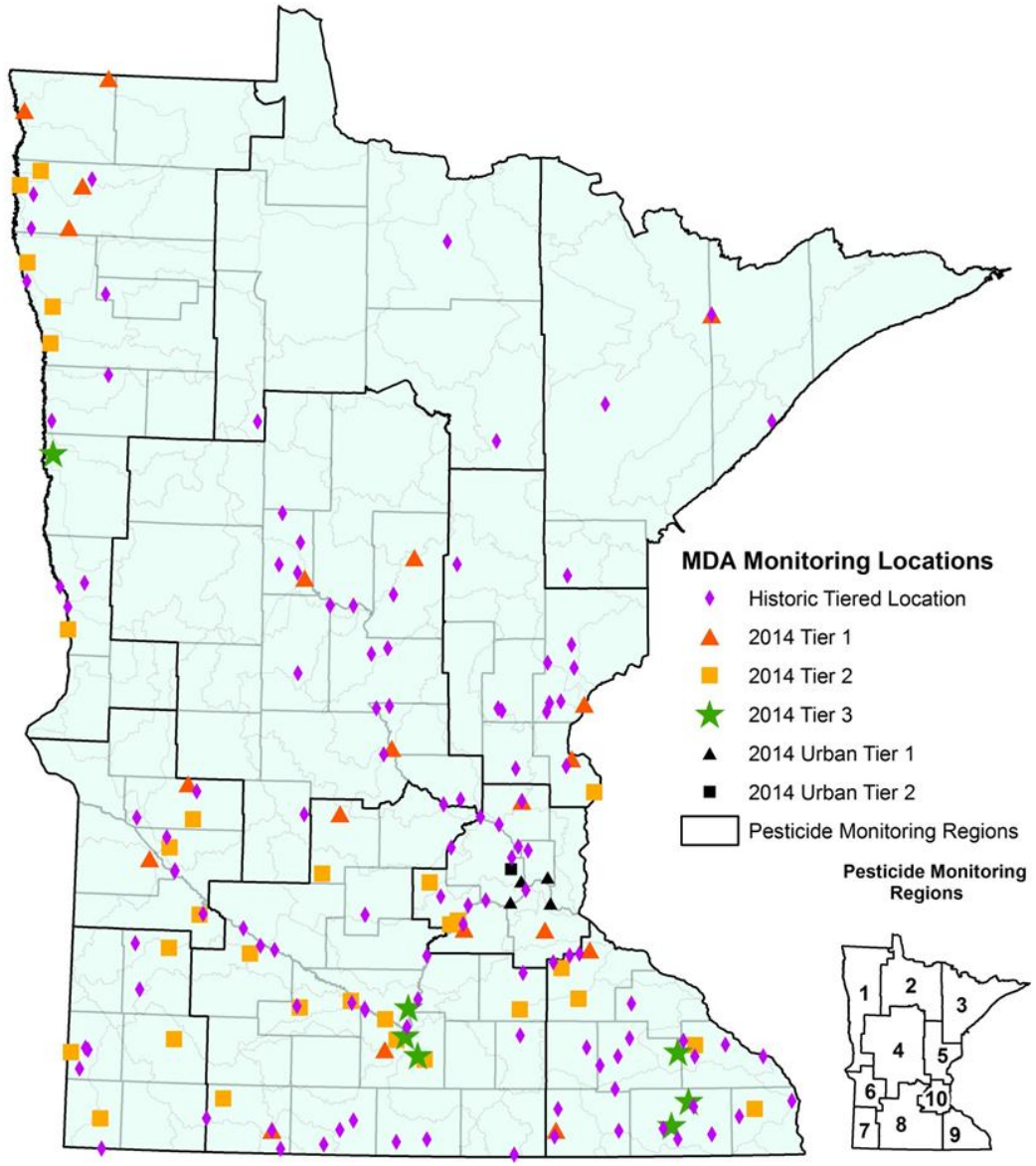
Citizen Stream Monitoring - Trend analysis of stream water clarity data (Table 9) has been done using transparency-tube measurements collected by volunteers through the MPCA's Citizen Stream Monitoring Program (CSMP). For data collected through 2013, no clear water quality trend was exhibited in 817 of the assessed stream sites, six exhibited improvement, and nine exhibited statistically significant declines in transparency. See http://www.pca.state.mn.us/water/csmp-reports.html for state-wide and site-specific CSMP annual reports.

Table 9. Trends in Minnesota stream water clarity.

Description	Number of Streams
Assessed for Trends	832
Improving	6
Declining	9
No Clear Trend	817

MDA Pesticide Monitoring - The MDA began monitoring surface water for pesticides in 1991. Monitoring is conducted within a framework of Pesticide Monitoring Regions (PMRs) shown in Figure 13. In 2006 the MDA began monitoring surface water utilizing a tiered structure defined and described in the MDA Surface Water Monitoring Design Document (http://www.mda.state.mn.us/chemicals/pesticides/~/media/Files/chemicals/swqdesigndoc.ashx).

Figure 10. Current and historic surface water sampling locations.

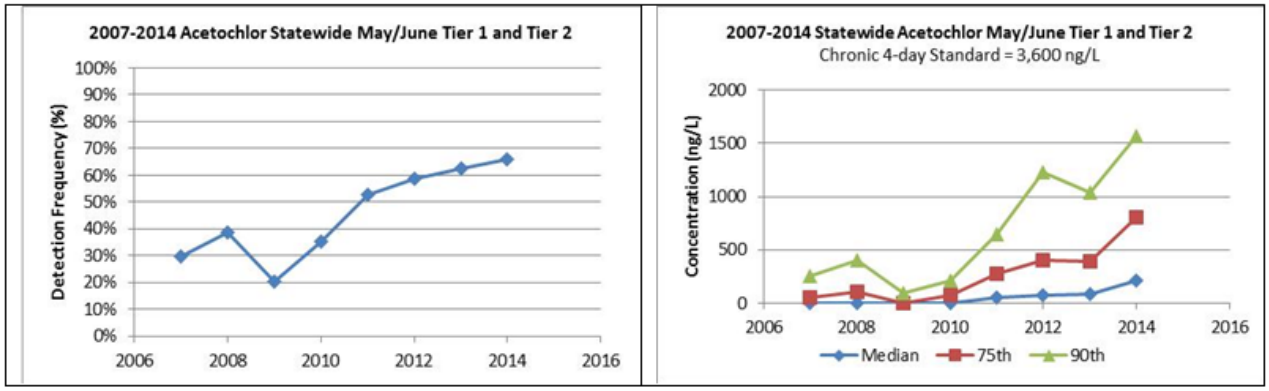


The MDA's tiered structure allows for increased monitoring intensity at locations that have exhibited elevated pesticide concentrations. Pesticide detections at concentrations above the applicable reference values or standards are rare; and MDA works with MPCA annually to review all water quality data for water quality impairment.

Three pesticide active ingredients have been designated by the Commissioner of Agriculture as a concern for surface water quality. Acetochlor and atrazine, both herbicides, have previously been designated as "pesticides of concern" for surface water. In 2012, chlorpyrifos, an organophosphate insecticide, was designated a "pesticide of concern" for surface water due to increased detections that occurred in 2010 and 2011. The criteria for such designations are summarized in the Pesticide Management Plan (PMP). The designation initiates several actions including pesticide BMP development and promotion, and increased water quality data analysis. Because pesticides, especially agricultural and home and garden pesticides, are typically applied to coincide with the seasonal need to control weeds,

insects and other pests or plant diseases, the presence of pesticides in streams and rivers is often linked to application timing, and subsequent rainfall and runoff events. Consequently, trends in water quality - especially individual streams and rivers - are difficult to establish. Nevertheless, the MDA analyzes data from its network of sampling locations in an effort to track certain statistics associated surface water pesticides of concern. Figure 14 presents statewide May and June 2007-2014 detection frequency and concentration statistics for acetochlor, a surface water pesticide of concern at all Tier 1 and Tier 2 sampling locations. Additional data analysis, figures, and results are available in the MDA 2014 Water Monitoring Report (http://www.mda.state.mn.us/chemicals/pesticides/~/media/Files/chemicals/maace/wqm2014rpt.pdf).

Figure 11. MDA statewide acetochlor water monitoring results.



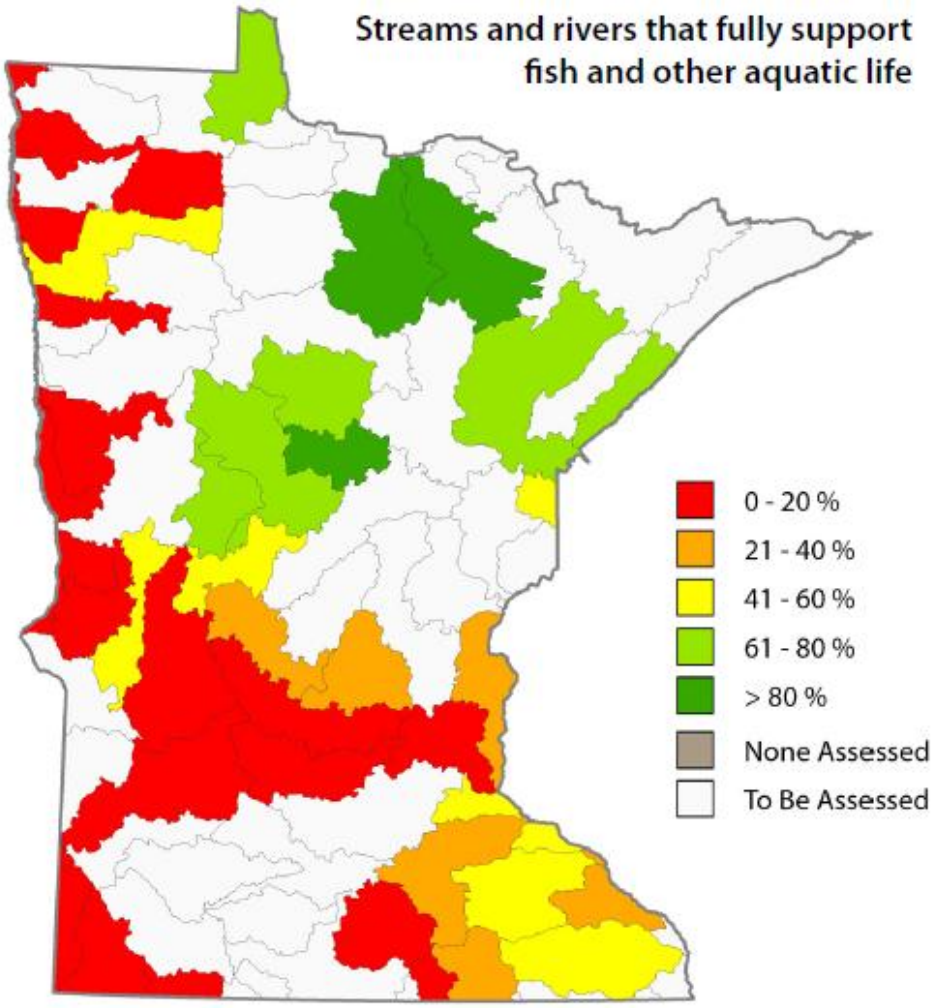
Three Minnesota streams; Grand Marais Creek in northwest Minnesota, Seven Mile Creek in south central Minnesota, and the Tamarac River in northwest Minnesota violated MPCA's acute water quality standard for chlorpyrifos of 83 ng/L. These three rivers were included on the Minnesota 2014 Impaired Waters List as a result of the detections that occurred in 2010, 2011, and 2012. Increased monitoring, and additional education and outreach have also occurred to address chlorpyrifos detections in Minnesota surface water.

Two Minnesota streams in south central Minnesota; the Little Beauford Ditch and Le Sueur River were listed on the Minnesota 2008 Impaired Waters List for violation of MPCA's 4-day toxicity standard (3,600 ng/L) for acetochlor. Because of education and outreach, both of these streams have met the acetochlor water quality standard for several years and were proposed for removal from the impaired waters list in 2014. Further information about acetochlor and chlorpyrifos is available at http://www.mda.state.mn.us/chemicals/pesticides.aspx

Neonicotinoids were first analyzed by the MDA in surface water samples in 2010. Currently, MDA analyzes water samples for six neonicotinoid pesticides including: acetamiprid, imidacloprid, thiamethoxam, clothianidin (analysis began in mid-2011), dinotefuran (analysis began in 2012) and thiacloprid (analysis began in 2014). All of these insecticide compounds are analyzed utilizing the LC/MS-MS method at a method reporting limit (MRL) of 20 to 25 ng/L. Annual statewide detection frequencies have ranged from 0 to 12%, and all detections have been well below applicable water quality reference values. Imidacloprid is detected more frequently in urban areas while clothianidin and thiamethoxam are detected more frequently in agricultural areas. More information on neonicotinoid pesticide water quality is available in the 2014 Water Monitoring Report available http://www.mda.state.mn.us/chemicals/pesticides/~/media/Files/chemicals/maace/wqm2014rpt.pdf .

Streams and rivers – fish and other aquatic life - The MPCA and partners have assessed a total of 1,054 stream and river sections statewide for fish and other aquatic life under the watershed approach. The map below shows the percentage of streams and rivers that fully support fish and aquatic life by watershed. Patterns in this map are similar to the previous map for swimming and recreational suitability, and for watersheds that have been identified as needing pollutant source reductions.

Figure 12. Percentage of Streams and Rivers by Watershed that support Fish & Aquatic Life.



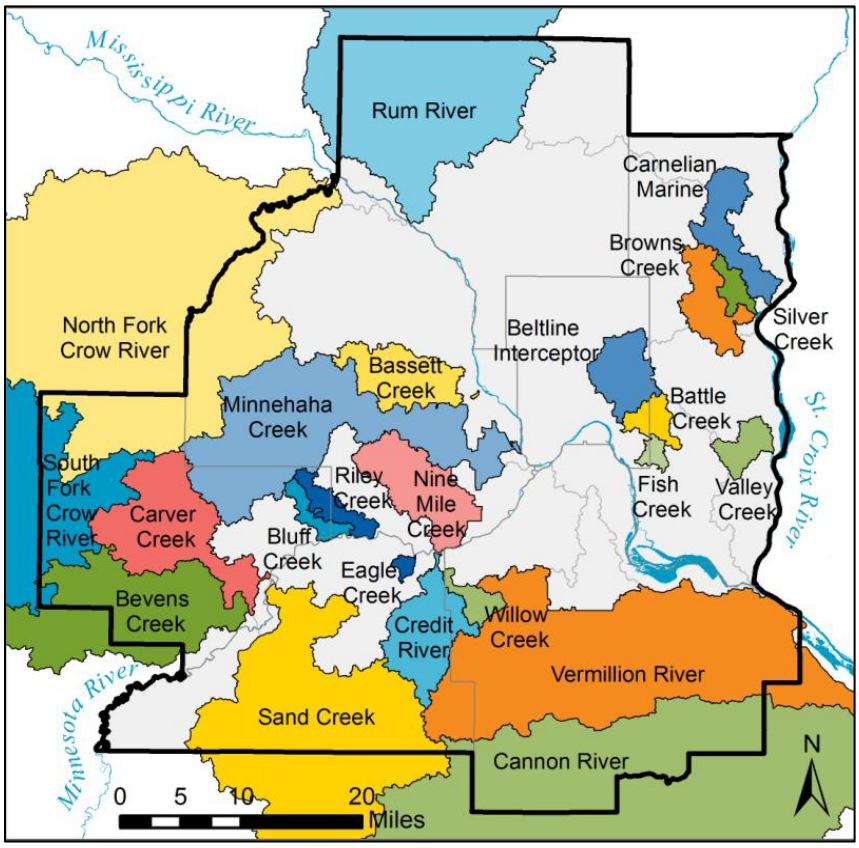
The northwest exhibits somewhat better conditions for recreation, while showing poor stream life. The southeast on the other hand shows somewhat better stream life, with poor conditions for recreation. This may be due to the steeper landscape of southeastern Minnesota, which facilitates runoff of bacteria and other pollutants, but results in better habitat for aquatic life. For further information, please see page 14 of the Swimmable, fishable, fixable? report (April, 2015). http://www.pca.state.mn.us/index.php/view-document.html?gid=22760.

Metro Area Surface Waters – nutrients & chloride

The Metropolitan Council, MPCA and numerous local government units have studied the water quality of streams, lakes and wetlands within the seven county Twin Cities metropolitan area (TCMA).

The Metropolitan Council Environmental Services (MCES) staff recently completed an assessment of water quality in 21 creeks, streams and rivers and their associated watersheds in the TCMA. Their report, titled a Comprehensive Water Quality Assessment of Select Metropolitan Area Streams, Technical Executive Summary, December, 2014, focused on four primary pollutants of concern: sediment, nitrogen, phosphorus and chloride and can be found at the web-link http://metrocouncil.org/METC/files/d7/d7b81f85-a1f1-4201-acff-781d9b02590f.pdf.

Figure 13. Location of assessed watersheds in the Metropolitan Council Study.



MCES identified elevated concentrations of nitrogen, phosphorus and sediment in a number of different streams, and associated this with specific land use activities and natural conditions within a watershed. However, in many of these streams the same pollutants showed improving water quality trends for the most recent five years of their data set.

These water quality improvements were thought to be due to multiple projects and actions taken over the past several decades by cities, watershed districts, watershed management organizations, state agencies, farmers, business owners and private citizens and are identified in the report on page 14.

Chloride - At present, there are a total of 37 chloride impairments in the Twin Cities for streams, lakes and wetlands as shown on the Twin Cities Metro Area Chloride Assessment map in the following web-link.
http://mpca.maps.arcgis.com/home/webmap/viewer.html?webmap=c87ebeedcfca49f2a272bff89cd20baf&extent=-94.7461,44.2747,-91.8979,45.6985.

The Twin Cities Metropolitan Chloride Management Plan (In draft) provides a detailed analysis of the status, sources and trends of chloride observed in many Twin Cities streams, lakes and groundwater, please see the report at http://www.pca.state.mn.us/index.php/view-document.html?gid=22754. A summary of the data analysis from this report shows that:

1) Chloride use increased in the TCMA in the latter half of the 20th century, 1950-2000,
2) Levels of chloride are continuing to increase in both groundwater and surface waterbodies in the TCMA,
3) The highest chloride concentrations have been found during snowmelt conditions during winter months and low flow periods in streams,

4) Chloride levels tend to be higher in the bottom of a lake versus the surface,
5) Chloride concentrations in TCMA waterbodies are positively correlated to road density in the contributing watersheds,
6) There is a lot that is not known about chloride concentrations in TCMA waterbodies, since a large majority of the TCMA waterbodies do not have any data and do not have data that would represent critical conditions, and
7) Winter maintenance activities as well as wastewater treatment plants tend to be the primary sources of chloride to TCMA waters.

Wetlands Water Quality Trends

In 2006, a statewide wetland monitoring program was initiated to assess the status and trends of both wetland quantity and quality. Based on the wetland quality survey, an estimated 158,435 depressional wetlands and ponds occur within the state of Minnesota, the majority of which are located on private property. Plant communities are in good condition in 29 percent of Minnesota's depressional wetlands and ponds, while 25 percent are in fair condition and 46 percent are in poor condition. The macroinvertebrate communities (including insects, snails, crustaceans, and leeches) inhabiting these waterbodies are in better condition with estimates of 47 percent good, 33 percent fair, and 20 percent poor. Macroinvertebrate community condition varied depending on whether the wetland or pond was natural or man-made in origin; 57 percent of the natural basins were in good condition compared to only 27 percent of the man-made basins. Plant community condition did not exhibit a substantial difference between these two categories.

Additional details from this study can be found at http://www.pca.state.mn.us/index.php/view-document.html?gid=17741. For further information on wetlands in Minnesota, please go to the following webpage http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/wetlands/wetlands-in-minnesota.html.

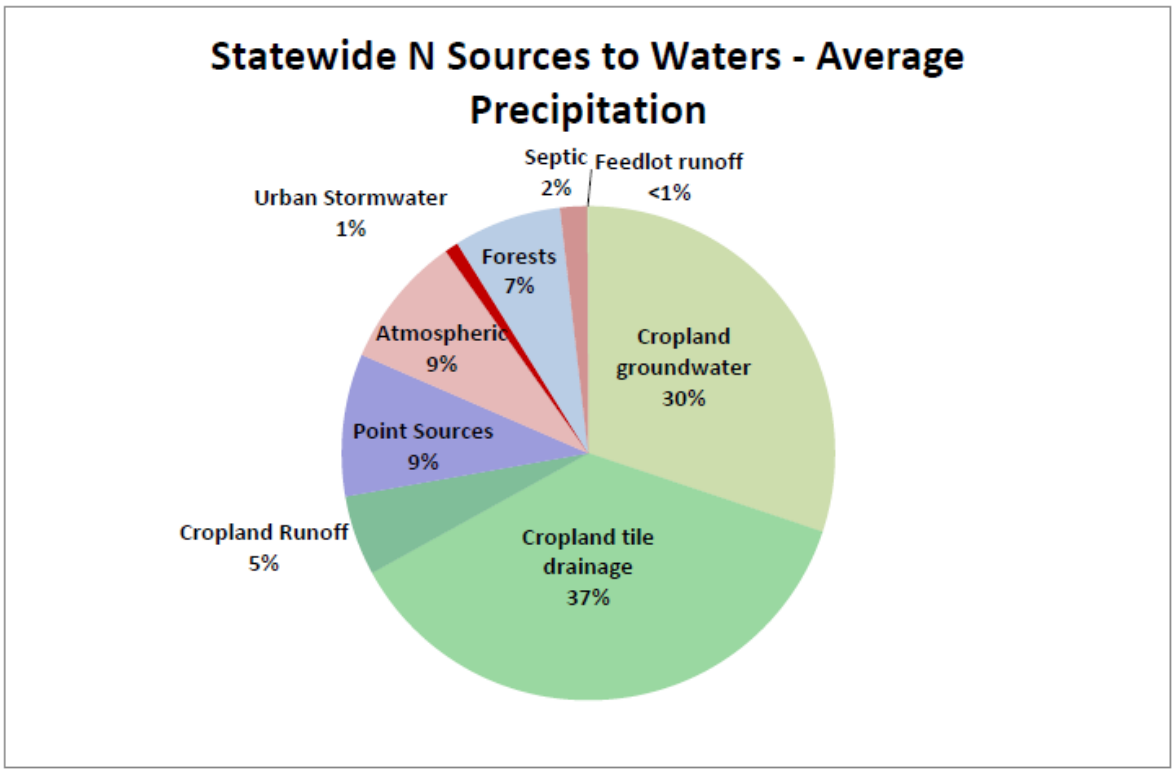
In 2014, MDA collaborated with MPCA on the collection of water column and benthic sediment samples from 19 wetlands across Minnesota for pesticide analysis. Water column samples collected in each wetland were analyzed at the MDA Laboratory using the GC-MS/MS and LC-MS/MS laboratory methods, and analytes included a total of 133 different pesticides and pesticide degradates. The MDA Laboratory developed an insecticide sediment analysis method that included 14 neonicotinoid related pesticide compounds for this project. This was the first time wetlands were analyzed for pesticides in Minnesota, and future wetland monitoring will allow for trend analysis. A summary of the project is included in the 2014 Water Monitoring Report available http://www.mda.state.mn.us/chemicals/pesticides/~/media/Files/chemicals/maace/wqm2014rpt.pdf.

Statewide Nitrogen Study

The MPCA, working in collaboration with the University of Minnesota and U.S. Geological Survey, completed a study in 2013 to characterize total nitrogen loading to Minnesota's surface waters. The Minnesota Legislature provided funding for the study, which used more than 50,000 water samples collected at 700 streams sites, 35 years of monitoring data, and findings from 300 published studies. The resulting report, titled Nitrogen in Minnesota Surface Waters – conditions, trends, sources and reductions, provides a scientific foundation of information for developing and evaluating nitrogen reduction strategies. The report executive summary can be found at http://www.pca.state.mn.us/index.php/view-document.html?gid=19623 and complete report at http://www.pca.state.mn.us/index.php/view-document.html?gid=19622.

An estimated 73% of statewide nitrogen (N) entering surface waters is from cropland sources and 9% is from wastewater point sources, with several other sources adding the other 18% (see figure below). Most of the cropland N reaches waters through subsurface agricultural tile drainage and groundwater pathways, with a relatively small amount in overland runoff.

Figure 14. Estimated statewide N contributions to surface waters during an average precipitation year.



The study concluded that surface water N concentrations and loads are high throughout much of southern Minnesota, contributing to the N enriched hypoxic zone in the Gulf of Mexico, nitrate in excess of drinking water standards in certain cold water streams, and a potential to adversely affect aquatic life in a large number of Minnesota rivers and streams. Northern Minnesota has relatively low river N levels, and pollution prevention measures should be adopted in this area as landscapes and land management change.

Reducing nitrogen levels in rivers and streams in southern Minnesota will require a concerted effort over much of the land in this region, particularly tile-drained cropland and row crops over permeable soils and shallow bedrock. Nitrogen reduction strategies and BMPs can be found in the Minnesota Nutrient Reduction Strategy, **http://www.pca.state.mn.us/index.php/view-document.html?gid=20213** and are discussed in the next section Surface Water Quality: Reducing, Preventing, Minimizing & Eliminating Degradation.

Contaminants of Emerging Concern (CECs) and Perfluorochemicals (PFCs)

In the last decade, national and statewide studies have revealed that many chemicals with known or suggested endocrine-disrupting potential are found in the aquatic environment. These chemicals include pharmaceuticals, personal care products, chemicals associated with wastewater effluent, and a variety of industrial compounds. There is a growing concern that even at low concentrations, chemicals, or mixtures of them, may adversely affect fish, wildlife, ecosystems and possibly human health.

A recent study on pharmaceuticals, personal care products, endocrine active chemicals and other micro-pollutants in Minnesota lakes and streams shows that pharmaceuticals and micro-pollutants are more ubiquitous in surface water than was previously suspected. The study compares results to other recent studies in Minnesota and shows that DEET, Bisphenol A, androstenedione, amitriptyline, and caffeine are consistently the most frequently detected in lake water, as shown in the link below. http://www.pca.state.mn.us/index.php/view-document.html?gid=22915, Pharmaceuticals, Personal Care Products and Endocrine Active Chemical Monitoring in Lakes and Rivers, May, 2015).

Additional information can be found on the MPCA webpage http://www.pca.state.mn.us/index.php/water/water-monitoring-and-reporting/water-quality-and-pollutants/endocrine-disrupting-compounds.html.

Perfluorochemicals (PFCs) – The MPCA, MDA and MDH have jointly reviewed known and potential sources of PFCs from industrial, agricultural and other human activities. Subsequent MPCA studies detected perfluorooctane sulfonate (PFOS) at elevated concentrations in fish taken from the Mississippi River near the 3M Cottage Grove plant and downstream, and in some Twin Cities Metro Area lakes with and without known connections to 3M's manufacturing or waste disposal. The lower reach of Mississippi River Pool 2, which received 3M Cottage Grove effluent during the years of PFOS and PFOA manufacturing, is listed as an impaired water due to PFOS in fish tissue and water. This is based on fish tissue PFOS concentrations that prompted the MDH to issue a one-meal per month fish consumption advisory for certain species in Pool 2.

A recent report presents the results of an intensive monitoring of PFCs in fish, benthic macroinvertebrates (sediment-dwelling insects), water, and sediments in Pool 2 and provides an overview of the concern for PFCs in surface waters. The report titled, Perfluorochemicals in Mississippi River Pool 2: 2012 can be found at the web-link http://www.pca.state.mn.us/index.php/view-document.html?gid=19516. The report concluded that PFOS concentrations in fish have declined in Pool 2; however, PFOS concentrations remain high in fish, invertebrates, sediments, and water from the lower section of Pool 2.

Additional information on Perfluorochemicals (PFCs) in Minnesota may be found on the Minnesota Department of Health website: http://www.health.state.mn.us/divs/eh/hazardous/topics/pfcs/ and on page 24 of the 2014 Integrated Report: http://www.pca.state.mn.us/index.php/view-document.html?gid=19813.

Surface Water Quality: Reducing, Preventing, Minimizing and Eliminating Degradation

The major goal in preserving water quality is to enable Minnesotans to protect and improve the state's rivers, lakes, wetlands and groundwater so that they support healthy aquatic communities and designated public uses such as fishing, swimming and drinking water. The key strategies for accomplishing this goal include regulating point source discharges, controlling nonpoint sources of pollution, and assessing water quality to provide data and information to make sound environmental management decisions.

Land use is a major factor in our current water quality problems — agricultural drainage, urban and rural runoff, and erosion caused by removing vegetation from shorelines. MPCA website How's the water? describes what the MPCA is doing and what you can do to prevent pollution, rather than just controlling it. http://www.pca.state.mn.us/index.php/what-were-doing-and-what-you-can-do.html.

The MDA also considers the watershed approach for water quality protection, and has been guided for pesticides by the 2007 Minnesota Pesticide Management Plan (PMP): A Plan for the Protection of Groundwater and Surface Water http://www.mda.state.mn.us/protecting/waterprotection/pmp.aspx) and for nitrate by the Nitrogen Fertilizer Management Plan http://www.mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/nitrogenplan/~/media/Files/chemicals/nfmp/nfmp2015.pdf The PMP established the delineation of Pesticide Monitoring Regions (PMRs) and Pesticide Management Areas (PMAs) as indicated earlier in this report. The PMRs and PMAs are generally identical and are based on similar hydrologic, geologic, and agricultural management characteristics occurring within the region/area. The PMAs provide the MDA with a framework for outreach and education to agricultural stakeholders, further described in the Pesticide Management Plan (Chapter 8: Prevention) at http://www.mda.state.mn.us/protecting/waterprotection/pmp.aspx.

The watershed approach involves multiple program efforts focused on water quality protection and restoration. Information on the following efforts to prevent surface water quality degradation are provided below:

- Wastewater Discharges (point sources),
- Nonpoint Source Pollution:
    - Minnesota's Nonpoint Management Plan (2013),
    - Watershed Achievements Report (2014),
    - Clean Water Partnership Program,
    - Nitrogen in Minnesota's Surface Waters; Conditions, trends, sources and reductions (2013),
    - The Minnesota Nutrient Reduction Strategy
    - Swimmable, fishable, fixable?, and
    - Chloride (road salt)
- Agricultural Best Management Practices Loans
- Pesticides and Fertilizers

Wastewater Discharges **(point sources)**– The MPCA regulates the discharge of treated wastewater to surface waters of the state (primarily rivers and streams) through NPDES/SDS permits from both municipal and industrial facilities. Minnesota has been successful in controlling end-of-pipe (point source) discharges from wastewater treatment plants to our state's surface waters.

Improvements to wastewater treatment plants and a high level of regulatory compliance in meeting effluent standards are improving the overall quality of discharges to Minnesota's surface waters. As an example, total phosphorus, the primary pollutant associated with increased algae growth in Minnesota's lakes and streams, shows an average percentage decrease of 66%, from a baseline period in 2000/2001 through 2013. For more details, please link to the 2014 Pollution Report to the Legislature. A summary of Minnesota's air emissions and water discharges, pages 52-69. http://www.pca.state.mn.us/index.php/view-document.html?gid=20890.

A case study of upgrades at the Willmar Wastewater Treatment Facility shows reduced phosphorus discharges to Hawk Creek by 88 percent, as presented in the 2014 Clean Water Performance Report on pages 30-31. http://legacy.leg.mn/sites/default/files/resources/2014_CleanWaterFund_Performance_Report.pdf.

In addition, significant wastewater mercury loading reductions have been achieved since 2000. Mercury loading fell below the statewide mercury total maximum daily load (TMDL) waste-load allocation in 2003. On average the data show an annual 90 percent reduction in mercury loads from a 28 kilogram

per year baseline in 2000/2001 to 2.59 kilograms per year in 2013. Information on mercury in fish and mercury reductions in air emissions can be found in the 2014 Clean Water Performance Report on pages 28-29.
http://legacy.leg.mn/sites/default/files/resources/2014_CleanWaterFund_Performance_Report.pdf.

Nonpoint Source Pollution - Water quality in Minnesota is mainly degraded by the pollutants entering surface waters from nonpoint sources derived from both air pollution and runoff from land, particularly from watersheds dominated by agricultural and urban land use. Nonpoint source pollution is the major cause of degradation of Minnesota's surface and groundwater.

Minnesota's Nonpoint Source Management Program Plan 2013 - describes Minnesota's five year plan to control nonpoint sources of water pollution and the numerous activities directed towards this effort,

http://www.pca.state.mn.us/index.php/view-document.html?gid=19810.

Watershed Achievements Report - The 2014, Watershed Achievements Report describes statewide and watersheds-based projects being implemented that are cleaning up nonpoint sources of pollution, mainly through funding from the Section 319 Grant Program and the Minnesota Clean Water Partnership Program.

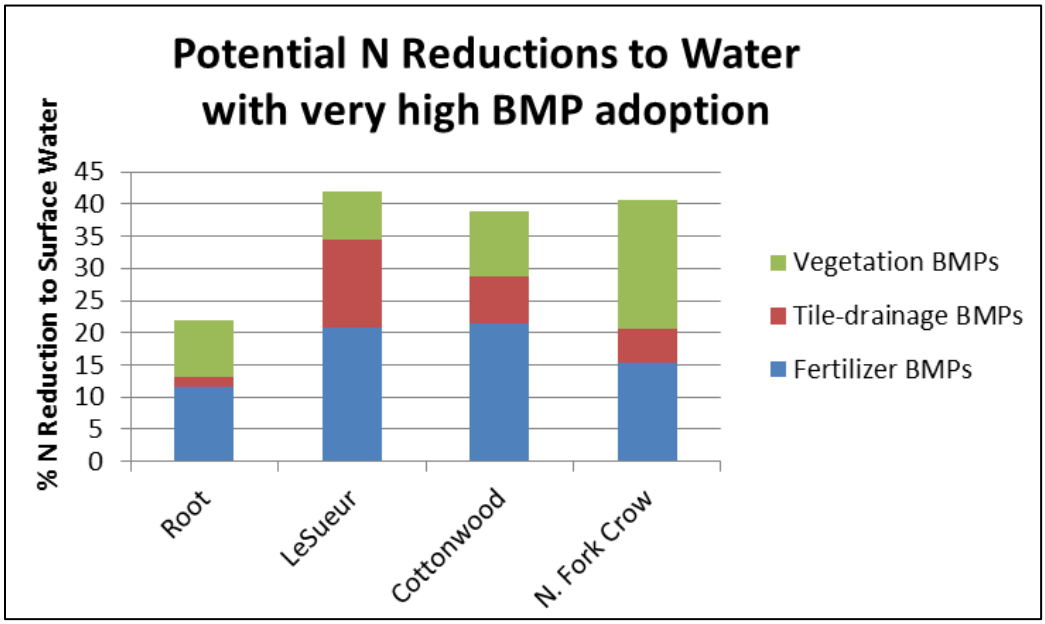
The Report presents numerous examples of BMP implementation that have led to reductions in nonpoint source pollution, including: sedimentation ponds, manure management, conservation tillage, terraces, new ordinances, wetland restoration, fertilizer management, and education. The information is presented in a user-friendly manner, using maps, tables, figures and numerous case studies to describe pollution prevention projects.

http://www.pca.state.mn.us/index.php/view-document.html?gid=22665.

Additional information on the Clean Water Partnership Program can be found on the MPCA's web page at: http://www.pca.state.mn.us/index.php/water/water-types-and-programs/water-nonpoint-source-issues/clean-water-partnership/more-about-the-clean-water-partnership-program.html.

Nitrogen in Minnesota Surface Waters - The Statewide Nitrogen Study, referenced above, concluded that reducing nitrogen levels in rivers and streams in southern Minnesota will require a concerted effort over much of the land in this region, particularly tile-drained cropland and row crops over permeable soils and shallow bedrock. The figure below depicts the potential nitrogen reductions needed in four southern Minnesota watersheds with a very high adoption of BMPs.

Figure 15. Potential N Reduction to Water with BMP Adoption



The Minnesota Nutrient Reduction Strategy – is a guide for Minnesota to reduce excess nutrients in water to meet both in-state and downstream water quality goals. The strategy sets goals and milestones to meet phosphorus and nitrogen reductions for the Great Lakes, Lake Winnipeg, the Mississippi River, and the Gulf of Mexico. The Nutrient Reduction Strategy report, executive summary, and summary are on the MPCA website

http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/nutrient-reduction/nutrient-reduction-strategy.html.

Swimmable, fishable, fixable? – The "Swimmable, fishable, fixable?" report presents the strategies needed to restore and protect waters in the different watersheds across the state. The report can be viewed at the web link, http://www.pca.state.mn.us/index.php/view-document.html?gid=22760.

The strategies are provided in Watershed Restoration and Protection Strategies (WRAPS) reports. To date, nine watersheds and portions of two others have progressed through public review of WRAPS, with 13 more watersheds scheduled to finalize restoration and protection strategies in 2015. For more details please link to the MPCA website, http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/watershed-approach/index.html.

For the 11 watersheds that have completed the WRAPS, some general themes have emerged:

- In watersheds where agriculture dominates the landscape, prominent strategies include stream buffers, nutrient and manure management, wetland restorations and other forms of water storage, and stream channel stabilization,
- For more urbanized areas, strategies focus on stormwater runoff controls ranging from site planning and rain gardens, to the construction of stormwater ponds and wetlands,
- Not all strategies relate to traditional water pollutants. Throughout Minnesota, common strategies include improving habitat and reducing barriers (connectivity) for fish and other aquatic life, and

- Some strategies call for stronger and more targeted application of state and local laws on feedlots, shoreland, and septic systems. The MPCA leads the permitting of stormwater controls and wastewater discharges.

Chloride - The Twin Cities Metropolitan Chloride Management Plan (CMP) highlights the impacts of chloride on Twin Cities Metropolitan Area water quality with an overarching purpose to: set goals for restoration and protection of water quality, improve winter maintenance practices and policy needs, and demonstrate the success and economic benefits of improved practices. The CMP is available at the web link http://www.pca.state.mn.us/index.php/view-document.html?gid=22754.

The CMP provides in-depth strategies for reducing chloride through pollution prevention activities and BMPs that will help protect and restore water quality in Twin Cities' streams, lakes and groundwater.

Additional information can also be found on road salt and water quality at the MPCA website,

http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/tmdl-projects/special-projects/metro-area-chloride-project/road-salt-and-water-quality.html.

Pesticides and Fertilizers– The foundation of the MDA's programs to reduce, prevent minimize and eliminate degradation of water resources from pesticides and fertilizers begins with the registration of products and, for pesticides, EPA's risk assessments and development of product labels. Pesticide regulation also includes the certification and licensure of certain commercial and private applicators, and education and regulatory oversight of label use provisions (e.g., restrictions on use rate per acre and according to soil type; application setbacks from water bodies; and other water resource-related use restrictions or hazard statements) through outreach and inspections.

The MDA surface water programs for prevention, evaluation and mitigation of pesticide and fertilizer impacts adhere to guidance documents and plans (i.e., the Pesticide Management Plan [PMP at http://www.mda.state.mn.us/protecting/waterprotection/pmp.aspx], or other efforts that are implemented through monitoring, assessment and multi-stakeholder committees that review the activities of MDA and cooperators. These plans, along with cooperator assistance, guide the MDA in evaluating Best Management Practices established to prevent and minimize agricultural chemical impacts to water resources. In addition, groups external to the MDA play a role in advancing key issues related to environmental protection and farming profitability. Information about the Pesticide Management Plan Committee is available at https://www.mda.state.mn.us/protecting/waterprotection/pmp/pmpc.aspx, along with links to the biennial PMP Status Reports required under statute. The PMP Status Reports provide additional detail about MDA prevention, evaluation and mitigation efforts to protect Minnesota's water resources from pesticide impacts. Information about nutrient-related research and outreach conducted via the Agricultural Fertilizer Research & Education Council is available at http://www.mda.state.mn.us/afrec

Once pesticides are observed in water resources, the MDA's PMP provides guidance for evaluating monitoring results and addressing any impacts through voluntary or regulatory actions supported by the Pesticide Control Law (Minn. Stat. chapter 18B), and the Clean Water Act as administered by the MPCA (Minn. Rules chapter 7050).

Other examples of MDA programs and efforts related to protecting water resources from pesticide and fertilizer impacts include:

- Education and promotion of pesticide BMPs (http://www.mda.state.mn.us/protecting/bmps/herbicidebmps/promotingbmps.aspx);

- Protection of public drinking water supplies from fertilizers and pesticides (http://www.mda.state.mn.us/protecting/waterprotection/drinkingwater.aspx);
- Guidance to homeowners on testing domestic wells for pesticides (http://www.mda.state.mn.us/protecting/waterprotection/pesticides.aspx);
- The Nutrient Management Initiative (NMI) program provides a framework for farmers to evaluate their current nutrient management practices compared with an alternative practice on their own field. (http://www.mda.state.mn.us/protecting/cleanwaterfund/onfarmprojects/~/media/Files/protecting/nmi/nmi-brochure.pdf);
- General pesticide management education and outreach (http://www.mda.state.mn.us/chemicals/pesticides/outreach.aspx)
- General guidance on nutrient management (http://www.mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt.aspx); and
- MDA Clean Water Fund activities (https://www.mda.state.mn.us/protecting/~/media/Files/protecting/cwf/cwfbrochure2014.pdf)

Surface Water Summary

Within the last 5 to 10 years there has been a renaissance of environmental monitoring and assessment, which has resulted in the numerous reports cited above. To a large degree this has been the result of the Clean Water Legacy Act and amendment. Because of this we now have a better understanding of the water quality conditions of our lakes, streams and wetlands, than ever before.

Most of the pollution originating from point sources (municipal and industrial facilities discharging to a state water) has been controlled for total phosphorus, ammonia, and bacteria, as cited in the reports above. Surface water quality is mainly degraded by the pollutants entering surface waters from nonpoint sources derived from runoff, particularly from watersheds dominated by agricultural and urban land use. Nonpoint source pollution is the major cause of degradation of Minnesota's surface water; impairing recreation, fish consumption, drinking water use, and aquatic life (2014 Integrated Report).

Statewide monitoring of watersheds has now been initiated or completed in 45 of the state's 80 major watersheds, 56% of the state's watersheds. In some regions of the state, our major watersheds are characterized as moderately to severely polluted. Constituents of concern often include: suspended sediments, excess nutrients (primarily nitrogen and phosphorus), pesticides, pathogens and biochemical oxygen demand. The sources of pollutants have been defined by major watershed for the areas studied and the first 10-year cycle of monitoring and assessment of the state's watersheds will be completed in 2 or 3 years.

The challenge now will be to implement the strategies to restore and protect our water resources to meet the water quality goals and nutrient load reductions, defined in our reports and planning documents; that include:

- The Minnesota Nutrient Reduction Strategy,
- Minnesota's Clean Water Roadmap, Setting long-range goals for Minnesota's water resources,
- Watershed Restoration and Protection Strategies (WRAPS),
- Total Maximum Daily Load (TMDL) Reports, and
- Nitrogen in Minnesota Surface Waters, conditions, trends, sources, and reductions.

Finally, implementation of all of the tools available for reducing and preventing pollution, from regulatory permits to voluntary BMPs, is key to achieving water quality standards and ensuring that the designated uses of Minnesota's surface waters are restored and maintained.

Conclusion

In accordance with 2008 legislation that modified state agency reporting requirements for water assessments and reports, this report summarizes relevant water quality monitoring data for both groundwater and surface water in Minnesota from the MPCA and MDA.

The MPCA and MDA collect water quality information in response to both broad and specific statutory mandates to explore water quality issues of current and emerging concern, and in accordance with formal interagency agreements, and through continuous cooperation and open communication.

Significant progress has been made by MPCA, MDA and stakeholders in addressing sources of groundwater contamination, particularly through remediation, permitting and BMP activities. However, concerns still exist, and continued effort is needed to fully realize the state's groundwater quality goals.

Improvements in state surface water quality have also been significant, along with voluntary and regulatory reduction of point and nonpoint sources of pollution through MDA and MPCA programs and stakeholder support. Coupled with these gains are opportunities for continued improvements, and additional actions are needed to realize Minnesota's surface water quality goals.

For both groundwater and surface water resources, ongoing monitoring is required to characterize vulnerable aquifers and landscape settings. Additionally, MDA and MPCA must continue to identify and investigate contaminant problems, including the presence and extent of emerging contaminants. Ongoing monitoring provides the trend data that is critical to evaluating progress and refining management actions. Protection strategies – whether regulatory or voluntary –must be developed that avoid the occurrence of new problems, and all strategies should be periodically re-evaluated and refined in order to adapt to changing situations in chemical and land use.

Appendix B: 2015 Groundwater Monitoring Status Report

Minnesota Pollution Control Agency and Minnesota Department of Agriculture

September 2015

1. Introduction

The 1989 Groundwater Protection Act (GWPA) (Minn. Stat. ch. 103H.175) requires the Minnesota Pollution Control Agency (MPCA), in cooperation with other agencies participating in the monitoring of water resources, to provide a draft report on the status of groundwater monitoring to the Environmental Quality Board for review every five years. This report is written to provide an update of groundwater monitoring activities in Minnesota to fulfill the MPCA's 2015 GWPA reporting requirements. For additional information on the background and history of groundwater monitoring in Minnesota, see *Minnesota's Groundwater Condition: A Statewide* View (O'Dell 2007) or *The Condition of Minnesota's Groundwater, 2007-2011* (Kroening and Ferrey 2013).

2. Agency Roles in Groundwater Monitoring and Assessment

Minnesota state law splits the groundwater monitoring and protection responsibilities among several state agencies. Each of the agencies involved handles a unique facet of groundwater monitoring and protection. It takes the concerted effort of all these agencies, along with local and federal partners, to build a comprehensive picture of the status of the state's groundwater resources.

Three state agencies, the MPCA; Minnesota Department of Agriculture (MDA); and Minnesota Department of Health (MDH), have important statutory roles and responsibilities in protecting the quality of Minnesota's groundwater as shown in Figure 1. The MPCA and MDA both conduct statewide ambient groundwater quality monitoring for non-agricultural chemicals and agricultural chemicals, respectively. These two agencies share many monitoring resources, including the computer database that stores the data that is collected, the technical staff that manage this information, and occasionally the sampling staff that collects the state's groundwater samples. For example, each year MPCA field staff collects pesticide samples from 20 wells in their network for the MDA. Similarly, the MDA staff collected chloride samples from all of their network wells for the MPCA in 2014 and this summer (2015), the MPCA and MDA staff jointly sampled selected wells in the MDA's network for contaminants of emerging concern (CECs), such as prescription and non-prescription medicines. The MDH conducts monitoring to evaluate and address the human health risk of contaminants in the groundwater that is used for drinking. In addition to these agencies, the Minnesota Department of Natural Resources (MDNR) monitors groundwater quantity conditions across the state through a network of groundwater monitoring wells, and the Metropolitan Council conducts regional water supply planning using the information collected by the MPCA, MDA, MDH, and MDNR.

A 2004 Memorandum of Agreement (MOA) between the MPCA, MDA, and MDH clarifies the agencies' roles in operating a statewide integrated groundwater-quality monitoring system and is provided in Appendix A.

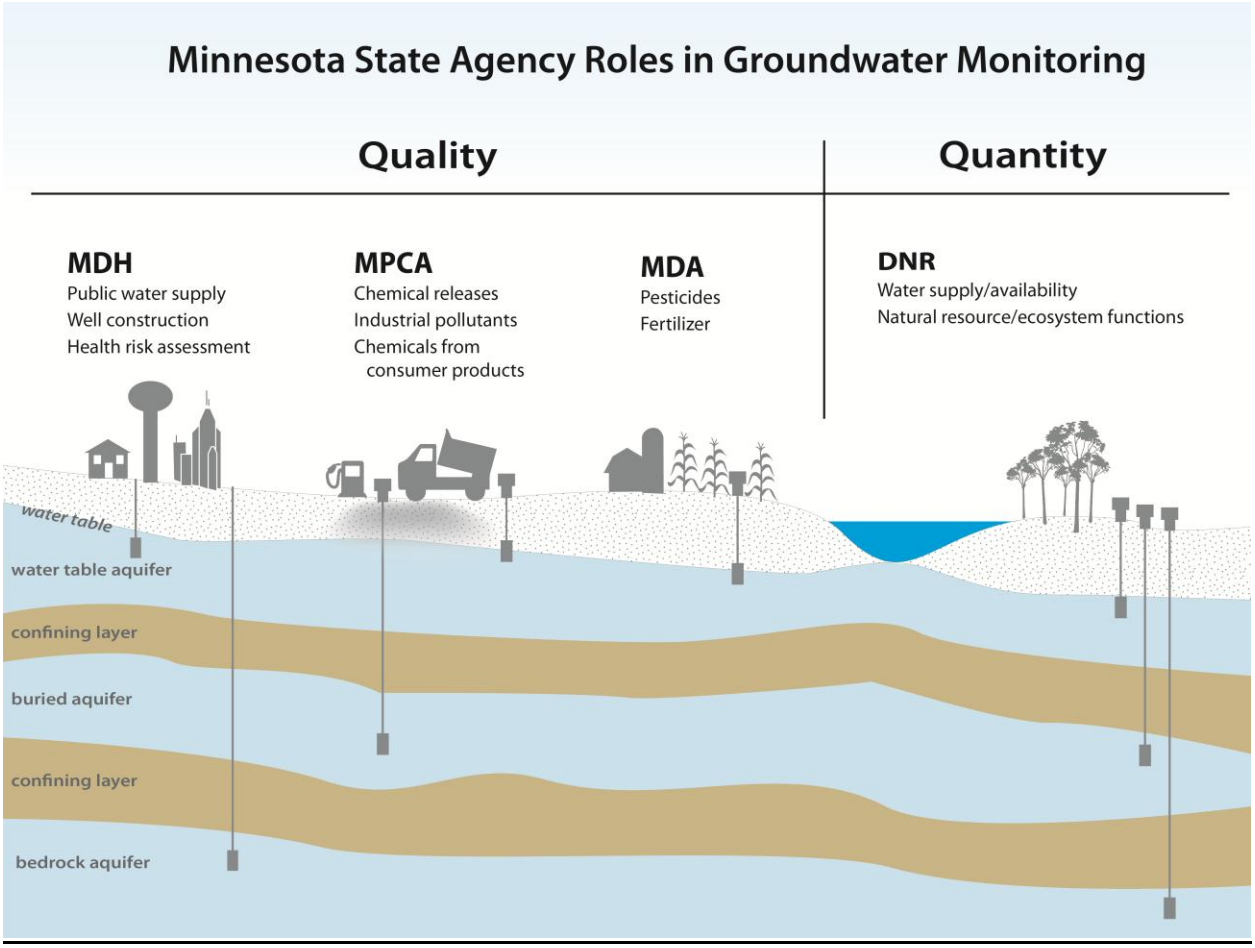


Figure 1. State agency roles in groundwater monitoring [Graphic courtesy of the MDNR].

3. Water Quality Monitoring and Assessment

Between 2010 and 2015, groundwater quality monitoring in Minnesota mainly was conducted by state agencies in partnership with local entities and the federal government. The following sections provide more detail about these monitoring activities.

3.1. National Water Quality Monitoring

The federal government operated two separate national-scale groundwater monitoring programs from 2010-2015: the National Water Quality Assessment (NAWQA) program and the National Groundwater Monitoring Network (NGWMN). The NAWQA program is operated by the U.S. Geological Survey (USGS). The NGWMN is a new national-scale monitoring effort that was fully implemented during this period by the Subcommittee on Groundwater of the Federal Advisory Committee on Water Information (ACWI). The ACWI is a committee that advises the federal government on the effectiveness of the current national programs to meet water information needs. The major differences between the NAWQA program and the NGWMN are described in the following paragraphs.

The USGS's NAWQA program provides an understanding of the nation's water-quality conditions, whether water quality conditions are getting better or worse, and how human activities and natural features affect water quality conditions. The NAWQA program collects data within select study units,

which are not located in every state. This program has sampled over 200 wells in Minnesota since 1991 and currently samples 17 wells in the Upper Mississippi River Basin biennially for trend assessments (USGS 2015).

The NGWMN provides information needed for planning, management, and development of groundwater supplies to meet current and future needs and ecosystem requirements. The NGWMN differs from the NAWQA program in that it focuses on the principal and major aquifers of the United States; these are the primary aquifers used for potable water supplies. Additionally, the NGWMN will use information from all 50 states. The NGWMN generally does not collect new information. Instead, the network typically uses data that already is collected by the states, tribes, and other local units of government. The NGWMN initially was developed using data from five pilot studies, one of which was jointly conducted by the MPCA and MDNR (MacDonald and Kroening, 2011). In 2015, the NGWMN received federal funding to encourage other partners, including those in Minnesota, to participate in the network and for the long-term operation and maintenance of the network.

3.2. Statewide Water Quality Monitoring

The MPCA and MDA continued statewide ambient groundwater quality monitoring during 2010-2015. This monitoring still focused on aquifers that are vulnerable to anthropogenic (manmade) contamination from the land surface. Monitoring groundwater in vulnerable aquifers increases the likelihood that human impacts on groundwater quality will be detected within a reasonable time frame. The MPCA ambient monitoring efforts were conducted in non-agricultural areas of the state with a majority of samples collected in quaternary (glacial) sand and gravel aquifers. The MDA monitoring focused on agricultural regions in quaternary sand and gravel aquifers, with additional samples collected from springs in the southeastern part of the state where little or no quaternary deposits are present. The locations for ambient monitoring wells for both of these programs are shown in Figure 2.

MDH water-quality monitoring efforts continued to focus on assessing public water supplies, which often utilize groundwater. The MDH facilitated the water quality sampling of the state's finished drinking water in cooperation with the public water supply systems to determine contaminant concentrations as part of the Safe Drinking Water Act regulations.

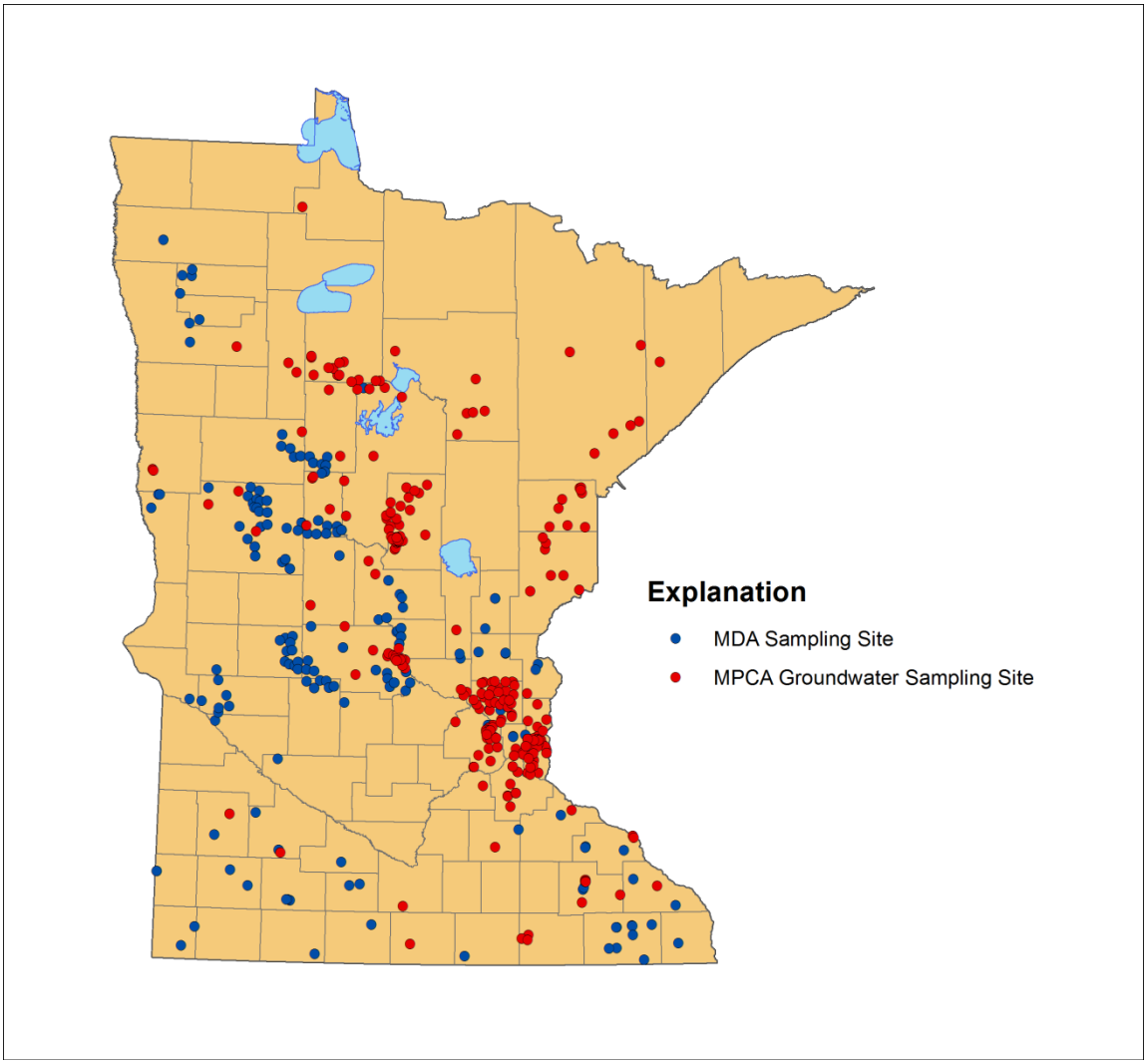


Figure 2. Statewide Ambient Groundwater Monitoring Well Networks maintained by the MPCA and MDA.

3.2.1. Minnesota Pollution Control Agency

The MPCA currently monitors a network that includes almost 250 wells, which are located mostly in typical urban settings. The majority of the wells are sampled to provide an early warning of groundwater contamination within different urban land use settings. This allows the agency to better understand how groundwater quality varies with land use and quickly detect any changes over time. The early warning network wells intersect the water table and are located in commercial/industrial and residential areas served by centralized sewer systems and subsurface sewage treatment systems. The agency also samples some deep wells in areas vulnerable to groundwater contamination; these primarily are domestic wells that supply water to private residences.

Since 2010, the MPCA has enhanced its early warning network wells. This network originally was developed in 2004 solely using existing wells to minimize costs. Most monitoring wells originally sampled by the MPCA's network were installed for the purposes of remedial investigations; the wells that were installed "upgradient" of the suspected contamination (usually a few hundred feet) were also used for ambient monitoring to minimize network installation costs. Using remediation wells resulted in a bias towards detecting gasoline-related volatile organic compounds in surficial aquifers and likely was

not representative of ambient groundwater conditions. The network enhancements focus on the groundwater quality underlying vulnerable, shallow sand and gravel aquifers to provide an early warning of groundwater contamination. The well installation associated with these network enhancements is nearly complete, and almost 140 new monitoring wells have been added to the MPCA's network since 2010.

MPCA staff test the groundwater contained in these wells each year for over 100 chemicals, including nutrients, inorganic compounds, volatile organic compounds, and CECs, such as prescription and non-prescription medicines and chemicals in commonly-used household products. Assessing CECs in the groundwater is part of the MPCA's larger efforts to determine the occurrence, distribution, sources, and fate of these contaminants in the hydrologic system.

The MPCA Sentinel Lakes Groundwater Monitoring Network is an offshoot of the larger ambient monitoring network, and is focused on the movement of groundwater near lakes enrolled in the MDNR's SLICE program (Sustaining Lakes in a Changing Environment). These lakes are called Sentinel Lakes and represent the state's most common aquatic environments. The MDNR is studying the lakes to develop management approaches that can reduce and mitigate negative of agriculture, residential development, invasive species and climate change. By placing monitoring wells next to selected Sentinel Lakes, the MPCA can better understand the interaction of groundwater and surface water, contribute to the MDNR project, and help protect these important resources.

Thirteen wells have been installed next to Sentinel Lakes from 2012-2015 in St. Louis, Stearns, Blue Earth, and Lincoln Counties. Transducers have been placed in all wells to collect continuous records of barometric pressure, groundwater temperature, and groundwater elevation. The land use near the monitored lakes selected ranges from farming country with a high density of large capacity groundwater irrigation systems, to isolated north country lying entirely within the boundaries of a state park. The data collected from this monitoring effort has been used to build groundwater models, augment groundwater reviews of selected watersheds, and highlight the relation between groundwater use, lake levels, and quality.

The MPCA also is conducting a three-year study to determine the occurrence of CECs in the shallow groundwater near large subsurface treatment systems and rapid infiltration basins receiving wastewater effluent. The study also will evaluate CECs in the shallow groundwater at a land application site receiving wastewater and solids from domestic septic systems. The project is a collaborative study with the USGS that complements ongoing CEC monitoring being conducted by the MPCA's Ambient Groundwater Monitoring Program. The data from this project will help explain the occurrence of CEC detected in areas of the state where no identified sources of CEC are known to be present and evaluate the effectiveness of MPCA program best management practices designed to prevent groundwater contamination.

In addition to monitoring ambient groundwater conditions, the MPCA continues to collect groundwater quality information at contaminant spill and release sites, permitted landfills, and land treatment facilities. The MPCA remediation programs alone have investigated a cumulative total of 22,321 sites with the main focus of protecting groundwater resources. Approximately 1,798 of these sites have ongoing corrective actions, many of which include groundwater monitoring. Petroleum product spill sites and voluntary investigation and cleanup sites (brownfields) make up the majority of these sites, followed by Superfund, Resource Conservation and Recovery Act (RCRA), and closed landfills. The most common contaminants detected at remediation sites are volatile organic compounds and major and trace inorganic elements.

3.2.2. Minnesota Department of Agriculture

The MDA began monitoring groundwater in November of 1985 and redesigned its network in 1998. New wells were installed in 1999, and the MDA began sampling these wells in 2000, shown as blue dots on Figure 2. Wells were first installed in the vulnerable aquifers located in the central sand plains (Pesticide Management Region 4 (PMR 4) for the purpose of tracking trends over time. Monitoring of other PMRs of the state began in 2004 that included sampling of naturally occurring springs in the southeast portion of the state PMR 9. In 2009 natural spring monitoring was augmented with the sampling of domestic drinking water wells. Groundwater in the north central and northeastern part of the state are not currently monitored due to very limited agricultural production in these heavily forested regions.

The MDA collected samples from 167 wells and springs in 2014. Of the total sites, 142 were monitoring or observation wells, 13 were private drinking water wells, and 12 consisted of naturally occurring springs emerging from karst bedrock formations in southeastern Minnesota. All of the locations are considered sensitive to contamination from activities at the surface (MDA 2014).

The MDA also manages a remediation program which oversees the collection of a large volume of groundwater quality information from contaminant spill and release sites. Over 700 sites have been investigated and one of the main priorities of these investigations is to protect groundwater resources. Soil corrective actions are completed at most sites, and groundwater monitoring is completed at many of these sites. Typical sites include agricultural chemical storage and distribution cooperatives in rural Minnesota, agricultural chemical manufacturing facilities and wood treating facilities. Groundwater monitoring also is conducted at sites managed by the MDA, including the former Kettle River Creosoting Company site in Sandstone, Minnesota. Common constituents that are monitored at MDA remediation sites include fertilizers, herbicides and insecticides and wood treatment compounds

The revised Nitrogen Fertilizer Management Plan outlines a new Township Testing Program (TTP) designed to identify the agricultural areas with the elevated nitrate concentrations in in groundwater. Townships with greater than 20% row crop agriculture and vulnerable groundwater will be sampled. All private wells in these townships will be offered a free nitrate test and the results summarized and prioritized for further action.

3.2.3. Minnesota Department of Health

The MDH continues to facilitate the monitoring of public water supplies across the state as required by the Safe Drinking Water Act. There are roughly 1,000 community public water supply systems in the state and an additional 5,900 non-community public water systems. MDH estimates a total of 4 million or 74% of the state's population relies on groundwater for drinking water.

The MDH routinely monitors public water supply systems for a number of different contaminants, including pesticides and industrial compounds, bacterial contamination, nitrate/nitrite, radioactive elements (radium), disinfection by-products, arsenic, lead, copper, and other inorganic chemicals. MDH reviews monitoring results to determine if they meet applicable federal or state drinking water standards. In the event of an exceedance, the people who use the water are notified and appropriate steps are taken to correct the problem.

The MDH reviews nitrate/nitrite, coliform bacteria, and arsenic data collected by well drillers from newly installed private drinking water wells to determine the potability of the water. Approximately 20% of Minnesotans are served by private water systems (almost entirely wells). State regulations, administered by the MDH, require licensed water well contractors (and anyone constructing a new well for personal use) to have the water from each new drinking water well tested once for arsenic.

The MDH continues to administer the state's Wellhead Protection Program which is designed to protect drinking water from sources of contamination. Public water supply systems serving places where groups of people live (municipalities, subdivisions, etc.) or spend much of their time (offices, schools, etc.) are required to develop and implement wellhead protection plans. MDH reviews, approves and audits the 10-year plans.

3.3. Statewide Water Quantity Monitoring and Assessment

The MDNR and Metropolitan Council continued statewide and regional groundwater quantity monitoring and assessments during 2010-2015. The MDNR conducted statewide groundwater level monitoring and developed more county-scale groundwater sensitivity maps during this period. The Metropolitan Council continued its work with regional water-supply planning, which included groundwater flow modeling.

3.3.1. Minnesota Department of Natural Resources

The MDNR maintains a groundwater level monitoring network across the state with approximately 1,000 wells in the statewide network. Data collected from the network is used to assess groundwater resources, determine long-term trends in water levels, interpret impacts of pumping and climate, plan for water conservation, and evaluate water conflicts. Traditionally, the MDNR has measured water levels monthly in cooperation with soil and water conservation districts or other local units of government. The MDNR is converting to a system with "continuous" water level monitoring; using in-well recording devises which record readings every 15 minutes.

Water level monitoring is also conducted at approximately 400 locations associated with groundwater appropriate permits. Information from these wells helps inform if pumping of groundwater is causing adverse impacts to surface water features or other water users. An ongoing water supply planning effort is guiding establishment or improvement of monitoring plans for all 650 public water suppliers.

Since 1995 the MDNR, in collaboration with the Minnesota Geological Survey (MGS) has produced county geologic atlases. The MDNR part of this atlas series (Part B) have been recently completed for Carlton (2011) Benton (2012), McLeod (2013), Carver (2014), and Chisago (2015) Counties. Atlases for Blue Earth, Sibley, Nicollet, Anoka, Renville, Wright, Sherburne, Clay, Morrison, Houston, and Winona are currently underway. As a part of all these projects, groundwater sampling is done at selected wells to support groundwater sensitivity mapping. Approximately 90 wells are sampled in each investigated county to determine major ion and trace element concentrations. In addition, tritium values, and values of oxygen and hydrogen stable isotopes, are evaluated to help understand groundwater recharge rates and possible surface water body sources, respectively. Additional groundwater samples are collected from 10 wells in each county for analysis of carbon-14 age dating at locations and in aquifers that likely have very old water in the range of thousands to tens of thousands of years.

The MDNR is implementing a plan to improve groundwater level monitoring in the greater Twin Cities Metropolitan Area. This monitoring is necessary to address the ever increasing demands on groundwater resources in this area. The report titled *Plan to Develop a Groundwater Level Monitoring Network for the 11-County Metropolitan Area* (MDNR 2009) is based on the NFGWM and identifies the long-term needs for monitoring to understand aquifers and groundwater movement in the region. This network informs groundwater protection activities, helps reduce water quality degradation, and ensures that water use does not harm ecosystems.

Special MDNR projects included an Environment and Natural Resources Trust Fund (ENRTF) funded aquifer investigation of the shallowest Mount Simon aquifer areas to better understand the physical and recharge characteristics of this important aquifer. The report and companion video were completed in 2013.

In 2014, also with funding from the ENRTF, two other special projects were initiated: the Minnesota Hydrogeologic Atlas (MHA), and Phase 1 of the State Spring Inventory. The purpose of the MHA project is to combine legacy county–scale maps of various hydrogeologic themes supplemented with some newly created information into a single state-wide layer. When completed, the hydrogeologic maps will include near-surface pollution sensitivity, pollution sensitivity for the top of bedrock surface (selected counties in central and southeastern Minnesota only), water table elevation, and water table depth. These compilations should increase the usefulness of these maps for projects and users that span county boundaries for regional or watershed-based evaluations.

The purpose of the Spring Inventory Project – Phase 1 is to devise best methods for researching and compiling legacy spring location and description data and verifying field locations. Springs are critical resources in Minnesota and occur all across the state. They create cold water and cool water fisheries, sustain base flow in streams, and create unique habitats. In order to maintain their flows, it is vital to inventory, assess, and monitor them on a comprehensive, statewide basis. When completed, this Phase 1 project will produce a new in-progress version of state-wide spring locations, a spring inventory guidance document, and a geographic information system database.

3.3.2. Metropolitan Council

At the direction of the Minnesota Legislature, the Metropolitan Council began a regional water supply planning effort in 2005. Five years of community outreach, data collection, and technical analysis culminated in the development and approval of the seven-county Twin Cities Metropolitan Area Master Water Supply Plan. After completing the Master Water Supply Plan in 2010, the Council continued to partner with state agencies, private consultants, and communities to complete several technical and outreach projects that strengthen regional and local water supply planning efforts, including better integration of water supply planning and local comprehensive planning. The 2015 update of the Master Water Supply Plan incorporates new technical information and feedback from many stakeholders, and it reflects changes to the regional development framework, Thrive MSP 2040, and the Water Resources Policy Plan. Most notably, the update incorporates new data and information that has been collected since 2010 and is available on the Council website:

- New Metropolitan Council population forecasts
- Metropolitan Council analysis of groundwater and surface water relationships
- MGS mapping of the vulnerability of bedrock aquifers to flow through glacial sediments
- Aquifer tests by the MDH based on data collected through community source water protection programs since 2009
- New surface water and groundwater level monitoring data from the MDNR
- Water supply alternative feasibility assessments conducted by Metropolitan Council in partnership with communities
- Updated regional groundwater flow model (Metro Model 3)

Tools including the revamped Water Conservation Toolbox and Stormwater Reuse Guide are available to help communities meet water supply challenges. Subregional water supply planning groups and the Metropolitan Area Water Supply Advisory Committee will help guide future efforts to plan for the region's water supply well into the twenty-first century.

3.4. Current and Emerging Groundwater Quality Issues

3.4.1. Nitrate

Nitrate continues to be one of the state's main groundwater quality issues, especially since a few communities have spent millions of dollars to ensure their water supplies do not contain excessive levels of this chemical. Most groundwater quality monitoring in the state includes a nitrate analysis and these data were summarized in several recently-published reports.

An assessment by the MPCA (Kroening and Ferrey 2013) found that nitrate concentrations in the state's shallow groundwater still vary with land use. This assessment was based on data collected from 2007-2011. In agricultural areas, the median concentration in the groundwater near the water table was about 9 mg/L; whereas, the median concentration in the shallow groundwater underlying various urban land uses ranged from 2-3 mg/L.

The MPCA assessment also noted that the shallow sand and gravel aquifers, which usually are the uppermost aquifer in most parts of the state, contained the highest nitrate concentrations. In central Minnesota, about 40% of the shallow sand and gravel aquifer wells that were tested contained nitrate concentrations that were greater than the Maximum Contaminant Level (MCL) of 10 mg/L set by the U.S. Environmental Protection Agency for drinking water. Groundwater data collection was more limited in southwestern Minnesota. However, the available data suggests that about 20% of the tested wells contained nitrate concentrations that exceeded the MCL.

Trends in nitrate concentrations in the groundwater also were quantified as part of the MPCA groundwater quality assessment. The data from almost 90 wells across the state, which primarily tapped the shallow sand and gravel aquifers, were tested for trends as part of this study. The nitrate concentrations in most of these wells had no significant change from the late 1980s to the present.

The MDA initiated two large monitoring efforts to assess nitrate concentrations in private wells across the state. The Central Sands Private Well Network started in 2011 and samples domestic wells in 14 counties in central Minnesota. The TTP was started in 2013 and assesses nitrate concentrations in private wells in selected counties on the township scale.

The MDA's Central Sands Private Well Network testing indicated that only a small percentage of the tested domestic wells in central Minnesota had nitrate concentrations that exceeded the MCL. Of the 1,555 wells tested in 2011, only 4.6% of the wells had a nitrate concentration that exceeded the MCL of 10 mg/L (Kaiser 2012). Almost 89% of the wells had a concentration that was less than 3 mg/L. The measured concentrations varied by county. The highest percentage of wells with nitrate concentrations exceeding the MCL was in Morrison County. In contrast, no tested wells had nitrate concentrations exceeding the MCL in Cass, Crow Wing, and Douglas Counties. Not surprisingly, almost one-half of the wells with nitrate concentrations greater than the MCL were shallow, less than 50 feet deep.

The nitrate data collected by the MDA's TTP further defined the extent of the high concentrations in the groundwater in selected counties in central Minnesota and other parts of the state. For this program, water samples from private wells in townships in Benton, Dakota, Morrison, Olmsted, Sherburne, Stearns, Wadena, and Washington Counties were collected in 2013 and 2014 (MDA 2015). Overall, the preliminary results from this testing indicated that 13% of the tested wells had a nitrate concentration

that exceeded the MCL. Similar to the results from the Central Sands Private Well Network, nitrate concentrations also varied among the sampled townships. The preliminary results from this network showed that the percentage of wells with concentrations that exceeded the MCL ranged from 0% in North Folk Township in Stearns County to 52% in Agram Township in Morrison County (MDA 2015). The MDA will resample the wells that had nitrate concentrations greater than 5 mg/L using professional staff. These wells also will be assessed for obvious well construction issues and point sources of nitrate, such as subsurface sewage treatment systems and livestock.

USGS and MDH investigations studied some of the factors that affect nitrate concentrations in the groundwater. The USGS conducted a statistical analysis of the factors that affect nitrate concentrations in private wells in the sand and gravel aquifers (Warner and Arnold 2010). The age of the groundwater and changes in the oxidation/reduction potential with depth were found to be important factors affecting nitrate concentrations. The MDH (2012) assessed the factors affecting nitrate concentrations in the aquifers in southeastern Minnesota using information collected by the Southeast Minnesota Domestic Well Network. This investigation found that wells completed in carbonate bedrock aquifers were more likely to have moderate to high nitrate concentrations compared to those measured in wells completed in other types of aquifers. The nitrate concentration in the private wells also was strongly affected by the presence of materials that give natural geologic protection, such as shale or clay-rich glacial till. Well construction also was found to affect the measured nitrate concentration. The presence or absence of a grout seal in the well was examined by the MDH. About 20% of the wells lacking a grout seal produced water with nitrate concentrations that were greater than the MCL. In contrast, none of the wells that had the grout seal had a concentration that exceeded the MCL.

3.4.2. Chloride

Chloride contamination could affect the potability of some of the state's groundwater in the future. This water-quality issue was first brought to light about a decade ago when investigators documented high concentrations in the state's streams, lakes, and groundwater (Novotny et al 2007 and Wenck et al 2006). Stefan et al (2008) found that most of the chloride applied in the Twin Cities Metropolitan Area (TCMA) is either transported to the groundwater or remains in the area soils, lakes, and wetlands.

A recent statewide assessment by the MPCA found that the groundwater in the shallow sand and gravel aquifers in the TCMA is impacted by high chloride concentrations (Kroening and Ferrey 2013). This investigation determined that the median chloride concentration in the sand and gravel aquifers underlying the TCMA was 86 mg/L, which was about five times greater compared to the aquifers in the rest of the state, and concentrations as high as 8,900 mg/L are in some shallow wells in the TCMA. A substantial number of wells had concentrations that exceeded the secondary maximum contaminant level of 250 mg/L Twenty-seven percent of the wells installed in the sand and gravel aquifers in the TCMA had concentrations that exceeded the secondary maximum contaminant level; whereas, very few wells outside of this area contained water that exceeded this standard.

Salt application in urban areas affected chloride concentrations in the groundwater. Chloride concentrations were significantly greater in groundwater underlying urban land compared to those underlying undeveloped parts of the state. The water from the majority of the wells in the shallow sand and gravel aquifers underlying the TCMA also had a chemical signature that was consistent with halite, which typically is applied to de-ice roadways during the winter in Minnesota. The data analysis by the MPCA suggested that groundwater with chloride concentrations greater than 30 mg/L often originated from halite.

Chloride concentrations were found to have increased in about one-third of the wells that had sufficient data for trend analysis. In some wells, concentrations have increased by about 100 mg/L in the last 15-20 years. Most of the wells with increasing trends were shallow and tapped the sand and gravel aquifers, but increasing concentrations were found in two deep wells in the TCMA. If these trends continue, the water from more wells likely will have concentrations that exceed the MCL in the future.

These results were consistent with national-scale assessments of chloride trends in the groundwater. In 2012, the USGS released a report summarizing the decadal-scale changes in chloride across the U.S. from the late 1980s until 2010 (Lindsey and Rupert 2012). In this report, chloride trends were assessed by sampling network. One of the most notable results in this report were that chloride concentrations increased in almost 50% of the assessed networks, and a network of wells in Minnesota had a significant increase in chloride concentrations, with a median concentration change of greater than 20 milligrams per liter.

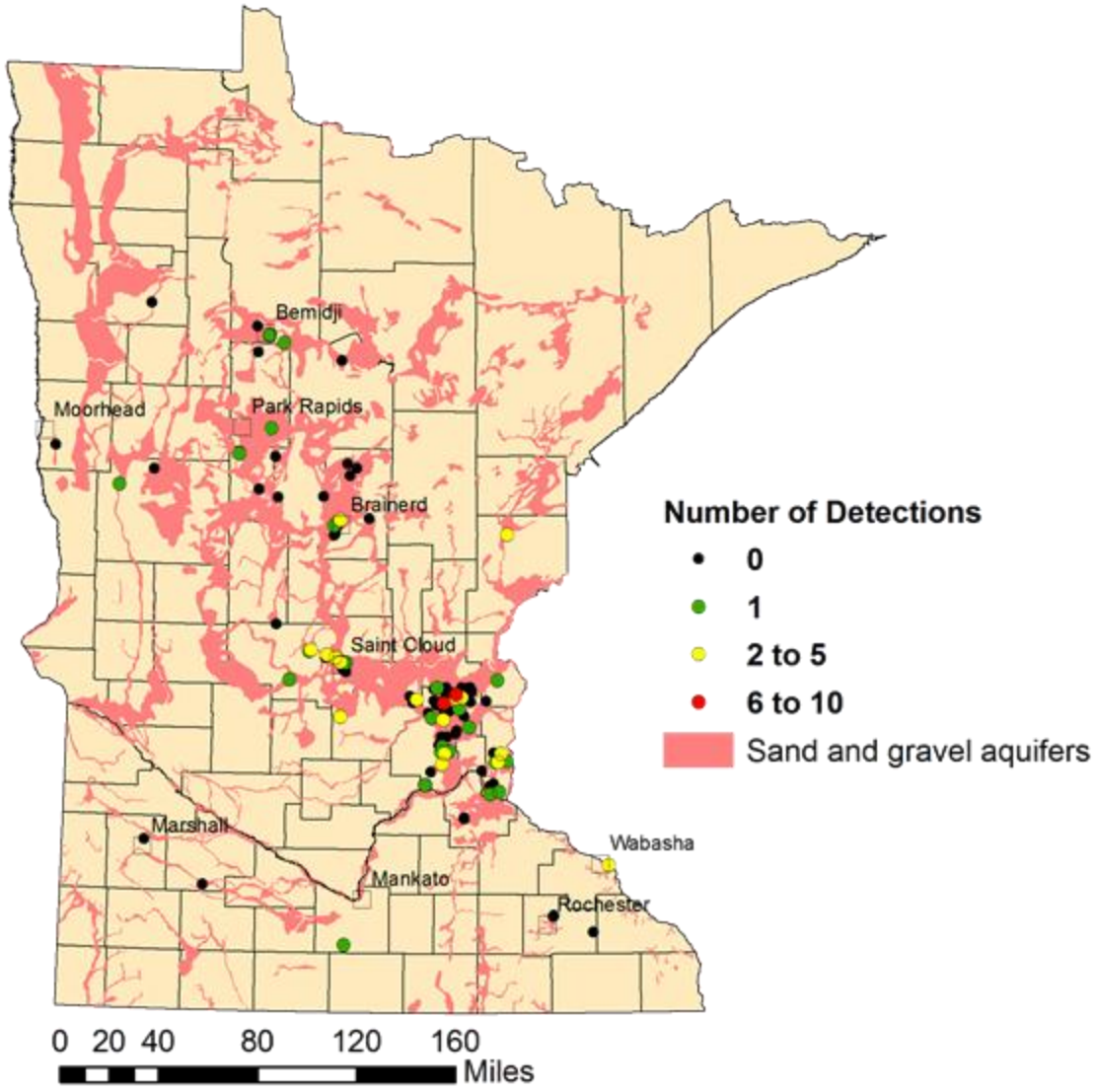
3.4.3. Contaminants of Emerging Concern

The MPCA continued to investigate the extent of any contamination from CECs in the ambient groundwater, such as prescription and non-prescriptions medications and chemicals in commonly-used personal care products. From 2009-2014, the agency sampled over 200 wells in its monitoring network for a large suite of CECs. From 2009-2014, this monitoring was conducted in cooperation with the USGS. In 2015, the MPCA contracted with AXYS Analytical Laboratories in British Columbia, Canada to analyze for CECs in the groundwater samples collected for its network. This change was made to align the agency's groundwater and surface water monitoring activities.

The CEC data collected in the groundwater across the state from 2009-2012 was interpreted in a USGS report (Erickson et al 2014). Overall, 35 different CECs were detected in the ambient groundwater samples collected for this study. The greatest number of CEC detections in any individual groundwater sample was 10 (Figure 3). Three wells, located near closed landfills, were sampled as part of this study; the greatest numbers of CECs were detected in these wells. The CEC concentrations measured in this study generally were low; no concentrations exceeded any established human-health guidance values.

The antibiotic sulfamethoxazole was the more frequently detected CEC in the ambient groundwater. This chemical was detected in about 11% of the analyzed samples. Most detections of sulfamethoxazole were in samples from domestic wells or monitoring wells located in residential areas. The insect repellent N, N-Dimethyl-meta-toluamide, commonly known as DEET, was detected at the highest concentration in the groundwater, 7.9 micrograms per liter. Bisphenol A was the second most frequently detected chemical.

Figure 3. Number of Contaminants of Emerging Concern detected in ambient groundwater wells in Minnesota, 2009-2012.



4. Groundwater Data Access and Management

Data from the MPCA's ambient groundwater monitoring network, previous monitoring efforts, and the open, closed, and demolition landfills are available on the MPCA's website through the Environmental Data Access (EDA) system. The EDA system was developed to improve access to environmental data and is available at the following web address (URL): http://www.pca.state.mn.us/index.php/data/environmental-data-access.html. The MPCA's and MDA's ambient groundwater information also is available through the EPA's Water-Quality Exchange http://www.epa.gov/storet/wqx/.

The MPCA and MDA now store the groundwater quality data that they each collect in the same database. The database is commercially available from EarthSoft Inc. and called the Environmental

Quality Information System or EQuIS. The DNR's County Well Atlas Program also is in the process of transitioning the storage of their groundwater quality data to this same database. The EQuIS database is managed as follows. A MnIT staff person serves as the EQuIS database administrator, and both the MPCA and MDA employ separate data coordinators to assist the data users in managing the information. The storage of these large sets of groundwater quality in the same database greatly simplifies regional or statewide analysis of groundwater quality conditions since the data are now stored in the same format. The MDH Environmental Laboratory, which analyzes a large number of the samples collected by the MPCA, also modified their systems and processes so the MPCA can easily store the data generated by the MDH laboratory in EQuIS.

5. Needs and Conclusions

The ambient monitoring conducted by the MPCA, MDA, and others, continues to provide valuable, long-term information on the water-quality conditions in aquifers vulnerable to contamination across Minnesota. As the demands for the state's groundwater increase, this record of groundwater quality will become increasingly important for the proper use and management of this resource. A long term commitment to the collection and analysis of groundwater data is necessary to identify changes in water quality and quantity over time and provide information needed to effectively manage and protect this critical resource. Groundwater movement is generally slow and often requires years of monitoring to assess the trends and impacts of human activities on this resource.

Recent groundwater quality assessments indicated that the chloride levels in the state's groundwater need to be watched. The high chloride concentrations present in some aquifers, especially in the shallow ones in the TCMA, either will be discharged into streams and lakes, or this chloride-laden groundwater will move downward into the deep aquifers that supply the state's drinking water. The inflow of groundwater containing chloride concentrations that exceed the chronic water-quality standard (230 mg/L) to streams may cause any chloride impairments to occur during baseflow conditions as well as during the usual winter period. Recent assessments have indicated that chloride concentrations have increased over time in the TCMA, in the shallow as well as parts of some bedrock aquifers. If these trends continue, more bedrock aquifer wells may be impacted by chloride in the future, and the water eventually may become unsuitable for drinking. There are some existing gaps in chloride monitoring that should be filled. A large amount of the groundwater monitoring in the TCMA focuses on conditions at the water table. Additional deep wells should be installed to track how the depth to which chloride has penetrated into the groundwater system.

Nitrate concentrations in the state's groundwater also should continue to be watched, especially since some communities have had problems with high concentrations in their water supplies. The state's ambient monitoring networks should continue to monitor for nitrate in the groundwater, and MDA's two relatively new nitrate-testing programs, the Central Sand Private Well Network and Township Testing Program, should continue to be funded to complete this important work.

The presence of CECs in the groundwater also bears watching. Even though monitoring to date has found these chemicals are low in concentrations, it still is important to assess the presence of these chemicals because this monitoring identifies chemicals in the groundwater for which there are relatively few available human-health guidance values. Similarly, efforts by the MDH to develop human-health guidance values for these chemicals are invaluable because it allows scientists to determine whether the presence of these chemicals makes water unsuitable for drinking.

6. References

Erickson, M.L., S.K. Langer, J.L. Roth, and S.E. Kroening. 2014. Contaminants of Emerging Concern in Ambient Groundwater in Urbanized Areas of Minnesota, 2009-2012. U.S. Geological Survey Scientific Investigations Report 2014-5096, 38 p.

Kaiser, K. 2012. Central Sands Private Well Network—2011 Current Nitrate Conditions Summary, Minnesota Department of Agriculture, Pesticide and Fertilizer Management Division, St. Paul, Minnesota, 16 p.

Lindsey, B.D. and M.G. Rupert. 2012. Methods For Evaluating Temporal Groundwater Quality Data and Results of Decadal-Scale Changes in Chloride, Dissolved Solids, and Nitrate Concentrations in Groundwater in the United States, 1988-2010. U.S. Geological Survey Scientific Investigations Report 2012-5049.

MacDonald, M. and S. Kroening. 2011. Results of the Minnesota Pilot Study for the National Groundwater Monitoring Network. Minnesota Pollution Control Agency report number wq-gw1-03. http://acwi.gov/sogw/pubs/tr/pilot_results/MN.pdf accessed August 14th, 2015.

Minnesota Department of Agriculture. 2015. Initial Township Testing-- 2013-2014 Preliminary Results Update June 8, 2015. Pesticide and Fertilizer Management Division, St. Paul, Minnesota, 6 p.

Minnesota Department of Health. 2012. Volunteer Nitrate Monitoring Network—Methods and Results. Environmental Health Division, St. Paul, Minnesota, 19 p.

Minnesota Department of Natural Resources 2009. Groundwater: Plan to Develop a Groundwater Level Monitoring Network for the 11-County Metropolitan Area, October, 2009. Minnesota Department of Natural Resources, Waters.

Minnesota Department of Natural Resources 2010. Memorandum. South-Central Groundwater Monitoring and County Geologic Atlases, 4/12/10, Jim Berg.

Minnesota Pollution Control Agency 2008. Groundwater Monitoring Status Report, Environmental Analysis and Outcomes Division, St. Paul, Minnesota.

Minnesota Pollution Control Agency and Minnesota Department of Agriculture 1991. Nitrogen in Minnesota Groundwater, prepared for the Legislative Water Commission.

Novotny, E., et. al. 2007. Road Salt Effects on the Water Quality of Lakes in the Twin Cities Metropolitan Area. December, 2007. Project Report No. 505, University of Minnesota, St. Anthony Falls Laboratory, Engineering, Environmental and Geophysical Fluid Dynamics.

O'Dell, C., 2007. Minnesota's Groundwater Condition—A Statewide View: Minnesota Pollution Control Agency, Environmental Outcomes and Analysis Division, St. Paul, Minnesota, 47 p.

Stefan, H., E. Novotny, A. Sander, and O. Mohseni. 2008. Study of Environmental Effects of De-icing Salt on Water Quality in the Twin Cities Metropolitan Area, Minnesota, Minnesota Department of Transportation, St. Paul, Minnesota.

Warner, K.L. and T.L. Arnold, 2010. Relations That Affect the Probability and Prediction of Nitrate Concentration in Private Wells in the Glacial Aquifer System in the United States: U.S. Geological Survey Scientific Investigations Report 2010-5100.

Wenck Associates, Inc. 2006. Shingle Creek Chloride TMDL Report, Wenck File # 1240-34, Maple Plain, Minnesota, December, 2006.

U.S. Geological Survey, 2015. National Water Quality Assessment in the Upper Mississippi River Study Unit. http://mn.water.usgs.gov/nawqa/umis/index.shtml accessed August 3rd, 2015.