Optimization of Water Softeners for Reduced Influent Chloride

The Reduction of Influent Chloride to Wastewater Treatment Plants by the Optimization of Residential Water Softeners

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EXECUTIVE SUMMARY

OBJECTIVES

The main goal of this project was to determine if reducing the chloride contribution from water softeners can aid the wastewater utility in meeting wastewater discharge limits.

Project Objectives:

1. Quantify concentration and mass of chloride in residential wastewater as contributed by water softeners.
2. Determine to what degree the chloride can be controlled in residential wastewater.
3. Establish costs of controlling chloride by modifying or replacing water softeners for higher efficiency of salt usage.

BACKGROUND

Chloride is a significant threat to freshwater ecosystems, and as such is addressed in wastewater discharge regulations. Chloride cannot be removed using standard wastewater treatment technology; therefore, chloride that arrives in wastewater passes through treatment plants and enters natural water bodies as treated effluent.

Stringent discharge limits for chloride into natural water and the inability to remove chloride in standard wastewater treatment technology have motivated wastewater utility managers to look for source reductions of chloride to wastewater treatment plant influent. Among the sources of chloride to wastewater: road salt, industrial processes, salt-water swimming pools, and water softeners. This study examines the significance of water softener chloride contributions to wastewater effluent, and to what extent that is controllable.

Previous studies have addressed water softener chloride discharges; however have not undertaken direct monitoring studies to provide a basis for chloride discharge scenarios resulting from optimization and replacement of water softeners. This study's goals were to fill gaps in understanding if chloride discharge from water softeners is significant, and if optimization or replacement of softeners can aid in chloride reductions to the wastewater stream.

APPROACH

To study the relationship between household softener operation and chloride release to wastewater streams, four sewersheds (two pairs of sewersheds) in the City of Madison were studied over two monitoring periods 2013-2014. These pairs of sewershed basins were selected to be monitored for chloride output in wastewater to local sewers. The two study areas compared chloride output between a sewershed where households optimized/replaced softeners for higher efficiency and a sewershed where households did nothing to their softeners.

Initially, plumbing and softener equipment were surveyed for a majority of residences in the four sewershed study areas for baseline information. Daily flow (of water into and out of homes), conductivity, and 24-hour composite chloride concentrations in the wastewater of each sewershed were measured. The baseline conductivity and concentrations of calcium, magnesium, chloride, iron, and manganese data from the original source drinking water wells, and daily weather data were also recorded.

Sewershed monitoring data were analyzed to calculate the average chloride release and wastewater flow from each residence. By measuring these flow and chloride observations and then extrapolating the data, the amount of chloride contributed to Madison Metropolitan Sewerage District (MMSD) inflow by residential water softeners was calculated.

The comparison from before and after softener efficiency upgrades were made was analyzed using non-parametric techniques to determine to what extent chloride output can be controlled by alterations to household water softeners.

Following data collection, a cost analysis was performed on the efficiency upgrade costs in relationship to the mass of chloride prevented from entering the wastewater stream to estimate the potential cost of mitigating chloride inflow though home water softener intervention.

RESULTS/CONCLUSIONS

On average, 0.255 KGD chloride per house was contributed by home water softeners to wastewater in the monitored sewersheds. The amount ranged from 0.01 to 1.06 KGD per household and is comparable to other estimates in south central Wisconsin. By optimizing or replacing softeners, 27% and 47% reductions, respectively, in chlorides were realized. The cost of implementing these upgrades is estimated to be $2,614 per kilogram chloride reduced for optimization and $11,509 per 1 kilogram chloride reduced by replacement ($1,188 per pound chloride reduced for optimization and $5,231 per pound reduced by replacement).

APPLICATIONS/RECOMMENDATIONS

This study's findings related to monitoring methods will be particularly helpful to the wastewater industry. Through trial and error, MMSD developed a manhole monitoring method that yielded consistent results, including the development and use of a flow through conductivity cell, monitoring plan methods, and use of a combination of devices suited for the variability of conditions in manholes.

Findings related to mass of chloride in wastewater from individual houses, as well as findings about the possible reductions in the mass of chloride in wastewater from softener efficiency upgrades will be helpful to wastewater industries; estimates provided in this report can serve as a guideline to aid in planning source reduction measures. Although the cost of replacing softeners, no doubt, varies by geographical location, an idea of the approximate cost per pound of salt removed from the wastewater is estimated in this study and can also assist in planning for source reduction measures.

Based on research findings in this study, MMSD updated their best practices guideline for water softening. Revisions to the updated best practices guideline, available on Appendix D, included changes in the gallons used per household per day, and increased the standard for minimum hardness removal efficiency from the former 2011 version. This guideline is often used by for water softener companies and households in setting up softeners for maximum efficiency and chloride pollution prevention in our basin.

Given that results from this study show reductions in chloride discharge through both replacing and optimizing softeners, using softener treatments as source reduction measures can be expected to prevent chloride pollution, however cannot be relied on as a sole strategy for MMSD to achieve their 20,000 pound per day chloride reduction goal. For MMSD to meet discharge limits, with a goal of reducing 20,000 pounds of chloride per day from their influent, water softener efficiency upgrades may be one part of a multi-faceted pollution prevention campaign.

CHAPTER 1: INTRODUCTION

BACKGROUND ON CHLORIDE POLLUTION

Chloride is the negatively charged ion of salts, such as sodium chloride or potassium chloride. It is naturally found in fresh and saltwater bodies, and is essential to biotic life. In freshwater, chloride concentration is usually between 1-100 mg/l (Hunt, Herron and Green 2012). Naturally occurring sources of salt in freshwater include seawater intrusion or spray, or ions dissolved into groundwater. Anthropogenic chloride contributions include road salt, water softeners, industrial sources, urban and agricultural runoff, discharge from wastewater treatment plants, and oil and gas well drilling (Benoit 1988). Overabundance of chloride however can harm freshwater and terrestrial ecosystems. In freshwater aquatic ecosystems, it disrupts osmoregulation, reproduction, and plant growth activities in freshwater (Hunt, Herron and Green 2012). On land, presence of chloride, primarily in irrigation water can inhibit crop growth due to salinization of soils and cause legal issues for property and water rights (Holt 2015).

Chloride is a particular problem because of its persistence in waterbodies. Traditional mechanical and chemical/biological wastewater treatment processes do not remove chloride in effluent; therefore chloride passes through the system as effluent and is typically discharged into freshwater bodies (MMSD 2015). Technologies such as reverse osmosis that can remove chloride are expensive, energy-intensive processes with high residual streams.

Chloride Concerns at the National Level

Chloride is regulated by the Environmental Protection Agency (EPA) as a water pollutant under the Federal Water Pollution Control Act, also known as Clean Water Act. Under section 304(a)(1) of the Clean Water Act (33 U.S.C 1314(a)(1)) the EPA is required to set limits based on latest scientific knowledge on water quality criteria for the protection of health, welfare, biodiversity of identifiable species. These criteria are not laws; however, they are intended to be used as a suggestion for regulatory measures.

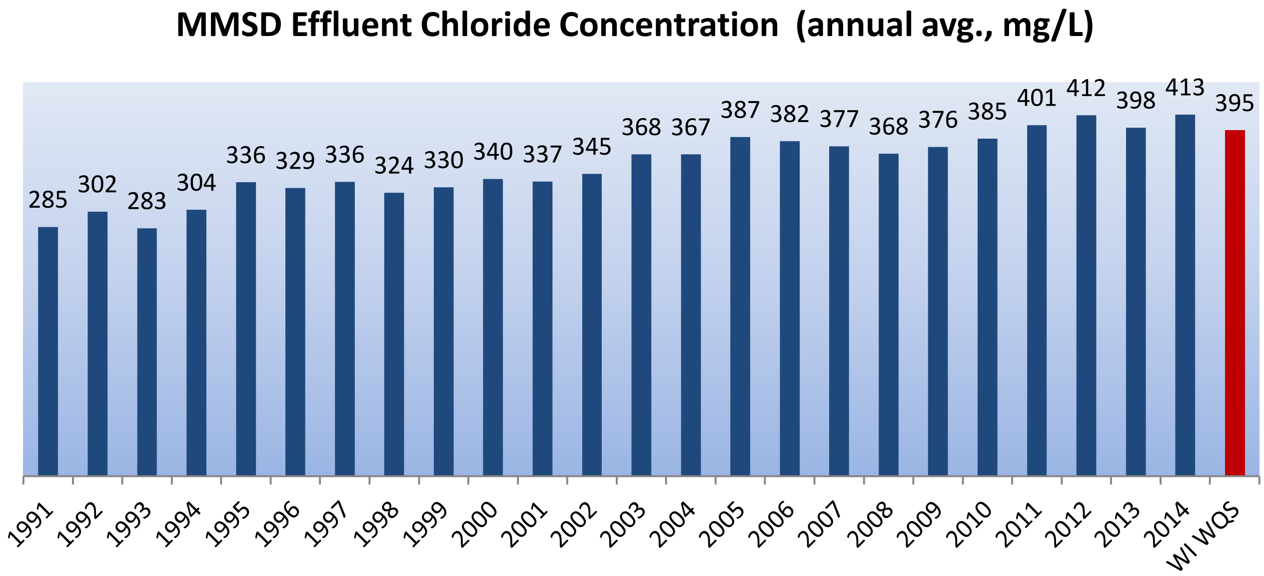
The 1972 amendments to the Clean Water Act include parameters for pollution discharge to natural water bodies. Pollution discharges must be permitted by the National Pollution Discharge Elimination System (NPDES). The EPA recommendations aforementioned are used as a guideline for states to make decisions on levels for pollutant discharge.

In 1986, the EPA set the criterion for chloride at 250 mg/l (EPA 1986). In 1988, research expanded this limit to what is currently the EPA chronic limit for chloride of 230 mg/l Cl and the acute limit at 860 mg/l (Benoit 1988) (EPA 2014).

Chloride Concerns at the Local Level

In Wisconsin, the Wisconsin Department of Natural Resources (DNR), administers and enforces the federal NPDES requirement as the Wisconsin Pollutant Discharge Elimination System (WPDES). The Madison Metropolitan Sewerage District (MMSD) WPDES permit allows chloride discharge, based on an invertebrate chronic toxicity, of 395 mg/L of chloride, and an acute toxicity of 757 mg/l (Wis. Admn. Code NR 106.80). The chronic toxicity limit equates to about 1 teaspoon of salt per gallon of water. Over fifty municipal treatment plants in the state, including MMSD, currently have effluent chloride levels higher than the state's water quality standard and therefore are operating with a temporary permit allowance to exceed the Wisconsin Water Quality Standards; these permits are "variances" (Section 283.15 Wis. Stats.).

Figure 1 MMSD Effluent Chloride Concentration



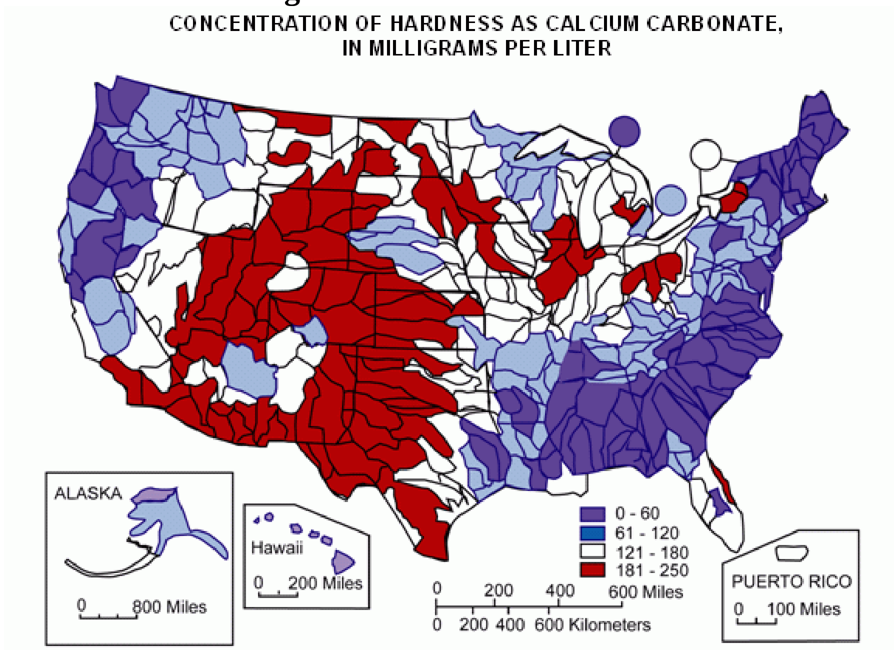
For MMSD, the variance allows for a chloride concentration of 481 mg/L and 214,000 pounds per day as a weekly average. It requires a chloride source reduction and pollution prevention plan to be implemented and reductions to be made over time (DNR 2014). MMSD's current permit states that after October 1, 2015, the effective limit will be 430 mg/L. In each permit term, reductions are expected until a weekly average below 395 mg/l can be maintained. Both concentration and mass of chloride need to be taken into account for these limits.

MMSD provides wastewater treatment services to approximately 350,000 people, businesses, and institutions in the Greater Madison, Wisconsin area. On average, MMSD receives and treats 40-million gallons of wastewater each day. Within 20-hours, that water is returned to local streams as treated effluent. MMSD's plant provides high-level treatment, but, as is typical for current wastewater treatment plant technology, does not remove dissolved solids. The treatment needed to remove chloride involves adding unconventional and costly processes, such as reverse osmosis, to the existing plant. Subsequently, about one million pounds of chloride pass through MMSD's plant each week. Figure 1 above shows the average annual concentration of chloride in effluent for the Nine Springs Water Treatment Plant compared to the DNR water quality standard limit of 395 mg/L.

As seen in Table 1 below, approximately 57% of all influent chloride estimated to come to MMSD's Nine Springs Wastewater Treatment Plant (NSWTP) is due to water softeners (AECOM 2015). The high percentage is partially due to the fact that drinking water in Southcentral Wisconsin has hard water (see Figure 2 US Water Hardness). In Madison, WI, for example, water comes from twenty-three deep wells with a total hardness range of 300 to over 500 mg/L as $CaCO_3$ (about 18 to 30 gpg) (Madison Water Utility 2015). In a cross connection survey conducted by the Madison Water Utility (MWU) in 2012-2014, 96% of respondents reported having an ion exchange water softener (Madison Water Utility 2014). Extrapolating the percent of homes with water softeners from MWU's survey to MMSD's total service area of

105,000 wastewater connections, it is expected that there are approximately 101,000 softeners in MMSD's service area. Softeners are used in residential homes and commercial facilities among many reasons, primarily to protect the plumbing system's hot water tank from calcium carbonate scale build-up, which can subsequently increase the energy costs of heating water for domestic use (Water Quality Research Foundation 2009).

Figure 2 US Water Hardness



Mean hardness as calcium carbonate at NASQAN water-monitoring sites during the 1975 water year. Colors represent streamflow from the hydrologic-unit area. Map edited by USEPA, 2005. Modified from Briggs and others, 1977. (USGS 2013)

Table 1 Estimate Sources of Chloride to MMSD Inflow

Chloride Source	Annual Average Chloride Mass (lb./day)	Annual Average Percent of Total
Background from Potable Water Supply Wells	11,491	8%
Typical Contribution from Domestic Wastewater	11,829	8%
Zeolite Water Softener Contribution	80,500	57%
Industrial Input	25,000	18%
NSWTP Chemicals, Septage and Hauled Waste	3,138	2%
Road De-Icing	10,000	7%
TOTAL	141,958	100%

(AECOM 2015)

PROJECT GOALS

Project goals were to quantify the concentration and mass of chloride in residential wastewater as contributed by water softeners, to determine to what degree chloride can be controlled in residential wastewater, and to establish costs of controlling chloride by modifying or replacing water softeners.

PROJECT TEAM

The project team included, Madison Metropolitan Sewerage District, Water Quality Research Foundation, Salt Institute, Cargill, water softener dealers, (Hellenbrand Inc., Culligan Total Water, Capital Water Softener, and Fox Soft Water), Madison Water Utility, Process Research Solutions, LLC., and WE Badger Volunteers.

PROJECT FUNDING

Table 2 Project Funding

Source	Amount
Water Quality Research Foundation	$50,000
Salt Institute	$15,000
Cargill	$5,000
Water Quality Professionals	$2,340 contributed optimizations $9,450 contributions for softener replacements in kind support $500 In kind training for volunteers
Madison Water Utility	$9,450 contributions for softener replacements in kind support $3,600 In kind support for sampling
WE Badger Volunteers	$4,000 In kind support for surveys
Process Research Solutions	$6,000 in kind support for data analysis
Madison Metropolitan Sewerage District	$9,450 contributions for softener replacements $14,000 research and data analysis $10,000 staff time for project overview $3,000 intern time for report writing $4,700 Monitoring crew labor $5,150 Equipment
Total Funding	**$150,000**

CHAPTER 2: METHODS AND MATERIALS

SITE SELECTION

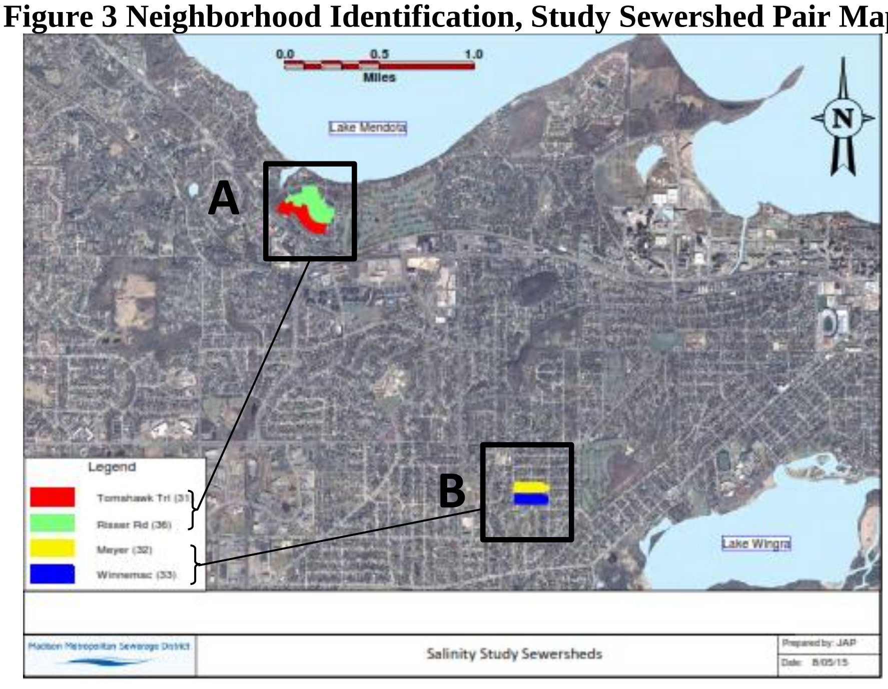
Two neighborhoods with two sewersheds each, totaling four sewersheds in the City of Madison were selected for this study. Neighborhoods were selected based on certain criteria:

- Small, 30-35 home sewersheds (with similarly aged homes) that were on the upper end of a sewer line to allow for isolation of the sewer area,
- Sewers serving the homes should be similar size,
- Had two sewersheds in close proximity of each other, drawing similar source water,
- Sewersheds should be made up of only single-family residential units,
- And manholes at the lower end of the sewershed will allow monitoring equipment to be installed.

Using these criteria, the City of Madison Engineering Department identified a few potential neighborhoods. Madison Metropolitan Sewerage District (MMSD) crews reviewed the manholes and determined which would be suitable for monitoring. Locations were confirmed as viable for the study during the week of July 1-5, 2013, when a test pilot of the monitoring program yielded successful results for conductivity versus time of day (later described in Chapter 2).

Neighborhoods selected were Spring Harbor and Glenway, shown in Figure 3. Within those neighborhoods, two similar adjacent sewersheds were selected. Sewershed Pair A, Spring Harbor neighborhood, consisted of the Tomahawk and Risser sewersheds, and Sewershed Pair B, in the Glenway neighborhood, consisted of Meyer and Winnemac Sewersheds. Each sewershed had 29 to 49 single family residential homes. Maps of individual sewersheds are included for reference in Appendix A.

Figure 3 Neighborhood Identification, Study Sewershed Pair Map



Both pairs of sewersheds, A and B, are served by MWU. Pair A is served by MWU's Well 14, and Pair B is served by MWU Well 12. Well 14 has consistently higher chlorides and hardness than Well 12.

Following selection of the study neighborhoods, the Madison Water Utility installed 'Smart Meters', which digitally send water usage data to MWU throughout the day. All homes included in this study, except for one house in the Risser sewershed, and one house in the Winnemac sewershed, had new MWU Smart Meters installed before the study. MWU's Smart Meters allowed the project to access hourly water use for each home.

MONITORING PLAN AND METHODOLOGY

Overview

This study was conducted in strategic periods to minimize weather related effects as well as to limit road salt inflow into the sanitary sewer system. It began in the summer of 2013 with a survey by MMSD of home softener equipment in the selected sewersheds. MWU set up a schedule of municipal well monitoring to collect background water quality information to characterize the water entering the homes in the sewershed during the wastewater monitoring periods and to inform later analysis, and MMSD deployed manhole monitoring equipment to measure flow, conductivity, and chloride concentration in wastewater beginning in September 2013. Following baseline data collection, houses in two sewersheds were given treatments consisting of water softener optimization or replacement. Continual monitoring ended in December 2013 but was resumed for another period of monitoring in 2014. Weather data were also collected throughout.

Baseline Information

Water Softener and Water Use Survey

In June through August 2013, surveys of all homes in the four sewershed areas commenced to gather background information. Residents were primed for surveys with a mailing (Appendix B). The mailing contained an introductory letter with general information about the study, and a postage pre-paid appointment postcard to set up a time for the survey with MMSD.

On-site surveys took place July through August 2013 by UW-Madison's WE Badger Volunteers. Volunteers were organized into two teams, made up of two or three volunteers each, led by a team leader who coordinated with MMSD for scheduling, assistance and quality control. The volunteer teams were trained in their first week of service by local water quality professionals who educated teams about various types of softeners as well as many of the other home water infrastructure items that they might encounter during their in-home surveys. Volunteers also went through training from the MMSD laboratory staff on how to properly use water hardness field test kits.

Homes that responded with the appointment post card were visited first in each sewershed. Initial response rate of the appointment post card was 40%. Residences that did not respond were visited using on the ground canvasing, where volunteers started on one random address in the sewershed neighborhood and went down the block knocking on doors until a resident responded and was willing to take the survey.

Participation in the survey was voluntary and homeowners had an opportunity to opt out. Although this study did collect information through a survey of individual homeowners or residents, this study did not require Institutional Review Board or Research Ethics Board (IRB or REB) approval for human subjects research due to the fact that the survey, as seen in Appendix B, did not focus on people and their opinions, perceptions, or choices- only on products, methods, and procedures related to in-home water treatment and usage. Data about individual survey responses were not publicly published. Measures were taken to protect the homeowners' names and personal information.

One volunteer team per residence administered surveys to participating households in person orally. In some cases, respondents asked to fill out the survey in writing themselves rather than through the aural interview Q&A method. Volunteers allowed these respondents to complete the survey in writing. Due to the fact that many of the survey questions were quantitative in nature, this multiple method of administering surveys likely did not have an impact on responses.

As each team visited a home, one team member took the lead on talking to the homeowner to learn about the home, administering the survey, gathering other general information about the home's water treatment processes and water use. In addition, that volunteer performed hardness tests with the use of reagent impregnated paper test strips. When held briefly under a water flow, the strips turn a designated color to indicate the range of hardness in the water. This quickly allows a person to determine which water flows in a building are softened – cold water, hot water, water to showers and bathrooms, water to kitchens, etc. The other team member gathered information about the home's water softener, took water samples, and tested the hardness of the water entering the softener using a HACH hardness test kit. Samples tested for hardness were also taken from outside the hose bib, and brought to MMSD's laboratory to be tested for Calcium and Magnesium. Results were translated to hardness; results analyzed by the MMSD lab very consistent with MWU's reports on source well hardness, whereas other testing methods were not, as will be later discussed. They also recorded photos, serial numbers, and softener make/model and current settings. The second volunteer reviewed the plumbing system and determined if any other treatment devices are present. They also adjusted softeners to regenerate at 2am (per the softener industry standard), so that the softener brine flows would occur in as many residences as possible at the same time of the day.

Out of the 147 of homes in the 2013 study group, 132 were approached for the survey. With 52 homes successfully surveyed by The WE Badger volunteers, response rate was approximately 39%. Of the total 2013 study group, there were 15 houses that opted out or were not able to be surveyed, and 80 homes where volunteers did not have success completing the survey after numerous attempted visits.

Background Municipal Drinking Water Quality

To coincide with each manhole monitoring period, water samples were taken from the drinking water distribution system entry point associated with each of the two wells that serve the sewersheds. Samples were collected approximately once a week by MWU and sent to a certified drinking water laboratory to be analyzed for chloride, calcium, magnesium, iron, and manganese concentrations. Additionally, samples were tested in the field using MWU's conductivity meter. These data characterized the drinking water entering the residences.

Manhole Data Collection

Manholes were monitored in an initial trial and then two main monitoring phases, each phase measuring flow, chloride concentration, and conductivity. Three phases are as follows:

Trial Phase – July 2013

Phase 1 – September 2013 to December 2013

Phase 2 – July 2014 to August 2014

Equipment used in manhole monitoring for this project included:

- ISCO 730 Bubbler flow module
- Portable Sampler, ISCO 6712C
- Thermo Scientific ™ Orion Star ™ A322 Conductivity, TDS, Salinity, Resistivity and Temperature Portable Waterproof Meter
- 45 degree notched plywood weir
- ISCO Model 2160 Area Velocity Flow Metering Inserts
- Flow through cell

All manhole monitoring was conducted by MMSD staff in the downstream manhole of each sewershed. For all devices in the four manholes, manufacturer instructions for routine cleaning and quality control checks were followed. Each manhole was visited daily, Monday through Saturday, by MMSD personnel to check that the equipment was operating properly and to take the 24-hour composite wastewater sample to MMSD's certified laboratory for chloride analysis.

Chloride Measurement

Chloride was measured in two ways in order to compare results for accuracy. Chloride was measured in the manholes via 1) a daily composite sample of chloride concentration and 2) hourly with a flow through probe for conductivity, which can be related to chloride concentration if other ionic species are not present in significant quantities.

A daily average chloride concentration was determined by collecting a 24-hour wastewater composite sample in each sewershed with ISCO 6712C Portable Samplers. The sampler was programmed to take a 120 mL sample of wastewater every 10 to 20 minutes to create a daily composite chloride sample at each site. After 24 hours, the bottle was taken from the manhole to the MMSD laboratory for analysis and a new empty bottle was put in its place to begin the collection process for the current day. This was done every day except for Sunday, when crews were not working. Machines were recalibrated to take the sample over a longer period of time on Sundays.

Conductivity of the wastewater was measured using Orion Thermo Scientific Conductivity Probe, every 1 to 15 minutes, measured in micro Siemens per centimeter (µS/cm). These data were relayed to a data logger which was visited biweekly to manually download the information to a computer.

Flow Measurement

For this study, residential wastewater flow, the water coming out of individual homes, was measured in two ways for comparison as well:

1. MWU provided hourly drinking water flow data per home in the form of gallons per hour, from Smart Meters installed in homes,
2. and manhole monitoring .

MWU assembled hourly drinking water usage data sent digitally to the utility via the Smart Meters. The data for each residence in the sewersheds during the manhole monitoring time periods were transferred to one project team participant in Microsoft Excel® spreadsheets. Hourly water usage data were summed for all of the residences in each sewershed to determine hourly water usage per sewershed and average hourly usage per residence. To compensate for residences without Smart Meter data, the average hourly usage per residence times the number of missing residences was added in. In this way, all residences in the sewershed were accounted for. It became evident that sometimes a residential Smart Meter may not send the flow data for some time periods, but then send the totalized flow data at some later time during the day. This especially was the case during the first monitoring period in the fall of 2013 when the MWU Smart Meter had been recently put into operation. The drinking water usage data were summed to a per day basis so that hourly variation was eliminated.

In the manhole, flow was measured continuously in gallons per minute by the portable 730 bubble flow module for area-velocity meter sampler and forty-five degree V-notch weir in each manhole. The ISCO continual flow data was aggregated into a daily flow measure by Flow Link Software, and were downloaded by trained district monitoring crews weekly. Information from FlowLink Software was exported to Microsoft Excel® spreadsheet format. Both the flow meter and conductivity probe had to be manually collected from each manhole by a monitoring crew staff person. Excel macros were also used to transform the manhole wastewater data from GPH and GPM to GPD (gallons per hour or gallons per minute to gallons per day).

Evolution of Monitoring Methods

In July 2013, MMSD completed a one week test for manhole data collection in the Winnemac manhole. Devices to install flow measurement, conductivity and chloride were installed as seen in Figure 4. After success in the trial phase of testing, equipment was purchased and installed for the full scale project. Each of the four sewersheds' manholes was monitored for flow, conductivity, and chloride with the equipment and methods developed in the trail phase during the 2013 Phase 1 monitoring. After initial complications with Phase 1 monitoring data collection, this method of collection was ended in December 2013 and a second phase of monitoring efforts was planned for 2014.

Phase 2 built upon lessons learned in the trial and Phase 1 – further adapting the measurement techniques with new equipment and methods for both flow and chloride measurements. During Phase 2, weirs were removed and replaced with ISCO Model 2160 Area Velocity Flow Metering Inserts (Figure 5). The flow metering inserts were installed on all four manholes in the study to mitigate V-notch weir clogging. Problems with rags and grease clogging the V-notch weirs, complicating flow measurement, were alleviated with the new device. Working with suppliers and in-house monitoring services crew, MMSD also mitigated manhole data collection complications with the development of a flow-through cell for conductivity readings. The flow-through cell allowed conductivity readings to be taken as a chloride sample was drawn into the installed sampler, as opposed to the original method of a single probe placed directly in the wastewater stream. MMSD tested the ISCO Flow Insert and flow through cell in June of 2014 and started monitoring all the monitoring locations through August 22, 2014.

For the purpose of improving data collection in Phase 2, manhole monitoring locations in two sewersheds were changed or moved. In the Risser Sewershed, the manhole where Phase 1 monitoring was conducted was changed to a manhole down the street with better conditions for in sewer monitoring, see Appendix A, Phase 2 Monitoring Locations Maps. This resulted in removing three addresses in the Risser sewershed from the study. The position of monitoring equipment was changed in the Tomahawk sewershed for Phase 2, resulting in removal of seventeen addresses from the sewershed study area (Appendix A).

In addition to changing equipment and locations for monitoring, preceding the Phase 2 monitoring period, educational measures were also taken to prevent the weir clogging interferences seen in Phase 1. Homeowners were sent a district handout, “Flushable?” seen in Appendix E. The handout provides information about what is ‘flushable’, a list of things that should not be flushed. In addition, the city of Madison jetted and cleaned sewer lines before re installation of monitoring equipment. All monitoring ceased, and equipment was removed in August 2014.

Figure 4 Manhole Monitoring Equipment and Setup

ISCO 6712C Portable Sampler

Orion Conductivity Probe

Setup in Manhole

Figure 5 ISCO Flow Insert - Phase 2 Monitoring Equipment

Weather Data

Weather data were used in analysis to evaluate weather impacts on monitoring data. Daily total precipitation and daily minimum, maximum, and mean temperature were obtained from the Wisconsin State Climatology Office. Weather for the Spring Harbor pair of sewersheds came from the Charmany Farm weather station, and weather data for the Glenway pair of sewersheds came from the Arboretum weather station. Precipitation and temperature were recorded because precipitation can impact wastewater flow in the manhole via inflow and infiltration.

WATER SOFTENER OPTIMIZATION AND REPLACEMENT

Treatment Recruitment

To address the study's second goal of estimating the extent to which chloride pollution from home water softeners can be controlled with higher efficiency softeners, homeowners in two sewersheds received assistance to upgrade water softener efficiency. Approximately eight weeks after the first phase of monitoring was started, homeowners in the Meyer and Risser Sewersheds were contacted to make improvements to their water softeners. All residences in these sewersheds received a letter from MMSD sent in the first week of November. These letters, available in Appendix C, gave background on the study, explained the offer for efficiency upgrades, and instructed homeowners to contact their water softener service organization to participate in the program. Four Madison-area water quality companies scheduled appointments with the interested homeowners and completed the upgrades or optimizations. Companies and district staff both followed the initial letter with phone calls and visits to houses that did not respond to the original mailing. Participation in the efficiency upgrade program was completely voluntary, but was incentivized by a new, upgraded softener, and the potential savings on softener salt purchases and home energy bills from more energy efficient softeners.

Softener Optimization & Replacement

Risser Sewershed residences were offered free optimization of their existing softener and Meyer sewershed houses were offered free replacement of their existing water softeners. Participation in softener upgrades was voluntary; sewershed homeowners or residents in the treatment areas (Risser and Meyer) were asked to contact their water softening service companies to set up appointments for replacement or optimization installs. Water quality professionals from the four above-mentioned companies were given forms, available in Appendix C, to record initial observations and to track changes made. Companies filled out forms for all houses they attempted upgrades on, and then forms were sent back to MMSD for results to be compiled into a spreadsheet. Actual optimization and replacement treatments were not standardized, but instead left on a case by case basis per discretion of the water quality professionals who were completing the work. For the purposes of the study, optimizations were provided gratis by the water quality companies involved in the study, however itemized invoices were still provided for the cost benefit analysis of softener optimization. Costs for replacing softeners were split between MMSD, MWU, the Water Quality Research Foundation and the water quality companies.

CHAPTER 3: MONITORING RESULTS

SURVEY AND OPTIMIZATION/REPLACEMENT PARTICIPATION RESULTS

Response rate for the survey of all homes in the study was low; however, participation in the efficiency upgrades was high, at 48% and 88% for optimization and replacement, respectively. Out of the 32 addresses in the Meyer sewershed study area, 28 participated in the program to replace their softener, and four opted out or did not respond. Residents with softeners received one of four different models, depending on their service company. All new softeners installed, regardless of company had a minimum efficiency of 4,000 grains hardness removed per pound of salt consumed. Out of the 33 addresses in the Risser Sewershed study area, 16 participated in the program to optimize their softener, 14 did not respond, two houses did not have water softeners and one house had water service disabled. Out of the 16 that participated, three of the houses did not receive optimizations because their model of softener could not be optimized in any way. Thirteen houses total had optimizations completed on their water softeners.

DRINKING WATER QUALITY

As seen in Table 3 and Table 4, the drinking water supplied to the Glenway area, sewershed pair B, by Well 12 has an average of 3 mg/L chloride, while that supplied to the Spring Harbor, sewershed pair A, area by Well 14 averages 115 mg/L chloride. The wide difference in concentrations seen in the source water is also reflected in conductivity; the conductivity in the Glenway area (500 µS/cm) is about half of that of the Spring Harbor area (1000 µS/cm). Having more mineral content, Well 14 averages a hardness of 460 mg/L as CaCO3 (27 grains per gallon or GPG) while Well 12 averages a hardness of 280 mg/L as CaCO3 (17 GPG) according to results from the MWU. Hardness measurements from samples taken outside of the homes' hose bibs done by the Badger Volunteers and tested in the MMSD Lab, confirm these results (See Appendix F).

Iron and manganese presence are not factors in either study area well. Iron and manganese can deposit on softener media, blinding ion exchange sites and causing less efficient hardness removal. Iron and manganese were not measured in significant amounts at either well site.

Table 3 Well 12 Water Supplying the Glenway Area – Pair B

Monitoring Period	Collected Date	Hardness		Chloride	Conductivity	Iron	Manganese
		mg/L as CaCO3	GPG	mg/L	µS/cm	µg/L	µg/L
1st Phase	10/21/2013	280	16	3	520	<2	0.70
	10/29/2013	284	17	3	494	<2	<0.25
	11/6/2013	282	16	3	489	<2	<0.25
	11/12/2013	273	16	3	492	<2	<0.25
	11/20/2013	280	16	4		<2	<0.25
	11/26/2013	288	17	3		<2	<0.25
	12/3/2013	283	17	3		<2	<0.25
	12/11/2013	285	17	3		<2	0.30
	12/18/2013	282	17	3		<2	<0.25
	12/26/2013	283	17	3		<2	<0.25

2nd Phase	7/18/2014			3			
	7/24/2014	280	16	5			

Table 4 Well 14 Water Supplying the Spring Harbor Area – Pair A

Monitoring Period	**Collected Date**	**Hardness**		**Chloride**	**Conductivity**	**Iron**	**Manganese**
		mg/L as CaCO3	**GPG**	**mg/L**	**µS/cm**	**µg/L**	**µg/L**
1st Phase	10/21/2013	456	27	90	1060	<2	<0.25
	10/29/2013	459	27	117	999	<2	<0.25
	11/6/2013	459	27	118	1001	<2	<0.25
	11/12/2013	457	27	117	1003	<2	<0.25
	11/20/2013	456	27	122		<2	<0.25
	11/26/2013	461	27	117		<2	<0.25
	12/3/2013	454	27	117		<2	0.40
	12/11/2013	456	27	119		<2	<0.25
	12/18/2013	460	27	118		<2	0.30
	12/26/2013	457	27	116		<2	0.60
	12/30/2013			116			
Interim	5/9/2014			112			
	5/23/2014			118			
	6/4/2014			111			
	6/20/2014			112			
2nd Phase	7/2/2014			109			
	7/18/2014			114			
	7/24/2014	448	26	119			

WASTEWATER FLOWS

Wastewater flow measurements in the Tomahawk Sewershed manhole taken in May and June 2013 for the trial phase of monitoring is shown in Figure 6. Results were consistent with MWU readings and were therefore confirmed as viable for the full scale monitoring in Phase 1 scheduled for September 2013.

During the Phase 1 monitoring in September 2013, the results did not replicate the 2013 trial results. Obstacles to probes collecting accurate data included:

- Debris clogged monitoring weirs, leading to inaccurate flow readings. (When clogged, the flow readings would continue to artificially increase until the system flushed its self or was manually flushed),
- low or irregular flows leading to inconsistent conductivity readings,
- chloride sample bottles filled to different depths even though they were set to collect the same aliquot Monday through Saturday (120ml) at timed increments of every 10 minutes and every 20 minutes on Saturday through Monday,
- clogging in the suction lines due to either, incorrect settings or a suction line with insufficient flow depth available from which to draw a sample

Throughout the first phase of monitoring, MMSD worked to troubleshoot each issue. MMSD created data sheets for field crews to document a variety of parameters during each site visit. To mitigate the clogging of weirs, MMSD crews increased site visitation and attention to weir cleaning during visits. Even with increased visitation and cleaning emphasis, the weirs still caught substantial debris due to the low-flow environment.

Phase 1 manhole wastewater flow data were compared with MWU Smart Meter flow data for validation. Manhole wastewater flow should generally be equivalent to water meter flow due to the fact that most water coming in to a house also gets put down the drain as wastewater. The two would not be an exact match due to evaporation, landscaping water use and its infiltration into the ground, or water imports/exports to and from the home.

As seen in Figure 7, flow monitoring from Phase 1 manhole monitoring compared with MWU Smart Meter data had no correlation. In all of the sewersheds, the wastewater flow was greater than the drinking water flow. Based on observations, the manhole wastewater flow was measured higher than in reality as the water level, and therefore flow rate, increased over the weir due to manhole and weir clogging.

Figure 6 Trial Period Results
Manhole Wastewater Flow Measurements

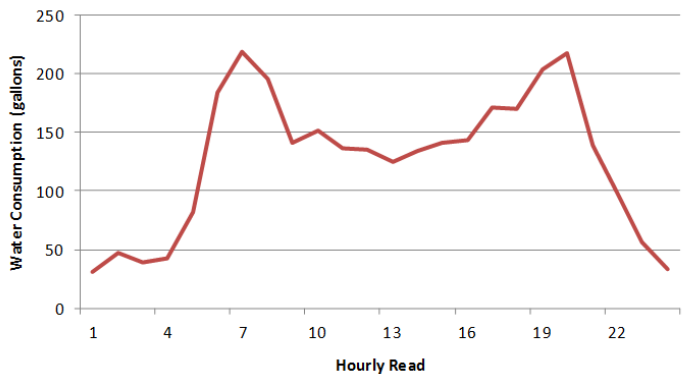
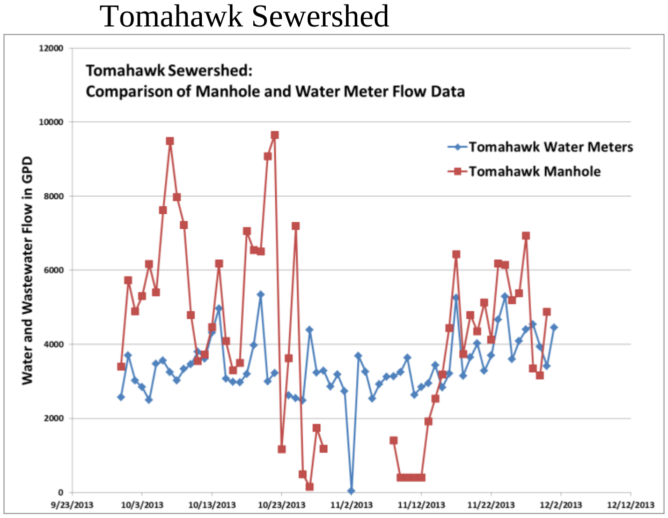
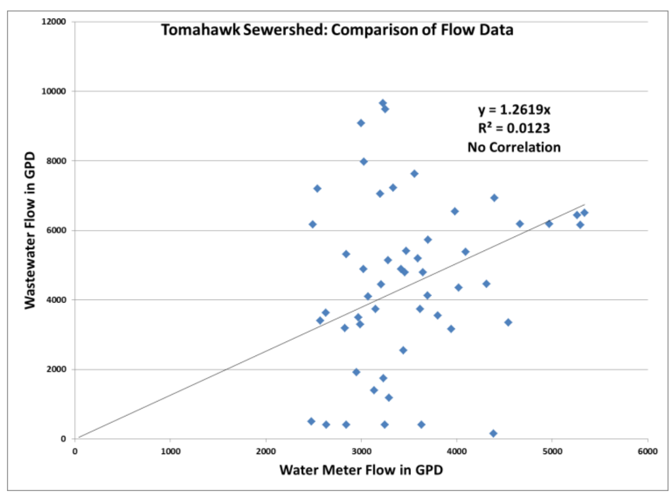


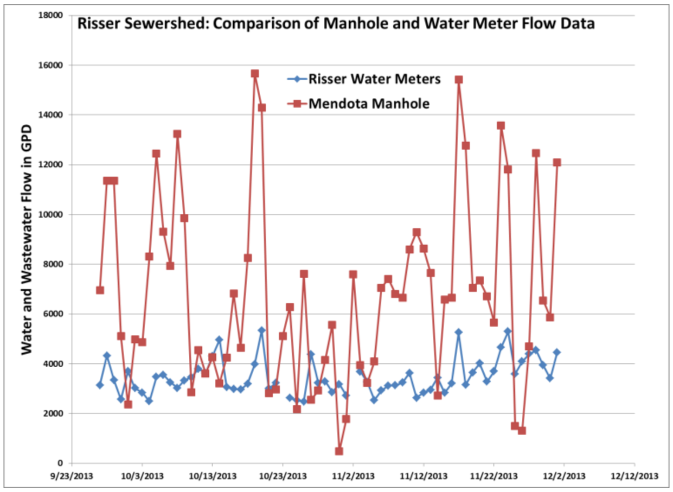
Figure 7 Phase 1, 2013 Wastewater Flow Comparison
Phase 1 - Spring Harbor Neighborhood Wastewater Flow Results Comparison

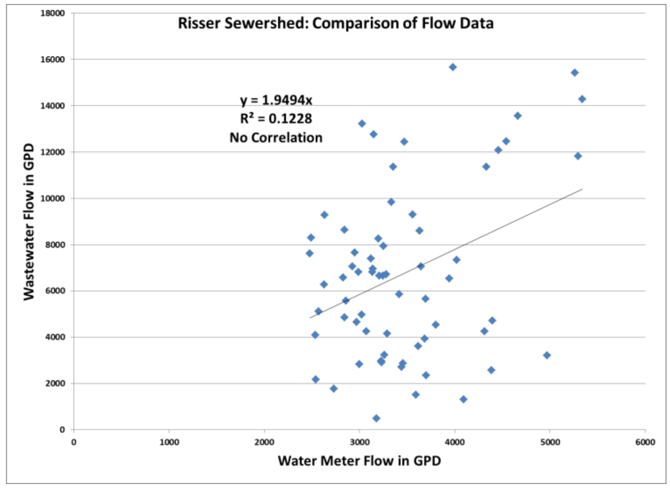
Tomahawk Sewershed





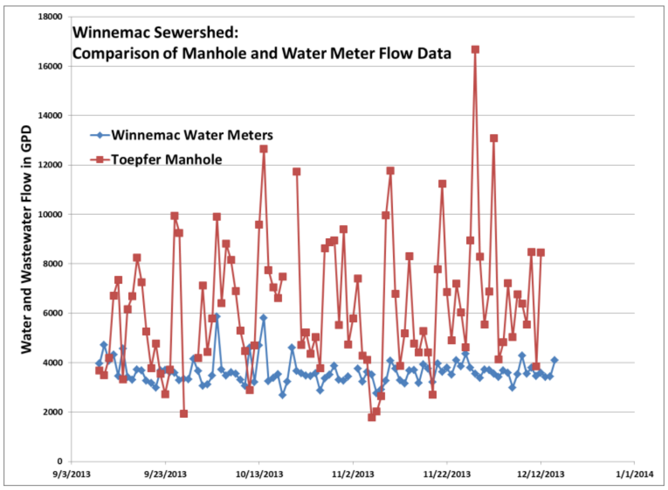
Risser Sewershed

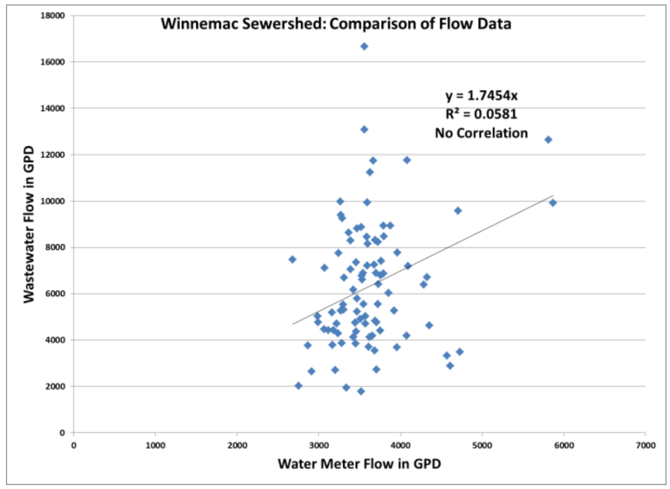




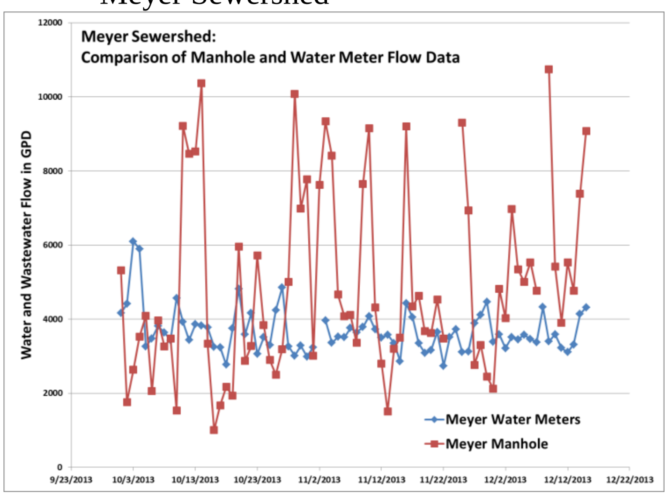
Phase 1 - Glenway Neighborhood Wastewater Flow Results Comparison

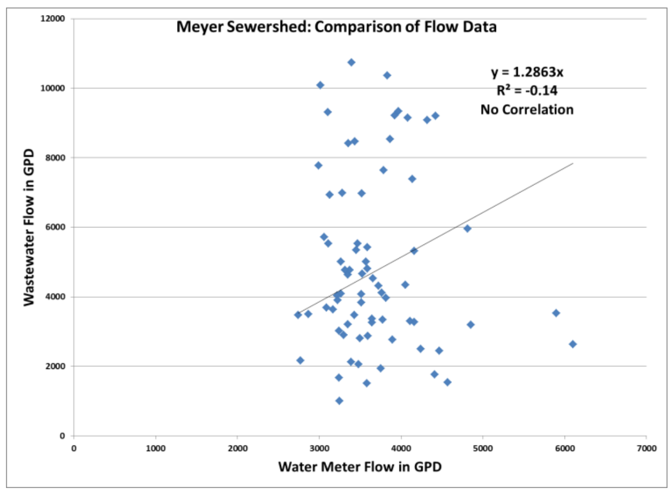
Winnemac Sewershed





Meyer Sewershed



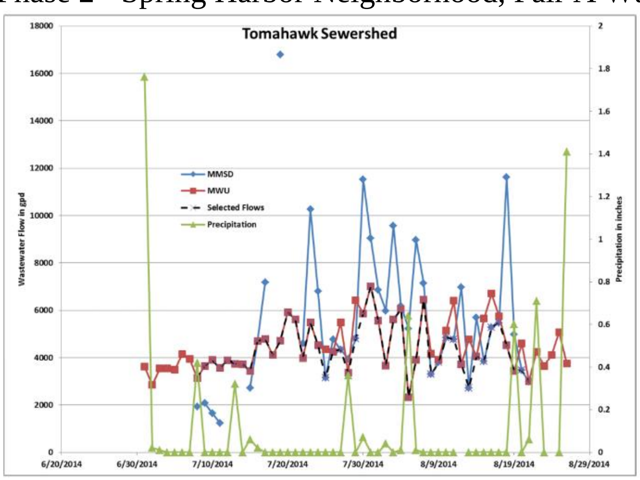


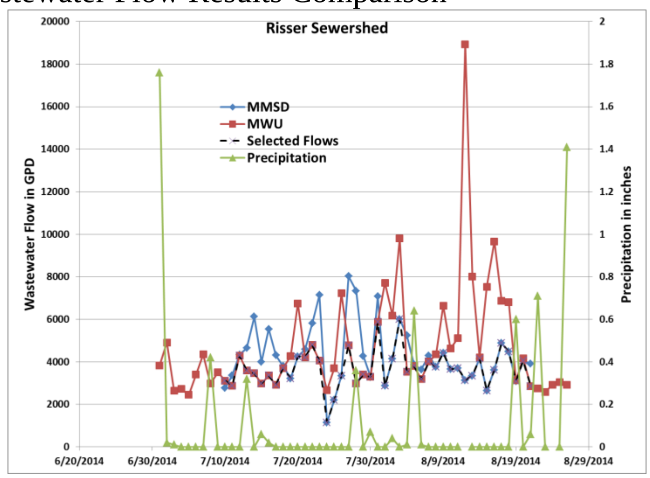
Phase 2 wastewater flow results, seen in Figure 8 below, showed a correlation as a result of improved monitoring techniques. In these figures, wastewater flow measured in the manhole is compared to MWU drinking water usage Smart Meter data and daily precipitation. The MWU drinking water usage Smart Meter data and measured wastewater flow data track closely together except for peak events. Areas where wastewater and Smart Meter data do not correspond can be explained through a few exception scenarios. A composite 'selected' flow dataset was constructed through logical combination of the two datasets to reflect the most likely actual flows.

Peaks in the measured wastewater flow are assumed to be manhole clogging events. Therefore, in that case, MWU drinking water usage data were selected as representative of daily wastewater flow and used in further data analysis.

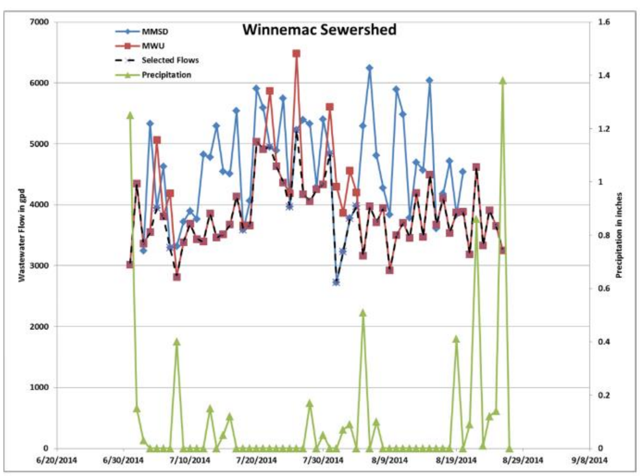
Figure 8 Phase 2, 2014 Wastewater Flow Comparison and Composite

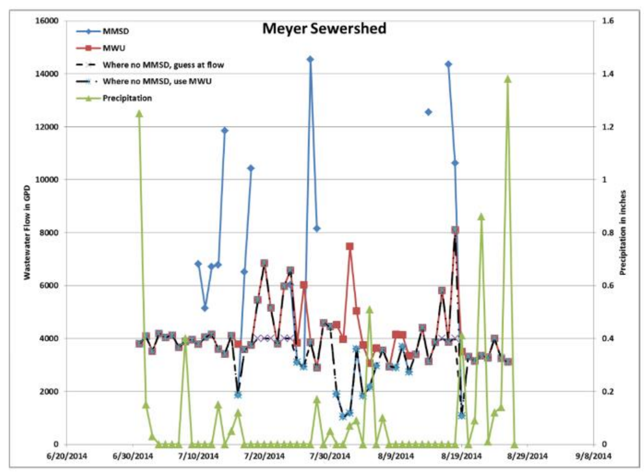
Phase 2 - Spring Harbor Neighborhood, Pair A Wastewater Flow Results Comparison





Phase 2 - Glenway Neighborhood, Pair B Wastewater Flow Results Comparison





There were time periods when the MWU drinking water usage data were greater than the manhole wastewater flow data, for example in the Risser Sewershed in Figure 8, from 8/9/14 to 8/19/14. Weather data corresponding to that time period show many days of zero precipitation, indicating drought conditions. It is assumed that the drinking water flow was greater than the wastewater measured flow due to landscaping watering during the drought. In these cases where landscaping water use is evident, manhole wastewater data are used in the dataset for further data analysis.

Another situation where the MWU drinking water data needed to be substituted for measured wastewater was when no manhole data were available. For example, in Meyer Sewershed in July 2014, no manhole wastewater flow data were available, but the MWU drinking water usage appeared elevated because of a drought. In that case, the wastewater flow was estimated by repeating the same daily flow until the next valid measured data point could be located.

In this way, a dataset of wastewater flow for the Phase 2 monitoring period in each sewershed was constructed using the most logical selection between MWU drinking water usage meter data and MMSD manhole measured wastewater flow data. The constructed data set of selected flows is seen as a dashed line in Figure 8, "selected flows". The selected flow data were used for all further calculations for 2014 data. Selected flows in GPD, for each sewershed were divided by the number of residences, seen below in Table 5, to indicate the daily flow in GPD per house. This yielded the average contribution of wastewater per house in each sewershed, Table 6. Having the average flow per house per day, allowed for later calculation of average mass of chloride contribution per individual household softener.

Table 5 Number of Residences in Sewersheds

Sewershed Pair		2013	2014
A	Tomahawk	49	31
	Risser	33	29
B	Winnemac	33	33
	Meyer	32	32

Table 6 Average and Median Wastewater Flows for Project Sewersheds in GPD per Household

Monitoring Phase	Year	Sewershed	Average	Median
2	2014	Tomahawk	140	130
		Risser	126	123
		Winnemac	116	112
		Meyer	107	115

CHLORIDE CONCENTRATION AND CONDUCTIVITY

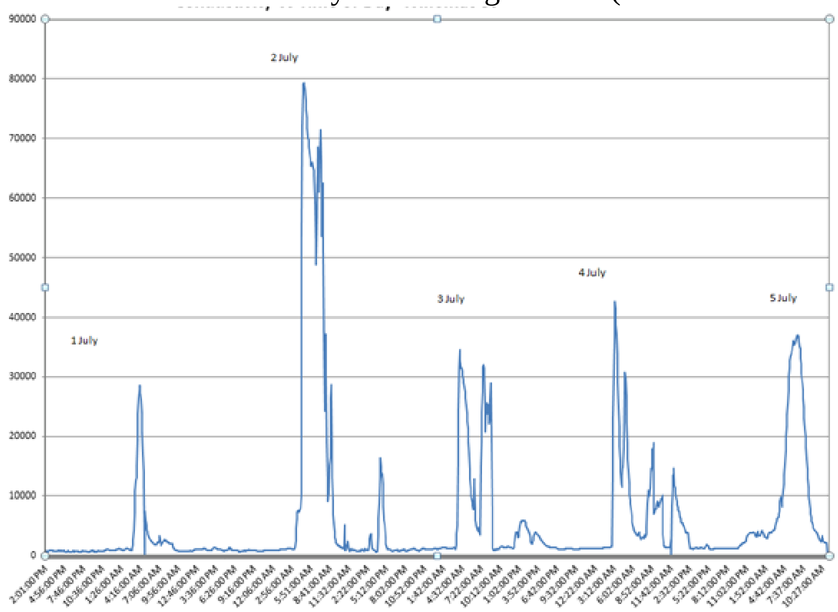
Mass of chloride is proportional to the product of the concentration of chloride in mg/L and wastewater flow in GPD per household. Using the proper conversion factors, the mass of chloride is calculated in kilograms of chloride per day per household (KGD per house).

As explained in Chapter 2, two methods were used to find the concentration of chloride in the wastewater; a daily chloride composite sample and conductivity probes were used.

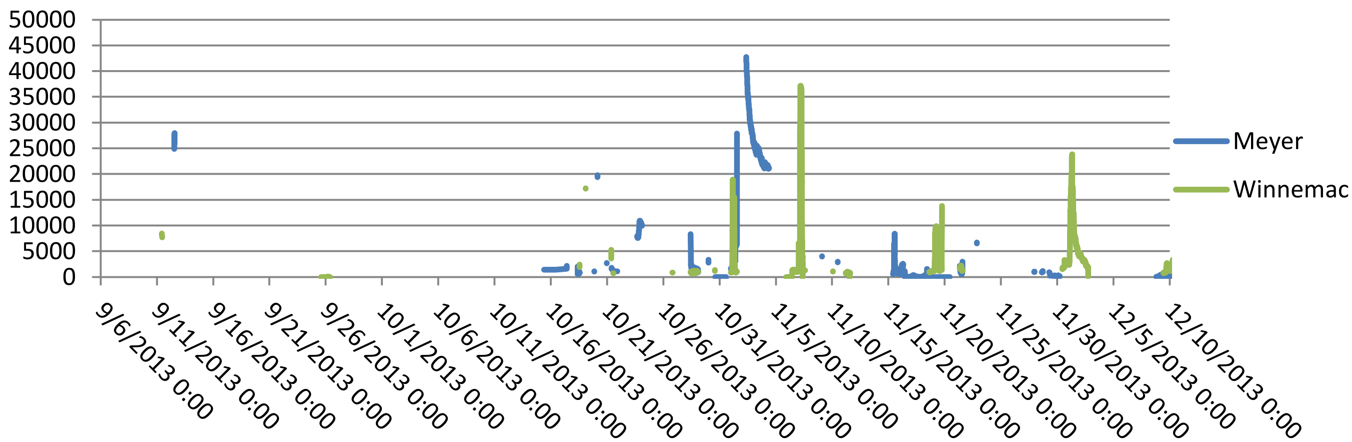
Similar to flow, the initial trial results for conductivity showed consistent and logical expected results, which were not replicated in Phase 1 monitoring – see Figure 9 comparison of trial conductivity vs. Phase 1 conductivity monitoring results. High peaks of conductivity (chloride concentration) can occur in wastewater during low flow periods. Most water softeners are set to regenerate in early morning hours around 1 or 2 AM so that household water use activities will not be interfered with by softener regeneration flow. Indeed, the initial trial measurements of manhole wastewater conductivity in June 2013 (trial phase) showed high peaks of conductivity during early morning low flow periods as seen in the Trial Phase Monitoring Result in Figure 9.

Figure 9 Initial Trial Conductivity Monitoring vs Phase 1 Results

Initial Trial Conductivity Monitoring Results (Winnemac Sewershed)



2013 Phase 1 Winnemac and Meyer Conductivity Monitoring Result



As previously discussed, Phase 1 manhole monitoring did not repeat the results of the trial phase. Conductivity measurements and composite sampling chloride results were found to have a number of invalid data points in Phase 1 monitoring. Phase 2 manhole monitoring was more accurate with the improved monitoring equipment (namely the flow through cell) and altered monitoring locations as discussed in the methods development section. Results for conductivity monitoring, seen in Figure 11, show consistent, improved results from phase 1 conductivity results.

Conductivity readings Conductivity readings less than 0.1 mS/cm were removed from the dataset because they were below the ability to measure accurately, indicating the flow through cell was not full of wastewater. High conductivities on July 18, 2014 due to known equipment malfunction were also removed. For chloride concentrations analyzed from 24-hour composite samples, sample bottles with less than nine inches deep of sample were eliminated because a specific volume of sample was expected daily if the sample was composited correctly.

In Figure 11 it is clear that the treated sewersheds, Meyer and Risser are different, in comparison to their respective paired control sewersheds, Winnemac and Tomahawk. By visual approximation, the softener regenerations in the treated sewersheds seem to have been consolidated, that is, softener regenerations happened less frequently, more predictably, and more coordinated (more softeners in each sewershed regenerating at the same time instead of individually). In comparing Meyer and Winnemac, this trend is especially visible. Softener regenerations are typically wherever conductivity rises above normal levels seen in home wastewater, generally above 5,000 uS/cm, meaning any time there is a spike in the graphs below. Softeners in Meyer tended to regenerate less frequently than the softeners in Winnemac, however the regenerations appear to generally be more conductive than the regenerations in Winnemac Sewershed.

Chloride concentrations analyzed from 24-hour composite samples, seen in Figure 12, yielded results that were more consistent than Phase 1 monitoring as well. Sample bottles with less than nine inches deep of sample were eliminated because a specific volume of sample was expected daily. Phase 2 measured chloride concentrations in the sewersheds' wastewater are shown in Table 7. To verify concentration and conductivity measurements, correlations between chloride data and conductivity were explored. Both datasets were missing some values due to the aforementioned factors, and so the two were plotted in Figure 10 to see if a best fit curve could be used to estimate values where monitoring data was compromised. Figure 10 shows that lower chloride concentrations had a satisfactory correlation to conductivity, however at higher concentrations, conductivity did not correlate as well even when fitted with a second curve for higher levels per the USGS method. The equation for translating conductivity readings into concentration could not be used because as seen in Figure 10 since there is a low correlation at high levels, the conductivity peaks, which were critical data points representing softener regeneration time periods. Difficulties in correlating concentration and conductivity at peak times prevented missing points from being calculated, but because of high correlation between measured conductivity and composite samples of concentration at low levels, despite missing points, it was assumed that measured chloride data was accurate to use for further analysis.

Figure 10 Correlation Between Conductivity and Chloride Concentration

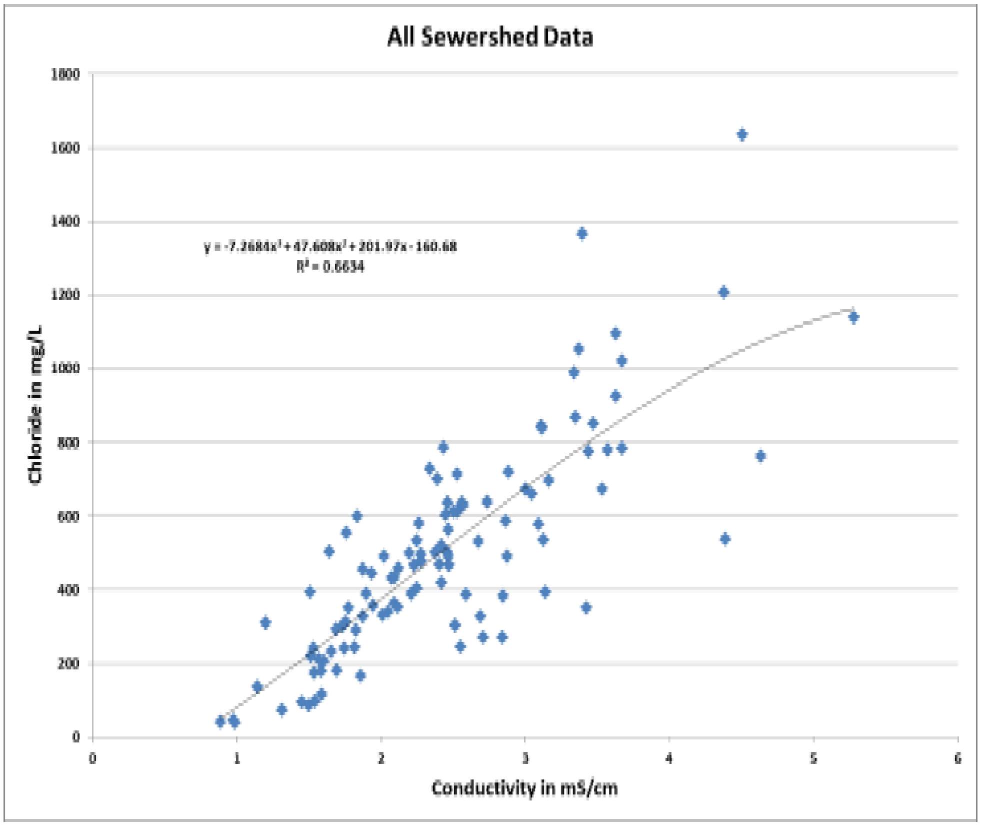
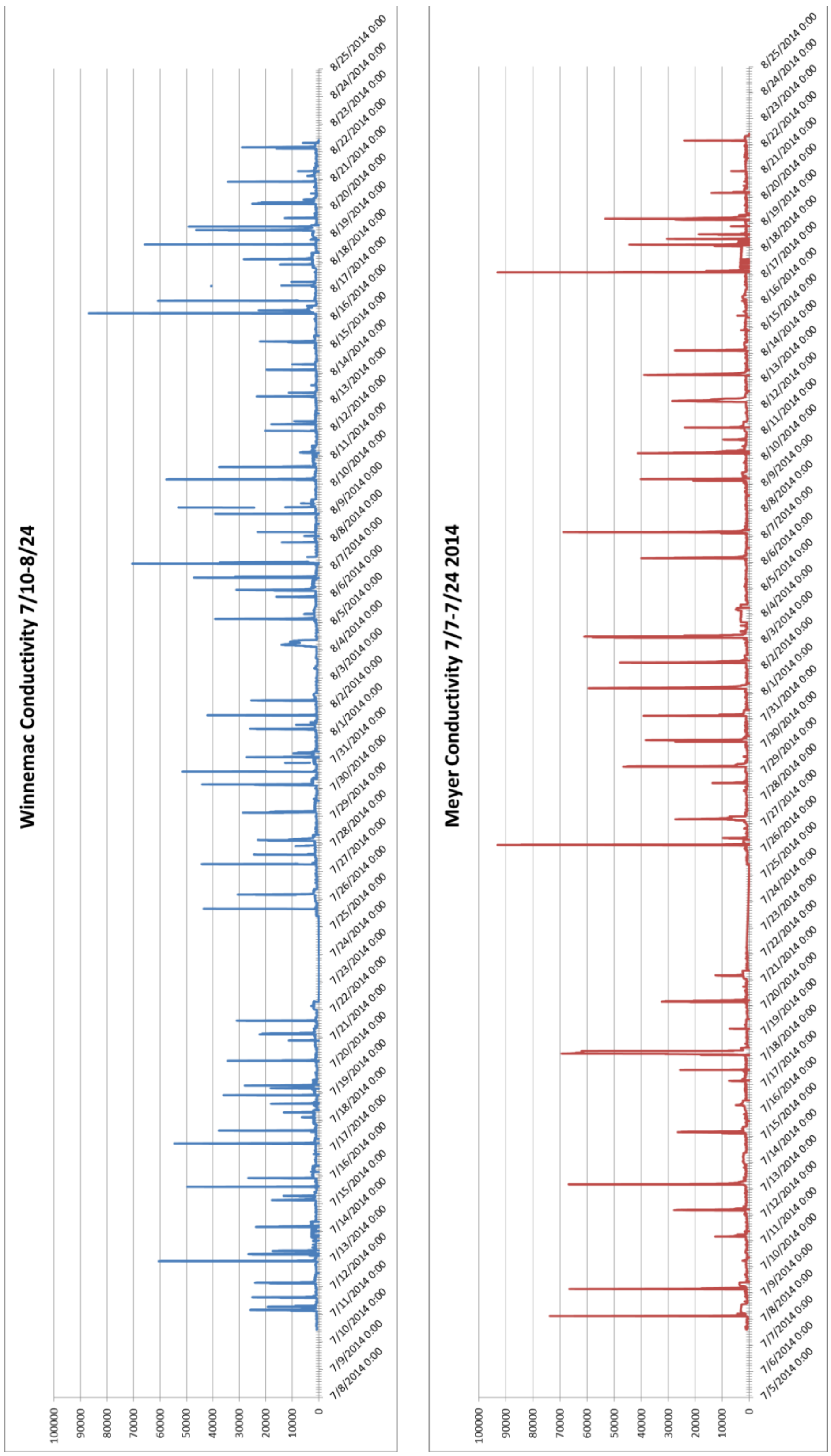
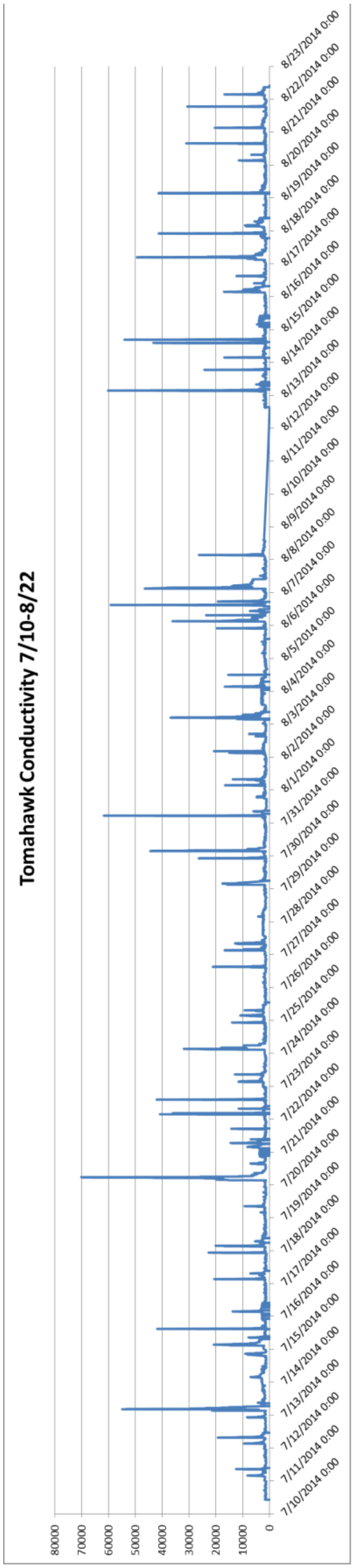


Table 7 Average and Median Phase 2 Chloride Concentrations by Sewershed In mg/L

	Risser	Tomahawk	Meyer	Winnemac
Average	560	678	388	521
Median	526	555	307	479
Min	166	182	39	175
Max	1207	2229	1220	1636

Figure 11 Phase 2 Conductivity Results




Tomahawk Conductivity 7/10-8/22
0
10000
20000
30000
40000
50000
60000
70000
80000
7/10/2014 0:00
8/23/2014 0:00

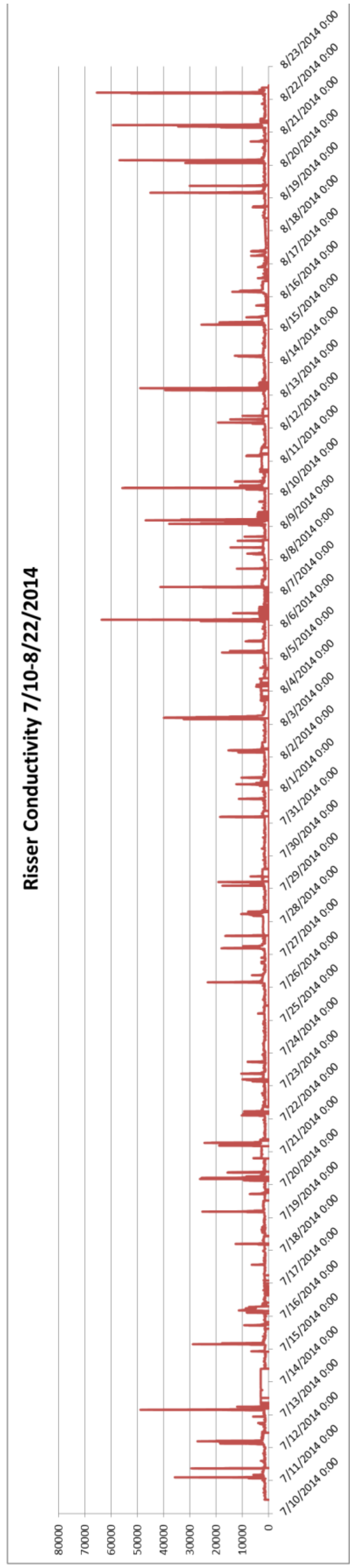
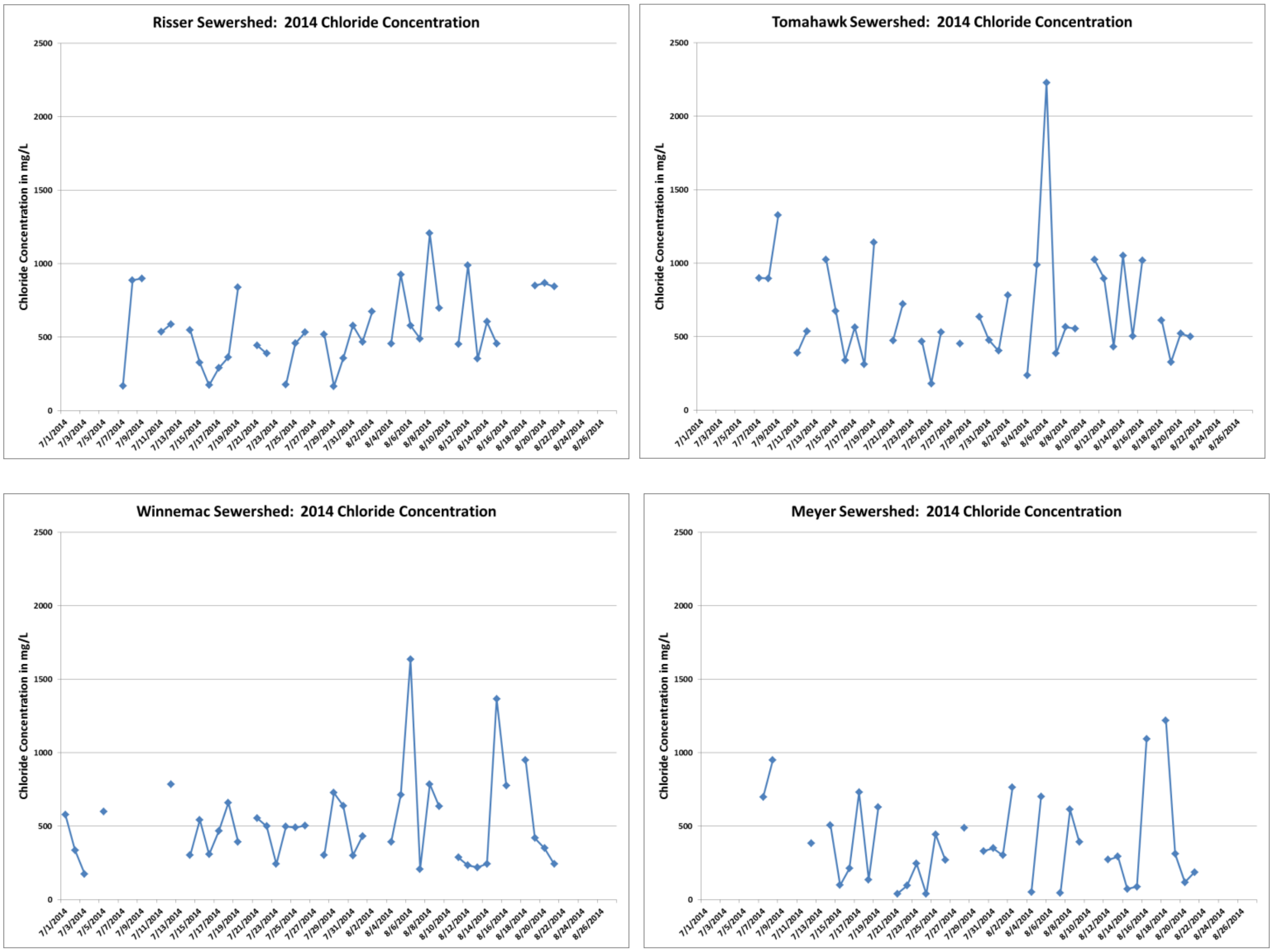

Risser Conductivity 7/10-8/22/2014
0
10000
20000
30000
40000
50000
60000
70000
80000
7/10/2014 0:00
8/23/2014 0:00

Figure 12 Chloride Concentration, Phase 2 Monitoring



MASS OF CHLORIDE IN RESIDENTIAL WASTEWATER FROM WATER SOFTENERS

Mass of chloride contributed from each home is equal to the product of wastewater flow (volume per day per house) and chloride concentration (mass of chloride per volume of wastewater per day). For this study, mass of chloride in residential wastewater from water softeners was calculated using Phase 2 measured chloride concentration data (from daily composite wastewater samples) and the composite flow seen as ‘selected flows’ in Figure 8.

Chloride mass from individual household softeners, is estimated to be between 0.01 – 1.06 kg per day per house (0.022-2.34 lb. per house, per day), with an average (for all sewersheds in the study) of 0.25 kg/house/day (0.55 lb. per house, per day) after controlling for other sources of chloride in the wastewater (Table 8). Background contribution from source well water, Table 8, was subtracted from the total mass of chloride in the wastewater to yield results for Table 9, the chloride mass contribution from households, including water softeners.

Table 8 Chloride from Source Water (Kg/House/Day)

Sewershed	2014	
	Average	Median
Tomahawk	0.060	0.060
Risser	0.050	0.050
Winnemac	0.001	0.001
Meyer	0.001	0.001

Table 9 Mass of Chloride in Wastewater Contributed by Households and Softeners (Kg/House/Day)

Phase	Sewershed		Average	Median	Max	Min
2 (2014)	A	Tomahawk	0.278	0.225	1.01	0.026
		Risser	0.204	0.181	0.535	0.010
	B	Winnemac	0.232	0.206	0.745	0.066
		Meyer	0.124	0.099	0.437	0.011
	Control Sewersheds Avg.		0.255			

COMPARISON OF SEWERSHED RESULTS

The data that were obtained for wastewater flow and mass of chloride in wastewater do not fall on a normal distribution curve, even after a logarithmic transformation; therefore many commonly used statistics cannot be used. Data taken over time in flowing water streams are similar to data taken over time on an assembly line where the conditions that produced one data point can influence the next data point taken; data are not independent of each other and a normal distribution cannot be assumed. Therefore, a non-parametric technique, the Shewhart Control Chart was used to compare wastewater flow and mass of chloride in wastewater of control sewersheds versus that of sewersheds where water softeners were either optimized or replaced. The Shewhart Control Statistics are conservative when comparing datasets because they are generalized to fit any possible data distribution (Wheeler & Chambers 1992). The statistics- average and expected variation- are charted for a scenario considered as the initial condition. Horizontal lines on these charts represent the Shewhart statistics, indicating horizontal lines for average, and measures of variation, as calculated by units of expected variation called ‘sigma units’, similar to standard deviation (Wheeler & Chambers 1992). The second scenario is plotted over the statistics of the initial condition. There are defined rules of Shewhart Control Charts based on the probability that certain data patterns will occur around an average. Using those rules, it can be determined if the two scenarios are the same or are statistically different. In Figure 13 the Shewhart Statistics for the daily mass of chloride in each of the control sewersheds’ (Tomahawk and Winnemac) wastewater is displayed first, and then the treatment sewershed masses are plotted over control statistics. Risser daily chloride mass has a 27% lower average than the control Tomahawk, and Meyer plotted on the Winnemac statistics has a 47% lower average mass of chloride. Both of the treatment sewersheds exhibiting lower means than their paired control sewershed indicates possible reductions of mass of chloride due to the optimization and replacement of those sewersheds’ softeners. Results for comparison of chloride masses are summarized in Table 10.

Table 10 Chloride Mass Comparison Conclusions Phase 2, 2014
*Average Chloride Mass in KGD per House

Control Sewershed	Treatment Sewershed	Control Average	Treatment Average	% Change	Comment
2014 Tomahawk	2014 Risser	0.278	0.204	-27	After softener changes, lower mass in Risser
2014 Winnemac	2014 Meyer	0.232	0.124	-47	After softener changes, lower mass in Meyer

Chloride Mass Comparison Conclusions Phase 2, 2014
*Median Chloride Mass in KGD per House

Control Sewershed	Treatment Sewershed	Control Median	Treatment Median	% Change	Comment
2014 Tomahawk	2014 Risser	0.225	0.181	-19	After softener changes, lower mass in Risser
2014 Winnemac	2014 Meyer	0.206	0.099	-52	After softener changes, lower mass in Meyer

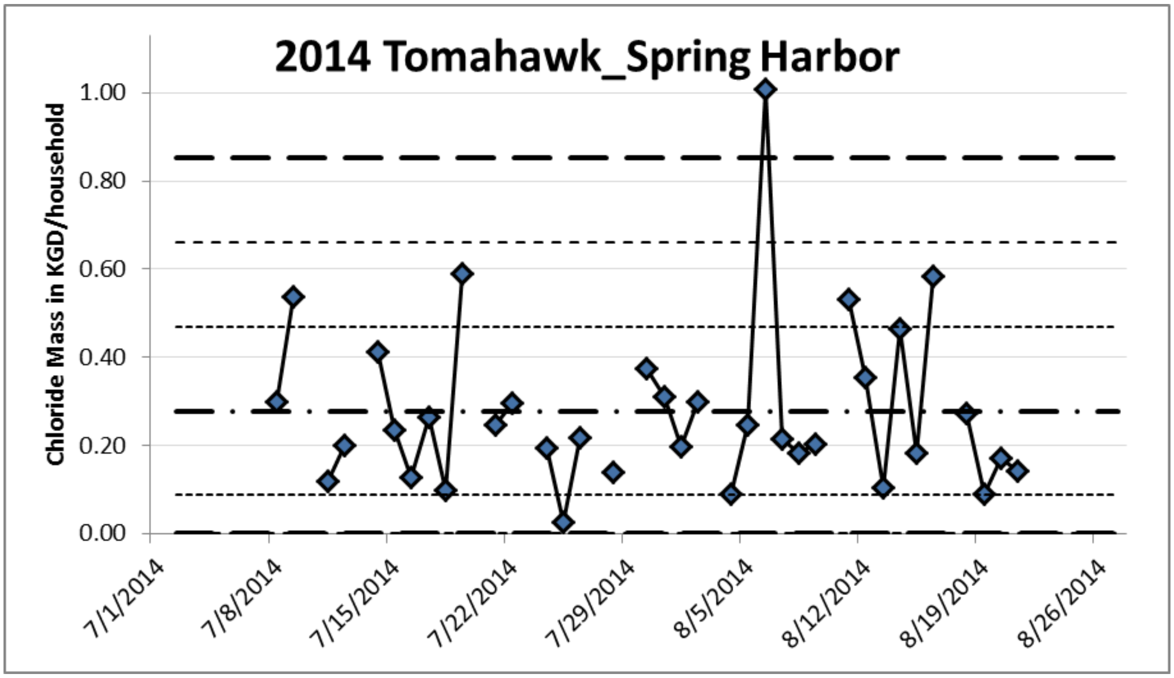
Chloride Mass Comparison Conclusions Phase 2, 2014 Using Welch's t-Test
*Chloride Mass in KGD per House

Control Sewershed	Treatment Sewershed	Control Average	Treatment Average	Average % Change	Low end of % Change Range	High end of % Change Range
2014 Tomahawk	2014 Risser	0.28	0.20	-27	-54	0
2014 Winnemac	2014 Meyer	0.23	0.12	-46	-80	-13

On average, the chloride mass is 27% lower in Risser than Tomahawk. Comparing medians, Risser has 19% lower chloride mass than Tomahawk. Using a Welch's t-test on the difference between averages, the difference can be anywhere from 0 to 54% lower in Risser at the 95% confidence level. On average, the chloride mass is 47% lower in Meyer than Winnemac. Comparing medians, Meyer has 52% lower chloride mass than Winnemac. Using a Welch's t-test on the difference between averages, the difference can be anywhere from 13% to 80% reductions at the 95% confidence level.

Figure 13 Mass of Chloride Shewhart Statistics and Comparison

Comparison of Spring Harbor Neighborhood (Pair A) Tomahawk and Risser



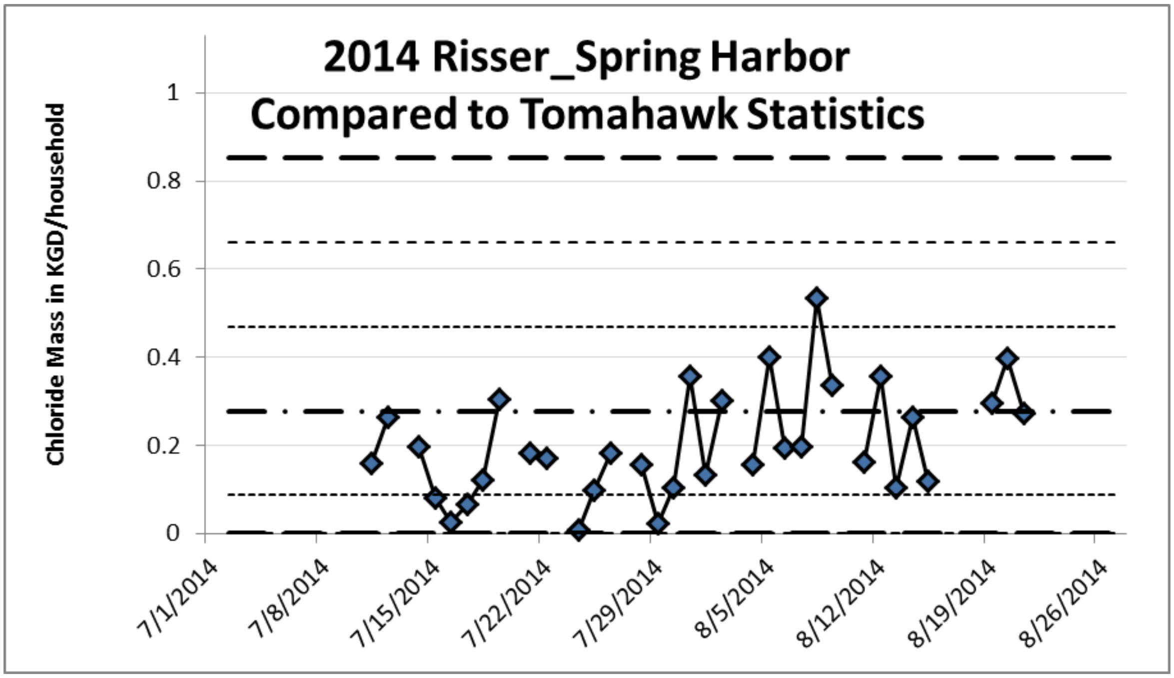
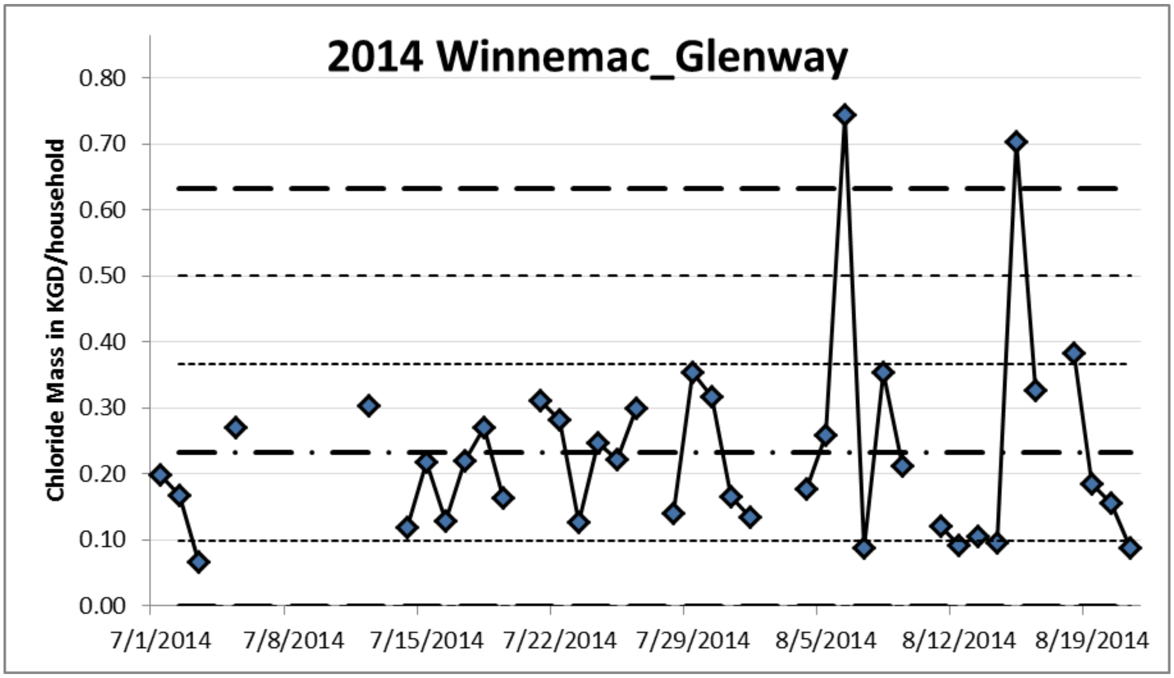
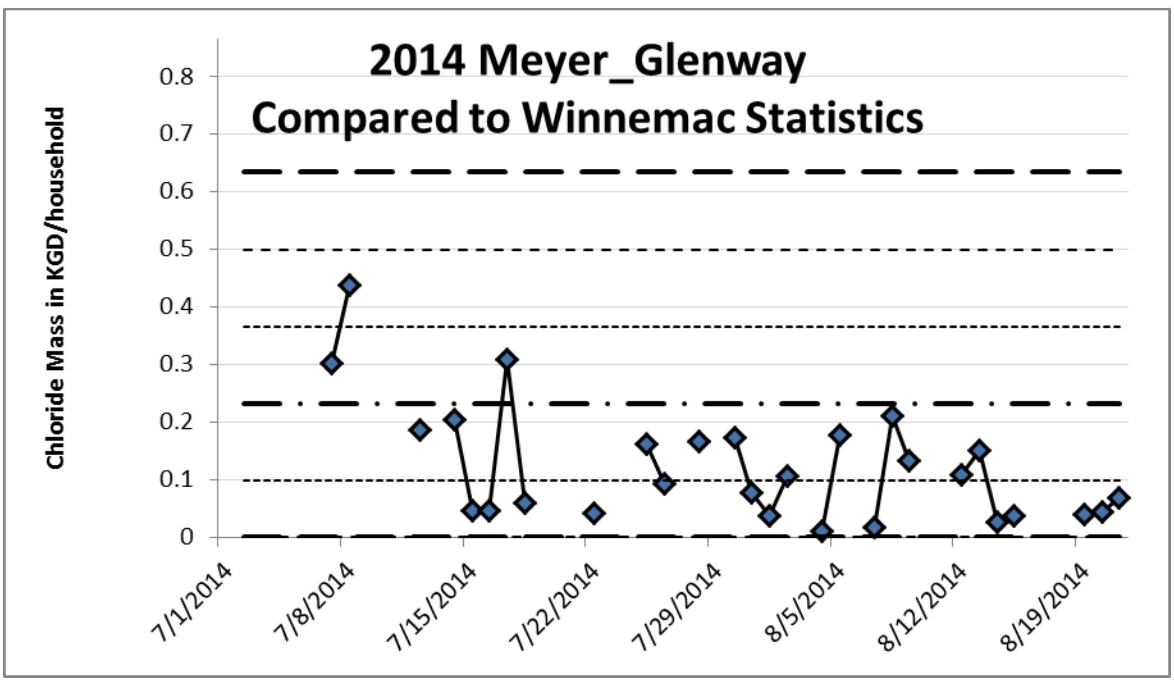


Figure 13 (Continued)

Comparison of Glenway Nieghborhood (Pair B) Winnemac and Meyer





CHAPTER 4: DISCUSSION

SOFTENER CONTRIBUTION TO CHLORIDE IN RESIDENTIAL WASTEWATER

The estimation of average contribution per home softener to the wastewater stream is derived from averaging the control sewershed phase 2 monitoring period, mean masses (Tomahawk and Winnemac), in which the background contribution of chloride from source well water has been controlled for. The average contribution of chloride to wastewater from an individual household softener alone figured in this way, is estimated at 0.255 kg per day per house, or about 93 kg chloride annually per single family residential house (Table 9).

One factor to consider with this figure is that in addition to accounting for well water as a background source, there may be other chloride sources which were not accounted for. Chloride contribution from a household's humans (domestic waste) that is not associated with water softeners is also a potential background source. Chloride can come from human daily contribution, and is estimated by one study to be about 35 mg/l/person/day (Metcalf and Eddy AECOM et al. 2014). If it is assumed that each house averages four people as residents and the range of daily wastewater flows from Table 6 are used, then the non-water softener domestic chloride contribution is between 0.04 to 0.07 KGD per household. Because this contribution was not measured directly in this study and the population of the sewershed is not known, this contribution was not been subtracted from Table 9 to identify the contribution of chloride from softeners only.

It should also be noted that the two sewersheds used to derive the average contribution from softeners to wastewater are assumed to be a representative sample of single family household softeners in the MMSD service area. Applicability of this number beyond this project and MMSD service area would require the assumption that the characteristics of another sewershed are similar to those in the study areas. This assumption does not account for differences like household size, total sewershed population, demographic composition of sewershed population, water use, cultural practices, age of softeners, age of plumbing systems/homes, etc., which can all impact the amount of chloride discharged from wastewater to a home.

For MMSD, 57% of influent chloride is coming from water softeners, therefore a portion of the 20,000 pound per day reduction goal will be focused on targeting water softeners. Large, institutional water softeners, multifamily dwelling units, commercial facilities' softeners (excluding industrial users), and single family residential homes all contribute to the average influent chloride mass of 80,500 pounds per day (Table 1). An estimated 58-63% of that 80,500 pounds per day comes from single family residential homes (as estimated by the proportion of single family home equivalent connections to MMSD to all connections reported in the Wisconsin Public Service Commission Annual Reports of Municipal Water Utilities). The product of the average mass discharged per house from water softeners per day (0.561 lbs/house/day) and 96% of the equivalent single family connections in MMSD's service area (85,315) is equal to the average mass of influent chloride (per day) at the NSWTP from single family home water softeners, about 47,861 pounds per day (59% of chloride influent from softeners can be expected to come from single family residential homes). Working in tandem with other chloride source reduction measures, reducing influent chloride by optimizing and upgrading softeners will be an important piece of MMSD's necessary chloride reduction efforts.

CONTROLLING CHLORIDE IN RESIDENTIAL WASTEWATER

Comparing sewersheds with efficiency upgrades (treatment) to their respective not changed (control) paired sewershed, a 27% reduction in wastewater chloride mass was calculated for optimized softeners, and 47% reduction for replaced softeners. Findings indicate that sewersheds with more efficient softeners reduce chloride contributions to wastewater; however we cannot confidently conclude that reductions are due exclusively to the softener optimization and replacements. Lack of data for a true paired basin comparison, varied optimization treatments, and small optimization sample participation size, raise questions about the actual effects of the efficiency upgrading treatments, but, when compared to other studies in the same area, findings are nonetheless on target with other estimations of chloride reductions through optimization and replacement treatments as discussed below.

Paired Basin Estimations

This study was originally planned with the structure of a "paired basin" study. However, a number of constraints limited the ability to follow through. In a true paired basin study, data are collected from two similar areas, one area undergoes a planned change while monitoring continues and data are compared for each area between the initial monitoring and the final monitoring for each monitoring period. Since Phase 1, 2013 data collection was compromised, there is no way of confidently comparing the chloride mass in wastewater of the sewersheds before treatments occurred. Enough data could not be obtained for a true paired basin study; estimates of reduction amounts due to the optimization and replacement treatments are making an assumption that the paired sewersheds have similar flows and masses of chloride before treatment. The method for comparing the paired sewersheds to see reductions does not account for the fact that sewersheds might have had some inherent differences, independent of treatment. If accurate Phase 1 numbers had been available, conclusions drawn about the ability to control chloride through optimization and replacement may have been different.

Optimization Variability, Unknown Influence of Plumbing Systems and Sample Size

Through the homeowner survey and replacement process a wide variety of systems were found to exist in homes, as were optimization and set up approaches by water quality professionals. In the optimization treated sewershed, only 45% of homes were actually given an optimization treatment, and of those, treatments varied widely. Choices of which treatments to apply for optimization were left to the discretion of the water quality companies that completed the optimization treatments; there was no one standard optimization treatment that softeners in this sewershed underwent. For example, some were able to be dramatically improved with a comparatively a simple recalibration of settings, some softener models could not be optimized at all (10%), some empty brine tanks were refilled (softeners were working properly, but homeowners did not know they had them and therefore never added salt, adding the salt to return the softener to working order was considered an optimization), while others underwent costly measures such as completely replacing brine tanks or resin.

The fact that optimization was not standardized may introduce another aspect of unmeasurable variation to the study. An extreme example of how optimization techniques varied is with the case of calibrating softeners for incoming water hardness. Companies used a variety of estimations; some companies set the softeners to the gpg hardness they found in their hardness tests, while other companies calibrated the softeners for higher hardness than necessary, using a conservative 10gpg higher than the actual hardness of the source water was.

The variability of the treatments which softeners received for optimization, combined with the fact that the sample size for optimized softeners was small, in comparison to the number of non-optimized softeners in the sewershed, is reason to believe that optimization results are underestimated.

It should also be noted that, a variety of factors including, softener sizing, softener type, quantity of water in the home softened (whole house versus cold only), softener settings, and softener age all influence amounts of chloride contribution from home softeners to wastewater. These factors were not evaluated in this study but appear to influence results, although quantifiable influence on results is unknown (as will be discussed later in recommendations).

Comparison to Similar Studies

Despite difficulties comparing the results in the form of a paired basin study or the unknown influence of other site specific factors abovementioned, estimates of chloride reduction by softener efficiency upgrades found in this study are consistent with other studies in the region. A mini-grant trial period for single family homes in Madison, WI conducted by MMSD and a local water quality company showed a 41% reduction in purchased salt by replacing water softeners with higher efficiency models. Preliminary results for a similar study on multifamily residential water softeners shows a range of 40-70% reductions in purchased salt realized by replacing softeners with higher efficiency models. A study done in Lake Geneva, WI also estimates approximate salt savings of 30% by optimizing softeners.

COST OF SALT REDUCTION

With a total of $2,340 spent on optimizing 13 of softeners, and an estimate of 0.069 kg chloride reduced per day per home in the optimization area, optimization as a source reduction method can be expected to cost approximately $2,614 dollars per 1 kg chloride reduced. Methods for optimizing varied widely and included adding salt to softeners that had run out, washing out debris in brine tanks and refilling, reconnecting or cleaning blocked hoses, adjusting salt dosage or regeneration time, completely replacing brine tanks, recalibrating hardness, setting up or repairing floats and replacing gaskets. Cost of optimization also, therefore, varied from $90-233, averaging about $180. Interestingly, a number of softeners were either not in working order, or did not have any salt in the brine tanks. Even with these idle machines being restored to working order, chloride reductions were still seen in the optimization area. The biggest cost in optimizing softeners was the home visit from water softener company employees. The costs associated with refill of salt, replacement parts, or mechanical fixes were relatively small compared with the in-person labor expenses.

For replacement, $37,800 was spent on replacing 28 softeners, for an approximate reduction of 0.117 kg chloride entering the wastewater stream per house per day. Replacing softeners ultimately yielded a greater reduction of chloride in residential wastewater than optimization treatments, however, had higher per unit reduction costs than optimization. Replacing home water softening units averaged about $1,350 per unit to replace, including parts and labor fees, whereas the price for optimization averaged around $180.

Considering a the total cost of treatments, optimization is a cheaper option per pound of chloride reduced, at $2,614 per kg reduced, verses replacing softeners with high efficiency models costs $11,509 per 1 kg reduced. Based only on total cost, and dollars per pound reduction cost, optimization appears to be the more economically efficient option, however benefits of replacement beyond chloride pollution prevention were not addressed in this study. Based on previous research, it is clear that homeowners may reap other benefits in addition to chloride waste reduction, through optimization or replacement of their softeners, such as, savings from purchasing less softening salts, water utility bill savings, and energy bill savings as proven in previous studies.

For MMSD, knowing the tradeoff between cost and total units of chloride reduction will help inform a chloride reduction plan in which, incentives for homeowners to replace or optimize their softeners, may be included.

CHAPTER 5: SUMMARY AND CONCLUSIONS

SUMMARY

This project quantifies the mass of chloride contributed to wastewater from individual household water softeners, and then used efficiency upgrades to determine how much chloride can be controlled by modifications of existing household softeners, and at what cost.

Research questions were approached by selecting suitable study areas, completing homeowner surveys; monitoring flow, chloride concentration, and conductivity in three phases, and completing optimizations and replacements of softeners in two of the sewershed areas. Results were analyzed and compared to determine a best estimate of mass of chloride contributed by each house. This study found that each house on average contributes about 0.255 kg chloride per day to wastewater streams.

Obtaining results for a true paired basin study in which before and after results could be confidently compared was complicated by monitoring difficulties and funding deadlines, however the study yielded important results for flow and mass of chloride, as well as new methodologies for manhole monitoring. By optimizing and replacing softeners for higher efficiencies, reductions in chloride of 27% for optimization and 47% for replacement were observed. The cost of reducing each pound of chloride is estimated at, $2,614 per kg via optimizations and $11,509 per kg by softener replacement.

Given that household water softening contributes approximately 57% of the total chloride load in MMSD's wastewater inflow (AECOM 2015), replacing softeners with higher efficiency models can cut chloride contributions from home water softeners approximately by almost half (by 47%), contributing significantly to MMSD's chloride reduction goals. Optimizing and replacing softeners for increased salt efficiency will aid MMSD in reaching their target reduction of 20,000 pounds of chloride per day; be a viable and valuable piece of the chloride reduction strategy for MMSD, however not a sole solution.

Challenges and factors with unknown influence in this study present interesting research questions for future studies including, retrial of this study, softener impacts on home water use conservation, sustainability of water softener replacements, and the scientific and economic basis for softener optimization.

AREAS FOR FURTHER RESEARCH

Study Retrial

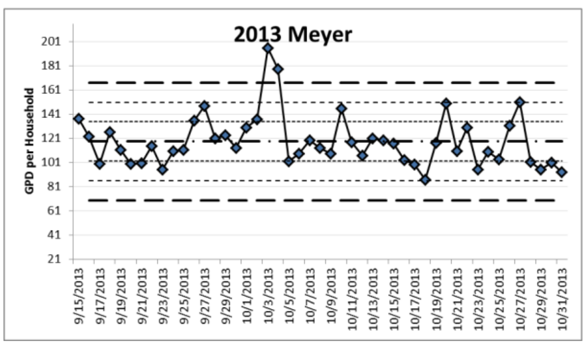
Because of initial challenges with data collection resulting in an originally small subset of data (only a few months) the most obvious area for further study would be a retrial of this study using lessons learned and improved monitoring technologies. With improved methods, it would be ideal to start this study from the beginning in four new sewersheds. Two new pairs, using Phase 2 monitoring techniques should be studied independently for a whole year for a larger set of background data, then one sewershed in each pair should be upgraded, and sewersheds tracked for another whole year. Studying sewersheds independently over a span of two years, one year of study pre and one year of study post treatment, it would be possible to draw conclusions about the long term changes in mass of chloride in wastewater as an output of residential softeners.

Further, having a true paired basin study, it would be possible to draw more conclusions about the amount of chloride that can be controlled through softener optimization and replacement.

Softener Impacts on Home Water Use Conservation

This study undertook significant efforts to measure flow as a factor in calculating mass of chloride in wastewater. Results for Phase 2, weather controlled for, closely followed the flow reported from inflow to homes via MWU's Smart Meters. Results for flow present an interesting facet of water softener upgrades. Results seen for flow raise the question of whether optimizing or replacing water softeners can aid in conserving home water use. In other words, is modifying water softeners a viable water conservation measure? In comparing the usable flow data from 2013 to the 2014 flow data, using Shewhart statistics, see Figure 14 graphs, it appears that the post replacement treatment flows are lower than the original observed flows. In comparing the 2014 control and treatment sewersheds, it also appears that there is some reduction in water use in the treated sewersheds, but as with chloride mass comparisons of the paired sewersheds, it is unknown how much this result is due to inherent differences in the sewersheds versus the applied treatments. Due to the aforementioned concerns with the 2013 dataset, and the lack of a true paired basin, these comparison cannot be considered entirely reliable, but do raise a question for further study.

Figure 14 Meyer Sewershed 2013 vs 2014 Flow



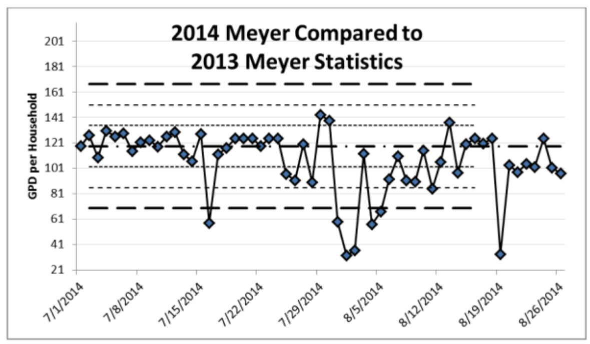


Table 11 Wastewater Flow Comparison Conclusions Phase 2, 2014
***Wastewater Flows in GPD per House**

Control Sewershed	Treatment Sewershed	Control Average	Treatment Average	% Change	Comment
2014 Tomahawk	2014 Risser	140	126	-10	After softener changes, small difference in flow
2014 Winnemac	2014 Meyer	116	107	-8	After softener changes, small difference in flow

Sustainability of Water Softener Replacement as a Chloride Pollution Prevention Strategy

In this study, the sustainability of using water softener upgrades as a means for reducing chloride level in effluent was not evaluated. Further research is needed to weigh the environmental impacts of making chloride reductions via softener replacement and optimization.

Benefits of ion exchange water softeners are well studied; softeners provide energy savings (from reducing water heating needs), prevent scale damage to other home appliances, and can reduce detergent use by up to 70%. Softeners provide conservation benefits which have the potential to reduce a home's heating carbon footprint by as much as 14% per year (Water Quality Research Foundation 2009). Waste generation and regression of softener efficiency is not well studied however. Further research is needed on waste products generated by replacing softeners. Disposal of tanks or old machines, electronics recycling options, toxicity of waste, waste generated by resin changes, are all aspects that need to be weighed against benefits for an estimation of sustainability.

Further, water softener resins degrade over time, with a lifetime of about 10 years. Reduction in the amount of salt used as a product of replacing old machines with newer models are not fixed; that is, the efficiencies gained in the replacement/optimization process regress as resin degrades. Ultimately, resin will need to be replaced to maintain salt use reductions. Using incentive programs for softener upgrades as a pollution prevention method may need to be ongoing to upkeep reductions.

Scientific and Economic Basis for Softener Optimization

In this study, MMSD learned valuable information about the challenges of optimizing household water softeners, the variability of systems, and important information about the average daily water use per person; however questions about the scientific basis for softener optimization still remain.

Considering findings from flow readings, flow measurements and information gathered through home surveys, MMSD made updates to their 2011Water Softening Best Practices Guidelines in Appendix D. These best practices are still somewhat limited in that more information on the scientific basis for softener optimization and upgrade is needed, including the quantifiable effects of softening water to only hot water systems, partial softening of hot water systems (to only about 100 mg/L as $CaCO_3$ (5.8 gpg)), lower fill rates for tubs, single faucet use in showers, softener size in comparison to the capacity needed for the home, and valve/figure selection (size of openings). Having information on the quantifiable effects of these various factors can aid in selecting pollution minimizing systems while still considering holistic assessment of a home's softening needs. Recommendations on these topics were not made in this study for the optimization process, but preliminary studies in the field indicate that the above mentioned are practices with potential for chloride reduction.

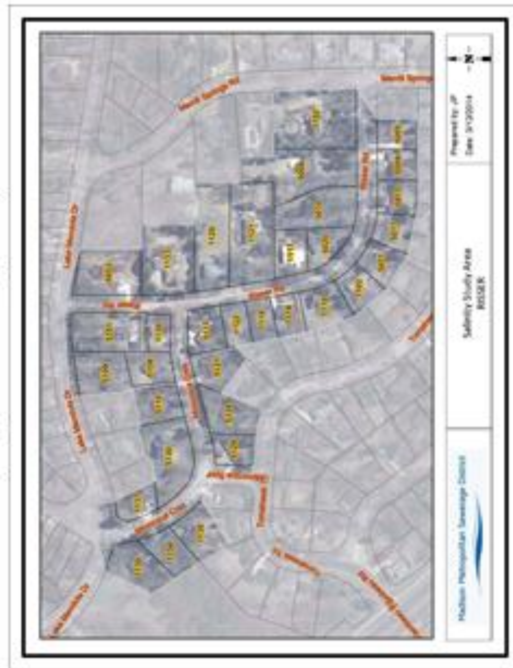
One factor in the scientific basis for softener optimization is measuring the source water for calibration of softeners. In the survey process, there was an inconsistency in measurement identified. There is a need for consistent and unified methodologies and metrics across the industry for water hardness measurements. Having accurate measurements of water hardness will aid water quality companies to properly assess the home's need for water softening equipment and set up type. In this study, a variety of hardness testing methods used by MMSD, volunteers, and water quality companies were found to produce differing results. For example, water quality companies and volunteers using hardness test strips and HACH hardness test kits all found differing water hardness in the household water ranging from 23-32 grains, whereas during the same period, at the same homes, the MWU and MMSD measured a hardness of only 26.6-26.8 grains (see Appendix F). Similar observations were present throughout all homes in the study, in all four sewersheds. Samples analyzed by the MMSD lab as mg equivalent $CaCO3/L$ = 2.497(Ca, mg/L) + 4.118(Mg, mg/L), hardness calculated in grains was equal to 1 grain=17.1mg, with the use of an ICP instrument to measure calcium and magnesium content yielded similar results to Madison Water Utility's titration method. While results from MMSD and MWU consistently matched each other, they did not regularly match results from other testing methods. Differing measurements are attributable to differing testing equipment and inconsistent testing methods. In order to precisely measure the hardness of water coming to a softener, water quality companies can rely on MWU measurements, which are publicly available and updated often, or can provide training to their employees about proper use of the HACH kits. Having an industry standard, unified and scientifically based method for measuring water hardness, and consistent training on how to perform tests correctly for home water quality professionals can both give consumers confidence in services offered by the softener companies, as well as give softener companies a solid basis for making decisions about machine/model selection, correct capacity selections, and important information when performing optimizations.

APPENDICES

APPENDIX A – SEWERSHED MAPS

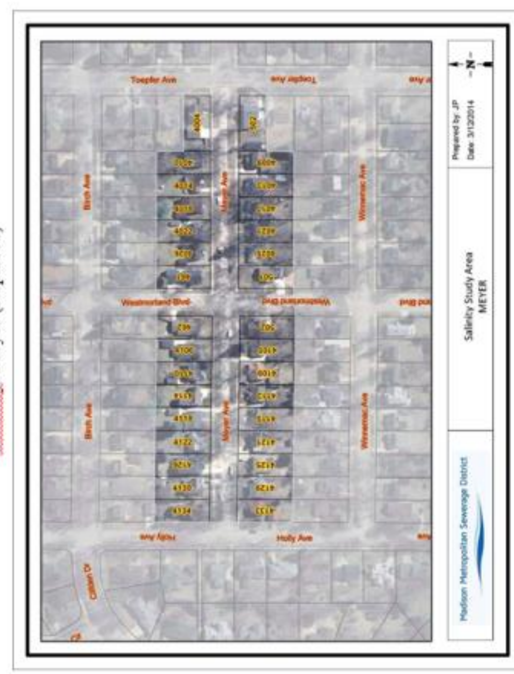
Phase 1Sewershed Maps

Spring Harbor: Tomahawk (No Modification)



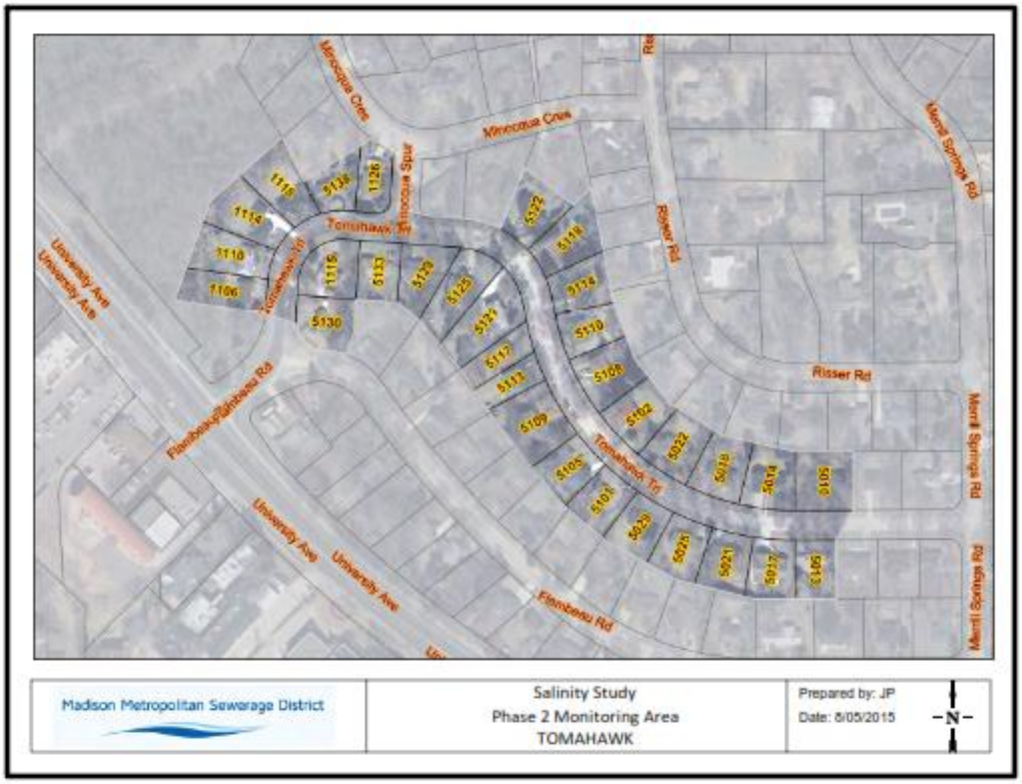
Spring Harbor: Risser (Optimized)

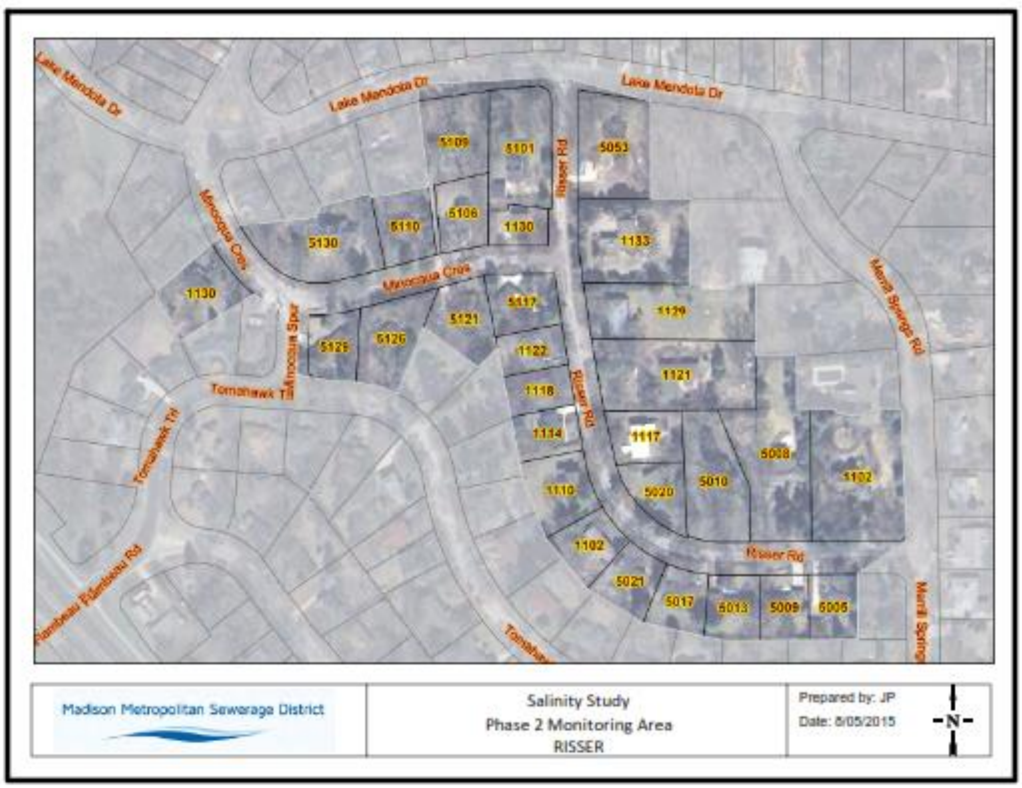
Glenway: Winnemac (No Modification)



Glenway: Meyer (Replaced)

Phase 2 Sewershed Maps – Tomahawk and Risser Modifications
(Winnemac & Meyer remain the same as Phase 1 maps for Phase 2)





APPENDIX B – SURVEY MATERIALS

First Post Card (front)

Madison Metropolitan Sewerage District
Attn: Kathy Lake
1610 Moorland Rd
Madison WI 53713

First Post Card (back)

Water Softening Optimization Study

Name: _______________

Address: _______________

Which day(s) work better? **Monday** **Tuesday**
The time (s) that works best?
4-4:30pm______ **4:30-5 pm**______
5-5:30 pm_____ **5:30-6 pm** ______
6-6:30 pm____ **6:30-7 pm**______

Comments? _________________________

Want a confirmation call or email? This is optional.
Phone# ___________Email:__________

If none of the times work, please contact kathyl@madsewer.org or 608.222-1201, ext. 278 to set up a more convenient time

Madison Metropolitan Sewerage District
Attn: Kathy Lake
1610 Moorland Rd
Madison WI 53713

Do you have a water softener? **Yes** **No** **Yes, but not working**

If yes, what brand? ________________________

Approximately what year was it installed? __________

Model Number and/or Serial Number __________________

Is any of your cold water softened? **Yes** **No** **Unsure**

Comments?

Introductory letter sent out with first postcard:

Our waterways need your help!

Too much salt is finding its way to our lakes and streams. Not only does the salt that we put on streets, parking lots and sidewalks in the winter get washed into our lakes and streams, but the salt from our water softeners eventually ends up in our streams, too.

The Madison Metropolitan Sewerage District's (MMSD) wastewater treatment plant can't currently remove salt from our wastewater. Therefore, once softener salt is in the water, it eventually ends up in local streams. Salts (chlorides) are bad for the fish and the beneficial plants in the lakes and streams.

Water softeners contribute over 60% of the salt that MMSD receives daily in wastewater. There is anecdotal evidence that existing water softeners can be tuned up to make significant improvements to their efficiencies, but there is no science that tells us if this is true and how significant these reductions could be. We will be conducting a pilot project aimed at answering these questions. The results will benefit our waterways and save rate payers money by allowing MMSD to avoid having to install new and expensive treatment equipment to remove salt.

MMSD needs your help to test water softener efficiency.

Homes on your street have been selected by MMSD and the Madison Water Utility to participate in a pilot project designed to improve water softening efficiency. As a first step, students from UW-Madison's WE Badger Volunteers program will visit homes on your street between **June 24 and August 6, 2013** to gather information on your water softener and how softened water is used within your home. To do this, they will need to enter your home for about 20-minutes to view the softener and plumbing configuration. The WE Badger Volunteers will be wearing t-shirts and will carry identification. Staff from Madison Metropolitan Sewerage District will be assisting the volunteers and will also have identification. **Please help our waterways and save money by participating in this important project**. To schedule a convenient time, please return the enclosed response card.

MMSD will show its appreciation.

For participating in this program, you will receive a free water softener tune up from one of the local water quality professionals. These will occur later this fall or next spring (confirmation will be sent to participants) as well as useful tips on water softener operation and maintenance.

Information from this project will help determine the most practical and cost-effective means of reducing salt entering the sewer system. The results will likely help you (and eventually others) save water, money and use less salt.

If you have any questions, please contact Kathy Lake at MMSD (email: kathyl@madsewer.org; phone: 608-222-1201, ext. 278). Thank you for your support with this very important project.

Sincerely,

Kathleen Lake, Environmental Specialist
Madison Metropolitan Sewerage District
1610 Moorland Road
Madison WI 53713

Survey P.1

Site ID: ________ Interview conducted by: ________________ Date: ________

A. SITE INFORMATION

Name of property owner: _ ______________________________ Preferred Phone: ____________

Street Address ________ ______________________________

B. RESIDENTS

1. Are you the owner of the residence? Yes / No
2. How many people live in the home?

Adults (18 yrs and older)	
Teens (≥13 and <18 yrs.)	
Children (>2 to <13 yrs.)	
Infants (0 to 2 yrs.)	

C. HOME DETAILS

1. What year was the house built? ________
2. How many are in the house? ___Full Baths ___ Half Baths ___ Kitchens ___Wet Bar
3. Is the residence _____Permanent or _____Seasonal? If seasonal, how many months per year is it used?_________
4. Is the residence a _____ Single-family or a _____ Multi-family residence other _______________

D. WATER TREATMENT DETAILS

5. Are you satisfied with your water quality? Yes / No If no, why not? ____________________________
6. Do you have a water softener? _________
7. When was it installed? _______Year
8. Do you ever force regeneration? _________ If so, why? ____________________
9. Do you see/think that hard water is passing through the softener at times? ______________
10. When was the last time your water softener was serviced? __________Who did it? Self, Professional, other
11. What water in the house is softened? _______________________
    a. Faucets tested: Is kitchen cold hard?_____ Does other cold water appear soft?_____ Number tested?___
12. How many pounds of softener salt do you purchase per year? ______ Per month?_____
13. Are any exterior water faucets connected to the water softening system? Yes / No
14. Do you have any water treatment devices? If so, what?____________________
15. If you have a water softener, do you use the suggested amount of soap, detergent, etc. as recommended on the product instructions or half of that amount because you are using soft water? Suggested amt __ fraction of ___

E. WATER USE / APPLIANCES

1. Is there significant water use for: ____ Pool ____ Irrigation ___Car washing ___Hot tub (Exterior) Other? ________
   i. If a pool or hot tub: How often is it drained? ____, Where does it drain? ____ Is it salt water generating? _____
2. Are there water conserving fixtures/appliances in the home?
   a. ___Toilets __Shower heads ___ Faucets__ Front load washer ___ Unknown ___ Others: ____________
3. Do you have a garbage disposal? Yes / No How many times per week is it used? ______________
4. Do you have a dishwasher? Yes / No How many times per week is it used? ______
5. Do you have a single-head shower? Yes / No How many times per week is it used? ____
6. Do you have a panel shower (>3 heads or jets)? Yes / No How many times per week is it used? _______
7. How many baths (conventional size) are taken per week? ______
   a. Do you have a whirlpool tub? Yes / No How many times per week is it used? _____
8. Do you do laundry at home? Yes / No
   a. How many loads do you wash per week? _____Of these, how many are hot water cycles? ____
   b. What is the maximum number of loads you wash in one day's time? _____
   c. If yes, are the loads consecutive? Yes / No / N/A
9. Do you have a basement floor drain? Yes / No / Don't know
   a. Which, if any of the following, are using the floor drain? Water softener__Furnace__ Air Conditioner___ Humidifier___ Dehumidifier ___ Sump pump/foundation drain__

Do you have any questions? Q&A on back

Survey P.2

A. SITE INFORMATION

Site ID: ________ Interview conducted by: ________________ Date: ________

Survey Part 2 – conducted by Volunteer 2:

Interview conducted by: ________________ Date: ________

- Request homeowner permission for the following:
  - Photograph of treatment/softener/controller Permission? Yes No
  - Reset the regeneration time to 2 am Permission? Yes No
  - Adjust the time to match current time Permission? Yes No

F. WATER QUALITY AND TREATMENT

1. Is there a water softener? Yes / No
2. What is the hardness of the unsoftened water? ____________
   a. Test performed by__________
   b. Q/A performed by ___________
3. What is the hardness of the softened water?
   a. Hot Soft ___________
   b. Cold Soft ____________
4. Are there other treatment devices? __________
   Point of Entry "POE"/Wholehouse Systems:
   a. GAC/Carbon Filtration ___R.O. Reverse Osmosis ___U.V. Ultraviolet _____Other________________
   b. Before or after water softener?_______________________
5. Water Softener serial number: ________________
   Make: ___ Capital ___Fox ___Culligan ___Hellenbrand ___Bruner ___Eco ___Sears ___Other ________________
   Model: ______________ Capacity/Grains: __________ Current Salt Setting: ___Lbs.
   ___Time Clock (if time clock, regeneration frequency) every ___Days
   ___ DIR Demand Initiated Regeneration - ___Meter/Gallons (if meter, meter setting) ____gallons
   ___ DIR Demand Initiated Regeneration - ___Sensor

	Time Clock	Metered System	Hardness Sensor
Hardness Setting:			
Regeneration Setting:			
Salt Dosage:			
Reserve Capacity:			

6. What time is the softener set to regenerate at? _____________ (request permission from homeowner to adjust it to 2 am. If no, note actual time here).
7. Is the time shown on the softener the same as the actual time? ______ (request permission from homeowner to adjust it to the current time.) If not adjusted, note the time shown on the softener _____ and actual time _____

Thank you for taking the time to answer these questions for us. By doing so, you are assisting with important research on the way we can reduce the amount of chlorides that pass through our wastewater treatment plant.

What, if any, questions do you have?

Page 2

A. SITE INFORMATION

Site ID: ________ Name of property owner: ________ Street Address ________

Faucet ID	Water System (H or C)	Total Hardness from test strip (gpg)	Comment

APPENDIX C – OPTIMIZE OR REPLACE RECRUITMENT LETTERS AND FORMS

Free Tune-Up/Optimization Offer Letter

Re: Free Professional Water Softener Tune-Up

Dear Homeowner,

As part of our water softening efficiency study, a professional service technician from the local water quality companies: Hellenbrand, Inc., Culligan Total Water, Fox Soft Water or Capital Water Softener will optimize your softener to help it run as efficiently as possible. Your softener will be tuned up by its manufacturer. Our records indicate that your existing equipment is from:

Capital Water Softener, Inc.
2096 Helena St.
Madison, WI. 53704
Phone: (608) 241-1511
Fax: (608) 241-5709
Email: cws@capwater.com

Please contact them in the next couple days to set up a time for this service call. This service is FREE to you. These local professionals are donating their time and equipment to make this program a success. Information from this project will help determine the most practical and cost-effective means of reducing salt entering the sewer system. The results will likely help you (and eventually others) save water, money and use less salt while improving the environment.

If you have any questions or need assistance, please contact Kathy Lake at MMSD. Thank you for your support of this very important project.

Sincerely,

Kathleen Lake, Environmental Specialist
Madison Metropolitan Sewerage District
1610 Moorland Road
Madison WI 53713
608-222-1201, ext. 278
email: kathyl@madsewer.org

Madison Metropolitan Sewerage District

Free Replacement Softener Offer Letter

Re: Free High Efficiency Water Softener

Dear Homeowner,

As part of our water softening efficiency study, your home will be receiving a new high efficiency water softener. This softener will be professionally installed by the local water quality company that provided your existing softener: Hellenbrand, Inc., Culligan Total Water, Fox Soft Water or Capital Water Softener. Please confirm the brand of your softener and call the appropriate professional:

Culligan Total Water	Capital Water Softener, Inc.	Fox Water	Hellenbrand Water Center
5002 World Dairy Drive	2096 Helena St.	1017 N. Sherman Ave	404 Moravian Valley Rd.
Madison WI 53718	Madison, WI. 53704	Madison WI 53704	Waunakee, WI 53597
Phone: 608-221-2236	Phone: (608) 241-1511	Phone: (608) 244-6215	Contact Person: Loran Schulz
			Direct Line: 608-849-0922

If your softener is from a different manufacturer, you can contact any of the companies listed above. Please contact your professional in the next couple days to set up a time for your new softener to be installed. This service is FREE to you because it is being paid for by a partnership which includes the local water quality professionals, the Water Quality Research Foundation, the Madison Water Utility and the Madison Metropolitan Sewerage District. This new softener will save you money and improve the environment by using less salt and less water. Information from this project will help determine the most practical and cost-effective means of reducing salt entering the sewer system.

To complete this study, we want to replace these softeners in the next two weeks. These units retail for approximately $1350. If you have any questions or need assistance, please contact Kathy Lake at MMSD. Thank you for your support of this very important project.

Sincerely,

Kathleen Lake, Environmental Specialist
Madison Metropolitan Sewerage District
1610 Moorland Road
Madison WI 53713
608-222-1201, ext. 278
email: kathyl@madsewer.org

Madison Metropolitan Sewerage District

Optimization Form

Water Softening Study – Optimization Phase

Site Address: ________________Optimization conducted by: _____________ Date: ________

1. Family Size? ______________
2. Plumbing Configuration? **Hot Soft only**__________
   Hot and Cold Soft, except for outside hose bibs & kitchen sink_________
   Other? (explain)______________________________

3. Are there other treatment devices? __________
   Point of Entry "POE"/Wholehouse Systems:
   a. Activated Carbon____, R.O. (POU) (POE), U.V. ___Other______________________
   b. Before or after water softener?________________________

4. Water Softener serial number: _____________________
   Make: Capital __Fox __Culligan __Hellenbrand __Bruner __Eco ___Sears ___Other (   )_________

   Model: _______________Capacity/Grains: __________ Capacity (cf): _______________
   Current Salt Setting: ______Lbs
   ___Time Clock (if time clock, regeneration frequency) every ___Days
   ___ DIR Demand Initiated Regeneration - ___Meter/Gallons (if meter, meter setting) ____gallons
   ___ DIR Demand Initiated Regeneration - ___Sensor

	Original Settings	Optimized Settings
Hardness Setting:		
Regeneration Setting:		
Salt Dosage:		
Reserve Capacity:		
Other? _____________		

5. What time is the softener set to regenerate at? ______________ .

6. Is the time shown on the softener the same as the actual time? ______ If not adjusted, note the time shown on the softener _____ and actual time _____

7. Does the current softener appear to be working? ____________
   a. Hardness Reading: Cold Water _________, Hot Water _____________

8. Is there salt in the existing brine tank? _____________

9. Was the brine tank replaced? ___________ How much salt was added? ____________

10. Were any repairs made to the system: (list and describe)
    a. ________________
    b. ________________
    c. ________________

11. Are there any other recommendations or comments?

Replacement Form

Water Softening Study – REPLACEMENT

Site Address: _______________Replacement conducted by: _____________ Date: ________

1. Family Size? _____________
2. Plumbing Configuration? Hot Soft only__________
   Hot and Cold Soft, except for outside hose bibs & kitchen sink_________
   Other? (explain)___________________________

3. Are there other treatment devices? __________
   Point of Entry "POE"/Wholehouse Systems:
   a. Activated Carbon____, R.O. (POU) (POE), U.V. ___Other_____________________
   b. Before or after water softener?_______________________

4. Existing Water Softener serial number: ____________________
   Make: Capital __Fox __Culligan __Hellenbrand __Bruner __Eco ___Sears ___Other (   )_________

   Model: _______________Capacity/Grains: __________ Capacity (cf): _______________
   Current Salt Setting: ______Lbs
   ___Time Clock (if time clock, regeneration frequency) every ___Days
   ___ DIR Demand Initiated Regeneration - ___Meter/Gallons (if meter, meter setting) ____gallons
   ___ DIR Demand Initiated Regeneration - ___Sensor

	Original Softener Settings	New Softener Settings
Hardness Setting:		
Regeneration Setting:		
Salt Dosage:		
Reserve Capacity:		
Other? _____________		

5. New Water Softener serial number: ____________________
   Make: Capital __Fox __Culligan __Hellenbrand __Bruner __Eco ___Sears ___Other (   )_________

   Model: _______________Capacity/Grains: __________ Capacity (cf): _______________
   Current Salt Setting: ______Lbs
   ___Time Clock (if time clock, regeneration frequency) every ___Days
   ___ DIR Demand Initiated Regeneration - ___Meter/Gallons (if meter, meter setting) ____gallons
   ___ DIR Demand Initiated Regeneration - ___Sensor

6. What time is the softener set to regenerate at? ______________ .

7. Is the time shown on the softener the same as the actual time? ______ If not adjusted, note the time shown on the softener _____ and actual time _____

8. Does the current softener appear to be working? ____________
   a. Hardness Reading: Cold Water _________, Hot Water _____________

9. Was the brine tank replaced? ___________ How much salt was added? ____________

10. Are there any other recommendations or comments?

APPENDIX D – WATER SOFTENING BEST PRACITCES GUIDELINES

Madison Metropolitan Sewerage District

1610 Moorland Road • Madison, WI 53713-3398 • P: (608) 222-1201 • F: (608) 222-2703

Water Softening Best Practices Guidelines

The following best practices guidelines are steps that can be taken by water treatment professionals, whenever practicable, as part of an effort to reduce chloride contributions to wastewater treated by the Madison Metropolitan Sewerage District (MMSD):

1. Evaluate existing softening units during service calls, make adjustments as necessary to more efficiently use salt and verify the hardness settings are in line with the actual hardness tested on site. Review the historical softened water use, and family size and use that data to set softener as efficiently as possible.
2. Provide the consumer with educational material developed by MMSD and/or water treatment representatives regarding the benefits of upgrading to a more efficient softening system.
3. Setting residential and commercial applications to the same softening criteria
4. Residential softening:
    a. Following Wisconsin plumbing code's alternative sizing criteria for residential installations.
    b. Using a typical rate of 40 gallons of water consumed per person per day and the actual number of household residents, or by using the actual flow rates based on the history obtained from an existing softener.
5. Using a minimum softening efficiency for new softening equipment of 4000 grains per pound of salt.
6. Using a maximum regeneration water usage of 2.5 gallons of water per 1000 grains of hardness provided.
7. Sizing a regeneration frequency of no less than 3 days at 4000 grains/lb of salt.
8. The replacement of existing water softening systems or installation of new water softening systems within the Madison Metropolitan Sewerage District service area should be consistent with requirements in Wisconsin Administrative Code Comm 82.40(8)(j), which states that *ion exchange water softeners used primarily for water hardness reduction that, during regeneration, discharge a brine solution shall be of a demand initiated regeneration type equipped with a water meter or a sensor unless a wastewater treatment system downstream of the water softener specifically documents the reduction of chlorides.*

MMSD may modify these best practices guidelines from time to time as new information becomes available.

May 14, 2015

APPENDIX E – FLUSHABLE HANDOUT

A message from Madison Metropolitan Sewerage District

Think again...

What we put down our drains and toilets can negatively impact our environment and put our health at risk. Even items labeled flushable can clog pipes, tangle pumps and result in messy and costly sewer backups. By educating ourselves and each other, we can avoid expensive and dangerous mistakes while improving our sewer system practices.

Steps we can take

There are only two items that we should ever flush: human waste and toilet paper. If you cannot avoid purchasing and using items that have been labeled "flushable," throw them away after use rather than putting them into our sewer system.

If you need to discard hazardous materials such as used motor oil, antifreeze, paint, etc., visit the clean sweep collection site. You can find more information at **www.danecountycleansweep.com**. Dispose of unused medicines at the MedDrop site; information can be found at **www.safercommunity.net/meddrop.php**.

Learn about EnAct steps to greener living at **www.enactwi.org**.

Questions? Find us on the web at **www.madsewer.org** or call **608.222.1201**.

Never flush:

- Baby wipes, disinfectant wipes, moist wipes, etc.
- Vitamins, medicines or other pharmaceuticals
- Toilet bowl scrub pads
- Swiffer® products
- Napkins *(paper or cloth)*
- Paper towels
- Dental floss
- Fats, oils and greases
- Sanitary napkins, tampons, condoms or any non-organic materials
- Wash cloths, towels, rags, underwear or any cloth items
- Band-Aids® or dressings
- Plastic bags or wrappers
- Kitty litter *(even products labeled as flushable)*
- Cat feces or bagged dog feces
- Fish gravel

Madison Metropolitan Sewerage District

APPENDIX F – WATER HARDNESS TEST VARIABILITY

HOUSE Code	Setting Before Treatment	WQ Set/Test	MMSD Test	MWU Test	WQ Company	difference WQ & MWU
3	25	23	26	26.75	3	3.75
4	Unknown	Unknown	26	26.75	3	N/A
5	Unknown	Unknown	26	26.75	3	N/A
12	N/A	N/A	27	26.75	N/A	N/A
15	20	32	26	26.75	4	-5.25
19	20	25	26	26.75	2	1.75
22	N/A	N/A	26	26.75	N/A	N/A
26	22	25	26	26.75	2	1.75
29	27	31	26	26.75	1	-4.25
30	N/A	N/A	26	26.75	N/A	N/A
32	Unknown	Unknown	26	26.75	3	N/A
70	Unknown	19	17	16	3	-3
71	Unknown	19	17	16	4	-3
73	Unknown	19	16	16	4	-3
75	27	27	16	16	1	-11
76	Unknown	19	17	16	3	-3
78	25	27	16	16	1	-11
79	N/A	N/A	23	16	N/A	N/A
81	Unknown	19	16	16	4	-3
87	Unknown	Unknown	17	16	4	N/A
93	Unknown	19	17	16	3	-3
94	27	27	17	16	1	-11
95	27	27	18	16	1	-11
96	Unknown	19	17	16	4	-3
18	35	30	No MMSD Test	26.75	3	-3.25
6	Unknown	Unknown	No MMSD Test	26.75	3	N/A
33	Unknown	Unknown	No MMSD Test	26.75	3	N/A
25	Unknown	Unknown	No MMSD Test	26.75	3	N/A
9	Unknown	Unknown	No MMSD Test	26.75	3	N/A
11	Unknown	Unknown	No MMSD Test	26.75	3	N/A
97	Unknown	19	No MMSD Test	16	3	-3
98	Unknown	19	No MMSD Test	16	3	-3
88	Unknown	19	No MMSD Test	16	3	-3
20	Unknown	28	No MMSD Test	26.75	1	-1.25
68	Unknown	19	No MMSD Test	16	3	-3
83	25	27	No MMSD Test	16	1	-11
84	21	27	No MMSD Test	16	1	-11
74	25	27	No MMSD Test	16	1	-11
82	25	27	No MMSD Test	16	1	-11
80	Unknown	19	No MMSD Test	16	4	-3
69	Unknown	Unknown	No MMSD Test	16	4	N/A
89	Unknown	19	No MMSD Test	16	4	-3
91	Unknown	19	No MMSD Test	16	4	-3
72	N/A	19	No MMSD Test	16	4	-3
85	18	18	No MMSD Test	16	2	-2
92	15	20	No MMSD Test	16	2	-4
99	18	18	No MMSD Test	16	2	-2
34	32	32	No MMSD Test	26.75	4	-5.25
10	21	32	No MMSD Test	26.75	4	-5.25
1	26	32	No MMSD Test	26.75	4	-5.25
28	17	30	No MMSD Test	26.75	4	-3.25
8	20	Unknown	No MMSD Test	26.75	4	N/A
2	20	25	No MMSD Test	26.75	2	1.75
35	20	25	No MMSD Test	26.75	2	1.75

REFERENCES

AECOM. 2015. Chloride Compliance Study Nine Springs Wastewater Treatment Plant. Madison, WI: AECOM. [online] Available: <http://www.madsewer.org/Portals/0/ProgramInitiatives/ChlorideReduction/MMSD%20Chloride%20Compliance%20Study%20Report%20-%20Final%206-19-15bookmarks.pdf> [cited July 29, 2015]

Asche, Kelly, Sharice Fontenot, Sam Lee. 2013. City of Morris - Chloride Discharge Assessment. Morris, MN: University of Minnesota, Morris, Center for Small Towns. Book 66. [online]<http://digitalcommons.morris.umn.edu/cst/66> [cited July 9, 2015]

Benoit, Duane A. 1988. Ambient Water Quality Criteria for Chloride. Duluth, MN: United States Environmental Protection Agency.

Effluent Limitation & Variances to Water Quality Standard, 2011. Wisconsin Administrative Rules Code, Subchapter III, Variances to Water Quality Standard. Wis. Stats. NR 283.11-283.21.

Environmental Protection Agency. 1986. Quality Criteria for Water.Washington, DC: Office of Water Regulations and Standards. [online] Available: <http://water.epa.gov/scitech/swguidance/standards/criteria/aqlife/upload/2009_01_13_criteria_goldbook.pdf> [cited June 18, 2015]

Environmental Protection Agency. 2014. National Recommended Water Quality Criteria, Aquatic Life Criteria Table. [Online]. Available: <http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm> [cited June 18, 2015]

Holt, Jim. 2015. Chloride: Exploring the Water Quality Issue Outside the Box. Santa Clara, CA: Santa Clara Valley News. [online] Available: <http://www.signalscv.com/m/section/36/article/137866/> [cited June 18, 2015]

Hunt, Molly, Elizabeth Herron and Linda Green. 2012. Chlorides in Fresh Water. Kingston, Rhode Island: University of Rhode Island College of the Environment and Life Sciences, URI Cooperative Extension Watershed Watch.

Madison Metropolitan Sewerage District. Chloride FAQ: Madison, WI. [online] Available: <http://www.madsewer.org/Programs-Initiatives/ChlorideFAQ#WhyShouldICare [cited July 8, 2015]

Madison Water Utility. 2012-2014. “Residential Cross Connection Survey” (Public Utility Study, Madison, WI, 2012).

Madison Water Utility. 2015. Q&A. Madison Water Utility Education and Outreach : Madison, WI. [online] Available: <https://www.cityofmadison.com/water/faq> [cited June 19, 2015]

Metcalf and Eddy AECOM, George Tchobanoglous, David Stensel, Ryujiro Tsuchihashi, Frank , Mohammad Abu-Orf. 2014. Wastewater Engineering: Treatment and Resource Recovery, Fifth Edition. New York, NY: McGraw-Hill Education.

Procedures for Calculating Water Quality Based Effluent Limitations for Point Source Discharges to Surface Waters, 2005. Wisconsin Administrative Rules Code, Subchapter VII, Effluent Limitations for Chloride Discharges. NR 106.80-NR 106.96.

United States Geological Survey (USGS). Updated 2013. "Water Hardness and Alkalinity". [online] Available: <http://water.usgs.gov/owq/hardness-alkalinity.html#map> [cited August 6, 2015]

Water Quality Research Foundation.2009. Softened Water Benefits Study. Lisle, IL: Water Quality Research Foundation. [online] Available: <http://www.wqa.org/Portals/0/WQRF/ResearchStudy_BenefitsOfSoftenedWater_ExecSummary.pdf> [cited July 27, 2015]

Wheeler, Donald J. and David S. Chambers. 1992. Understanding Statistical Process Control (2nd ed.). Knoxville: SPC Press.

Wisconsin Department of Natural Resources. 2014. DNR's Recommendations for PMPs and SRMs for Arsenic, Chloride, Copper and mercury Variances. Madison, WI: Department of Natural Resources Bureau of Water Quality Program Guidance Wastewater Program.

GLOSSARY & ABBREVIATION LIST

DNR – Wisconsin Department of Natural Resources

EPA – also known as US EPA, the United States Environmental Protection Agency

GPD – Gallons per day. How wastewater flow was measured for this study.

GPG – Grains per gallon. A measure of water hardness

High Efficiency Softener – A water softener that removes 4,200 grains of hardness per pound of salt or greater is considered a high efficiency softener. Older model softeners usually remove 0-3500 grains per pound of salt.

KGD – Kilograms per day

MMSD – Madison Metropolitan Sewerage District

MWU – Madison Water Utility

Non-parametric statistical technique – a statistical technique that does not depend on the assumption that measurements fall into a "Normal Distribution"

Optimized – in the context of water softener optimization, means that the water softener's operating parameter, pounds of salt used per cubic foot of softener resin, will be set in existing water softeners to an agreed upon amount which will be lower than the typical settings of older water softeners

Sewershed – an area where all wastewater drains to a single manhole for the sanitary sewer system

WPDES – Wisconsin Pollutant Discharge Elimination System