TECHNICAL MEMORANDUM

Reverse Osmosis Concentrate Disposal Issues

PREPARED FOR: Wisconsin Department of Natural Resources

COPY TO: Waukesha Water Utility

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Introduction

In conjunction with its technical review of the City of Waukesha Application for a Lake Michigan water supply, the Wisconsin Department of Natural Resources (WDNR) requested additional information about reverse osmosis (RO) for community water systems. RO is used to achieve a variety of water treatment objectives, including the removal of radium and total dissolved solids (TDS). If the City of Waukesha continues to rely on the deep aquifer for its water supply, RO treatment will likely be needed in the future to remove TDS from the groundwater. An increase in TDS has already occurred in well #9 in Waukesha Wisconsin. Other wells have shown an increase in TDS as pumping increases.

Advantages of RO treatment include the ability to remove a wide range of contaminants in a relatively small footprint. RO treatment is commonly used in arid regions for the removal of TDS from saltwater or brackish water sources. In the Midwest, RO treatment is typically used to remove specific contaminants like nitrates or radium, which may be present in groundwater or surface water supplies. It can also be used to remove hardness from the water in lieu of lime softening or ion exchange. In some cases, RO can remove TDS where other technologies such as lime softening and ion exchange cannot.

Disadvantages of RO treatment include relatively high capital and operating cost, need for pre-treatment systems upstream of RO, use of several chemicals for routine cleaning of membranes, neutralization and disposal of spent cleaning chemicals, and generation of a high volume of concentrated wastewater (i.e., 25 percent of total flow).

The purpose of this technical memorandum (TM) is to present some information on alternative approaches community water systems use to address RO concentrate disposal issues.

Background

Membranes act as selective barriers, allowing some constituents to pass through the membrane while blocking the passage of others. The movement of material across a membrane requires a driving force (i.e., a potential difference across the membrane), and the membrane processes commonly employed in drinking water applications use pressure as the driving force. There are four categories of pressure-driven membrane processes: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). RO and NF processes are typically applied for the removal of TDS including both inorganic and organic compounds. These processes operate at pressures (i.e. 150 – 1,200 pounds per square inch gauge [psig]) significantly higher than MF and UF. MF and UF processes are often used as pre-treatment for RO and NF systems.

RO concentrate disposal issues present significant design and operational challenges that must be addressed. A summary of the typical RO concentrate disposal options is summarized in Table 1.

Table 1. RO Concentrate Disposal Approaches

Disposal Option	Description	Applicability to Midwest
Ocean Outfall	In coastal areas, the common alternative for the disposal of RO concentrate is through an ocean outfall. Although the TDS values of RO concentrates from brackish water desalting are significantly less than seawater TDS, they are typically greater than 10,000 milligrams per liter (mg/L), which makes them more compatible with ocean water than fresh waters. Often, it is practical to combine the concentrate with wastewater treatment plant effluent that is being discharged via an ocean outfall.	Not applicable to Midwest.
Surface Water Discharge	Surface waters represent probably the least-cost alternative for concentrate disposal because disposal costs are limited to pipelines to transport the concentrate to the point of gravity discharge. Surface water discharge is regulated by the Clean Water Act through issuance of a National Pollutant Discharge Elimination System (NPDES) permit. Securing an NPDES discharge permit for RO/NF concentrate disposal is becoming more difficult and costly as stream standards become more stringent nationwide.	High TDS in RO concentrate makes NPDES permitting very challenging. For example, the City of Columbus, Ohio abandoned pursuit of RO treatment for nitrate due to NPDES discharge issues.
Sanitary Sewer Discharge	Sanitary sewer discharge is probably the most common method for RO concentrate disposal in the Midwest. A nearby sanitary sewer with high carrying capacity must be readily available. Sanitary discharge fees also apply. Since most wastewater treatment facilities discharge to surface waters, NPDES limits will apply. Elevated levels of TDS or radium can prohibit discharge to a sanitary sewer.	Applicable to Midwest, but sanitary sewer connection must be available and NPDES permit issues addressed for TDS, radium, and other constituents.
Deep Well Injection	Deep well injection of RO concentrate can be used in locations that have favorable hydrogeological conditions for injection into zones that are not classified as an underground source of drinking water (typically aquifers with TDS concentrations in excess of 10,000 mg/L). Limited well capacity and high pressure requirements often limit the use of this approach. This method also requires high energy consumption due to high pressure required to pump into deep aquifers.	Applicable mostly to FL, TX, and other inter-coastal locations with brackish water geologic formation. Not applicable in Wisconsin because deep well injection is not allowed per regulations.
Evaporation Ponds	Evaporation ponds utilize solar energy to separate salts from water. Evaporation ponds are only viable in regions where the climate affords high rates of evaporation and adequate space is available.	Not practical in the Midwest due to long, cold winters and wet springs and summers.
Wetlands Treatment (Salt-Tolerant)	Constructed engineered wetlands consisting of upflow biochemical reactors or naturally occurring salt-tolerant wetlands can reduce RO concentrate. In some cases, blending with treated water is required to achieve target TDS levels.	The use of engineered salt-tolerant wetlands has been demonstrated at the pilot-scale only. Full scale application may not be feasible and the total salt balance may not be managed adequately.
Mechanical Evaporation/Zero-Liquid	Mechanical evaporation of the RO concentrate includes heating and vapor compression to evaporate pure water and thus separate it from	Not common in the Midwest due to high capital and operating cost.

Discharge	the salt. This technology is very capital-intensive and consumes large amounts of power. For example, 9.7 megawatts of power (13,000 horsepower [hp]) would be required to treat the 3 mgd of RO concentrate by brine concentrators and brine crystallizers. Also, radionuclides may be concentrated to the point that it is classified as a low-level radioactive waste, requiring special disposal.	

In the Midwest, options for disposal of high TDS RO concentrate are limited. Discharge to a sanitary sewer, if allowed by permit, is currently the most common practice.

Even where sanitary sewer discharge is permitted, the concentrate must pass whole effluent toxicity testing and must not degrade receiving water quality. Waukesha already faces challenges with chlorides in their wastewater plant effluent. Discharging RO concentrate could make the problem worse. Madison Wisconsin MSD recently completed a study on removing chlorides. Future wastewater plant discharge regulations are likely to be more stringent and apply to more water quality constituents.

Given the current trends in regulating discharges to surface waters, disposing RO concentrate to a sanitary sewer will be much more difficult in the future. RO concentrate containing other contaminants like radium and strontium found in the deep aquifer will present further disposal challenges. In addition, the radioactive constituents are concentrated in RO concentrate, and can be further concentrated in wastewater sludge, which has its own regulations and disposal limitations.

If RO disposal to a sanitary sewer is not feasible, then RO treatment may not be viable. RO concentrate disposal can in some instances become more expensive than the RO treatment system itself, if thermal/mechanical evaporation or deep well injection is needed. Deep well injection is not allowed in Wisconsin, so that is not an option. Thermal/mechanical evaporation is essentially evaporating the water and crystallizing the salt. It requires extensive equipment and uses large amounts of energy. The Waukesha Application discusses the high costs and energy usage when using these technologies.

RO Concentrate Examples

Some real world examples of RO concentrate disposal challenges and solutions are presented below.

Colorado

The Front Range of Colorado is the most populated area of the state and includes major cities like Denver, Aurora, Boulder, and Fort Collins. Historically, runoff from melting mountain snowpack has served as the primary water source for many Front Range cities. Recent drought conditions in the central Rockies have forced many utilities to search for alternative long term water supplies. For example, the City of Thornton investigated an alternative water supply with high TDS that would have required 10 mgd of RO treatment. The most viable RO concentrate disposal alternative for the City of Thornton was surface discharge to the South Platte River.

The river discharge was not permitted due to high levels of TDS and other contaminants; therefore, further pursuit of RO treatment was abandoned. Alternatively, the East Cherry Creek Valley Water and Sanitation District in the Denver metro area did install an 8 mgd RO treatment plant, but utilizes deep well injection of the RO concentrate at pressures exceeding 2,000 psig to avoid surface water discharge. Table 2 shows the capacity of most of the RO plants constructed in Colorado as well as some challenges associated with their operation.

TABLE 2
RO-Based Plants in Colorado

Plant Location / Owner	Plant Capacity	Notes
Sterling, CO	9.6 mgd	RO concentrate disposed into two deep injection wells (6,000 to 7,000-feet below ground surface)
Joint Water Purification Plant	9 mgd	Significant challenges with disposal of RO concentrate to Windmill Creek due to high selenium
Brighton, CO	4 mgd	Challenges with disposal of RO concentrate to South Platte due to high total inorganic nitrogen
East Cherry Creek Valley	8 mgd	RO concentrate treated with an additional stage of RO and then deep well injected at 600 – 1,400 psi and 150 – 400 gpm to depths of more than 9,000-feet below ground surface
Milliken, CO	0.7 mgd	Challenges with disposal of RO concentrate to Little Thompson River due to high selenium

New Jersey

In New Jersey communities rely primarily on groundwater for municipal water supply. Groundwater quality varies widely. In some cases, water requires softening. The Middlesex Water Company investigated the use of RO to soften its groundwater supply at the Tingly Lane water treatment plant. Sanitary sewer disposal of the RO concentrate was not available. Instead, constructed wetlands or a long transmission pipeline with ocean discharge were evaluated. The pipeline option was considered too expensive and the wetlands options was deemed too theoretical for full-scale application. As a result, further investigation of RO treatment was stopped.

Illinois

Similar to communities in Wisconsin including Waukesha, several Illinois communities rely on the deep aquifer for water supply. Radium is present in the deep aquifer (refer to Figure 1); consequently several Illinois communities have abandoned the deep aquifer for a Lake Michigan water supply.

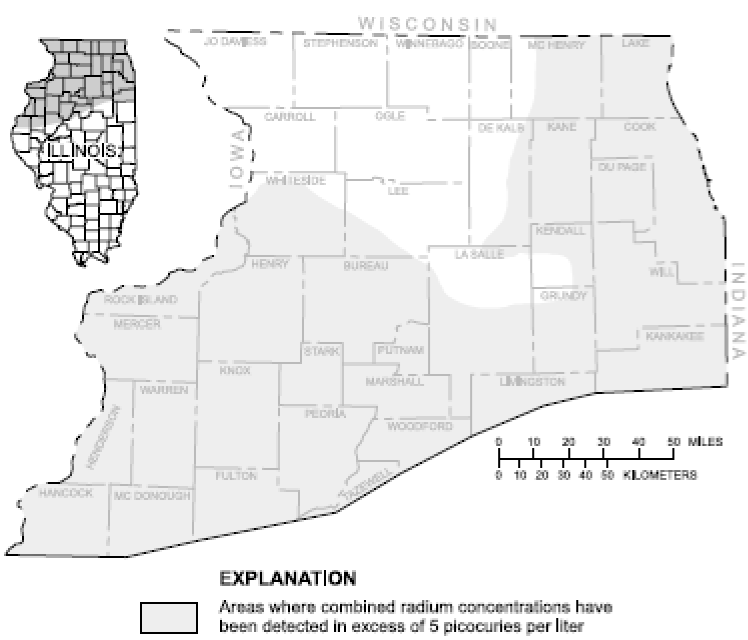

Figure 1. Areas where radium concentrations in excess of 5 picocuries per liter have been detected in aquifers used for public-water supply in northern Illinois. (Source: USGS Fact Sheet 137–99, September 1999).

Figure 2 shows the source of public water supply by municipality in the 11-county northeastern Illinois planning region. A large portion of the population is served by Lake Michigan water supply. The systems that have implemented RO for radium treatment remain on groundwater supplies are located outside of the areas supplied with Lake Michigan water supply.

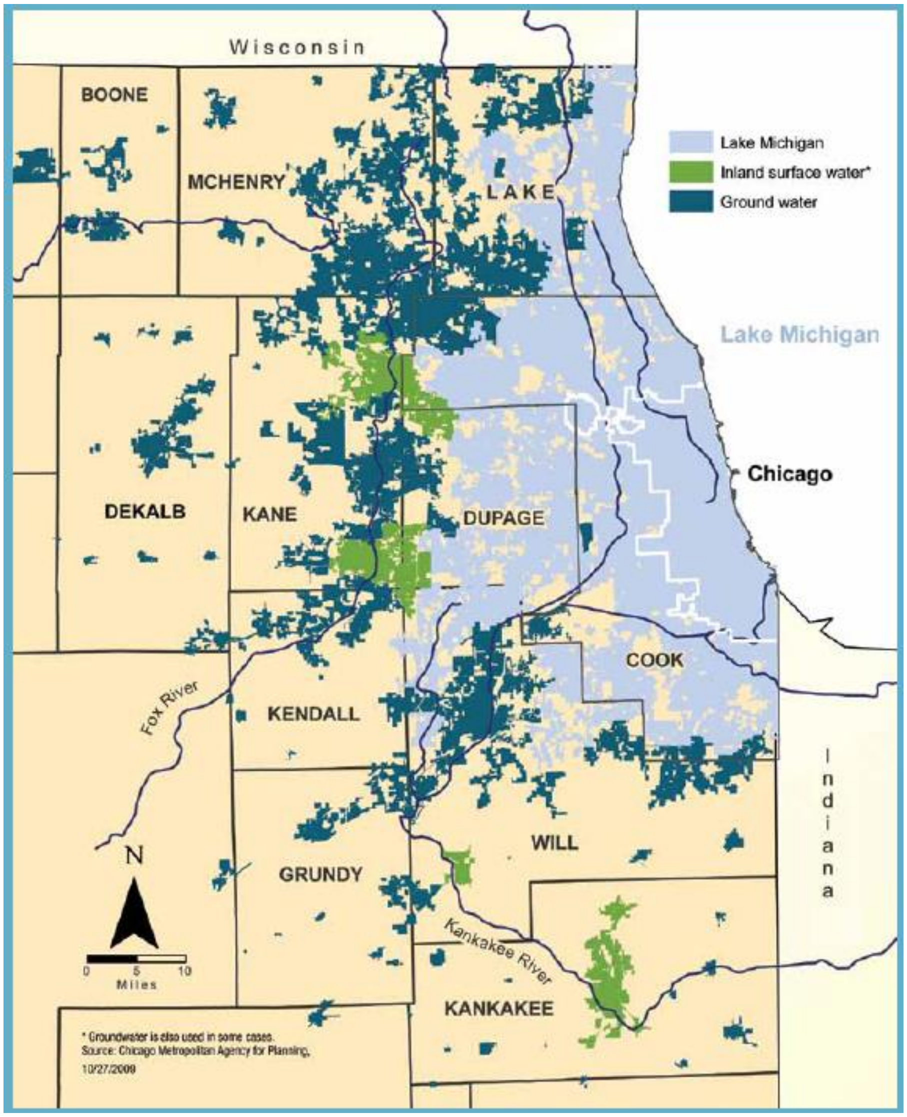

Figure 2. Eleven-county northeastern Illinois water supply planning region and currently utilized community water supply sources (CMAP, 2010).

Long term viability of using deep aquifers in northeastern Illinois has been studied recently by the Chicago Metropolitan Agency for Planning (CMAP) and Illinois State Water Survey (ISWS). Continued drawdown of the deep aquifer is anticipated as demands exceed recharge rates. The ISWS suggested that deep aquifer pumping rates be reduced to prevent the possibility of desaturation of the aquifer (Water Supply Project Plan Report, Village of Shorewood, Illinois, August 2014).

Since the 1980's, many northeastern Illinois communities have switched from unsustainable deep and shallow groundwater aquifer supplies to Lake Michigan, eliminating the need for RO treatment of local groundwater for radium and TDS removal. Population growth, declining groundwater tables, and more stringent drinking water regulations drove many communities toward purchasing treated water instead of treating their own supplies. Many of the groundwater wells were abandoned, or remain in place as emergency water supplies only.

Across the state of Illinois, there are at least a dozen RO treatment plants for municipal systems. The capacity of these systems is small, varying from 100 gallons per day (gpd) to a few million gallons per day (mgd). Illinois EPA has allowed the RO concentrate to be discharged to the sanitary sewer system under certain conditions. Typically, the RO concentrate is stored in a holding tank and slowly discharged to the sewer system to minimize TDS issues. If the facility does not have access to a sanitary system, IL EPA declines the discharge permit. A few small scale RO plants were not constructed because they did not have the infrastructure to discharge the concentrate to the sewer system.

The City of Shorewood, Illinois evaluated four water supply options: deep aquifer, shallow aquifer, river and Lake Michigan water supplies. One alternative considered RO for radium and TDS removal for deep aquifer water supply. The RO alternative was rejected due to the large RO waste volume (25 percent) and discharge permit challenges. The deep aquifer supply was deemed unsustainable. The Lake Michigan supply was deemed the preferred alternative (Water Supply Project Plan Report, Village of Shorewood, Illinois, August, 2014).

Indiana

Indiana has only two very small capacity operating RO treatment facilities for community water supplies: New Carlisle (200 gallons per minute [gpm]) and Bloomington Water Works (240 gpm). The New Carlisle water treatment facility is a lime softening plant that includes side stream RO treatment for an industrial steel mill. RO concentrate is blended with the lime softening residuals. The Bloomington Water Works disposes of RO concentrate on a nearby drain field.

Ohio

Ohio has 13 operating RO facilities for community water systems. The largest system is located in Lancaster, OH. Lancaster operates two water treatment plants and 14 groundwater wells. One of the treatment plants, the South Plant, utilizes RO treatment to soften and filter the water. RO concentrate disposal is to the sanitary sewer.

Based on recent conversations with Ohio EPA, some utilities have considered using RO or have used RO in the past, but have chosen not to due to RO concentrate disposal issues. One such example is the City of Columbus. Based on preliminary studies and pilot testing, the City of Columbus planned on addressing upcoming requirements for limiting formation of disinfection by-products and intermittent periods of high nitrate concentrations in source water by implementation of RO treatment. One of the critical issues identified at the early stages of the project was a lack of a comprehensive approved disposal plan for RO waste streams and capital costs that would have exceeded the City’s $200M project budget by approximately $100M.

Minnesota

In Minnesota, nearly 75 percent of residents derive their drinking water from groundwater sources (Fairbairn, 2011). Radium and nitrates are contaminants present in many municipal water supplies in Minnesota, requiring additional treatment to meet drinking water regulations. Most of the systems with radium selected HMO plus filtration as their method of treatment. This includes the cities of Goodview (2.6 mgd), La Cresent (1.4 mgd). Mankato (12 mgd) utilizes a combination of river water and deep aquifers for its water supply. The deep aquifer wells contain elevated levels of radium, which is removed with lime softening and filtration used to treat the river water supply.

RO concentrate for most of these systems is discharged to the sanitary sewer system. There is one rural system (City name not released by Minnesota Department of Health) that discharges its RO concentrate to a river due to lack of sewer availability, but has routinely exceeded its NDPES permit limits. As a result, this system is investigating alternate treatment options to RO as sanitary sewer discharge is not readily available. Other systems with nitrate issues include Hastings, which selected ion exchange instead of RO, to reduce the waste disposal issues associated with RO.

Summary

RO is used to remove a broad range of contaminants, but produces a high volume of salty wastewater. When TDS increases in a water supply, RO may be more effective in removing the TDS than other technologies such as ion exchange or lime softening.

In the Midwest, disposal of high TDS RO concentrate is especially problematic as ocean disposal or deep well injection are not options. Discharge to a sanitary sewer, if allowed by permit, is currently more common. However, many Midwest RO treatment systems are small and the waste is blended to reduce TDS concentrations. Many current plans for RO projects have been abandoned due to inability to obtain a sanitary sewer discharge permit, or concerns about getting a permit in the future. RO concentrate disposal to a sanitary sewer must pass whole effluent toxicity testing and must not degrade receiving water quality.

Given the current trends in regulating discharges to surface waters, disposing RO concentrate to a sanitary sewer will be much more difficult in the future. The presence of radium or strontium in the RO concentrate will further complicate the permitting process. Concentration of contaminants such as radium in the wastewater sludge may reduce future wastewater solids disposal options.

If RO disposal to a sanitary sewer is not feasible, then RO treatment may not be viable. RO concentrate disposal by thermal/mechanical evaporation can be much more expensive than the RO treatment system itself.

RO is one of a number of treatment technologies to remove radium. However, treatment to remove radium is not the main water supply issue. The main issue is that the deep aquifer is unsustainable. As the aquifer declines and TDS increases, treatment by RO may become necessary in the future. However, all the RO treatment in the world isn't going to fix the problem of declining aquifer levels. In fact, RO will make the problem worse since a large portion of the water is wasted as RO concentrate and more groundwater is needed. Obtaining a sustainable water supply like Lake Michigan, that does not require radium or TDS treatment, and can be recycled with no adverse environmental impacts, is the solution to the water supply issue.