

2.01 OBJECTIVE

The 2009 *Lake Wingra: A Vision for the Future*, prepared by FOLW, cites addressing Lake Wingra chloride concentrations as a critical element of Goal 1, clean, clear water. The report goes on to establish a target surface chloride concentration of 40 milligrams/liter (mg/L). This 40 mg/L target was about one-half of the Lake Wingra surface chloride concentrations sampled in 2008.

In an effort to achieve this goal, this portion of the management plan:

1. Describes the current chloride concentration trend in Lake Wingra and the contributing factors.
2. Identifies primary road salt contributors, and estimates the magnitude of each contribution.
3. Performs a conceptual mass balance of lake chloride concentrations, and uses this mass balance to estimate what chloride load reductions are necessary to achieve 40 mg/L surface chloride concentration.
4. Reviews management changes that have the potential to achieve the chloride reduction goals.
5. Recommends management changes to pursue.

This study looks only at road salt application as it applies to chloride concentrations; it does not address issues regarding traveling safety affected by salt use.

2.02 BACKGROUND

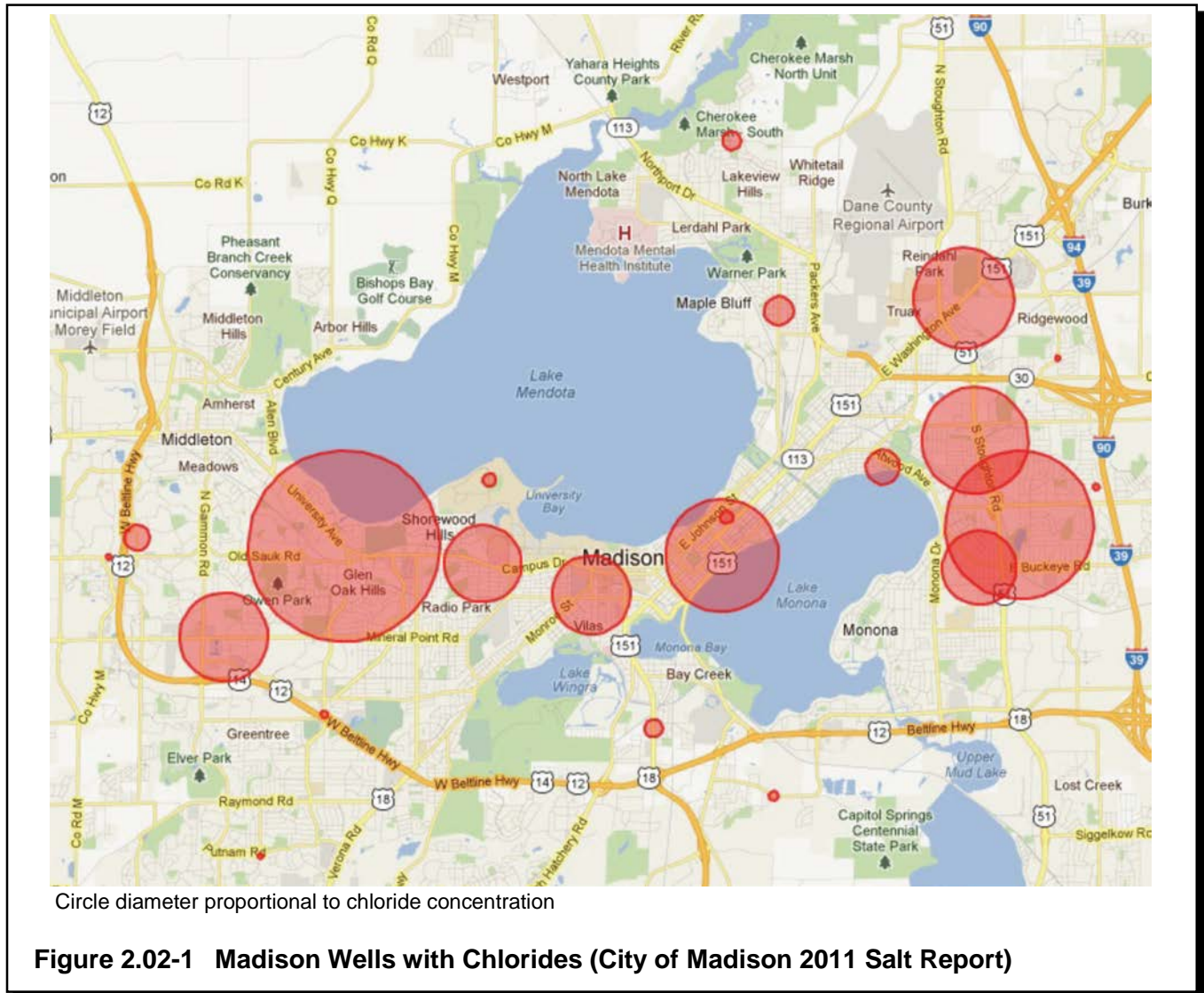
A. Effects of Chloride

Chloride is soluble and very mobile. There is no natural process by which chlorides are removed from the environment. Chloride in surface waters can be toxic to fish, macroinvertebrates, insects, and amphibians. High chloride concentrations also affect food sources for these aquatic species. Salinity stress on sensitive aquatic communities can impact species diversity. Salt use also impacts vegetation. High concentrations of chloride interfere with a plant's absorption of moisture from soil, which can cause browning or burning of leaves. High sodium concentrations, often associated with high chloride concentrations, may affect plant growth by altering soil structure, permeability, and aeration.

Because of the adverse effect on surface waters, the United States Environmental Protection Agency (USEPA) has set the Criteria for Continuous Concentration (CCC) for chloride at 230 mg/L, while the Wisconsin Department of Natural Resources (WDNR) has set the Chronic Toxicity Criterion (CTC) at 395 mg/L. Both the USEPA and WDNR define the duration of chronic exposure as four days, with frequencies limited to once every three years. The Canadian Government has estimated that prolonged

exposure to chloride concentrations as low as 120 mg/L can have toxic effects on 5 percent of the species.

Chlorides also have the potential to affect groundwater. Chlorides are increasing in some city wells that are located next to arterial roadways. Wells with shorter steel casings have higher chloride concentrations, with some as high as 50 mg/L. Figure 2.02-1 illustrates Madison wells affected by chlorides, taken from the 2001 Salt Report.



The WDNR secondary standard for drinking water is 250 mg/L chloride. The USEPA does not have any drinking water standards for chlorides, but sodium is included on the Drinking Water Contaminant Candidate List (CCL). The CCL is a list of contaminants that are not subject to any proposed drinking water regulation but that are known to occur in public water systems and may require regulations under the Safe Drinking Water Act (SDWA). The USEPA has recommended Secondary Drinking Water Standards through the SDWA, and the chlorides secondary standard is 250 mg/L.

B. Chloride Use

Since the late 1950s, the City has used salt in its winter pavement deicing program. Since that time, there has been a continuing awareness and concern regarding the detrimental effects of road salt to Madison area lakes. In 1973, the City's common council called for a reduction in salt usage in the Lake Wingra watershed, which was extended city-wide four years later. The Madison Department of Public Health has issued an annual report documenting the city's use of salt.

The 2012 Salt Report states the average chloride concentration for Lake Wingra in 2012 was 115 mg/L, with a sustained concentration of over 125 mg/L being observed between August 2 and September 24, 2012. A prolonged drought and reduced lake discharge likely contributed to this late and prolonged chloride concentration. Figure 2.02-2 is Figure 3 from the Madison 2012 Salt Report and shows the chloride concentrations in Lake Wingra compared to the other Yahara Lakes. Figure 2.02-3 shows Figure 2 of that same report that compares city salt usage with chloride concentrations in Lake Wingra.

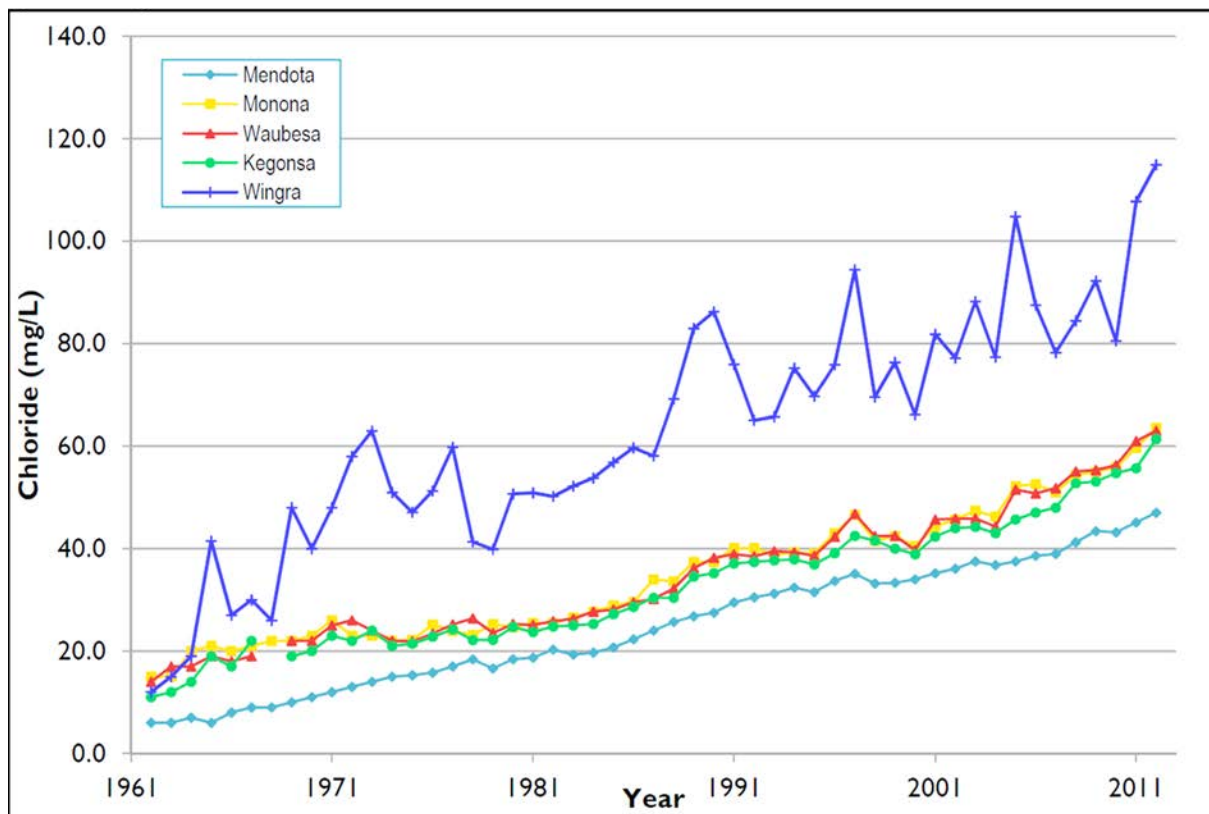


Figure 2.02-2 Yahara Lakes Chloride Levels (City of Madison 2012 Salt Report)

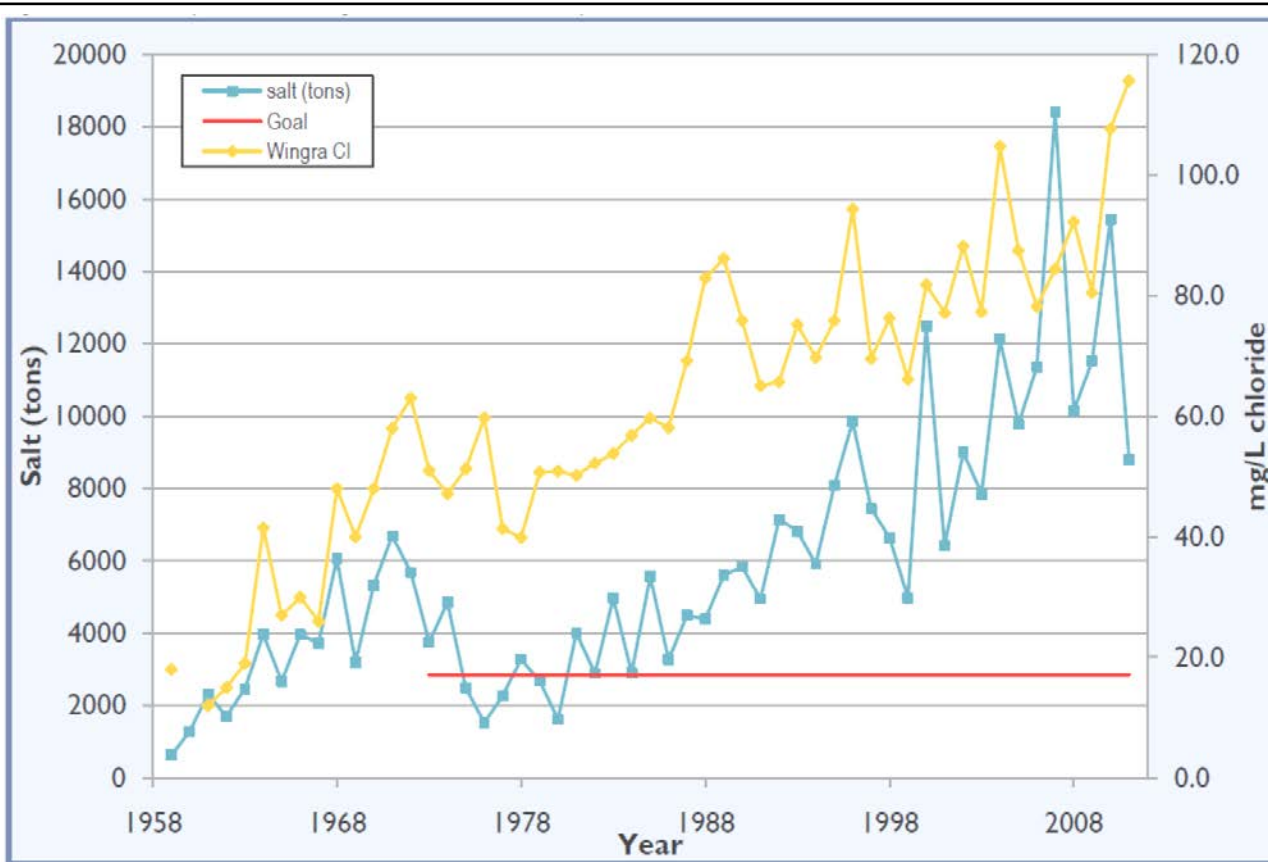


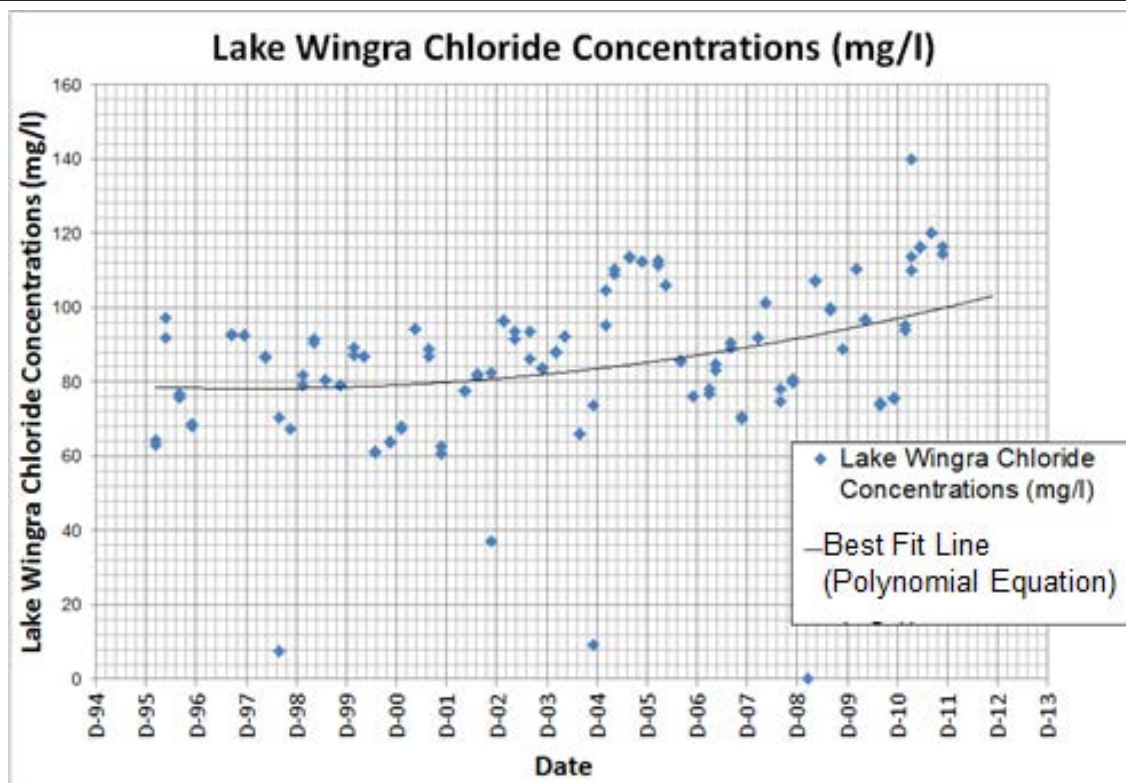
Figure 2.02-3 Madison Salt Use Compared with Lake Wingra Chloride Levels
(City of Madison 2012 Salt Report)

Figure 2.02-4 provides more recent data on Lake Wingra chloride concentrations obtained from research on the *Chemical Limnology of North Temperate Lakes*.¹ This research shows Lake Wingra chloride concentrations averaging about 80 mg/L from 1994 to 2004, with the trend increasing to above 100 mg/L between 2004 and 2012. Chloride levels within Lake Wingra have appeared to reach an equilibrium with winter maintenance practices being relatively constant within the watershed area and a flushing rate of approximately one year. With this equilibrium and absent management changes, chloride levels are influenced by the number of salting events per year.

Chloride concentrations vary within a water column, with surface chloride concentrations being lower than chloride concentrations deeper in the water column because water density increases with increasing ion concentrations. Figure 2.02-5 provided by Roger Bannerman, WDNR and United States Geological Survey (USGS), shows the chloride concentrations at different depths in Lake Wingra in late winter of 2008. This graph indicates the average chloride concentration is much higher than the surface chloride concentrations that have been monitored. This graph also shows the chloride loadings per water depth. Even though higher concentrations occur at greater

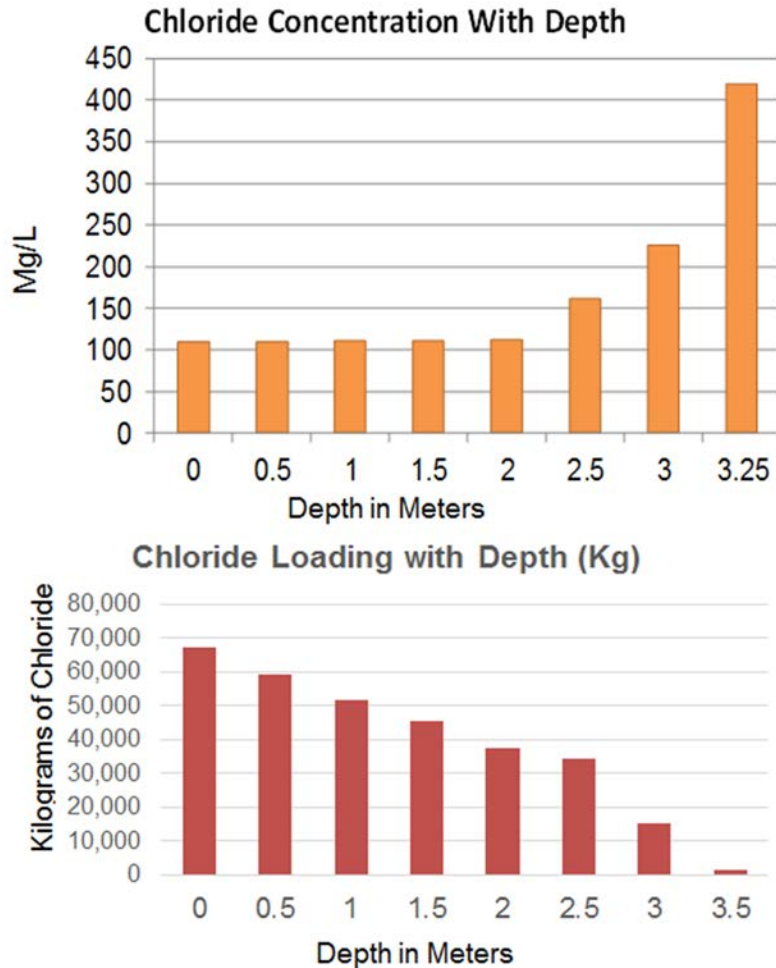
¹<http://lter.limnology.wisc.edu/datafile/chemical-limnology-north-temperate-lakes-lter-primary-study-lakes-major-ions>

water depths, because Lake Wingra is relatively shallow, the surface levels still account for most of the lake's chloride.



<http://lter.limnology.wisc.edu/datafile/chemical-limnology-north-temperate-lakes-lter-primary-study-lakes-major-ions>
accessed on May 21, 2013 Note: D-94 = December 1994, etc.

Figure 2.02-4 Lake Wingra Chloride Levels



Source: Roger Bannerman, May 2013; David Liebl, November 2014. Modified to provide similar scales.

Figure 2.02-5 Chloride Concentrations and Loadings in Water Column in Lake Wingra

C. Factors Affecting Chloride Concentrations

Several factors affect chloride concentrations in Lake Wingra.

1. Sources and Extent of Salt

- All pavements maintained with salt within the tributary area of the lake (watershed area).
- The salt application rate for pavements within the watershed boundary.
- The number of salt events (winter storm events) and the number of applications per event where salt is applied to pavements.
- Chlorides that enter Lake Wingra from groundwater flow.
- The impervious area that is connected to the lake by storm drains.

2. Water Balance of Lake Wingra
 - a. The amount of precipitation within the watershed that falls into the lake.
 - b. The amount of groundwater flowing into the lake.
 - c. The amount of water leaving the lake through evaporation and evapotranspiration.
 - d. The amount of water leaving the lake via Wingra Creek.
3. Watershed Retention of Chlorides—Many studies have found that watersheds retain chlorides, so they are not discharged into the waterways. Novotny et al performed a chloride mass balance for the Twin Cities (Minneapolis-Saint Paul, Minnesota) seven-county metropolitan area. The analysis was used to estimate how much of the road salt applied annually was exported from the watershed by the Mississippi River and how much was retained in the soils, groundwater, and surface waters. The study found that there was a 77 percent chloride retention rate, meaning only 23 percent of the chloride that was applied reached the waterbody outflow.² Other studies cited in the article describe chloride retention rates of 55 percent in Toronto, Canada; 50 to 65 percent in Helsinki, Finland; 28 to 45 percent in Chicago, Illinois; 59 percent in Rochester, New York; and 35 percent in Boston, Massachusetts.³

The presence and introduction of wetlands as well as detention/infiltration basins may aid the retention of chlorides within a watershed. In a separate study,⁴ Novotny, the author of the Twin Cities study, states, “*The presence of a high salinity layer at the bottom of the lake causes the convective penetration of saltwater into the pore system of the lake sediments.*” This phenomena contributes to chloride retention within a water body and may lengthen the time necessary for lake restoration.
4. Chloride Equilibrium—The same Twin City study found a mean annual equilibrium chloride concentration is reached when all the chloride added to a lake during the winter season is flushed out during the summer and fall season. Smaller lakes with high flushing rates tend to reach chloride equilibrium sooner than larger lakes with low flushing rates. Lake Wingra’s flushing rate ranges from 0.75 to 1.5 years dependent on rainfall in a given year, yet chloride mixing is continuous and leaves a chloride presence even after a full flush. The recovery of many urban lakes to normal chloride levels could take from 10 to 30 years.⁵

²Eric Novotny et al., *Chloride Ion Transport and Mass Balance in a Metropolitan Area Using Road Salt*, Water Resources Research, Vol. 45, Issue 12, December 2009.

³Howard and Hayes 1993, Ruth 2003, Wulkowicz and Saleem 1974, Bubeck et al., 1971, and Juling and Hollocher 1972, respectively.

⁴Novotny’s *Increase Of Urban Lake Salinity by Road Deicing Salt* (2008).

⁵ Eric Novotny et al., *Chloride Ion Transport and Mass Balance in a Metropolitan Area Using Road Salt*, Water Resources Research, Vol. 45, Issue 12, December 2009. In this same article, the authors also mention chloride residence times in lakes ranging from 3 to 14 years.

2.03 CHLORIDE CONTRIBUTORS

The primary contributor of chlorides to Lake Wingra is pavement. While salt is also discharged from water softeners, this discharge is routed to the sanitary sewer system. Madison Metropolitan Sewerage District (MMSD) has been experiencing increasing chloride concentrations in its wastewater. MMSD taking measures to evaluate and reduce these chloride concentrations including monitoring of salt concentrations in the sanitary sewer. Through infiltration of groundwater and inflow of stormwater into the sanitary sewer system, pavement salt application is affecting chloride concentrations in the wastewater. The water softener discharge from the sanitary sewer system is likely a negligible contributor of chlorides to Lake Wingra. Similarly road salt infiltration into the sanitary system, while affecting wastewater chloride levels, is likely a very small portion of the road salt applied throughout the watershed.⁶

A. Watershed Area

The official watershed boundary for the management plan is shown in Figure 2.03-1. It includes areas that drain into Wingra Creek as well as the Gardner Marsh. While the study boundary includes these eastern areas, these areas do not drain into Lake Wingra and, therefore, do not affect lake chloride concentrations. The two different blue-shaded areas within Figure 2.03-1 illustrate the tributary area directly draining into the lake and the tributary area that affects the chloride concentrations in the lake. The red-shaded area represents the area draining into Wingra Creek and Gardner Marsh and does not affect lake chloride concentrations. There are numerous pavements and jurisdictions within this watershed boundary with pavements that receive road salt during the winter. Table 2.03-1 lists these pavements and who maintains them. The impervious areas shown in this table include only those likely to receive salt and do not include roofs. Figure 2.03-2 provides a larger display of the Wingra Watershed area with Salt Routes.

⁶ The study performed a cursory review of the difference in MMSD effluent chloride levels between the four quarters in 2013 (in tons). This difference in chloride levels from the baseline was multiplied by the wastewater traveling through the Plaenart Drive pump station that is attributable to the Lake Wingra Watershed (28 percent) divided by the total effluent from MMSD. This cursory analysis indicates that the Lake Wingra Watershed contributed up to 150 tons of salt to MMSD effluent chloride levels. This could suggest that from 3 to 4 percent of the salt applied within the watershed could reach MMSD pipes.

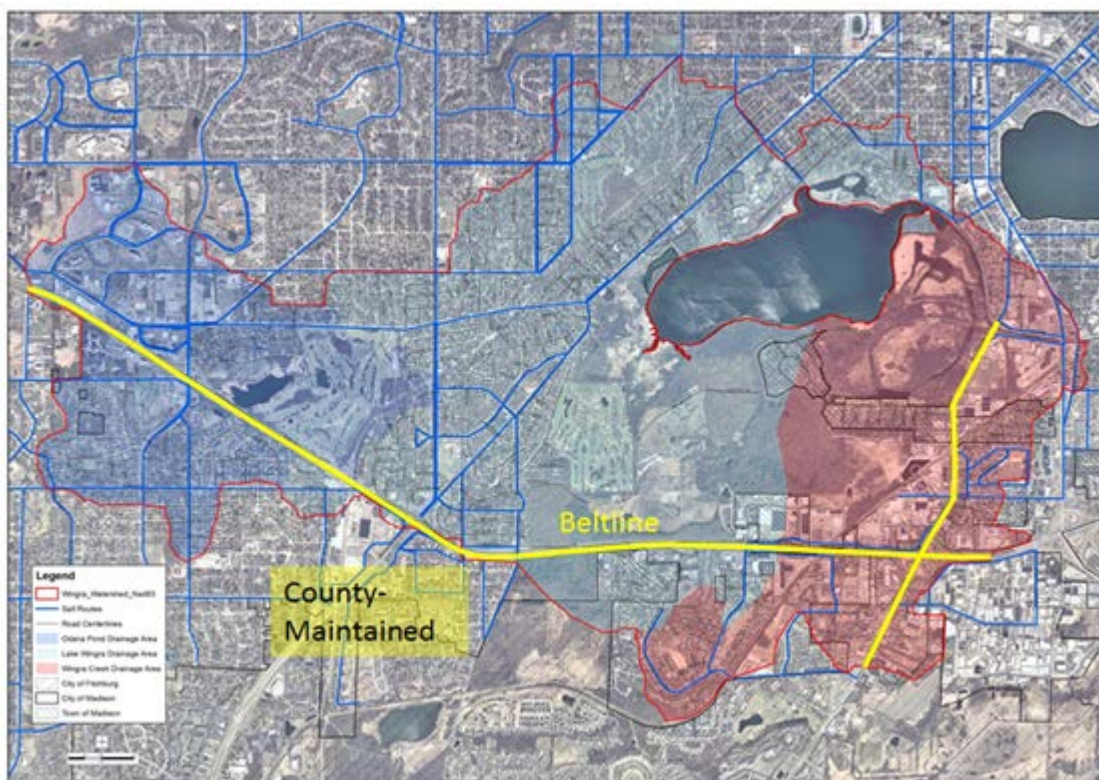
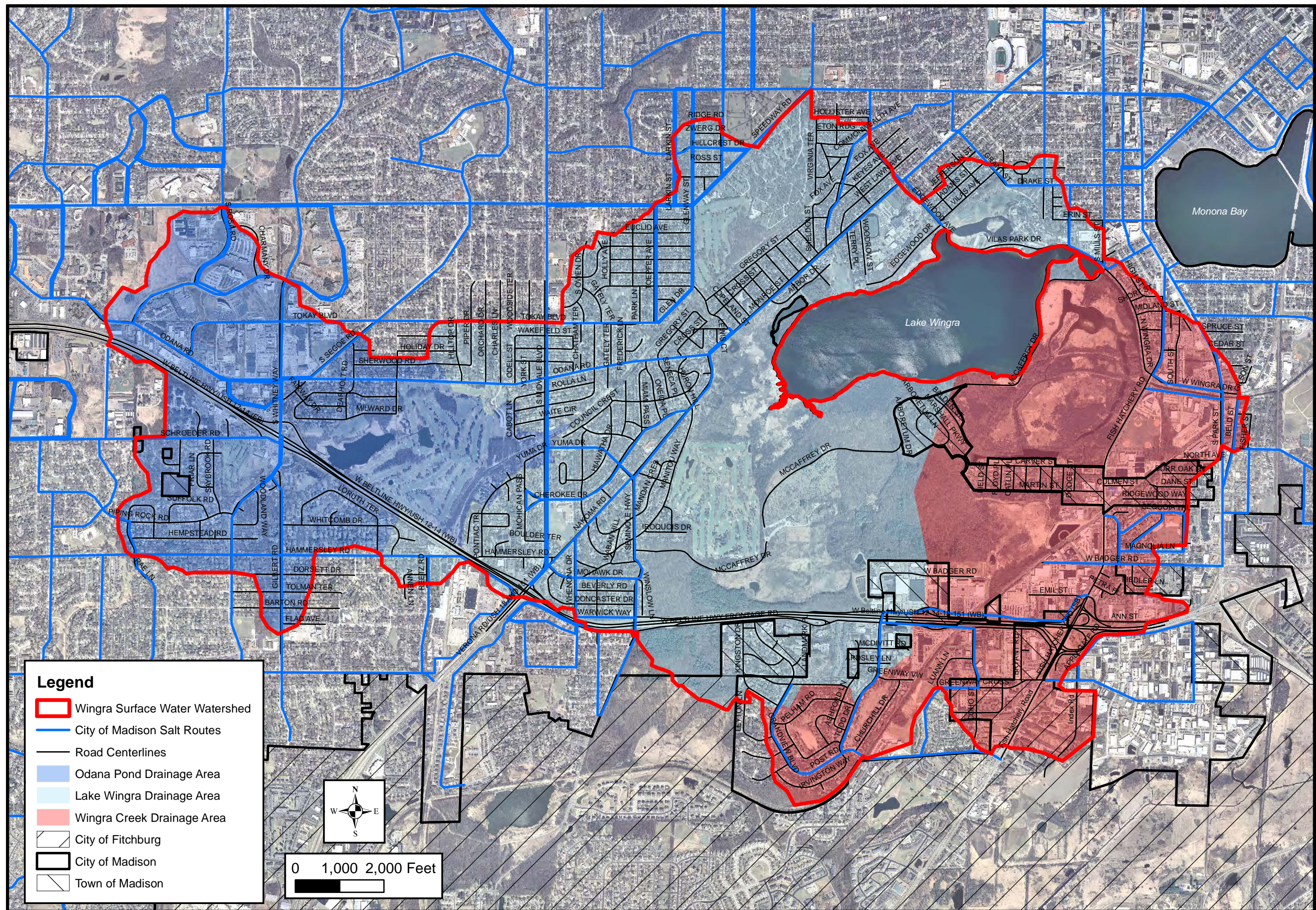


Figure 2.03-1 Lake Wingra Tributary Area with Salt Routes (Blue and Yellow)

Pavement	Maintainer	Tributary to Lake
Madison Salt Routes—No Curbs	City of Madison	0.44 lane miles—0.6 acres
Madison Salt Routes—Curb One Side	City of Madison	0.24 lane miles—0.4 acres
Madison Salt Routes—Curbs Both Sides	City of Madison	61.07 lane miles—88.8 acres
Madison No-Salt Routes—No Curbs	City of Madison	8.89 lane miles—12.93 acres
Madison No-Salt Routes—Curb One Side	City of Madison	0.08 lane miles—0.1 acres
Madison No-Salt Routes—Curbs Both Sides	City of Madison	69.49 lane miles—101.1 acres
WisDOT—No Curbs	Dane County	7.19 lane miles—10.5 acres
WisDOT—Curb One Side	Dane County	12.46 lane miles—18.1 acres
WisDOT—Curb Both Sides	Dane County	10.05 lane miles—15.3 acres
Streets within Arboretum—No Curbs	University of Wisconsin	3.14 lane miles—4.6 acres
Town of Madison Salt Route—Curb One Side	Town of Madison	0.12 lane miles—0.17 acres
Town of Madison Salt Route—Curbs Both Sides	Town of Madison	0.46 lane miles—0.7 acres
Town of Madison No-Salt Routes—No Curb	Town of Madison	1.51 lane miles—2.2 acres
Town of Madison No-Salt Routes—Curbs Both Sides	Town of Madison	2.20 lane miles—3.2 acres
Single-Family Residential	Individual owners	4,620 parcels totaling 67 acres of pavements
Commercial/Business/Institutional/Multifamily Residential	Commercial applicators	216 acres of pavements
Sidewalks within right-of-way	Individual owners/ commercial applicators	49 acres of pavements
Bike Paths	City of Madison	14 acres of pavements
Alleys	City of Madison	1 acre of pavements

Table 2.03-1 Pavements Tributary to Lake Wingra



SALT ROUTES

LAKE WINGRA WATERSHED MANAGEMENT PLAN
CITY OF MADISON
DANE COUNTY, WISCONSIN



FIGURE 2.03-2
1020.065

B. Application Rate

Salt application rates vary widely. For private pavements, the WDNR indicates 5 pounds of salt is sufficient to clear 1000 square feet of pavement. Yet May 2013 discussions with area winter maintenance providers indicate most applicators use much more. Similarly, Cornell University provides recommendations for road application that range from 50 pounds to 450 pounds per lane mile, depending on the temperature.⁷ The study team used a variety of methods to obtain application rates from those maintaining pavements during the winter months. Many applicators stated their application rate. The study also calculated application rates for the City by taking the amount of salt used and dividing it by the pavement maintained and the number of salt events. For Dane County, the average application rate was determined by obtaining the amount of salt distributed on a section of the Beltline in the 2011 winter season through global positioning system (GPS) technology and dividing the tonnage by the number of events and lane miles treated.

The stated application rate and the calculated salt applied per event varied considerably, with the calculated application rate per event being many times more than the stated application rate. This is probably attributable to multiple applications occurring per storm event. The calculated application rate was used in the chloride mass balance for this management plan. Table 2.03-2 lists general application rates for those maintaining pavements within the Wingra Watershed boundary per pass and per event. The residential and commercial application rates were obtained through interviews with property owners and commercial applicators. These rates could conceivably vary by 50 percent (or more).⁸

Pavement Maintainer	Stated Application Rate per Application	Rate Used in Analysis per Event+
City of Madison, Salt Routes	150 lbs per lane mile	1,072 lbs per lane mile
City of Madison, Nonsalt Routes	29 lbs per lane mile	27.6 lbs per lane mile
Dane County (highways)	Variable lbs per lane mile	1,072 lbs per lane mile
Town of Madison	300 lbs per lane mile	2,144 lbs per lane mile*
University of Madison Arboretum	29 lbs per lane mile	29 lbs per lane mile*
Single-Family Residential owners	3 to 5 lbs per 1,000 ft ²	5 lbs per 1,000 ft ² (2.5 lbs net)#
Commercial applicators	20 to 35 lbs per 1,000 ft ²	20 lbs per 1,000 ft ² (13 lbs net)#

*Based on City of Madison Ratios

+Average from 2006-2013

#Rate was applied to 50 percent of residential properties and 65 percent of commercial properties.

(For example, 20 lbs commercial application rate = a 13 lbs net application rate - 65 percent of 20 lbs)

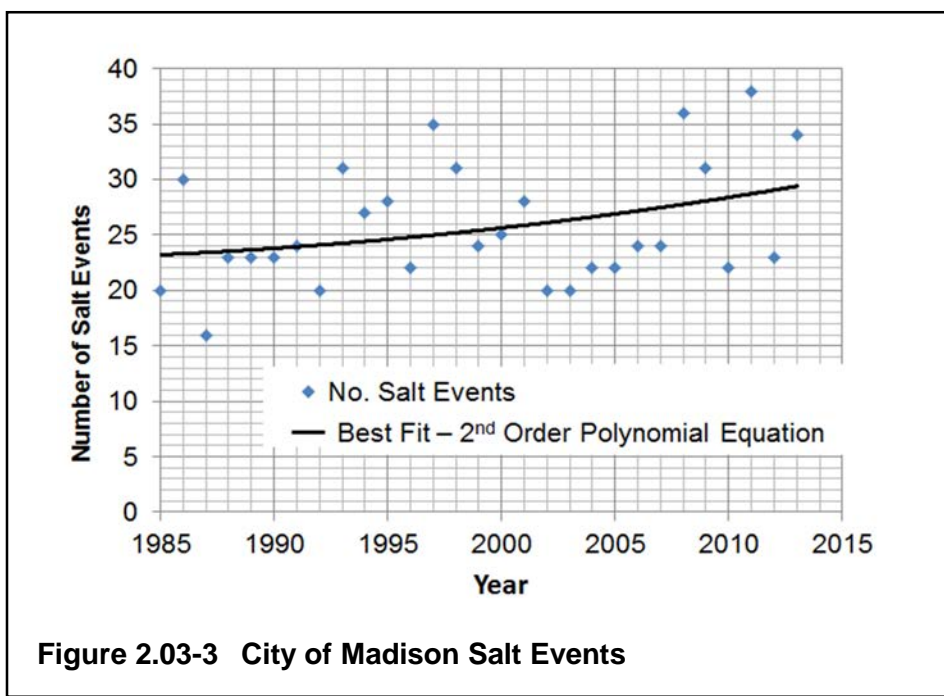
Table 2.03-2 Salt Application Rates

⁷<http://www.clrp.cornell.edu/techassistance/calibration%20chart.pdf> accessed on May 12, 2013.

⁸ Note: Two contacts with Dane County and WisDOT provided differing application rates per event. One contact indicated an application rate substantially below the City of Madison's application rate. The second contact provided an application rate substantially above the City of Madison's application rate. For the purposes of this study, Dane County's application rate is assumed to be identical to the City of Madison's application rate.

C. Frequency of Application

The number of storms per year varies as does snow and ice clearance and the use of salt varies. The variance leads to the amount of salt each municipality purchases and the amount that is applied. Figure 2.03-3 shows the number of “salt events” from 1985 to 2012. Discussions with City personnel also indicate that each “salt event” includes one to seven applications, with the average number of applications per salt event being between three and four. The figure shows that from 1985 to 2013, the number has generally increased. Again, the number of salt events influences chloride levels in Lake Wingra.



D. Relative Contribution

The study team identified main contributors of chlorides to Lake Wingra using calculated⁹ rates per event. The results can be seen in Table 2.03-3.

As part of the development of a predictive tool, the study team performed a chloride mass balance to predict past, current, and future chloride levels within Lake Wingra. In developing the predictive tool, it became evident that not all chlorides applied to city pavements within the watershed made it to the main waters of Lake Wingra. Figure 2.03-4 illustrates the discrepancy for the 2010 water year where the amount of salt applied to pavements tributary to Lake Wingra exceeded the amount of salt leaving the lake by a factor of four. If all the chlorides applied to pavements actually made it to the waters of Lake Wingra, chloride levels would approach 500 mg/L within two years. Instead, the watershed appears to retain the chlorides. Retention rates of 75 percent for roadways

⁹Instead of stated application rates which are lower.

with curb and gutter, and 88 percent for roadways without curb and gutter, were found to provide predictive results that were relatively similar to measured chloride levels in Lake Wingra. Roadways without curb and gutter were given a higher retention rate because chlorides in ditches have greater opportunity to infiltrate into the soil. These retention rates used in the prediction tool are similar to the 77 percent retention value found in the Novotny study.¹⁰

There are numerous possible contributors to the chloride retention. Factors contributing to the retention factor discussed in two different Novotny studies, as well as others, include the following:

1. Salt particles become airborne behind vehicles during strong winds. One study concluded that between 20 and 63 percent of the road salt was transported by air and deposited on the ground within 130 feet of the road.¹¹ These chlorides could then be infiltrated into the groundwater flow.
2. Wetlands and streetside ditches provide the opportunity for chlorides to infiltrate into the groundwater flow. Residence times in aquifers can be high ranging from decades to hundreds of years in the surficial aquifers and thousands of years in deeper ones.¹² This poses an additional concern. Surface waters have a relatively brief recovery period while subsurface aquifers, once contaminated, could take centuries to recover.
3. Chlorides can attach themselves to natural organic matter forming chlorinated organic matter when transported through soils.¹³ This chlorinated organic material could avoid detection.
4. There are higher chloride concentrations in the saline water layer at the lake bottom as well as the pore water in the lake sediments. Another study by Novotny et al looked at sediment cores at the bottom of two Minnesota lakes and found chloride concentrations higher than the overall chloride concentration in the lake.¹⁴

¹⁰A check was performed using average chloride concentrations from pipes feeding Lake Wingra and multiplying the concentrations by monthly flow volumes. This rough check yielded a retention rate of between 0.65 to 0.72, which is in the same range as the 0.75 retention rate being used in this analysis. This check also does not account for chlorides being stored in wetlands, ditches, and ponds.

¹¹Blomqvist and Johansson, "Airborne spreading and deposition of de-icing salt - a case study", *the Science of the Total Environment*, Vol. I 235, 1999, pp. 161-168.

¹²Novotny et al., "Chloride ion transport and mass balance in a metropolitan area using road salt", *Water Resources Research*, Vol. I 45. - Citing work performed by Bester et al., 2006, 2006 "Numerical investigation of road salt impact on an urban wellfield", *Ground Water*, 44, 2009, pp. 165-175.

¹³Bastviken et al., "Chloride retention in forest soil by microbial uptake and by natural chlorination of organic matter", *Geochim. Cosmochim. Acta*, 71, 2007 pp. 3182-3192.

¹⁴Novotny et al., "Increase of urban lake salinity by road deicing salt" *Science of the Total Environment* vol 406, 2008, pp. 131-144.

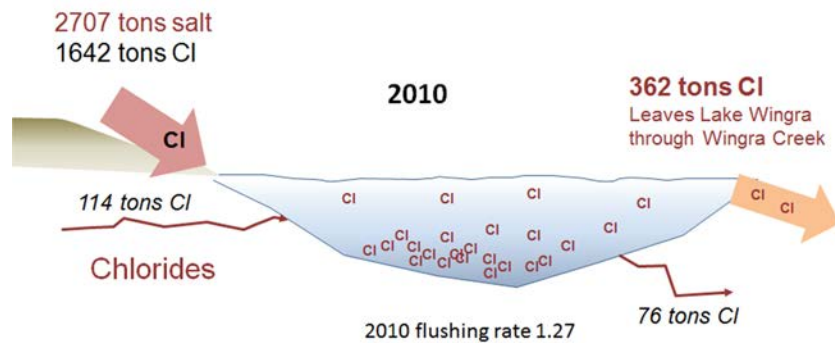


Figure 2.03-4 Example Salt Mass Balance Illustrates Watershed Chloride Retention

To apply the 75 and 87 percent retention rates used for the Wingra predictive tool, the study used the complement of the retention rate (an index) factor to reduce the amount of chloride that actually reaches the lake. The index factor is meant to acknowledge that the watershed, soil, groundwater, wetlands, and basins all capture and retain chlorides before they are transported to the lake. Even with potential variations in application rates and the corresponding index factors, the analysis is revealing.

Figure 2.03-5 illustrates the estimated average chloride contribution for all entities from 2006 to 2012. Table 2.03-3 shows contributions, by applicator, for the two most recent analysis years. Pavements treated by private commercial applicators, even with indexing, are large contributors to chloride concentrations in Lake Wingra. Other high contributors include the city of Madison followed by Dane County. This illustrates the importance of engaging all stakeholders to reduce chloride concentrations in Lake Wingra.

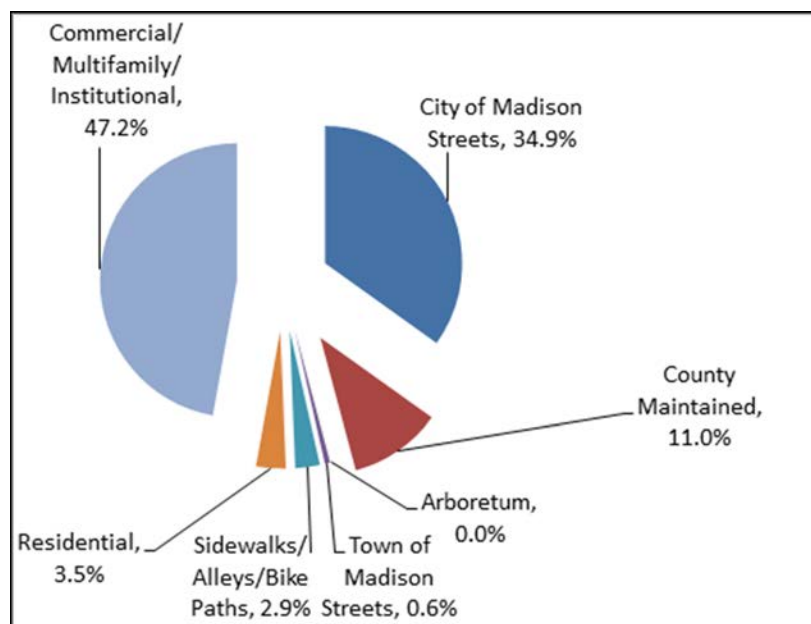


Figure 2.03-5 Approximate Chloride Contributions 2006-2012

Municipality	Lane Miles To Lake	Paved Acres to Lake	Retention Rate/Index Factor	2011-2012 Winter Season		2012-2013 Winter Season	
				Tons Contributed	Percentage Contribution	Tons Contributed	Percentage Contribution
Madison-Salt Routes–Not Curbed	0.68	1.0	0.87/0.13	1	0.2%	2	0.2%
Madison Salt Routes–Curbed	61.07	88.8	0.75/0.25	151	29.7%	284	33.8%
Madison-Nonsalt Routes–Not Curbed	8.97	13.0	0.87/0.13	0	0.0%	1	0.1%
Madison Nonsalt Routes–Curbed	69.49	101.1	0.87/0.13	4	0.7%	12	1.5%
County Maintained–Not Curbed (WisDOT)	19.65	28.6	0.87/0.13	24	4.8%	46	5.4%
County Maintained–Curbed (WisDOT)	10.05	15.3	0.75/0.25	25	4.9%	47	5.6%
University of Wisconsin–Not Curbed	3.13	4.6	0.87/0.13	0	0.0%	0	0.0%
Town Madison Salt Routes–Not Curbed	0.12	0.2	0.87/0.13	0	0.1%	1	0.1%
Town Madison Salt Routes–Curbed	0.46	0.7	0.75/0.25	2	0.4%	4	0.5%
Town Madison Nonsalt Routes–Not Curbed	1.51	2.2	0.87/0.13	0	0.0%	0	0.0%
Town Madison Nonsalt Routes–Curbed	2.2	3.2	0.75/0.25	0	0.0%	0	0.0%
Single-Family Residential		67	0.77/0.23	19	3.8%	29	3.4%
Commercial/Business/Institutional/Multifamily Residential		216	0.77/0.23	264	52.1%	390	46.5%
ROW Sidewalk		49	0.77/0.23	15	3.0%	23	2.7%
Bike Paths		14	0.77/0.23	1	0.2%	1	0.2%
Alleys		1	0.77/0.23	0	0.0%	0	0.0%
Total				507	100%	839	100.0%
Salt Events				23		34	

Table 2.03-3 Salt Contributors

2.04 CHLORIDE MASS BALANCE PREDICTIVE TOOL

This study developed a predictive tool for estimating chloride concentrations in Lake Wingra. The tool was developed using data from the 2006 to 2012 winters. The tool uses a mass balance of water and chlorides to predict chloride concentrations in Lake Wingra. The tool can be used to estimate how varying different parameters, such as commercial application rates, could affect chloride concentrations in Lake Wingra. The prediction tool uses four-time steps per month to simulate the continuous flow of water and chlorides in and out of the lake. While the weekly (approximately) time steps do not fully simulate the continuous flows into and out of the lake, it is as short a period as the data allows. The tool uses the following parameters.

Water Balance

1. Inputs

- a. Rainfall on Lake (cubic feet): The amount of precipitation by month during nonwinter months that falls on the lake. Data was obtained from the Wisconsin State Climatologist Office.
- b. Runoff and Snowmelt To Lake (cubic feet): The amount of rainfall that drains to the lake from the watershed area. Data obtained from the City's P8 model¹⁵ modified to include Wisconsin Department of Transportation (WisDOT) right-of-way, as well as Town of Madison, Town of Middleton, and City of Fitchburg areas. The yearly runoff was then factored by monthly rainfall/precipitation data to distribute the P8 runoff/snowmelt to each month.
- c. Groundwater to Lake (cubic feet): This value was obtained from Mike Parsen of the Wisconsin Geological and Natural History Survey (WGNHS) using a new groundwater flow model, MODFLOW.

2. Outputs

- a. Evaporation from Lake Surface per month was obtained from Monthly and Annual Water Budgets of Lake Wingra, Madison, Wisconsin, 1972-1977, USGS. Average rates from 1972 to 1977 were used.
- b. Evapotranspiration from Lake Wingra Wetlands was obtained from Monthly and Annual Water Budgets of Lake Wingra, Madison, Wisconsin, 1972-1977, USGS. Average rates from 1972 to 1977 were used.

¹⁵P8 is a model for predicting the generation and transport of stormwater runoff pollutants in urban watersheds

1. Factoring the salt flushing concentrations based on runoff volume, with higher volumes flushing lower concentrations of salt.
2. Estimating chloride infiltration into the sanitary sewer.
3. Understanding and incorporating the sequestration of chlorides in wetlands, ponds, and lake bottom sediment.

Figure 2.04-1 illustrates actual measured surface chloride concentration readings with those predicted from the tool. While not fully mimicking the actual measured chlorides, the tool can be useful for estimating how altering different management practices could influence chloride concentrations within Lake Wingra.

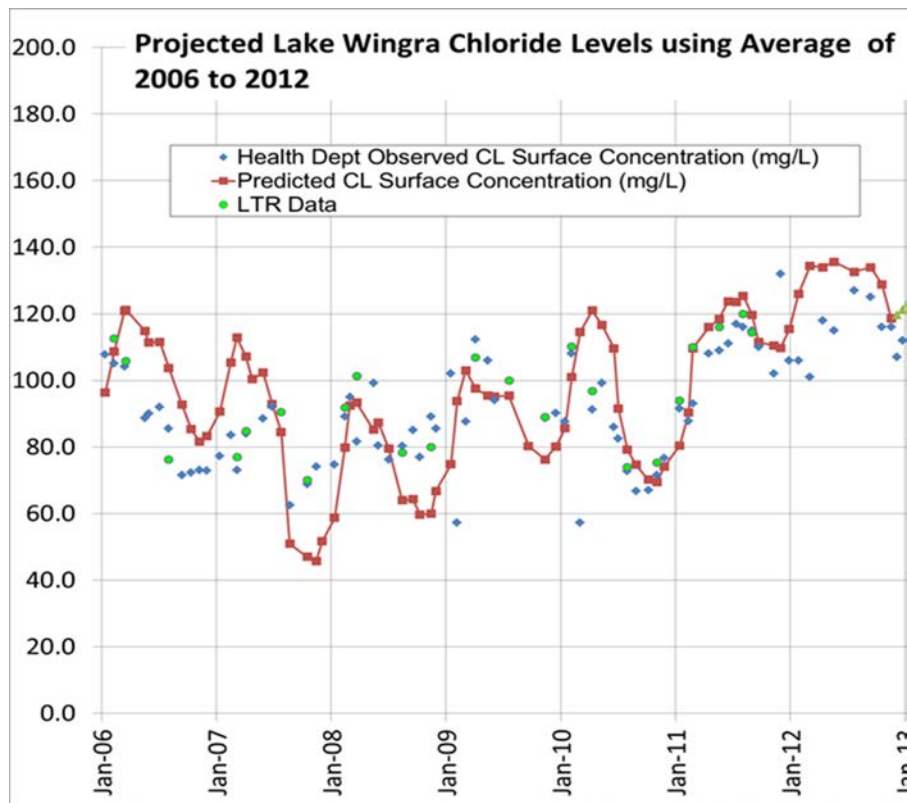


Figure 2.04-1 Chloride Predictive Model Results

2.05 MANAGEMENT ALTERNATIVES

A. Strategies

The relative salt contributions by entities shown in Table 2.03-3 are estimates, yet they provide guidance on where the greatest benefits may lie with winter pavement management changes. Private applicators that manage commercial and multifamily residential parking lots appear to have a large influence on chloride concentrations in Lake Wingra.

There are two feasible mechanisms to reduce chloride application in Lake Wingra.

1. Substitute road salt for other types of deicers such as calcium chloride, agricultural byproducts such as beet juice, or other organic juices. Several municipalities have had success using a non-salt-based deicer. This strategy, however, does add an organic load [biochemical oxygen demand (BOD)] to water bodies and may include undesirable nutrients like phosphorus.
2. Reduce the use of road salt through winter pavement management techniques including:
 - a. Anti-icing—The application of anti-icing products to the roadway before a winter storm. It forms a bond-breaker between the pavement and the snow/ice, decreasing the amount of deicing needed.
 - b. Reducing the number of salt routes.
 - c. Reducing the salt application rates.
 - d. Removing snow more completely, reducing the deicing need.

B. Deicers

Sodium chloride is the predominant deicer being used by the City as well as adjacent maintainers. Many different deicers have been and continue to be investigated. The following bullets summarize some of the more common deicers and list their benefits and drawbacks as obtained from Minnesota Pollution Control Agency's Winter Parking Lot and Sidewalk Maintenance Manual, revised 2010, and University of Wisconsin Deicing Chemical Summary, 2013.

1. Sodium Chloride—As mentioned, sodium chloride is the most common deicer and the least expensive. The lowest practical melting temperature is 15°F. It increases salinity of waters and soils, yet of the chemical deicers, it has a relatively low toxicity. Sodium chloride damages vegetation and is corrosive to steel.
2. Inhibited Magnesium Chloride—Inhibited magnesium chloride (as a liquid) has an effective deicing temperature down to -10°F. It increases salinity of waters and soils and has a relatively low toxicity. It is less harmful to vegetation than sodium chloride. It is corrosive to steel and is about twice as expensive as sodium chloride.

3. Calcium Chloride—Calcium chloride has an effective deicing temperature down to -20°F. It increases the salinity of waters and soils and has a relatively low toxicity. Calcium chloride can be corrosive to steel, but it is less corrosive than sodium chloride. It costs about three times more than sodium chloride.
4. Potassium Acetate—Potassium acetate has an effective deicing temperature down to -15°F. It does not increase the salinity of soils, but it can lead to oxygen depletion in the soil. It can deplete oxygen in water bodies. It causes minimal damage to vegetation and is noncorrosive. It costs eight times more than sodium chloride and is sometimes used on airport pavements.
5. Calcium Magnesium Acetate—Calcium magnesium acetate has an effective deicing temperature down to 20°F. It also does not increase the salinity of soils but can lead to oxygen depletion. It causes minimal damage to vegetation and is noncorrosive. It can cost twenty times more than sodium chloride and is sometimes used on airport pavements.
6. Agricultural Byproducts—The addition of agricultural byproducts to deicers has been in practice for years. Agricultural byproducts are generally noncorrosive and biodegradable and may improve the melting properties of other deicers. Agricultural byproducts added to salt brine has been shown to reduce corrosion in laboratory conditions. There are wide ranging claims by manufacturers and suppliers that the addition of agricultural byproducts can decrease the effective deicing temperature when mixed with salt. This is difficult to substantiate since typically these products are sold as a blend, which has a mixture of deicers with lower freeze points. Some highway maintenance agencies report that mixing agricultural byproducts can increase the residual retention time of the anti-icing liquids on the pavement in advance of a storm.

Some municipalities are experimenting with the use of beet juice as an anti-icer or as a mixing agent. Beet juice is less corrosive than salt and less damaging to vegetation but it carries an oxygen demand and can deplete oxygen in water bodies. Some have complained about soiling of vehicles.

The specific application of deicing chemicals and management of snow removal are complex. Each deicing substance carries benefits and drawbacks. There appears to be no substance having a clear advantage without substantial disadvantages. Because reviewing snow management techniques, procedures, and deicing chemicals is an ongoing effort by the City and Dane County, this study concerns itself primarily with the current snow management practices and chemicals. Different deicing substances and procedures could and should be explored further by pavement-maintaining entities in their effort to reduce overall chloride use. Table 2.05-1 shows the salt application rates per maintaining body along with recommended rates provided by the Minnesota Pollution Control Agency Salt Use Training Program. The table illustrates where there may be more room for management changes in salt reduction.

	Stated Rate lbs per 1000 sf per <u>Application</u>	Calculated Average Rate lbs per 1,000 sf per <u>Event**</u>	Recommended Rate per <u>Application+</u>
Madison Salt Routes	2.4	16.9	
Madison Nonsalt Routes	0.1	0.43	
County Maintained (assumed same as Madison) (Fish Hatchery, Beltline Road, and Verona Road)	3.9	16.9	
Single-Family Residential*#	5.0#	5.0	1.5 to 3.0
Commercial/Business/Institutional/Multifamily Residential*#	20.0#	20.0*	1.5 to 3.0
ROW Sidewalk*	5.0	5.0*	1.5 to 3.0
Bike Paths (City)*	1.0	1.0	1.5 to 3.0

*Assumed one application per event.
+According to Minnesota Pollution Control Agency Snow Removal Training, Dry Salt, varies with temperature.
#Applied to 65 percent of commercial pavements and 50 percent of residential pavements. Many commercial pavements, such as parking stalls, alleys, and storage areas may not be deiced. Also, not all commercial properties deice with every storm event. Residential deicing also is not a uniform practice and is not applied to all pavements within a residence.
**For roadways, calculated values were determined by taking total yearly salt tonnage and dividing it by the number of salt events and treated lane miles.

Table 2.05-1 Salt Application Rates

C. Scenarios

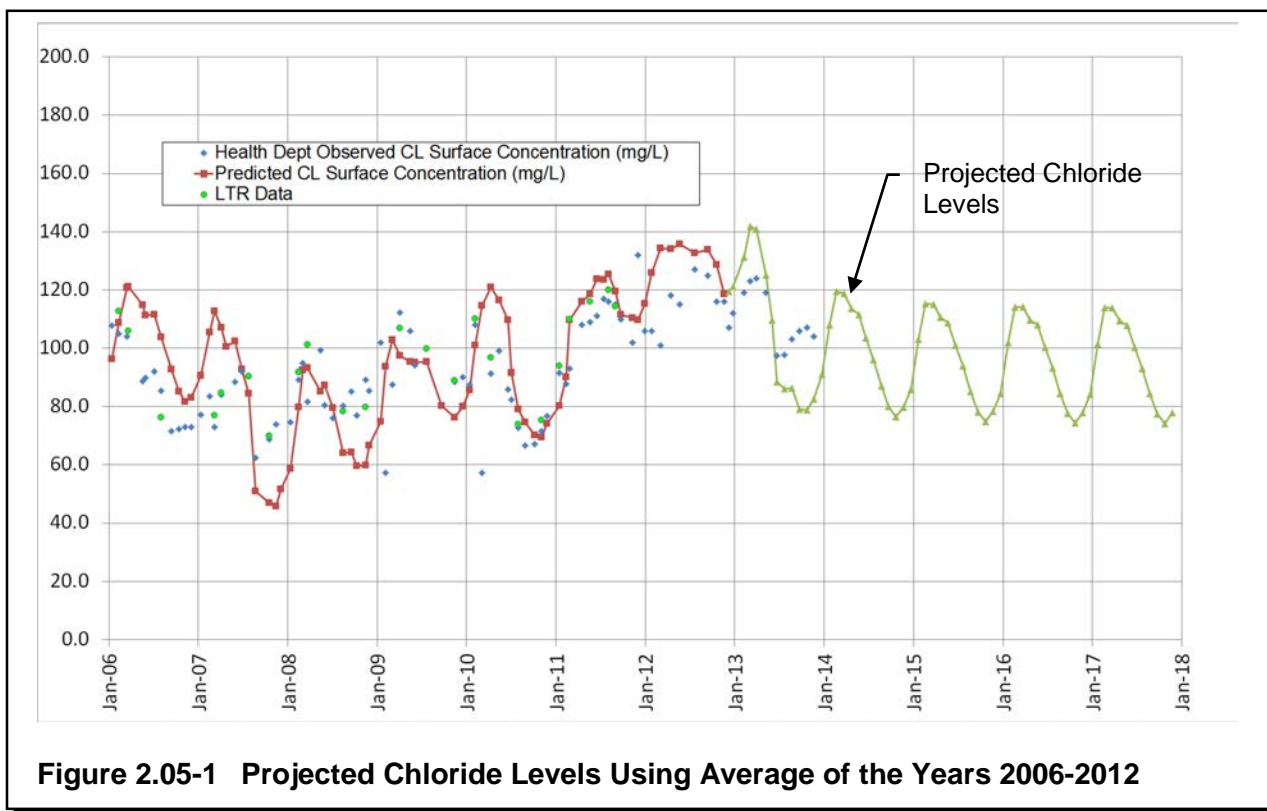
The study used the predictive tool to understand how chloride levels might vary based on different types of weather years and different types of management measures. In doing this the predictive tool:

- Uses a consistent weather year for each projected future year. Since the water balance and chloride input is uniform year after year, the lake reaches equilibrium relatively quickly.
- Does not account for latent chlorides being stored in soils, groundwater, wetlands, ponds, and the chloride layer at the bottom of the lake. While the tool may predict chloride reductions relatively quickly, these sources of latent chloride will likely slow the decrease in surface water chloride concentration levels. As mentioned in the Novotny article, even if all chlorides were fully prevented from entering Lake Wingra, it would likely take ten years or more for the lake to be restored.

The following paragraphs describe different scenarios that were modeled.

1. No Change—Average of 2006-2012 Weather Years

This analysis uses the average weather, salt usage, and salt events between 2006 and 2012. Figure 2.05-1 illustrates the chloride levels using the water balance from this average year. Chloride levels are projected to reach a yearly rhythm that varies from about 75 mg/L to 110 mg/L.

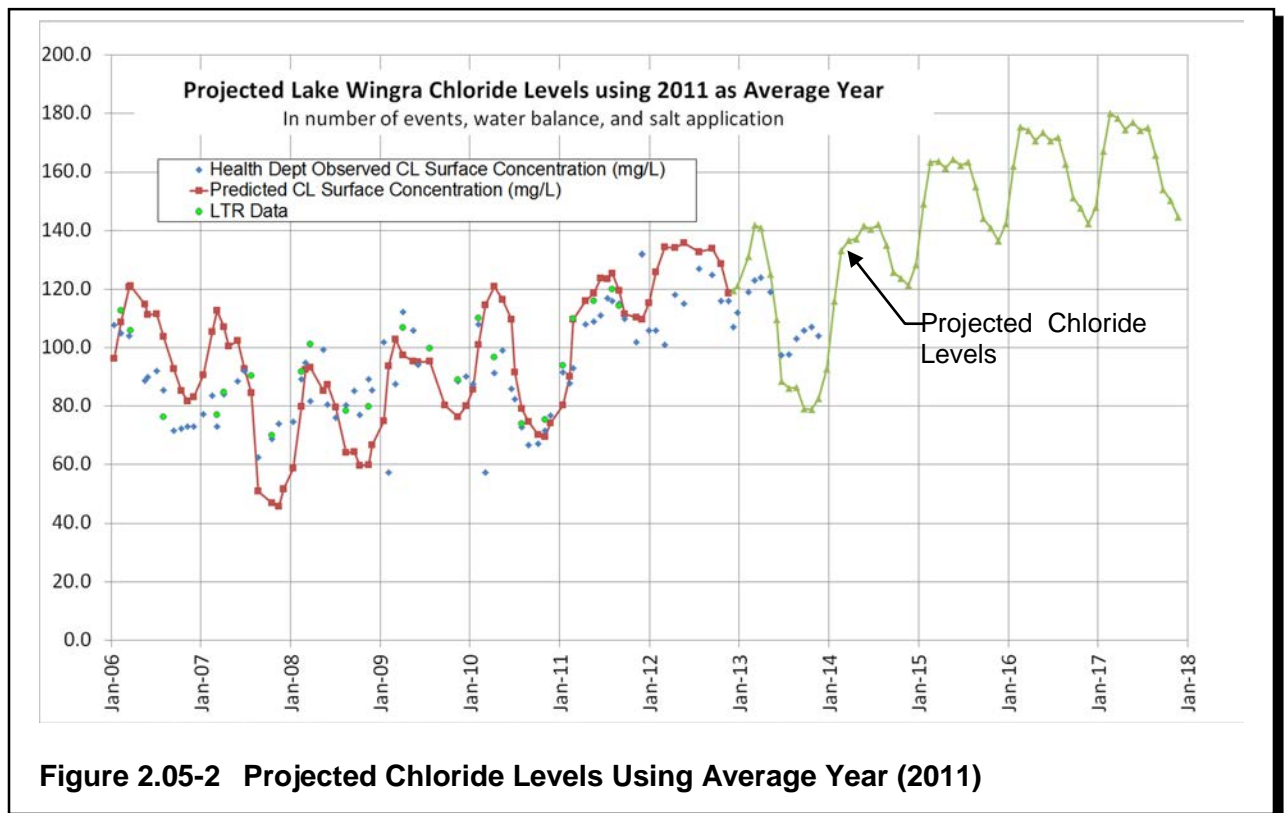


2. No Change—Average Weather Year (2011)

The Wisconsin Initiative on Climate Change Impacts released a report in 2011 titled *Changing Climate: Impacts and Adaptation*. That report summarizes an analysis by the University of Wisconsin-Madison climate scientists using 14 “downscale” global circulation models. The report predicts the following climate change trends for Wisconsin:

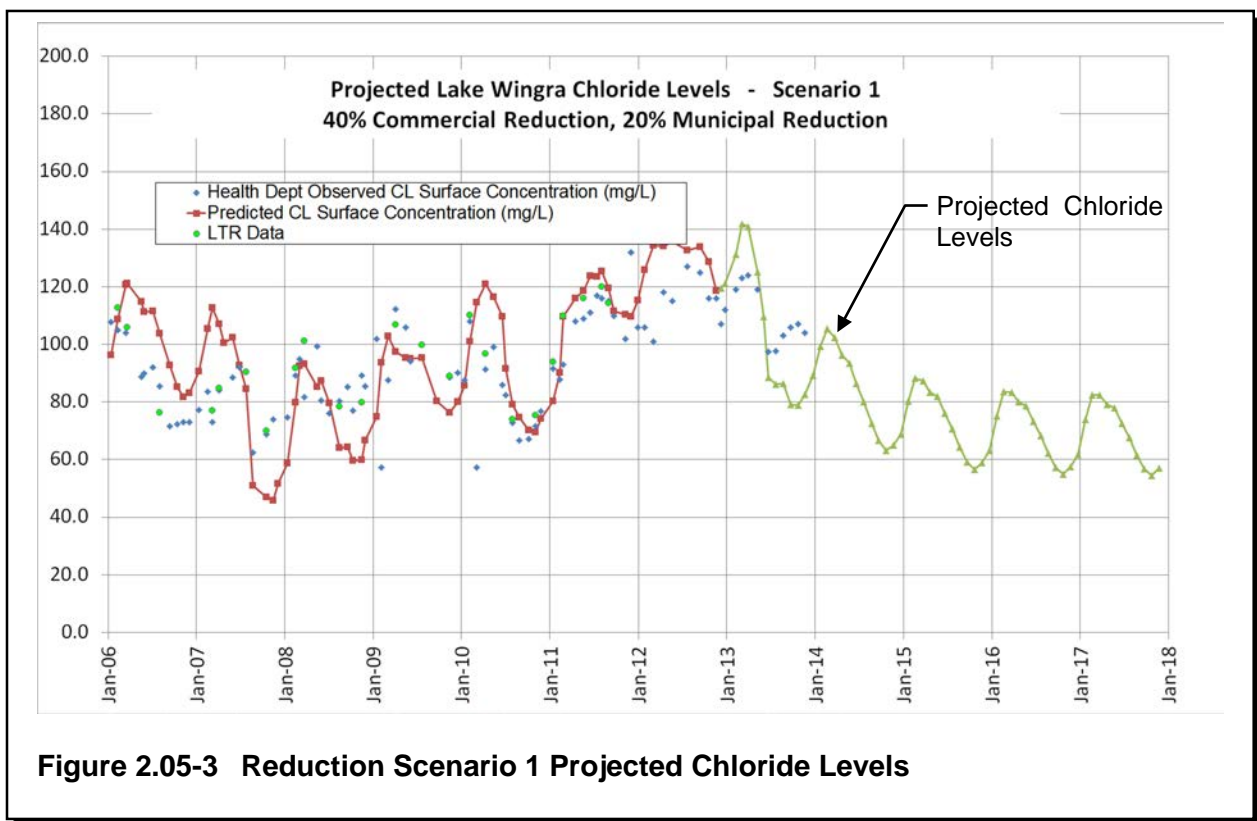
- a. Wisconsin’s warming trend will continue, with the statewide average annual temperature increasing 6°F to 7°F.
- b. Wisconsin is likely to continue the trend toward more precipitation, with probable increases in winter, spring, and fall.
- c. The amount of winter precipitation that falls as rain is predicted to increase.
- d. More freezing rain is likely to occur.

Based on these predictions, some speculate that the winter of 2011 provides a better base year for winters likely to occur in the future. Using the 2011 precipitation, salt use and salt event data indicates that chloride levels would rise to a cycle between 140 and 180 mg/L within three years (Figure 2.05-2).



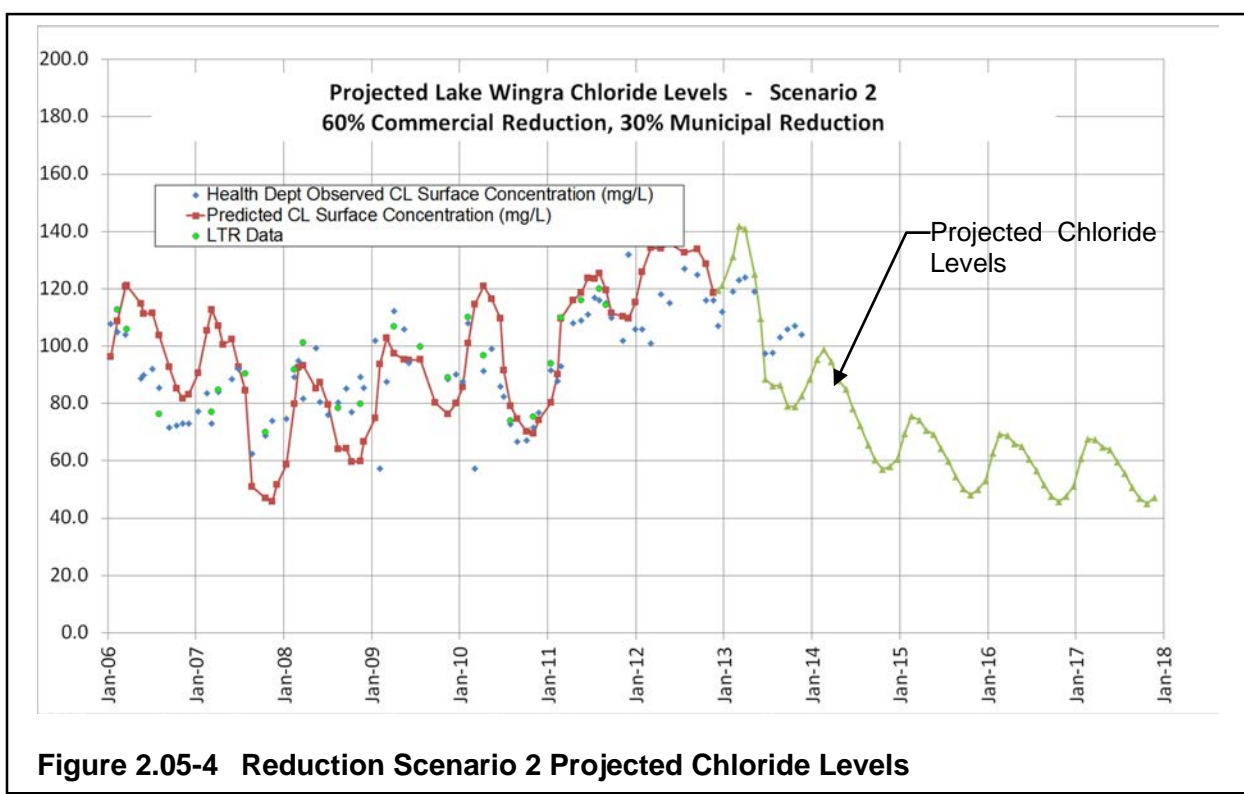
3. Reduction Scenario 1—Reduce Commercial/Residential Application Rates by 40 Percent and Municipal Application Rates by 20 Percent

Reduction Scenario 1 (Figure 2.05-3) is an aggressive chloride reduction that would seek to reduce the salt applied by residential and commercial applicators by 40 percent and municipal applicators by 20 percent. The average weather and application rates from 2006 to 2012 were used in the analysis. The analysis indicates that if these reductions were made, chloride levels in Lake Wingra would range from 55 to 85 mg/L. This would represent a substantial improvement from current chloride levels, yet it falls short of the target level of 40 mg/L stated in the *2009 Lake Wingra: A Vision for the Future*.



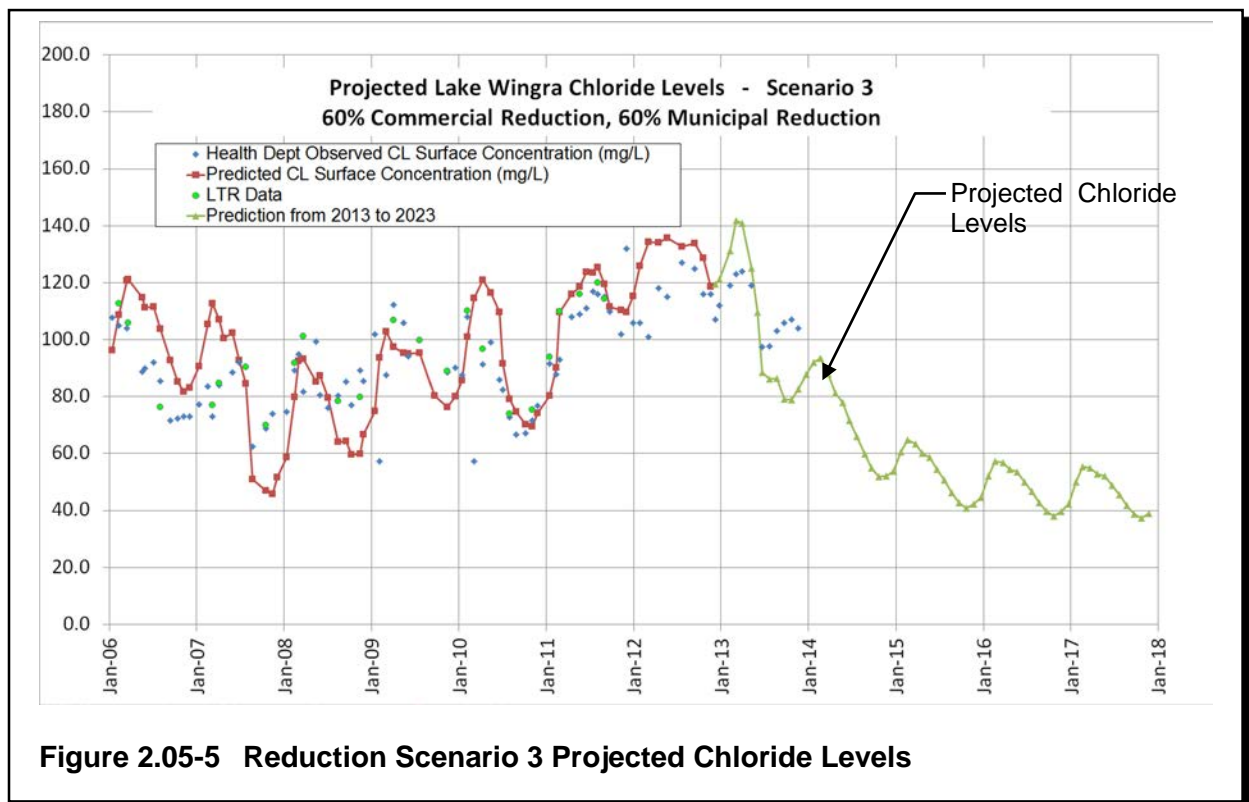
4. Reduction Scenario 2—Reduce Commercial/Residential Application Rates by 60 Percent and Municipal Application Rates by 30 Percent

Reduction Scenario 2 (Figure 2.05-4) is a more aggressive chloride reduction that would seek to reduce the salt applied by residential and commercial applicators by 60 percent and municipal applicators by 30 percent. The average weather and application rates from 2006 to 2012 again were used in the analysis. The analysis indicates that if these reductions were made, chloride levels in Lake Wingra would range from 45 mg/L to 70 mg/L. This represents an even greater improvement from current chloride levels. While reaching the 40 mg/L for a portion of the year, this reduction falls short of the intent of the target level of 40 mg/L stated in the *2009 Lake Wingra: A Vision for the Future*.



5. Reduction Scenario 3—Reduce Commercial/Residential and Municipal Application Rates by 60 Percent

Reduction Scenario 3 (Figure 2.05-5) is the most aggressive chloride reduction that would seek to reduce the salt applied by residential, commercial, and municipal applicators by 60 percent. The average weather and application rates from 2006 to 2012 again were used in the analysis. The analysis indicates that if these very aggressive reductions were made, chloride levels in Lake Wingra would range from 35 to 55 mg/L. This aggressive reduction seems to approach the target goal of 40 mg/L stated in the *2009 Lake Wingra: A Vision for the Future*. Interestingly, these chloride levels in Lake Wingra are similar to those measured in the 1970s.



D. Target Reductions Scenario

Table 2.05-2 shows the reductions that would be necessary to achieve the desired chloride reductions associated with the three reduction scenarios. The table also shows the resulting surface chloride concentration of Lake Wingra forecasted by the predictive tool. It should be noted the predictive tool uses the average weather, salt, and salt events from 2006 to 2012. This eliminates yearly variation and leads to a consistent chloride cycle within three to four years. Because of the latent chlorides that are stored in wetlands, ponds, and the chloride layer at the lake bottom, actual restoration time would likely be longer than ten years.

Municipality	Lane Miles To Lake or Acres	Base 2006-2012 Ave	Base 2011	Reduction Scenario 1 40% Com/ Res 20% Muni	Reduction Scenario 2 60% Com/Res 30% Muni	Reduction Scenario 3 60% Com/Res 60% Muni
		Salt Use Reduction	Salt Use Reduction	Salt Use Reduction	Salt Use Reduction	Salt Use Reduction
Madison Salt Routes	61.8	0%	0%	20%	30%	60%
Madison Nonsalt Routes	78.5	0%	0%	20%	30%	60%
County Maintained (Fish Hatchery Road, Beltline, and Verona Road)	29.7	0%	0%	20%	30%	60%
University of Wisconsin	3.1	0%	0%	20%	30%	60%
Town Madison	4.3	0%	0%	20%	30%	60%
Single-Family Residential	67 ac	0%	0%	40%	60%	60%
Commercial/ Business/ Institutional/Multifamily	216 ac	0%	0%	40%	60%	60%
Sidewalk in Right-of-Way	49 ac	0%	0%	20%	30%	60%
Bike Paths	14 ac	0%	0%	20%	30%	60%
Alleys	1 ac	0%	0%	20%	30%	60%
Surface Chloride Concentration Achieved		75 mg/L to 110 mg/L	140 mg/L to 180 mg/L	55 mg/L to 85 mg/L	45 mg/L to 70 mg/L	30 mg/L to 50 mg/L

*The retention rate represents the chlorides that are not delivered to the water body. Single-family residential refers to the amount of impervious residential nonroof surfaces in the watershed area. Sidewalk in right-of-way refers to sidewalks that are not on private property, but on public right-of-way. (Note: Most sidewalks adjacent to roadways are on public right-of-way.)

Table 2.05-2 Salt Reduction Strategy Predictions

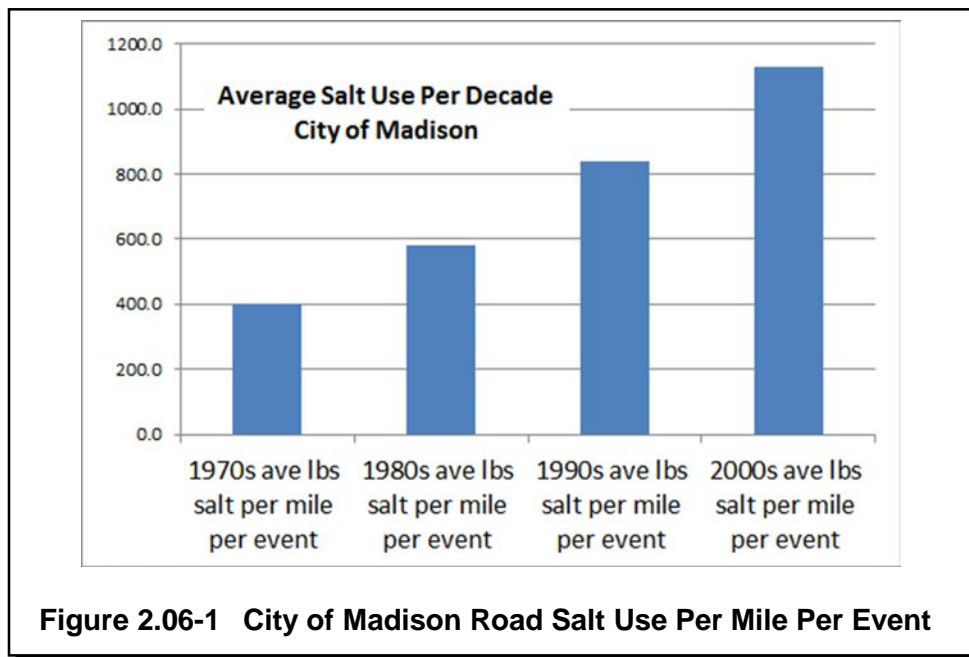
Because of the relatively rapid flushing rate of Lake Wingra, immediate management changes would produce lower chloride concentrations within ten years. However, it is likely that it would take several years to educate pavement managers and owners, change policies, change pedestrian and driver expectations, and implement meaningful management changes. Because salt water is denser than fresh water, higher concentrations of chlorides are in the deeper portions of the lake. This influences the ability of the lake to fully flush chlorides.¹⁷

¹⁷ Novotny and Stephan, "Road Salt Impact on Lake Stratification and Water Quality", *Journal of Hydraulic Engineering*, 2012. Novotny found the formation of a saline layer that varied in thickness based on water temperature and chloride input. Depending on the lake, the saline layer sometimes did and did not dissipate later in the year. The saline layer could affect chloride mixing within the lake and the release of lake chlorides into Wingra Creek.

2.06 FEASIBILITY OF CHLORIDE REDUCTIONS

A. Municipal Reductions

Some area governmental bodies are making efforts to reduce chloride use in winter pavement maintenance. This has led to recent equipment purchases and equipment upgrades in the past five years. Despite these upgrades and management changes, the average chloride use per event per road mile has increased from the 1970s to now. In the decade of the 2000s, the City of Madison applied 2.8 times more salt per mile per event than it did in the 1970s. Resident expectations of clear roads during most winter conditions are likely driving these application rates upward. Safety considerations also factor into resident expectations upon elected officials and, ultimately, city snow management operations. A 60 percent salt application reduction would require application rates that were used in the 1970s.



Barriers to these reduced application rates include customer, or resident, expectations. Significant education regarding the negative effects to water bodies, groundwater, and well water would probably be needed to facilitate such large reductions. These aggressive measures would also require changing winter pedestrian and driver expectations.

B. Commercial Applicator Reductions

This analysis surveyed several commercial applicators to obtain average application rates per event. The responses ranged from 20 pounds to 35 pounds per 1,000 square feet. Based on this information, the analysis used 20 pounds per 1,000 square feet and applied that rate to 65 percent of the commercial pavements. The 65 percent is meant to acknowledge that not all commercial pavements are salted. For example, often the isle of a parking lot may be salted, where the occupied stalls would not be. Commercial alleys and outside storage areas also may not be salted. The study used a 5 pounds per 1,000 ft² application rate for residential pavements but only assumed that 50 percent of the property owners performed winter maintenance using salt.

The Minnesota Department of Natural Resources recommended application rate is 3 pounds per 1,000 ft², while the WDNR recommended application rate is 5 pounds per 1,000 ft². The application rate used in this analysis is four to six times these recommended application rates. If two thirds of commercial applicators would reduce their application rate by half to 10 pounds per 1,000 ft², it would result in a net 33 percent reduction for commercial applicators. If the same two-thirds reduced their application rate to WDNR's recommended 5 pounds per 1,000 ft², it would result in a net 50 percent reduction for commercial applicators. To achieve the 60 percent reduction required by Reduction Scenario 3, about 80 percent of commercial applicators would need to reduce their application rate to the WDNR's recommended 5 pounds per 1,000 ft².

The threat of litigation to property owners and commercial applicators is a serious barrier to reducing commercial application rates. Interviews with commercial applicators indicate most have been sued. The threat of litigation leads to the liberal application of salt. Another barrier to reduced salt application is the structure of the winter maintenance contracts. Most contracts pay for salt by weight, providing an incentive for commercial applicators to use salt liberally. Changing commercial application rates will probably need to involve not only the applicator but also property owners and building tenants.

2.07 SOCIAL MARKETING OPPORTUNITIES

There are many measures that could be implemented to achieve these chloride reduction goals. Some of the measures may lend themselves to social marketing measures and/or social paradigm changes. The following bullets list some possibilities.

- Focusing on commercial applicators and property owners to encourage them to use less salt in their winter maintenance activities. A variety of measures could be used to do this including education, certification and/or incentives.
- Focusing on city residents/drivers to help them accept low salt roadways for several arterials within the watershed.

2.08 POSSIBLE MANAGEMENT CHANGES TO ACHIEVE TARGET CHLORIDE LEVELS

Many states have developed salt reduction projects and have excellent training materials. This study reviewed the New Hampshire Road Salt Reduction Initiative¹⁸ and Minnesota’s Road Salt Education Program.¹⁹ Both are good training materials that will not be replicated in this report.

The City and Dane County have instituted salt reduction recommendations from the 2007 Lakes and Watershed report on reducing road salt. This includes implementing GPS Automatic Vehicle Locating technology, providing training programs for applicators, calibrating truck application rates, and adding prewetting capacity to equipment.

Table 2.08-1 describes potential additional management measures that could be implemented to achieve the necessary salt application reductions to achieve the targeted chloride concentration in Lake Wingra. The table also rates their implementation feasibility and potential effectiveness in reducing Lake Wingra chlorides. Implementation feasibility is a qualitative assessment based on interviews with City Department managers, commercial applicators, and property owners. It is also based on the possible ease of implementation based on current City funds and resources. Potential effectiveness also is a qualitative assessment based on anticipated participation levels and the actual salt contribution the targeted audience. For example, “Establish Maximum Salt Guidelines” was given a “+” rating in potential effectiveness because it was anticipated that fewer than 25 percent of commercial applicators would participate and they are just guidelines. Yet “Establish Maximum Salt Application Rates by Ordinance” was given a “++” rating because a law is more likely to garner participation.

A third column is provided for implementation priority and is left blank. Catalyst teams (see Section 5) can determine the priority of the potential measures. The management changes could be implemented in any order, yet if the target chloride concentrations are to be achieved, it is likely that multiple or most measures will need to be implemented. Any combination that provides significant reductions in commercial and municipal application rates will help lower chloride inputs to Lake Wingra (i.e.: rising chloride levels may occur despite implementation of the measures).

Reduction Scenario 1 provides an attainable short-term goal and substantially improves chloride levels. Scenario 1 requires a 40 percent salt reduction by commercial applicators and a 20 percent reduction by municipal applicators. A varying combination of these two reductions could also be implemented to achieve chloride levels between 55 and 80 mg/L.

To come close to achieving the 40 mg/L target, Reduction Scenario 3 is required and should serve as the ultimate goal. Achieving this goal would require 60 percent reduction by all applicators, which in turn would require a change in community expectations.

¹⁸<http://www.des.state.nh.us/organization/divisions/water/wmb/was/salt-reduction-initiative/> May 2013.

¹⁹<http://www.pca.state.mn.us/index.php/about-mpca/mpca-events-and-training/road-salt-education-program.html> May 2013.

Table 2.08-1 Possible Management Change

Management Measure	Feasibility	Potential Effectiveness	Implementation Priority
Implement a Certification Program for Commercial Applicators Other states have had success with this measure and applicators have been able to use their certification in marketing efforts. The certification program provides measurable reductions quicker when property owners also attend training events.	+++	+	*
Provide Sample Contracts for Winter Pavement Maintenance on Web Site and with Certification This measure would help reduce the number of winter pavement maintenance contracts that use salt as a payment measure.	+++	+	*
Require Certification for Government Snow Removal Contractors This measure encourages certification and provides an economic advantage to commercial applicators who obtain certification.	+++	+	*
Establish Maximum Salt Guidelines This measure provides some coverage for litigation for commercial applicators.	++	+	*
Establish Maximum Salt Application Rates by Ordinance Discussions with other states indicate that commercial applicators encourage maximum guidelines, but prosalt interests make it politically difficult to implement on a state-wide concentration. It may be more feasible to implement on a county basis.	++	++	*
Expand the Practice of Anti-icing Anti-icing helps provide extra time for winter pavement maintenance and helps reduce overall road salt application.	+++	++	*
Reduce the Number of Applications per Snow Event The application rate per event is several times the recommended application rate per pass. Altering management techniques might allow municipalities to make fewer salt passes, reducing the overall salt usage per event.	++	++	*
Reduce the Salt Route Mileage The City and/or Town of Madison could transition current salt routes to sand routes. Signage could be used to alert drivers of the low salt routes. City streets that are currently salt routes within the Wingra watershed include Monroe St, Nakoma Rd., Midvale Blvd., Odana Rd., Mohawk Dr., Seminole Hwy., Tokay Blvd., Speedway, and Commonwealth. If sand routes are expanded, the sand could later be retrieved during the spring sweeping operations.	++	+++	*
Investigate Alternate Deicers Several municipalities are using different deicers, such as beet juice, as part of their snow removal strategy. No deicing substance is without its disadvantages, but using alternate deicers could help reduce the overall amount of chlorides reaching the lake.	++	++	*
*Note that Implementation priority will be determined in the future by the Chloride Catalyst Team. Multiple or most measures will need to be implemented to attain chloride reduction goals.			