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List of Abbreviations and Symbols

ALPC	American Legal Publishing Corporation
BGD	Billion gallons per day
B-MAG	Basin-Wide Management Advisory Group
CMAP	Chicago Metropolitan Agency for Planning
CSSC	Chicago Sanitary and Ship Canal
CWA	Clean Water Act
EIA	Energy Information Administration
FPA	Facility Planning Area
IAC	Illinois Administrative Code
IDNR	Illinois Department of Natural Resources
IDPH	Illinois Department of Public Health
IEPA	Illinois Envrionmental Protection Agency
IPCB	Illinois Pollution Control Board
MGD	Million gallons per day
MW	Megawatt
MWRDGC	Metropolitan Water Reclamation District of Greater Chicago
NIPC	Northeastern Illinois Planning Commission
NPDES	National Pollution Discharge Elimination System
SDWA	Safe Drinking Water Act
USACE	United States Army Corps of Engineers
U.S. EPA	United States Environmental Protection Agency
USGA	United States Golf Association
USGS	United States Geological Survey
WQM	Water Quality Management

Abstract

Water use practices in the Chicago metropolitan area are inefficient and they have led to violations of the United States Supreme Court decree that governs water diversions from Lake Michigan. An alternative approach that encourages reuse of municipal wastewater could address many of the inefficiencies. Although wastewater reuse has been practiced in Illinois, it is rare, especially in an urban setting. This report describes barriers and incentives to wastewater reuse in the Chicago metropolitan area and considers how that information could be used to promote changes in water management policies.

Major findings of this study include:

- A conservative estimate of the amount of treated municipal wastewater that could be used in industrial applications ranges from 2.1×10^5 to 2.9×10^5 m^3/d (55 to 77 MGD).

- Risks associated with reusing treated municipal wastewater can be divided into three groups. Human health risks are primarily associated with residual organic material and pathogens. Ecosystem risks are primarily related to nutrients and residual organic materials. Infrastructure risks (corrosion, scaling, biofilm formation) could be associated with changes in water quality, higher temperatures, and assimilable organic material.

- Human health risks associated with reusing treated effluent depend on the application. Relative to irrigation and groundwater recharge, closed-loop industrial processes probably exhibit less risk. Decades of research with groundwater recharge sites suggest that these processes can be designed and managed to minimize risks.

- Because the cost of municipal water in the City of Chicago is among the lowest in the nation, there is little economic incentive for wastewater reuse. Major economic barriers to wastewater reuse include the cost of installing a secondary water distribution system and the cost of installing and implementing chlorination at wastewater treatment facilities where chlorination does not already exist. Most of the cost for a nonpotable water distribution system is associated with the capital costs of installing a secondary distribution pipeline.

- The Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) has years of experience with wastewater reuse through many different applications and they could play a lead role in promoting wastewater reuse.

Some of the major recommendations from this work are to:

- Educate stakeholders (industry, government, the public) about water reuse.

- Develop reliable data on industrial and commercial water use patterns and water quality needs.
- Encourage federal, state, regional, and local authorities to adopt water reuse policies.

Introduction and Overview

Lake Michigan provides most of the water used in the Chicago metropolitan area. Rather than returning the water to the Lake Michigan watershed, most of the water used around Chicago is discharged to the Illinois River watershed. This transfer of water is known as the Lake Michigan diversion. Many stakeholders in the Great Lakes region believe that too much water has been diverted from the Great Lakes. Comprehensive accounting of the diversion has been conducted each year since 1981. Two major contributions to the problem are: (1) direct diversion for navigational make-up and discretionary (used to dilute treated effluent from wastewater treatment plants) purposes and (2) conventional municipal water use.

The amount of water involved is important not only because water is a valuable resource but also because of the large amount of energy involved. The aeration process in municipal wastewater treatment consumes a large amount of energy. Raw water pumping, treatment, and distribution also add to the requirements. A substantial amount of energy is carried away with the treated effluent because municipal wastewater is heated through various domestic, commercial, and industrial uses.

A more efficient alternative to managing local water resources is to reuse treated wastewater in applications where nonpotable water is appropriate. Water reuse is common around the world and in arid regions of the United States, but it is rare in Illinois. This report describes our assessment of the barriers and incentives to water reuse in the Chicago metropolitan area. We begin with an overview of current water resources management in the Chicago metropolitan area, including the diversion from Lake Michigan and municipal wastewater treatment practices. Subsequent sections address relevant federal guidelines and state regulations that apply to water reuse. Water quantity and quality issues and their effects on human health and ecosystem risks are also discussed. Costs and benefits, which are among the most important barriers and incentives, are presented. The report concludes with several case studies that demonstrate current or potential reuse opportunities.

Water Resources Management in the Chicago Metropolitan Area

Much of the information in this section is adapted from the report by Espy et al. (2004) and other reports produced by or for the U.S. Army Corps of Engineers (USACE). These reports can be found at http://155.79.114.198/divacct/index.html.

The Chicago River originally flowed into Lake Michigan (Figure 1). Diversion of water from Lake Michigan through Chicago to the Illinois River watershed began in 1848. The original average flow rate of 14.2 m^3/s (500 ft^3/s) increased to a maximum of about 283 m^3/s (10,000 ft^3/s) when the Chicago Sanitary and Ship Canal (CSSC) was completed in 1900. Lock and sluice gates at the mouth of the Chicago River (the Chicago River Controlling Works) regulate flow between the river and the lake. Water levels in the CSSC are regulated at the Lockport lock and dam. A second canal, the North Shore Channel, was completed in 1910. It connects the North Branch of the Chicago River with Lake Michigan at Wilmette. Exchange between this canal and the lake is controlled by the Wilmette Controlling Works. A third canal, completed in 1922, connects Lake Michigan through the Grand Calumet River to the CSSC. Flow through this canal is regulated at the O'Brien lock and dam (Figure 2).

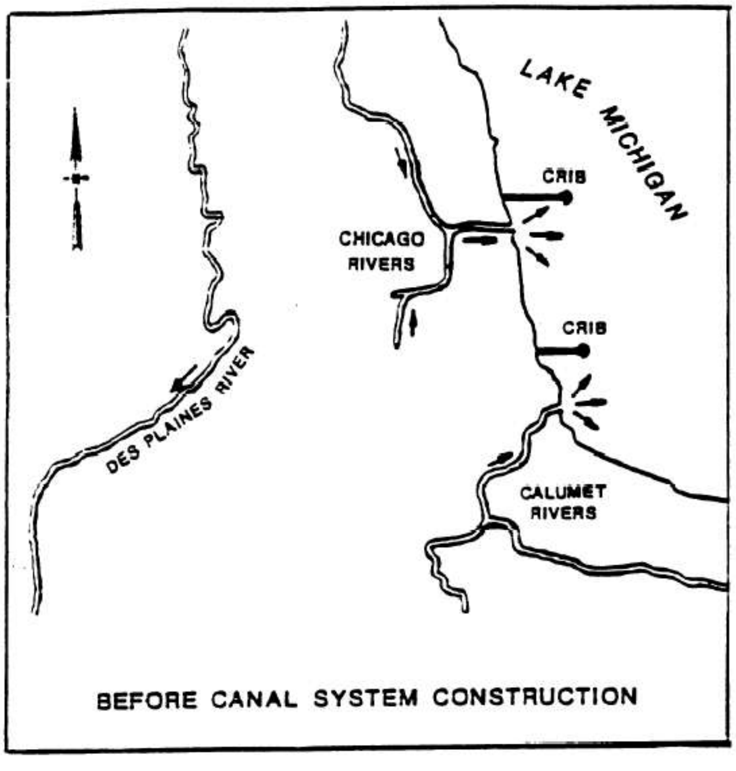

Figure 1. Chicago River system before the canal construction. Adapted from USACE (2001).

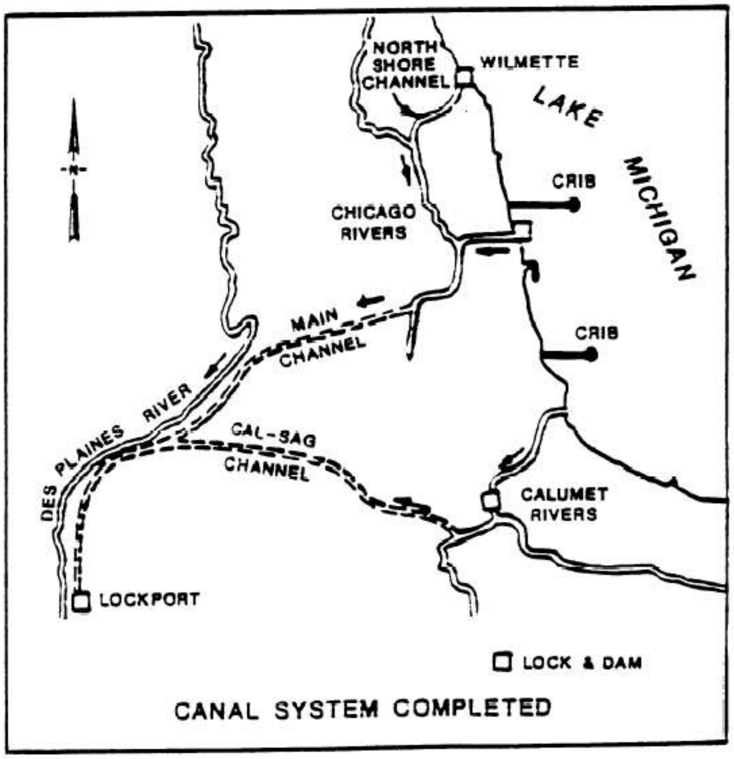

Figure 2. Chicago River system after completion of canals. Adapted from USACE (2001).

By the early 1920's several states around the Great Lakes were concerned that too much water was being withdrawn from Lake Michigan and they sought an injunction to prohibit diversion of Lake Michigan water by Illinois. The diversion could have an effect on the overall water supply, navigation, recreation, commerce, and invasive species (U.S. EPA, 2002a). In 1930, the U.S. Supreme Court decreed that the annual average water diversion from Lake Michigan to Illinois should be reduced in stages and by 1939 it was limited to 87.7 m^3/s (3,100 ft^3/s). About 42.5 m^3/s (1,500 ft^3/s) of the total was used to dilute and flush wastewater away from the city. The staged approach to the new limits was planned to allow the State of Illinois and the Chicago Sanitary District (now the Metropolitan Water Reclamation District of Greater Chicago – MWRDGC) time to provide wastewater treatment facilities that would minimize the need for dilution water.

In 1967 the U.S. Supreme Court issued a new decree that limited the diversion from Lake Michigan into the Mississippi watershed to an annual average of 90.6 m^3/s (3,200 ft^3/s) over a five year period. This new limit took effect on March 1, 1970. From 1970 to 1975 the average diversion rate was 90.1 m^3/s (3183 ft^3/s), and from 1975 to 1980 the average diversion rate was 86.1 m^3/s (3044 ft^3/s).

Following a series of meetings involving other Great Lakes states, the U.S. Supreme Court decree was modified in 1980. Those modifications included:

- A change from a five-year to a forty-year running average for calculating the annual average diversion rate;
- An annual average diversion limit of 104 m^3/s (3,680 ft^3/s) in any one water year;
- In the event of extreme hydrological conditions, the diversion limit is increased to 109 m^3/s (3,840 ft^3/s) for any two water years during the 40 year period; and
- The cumulative diversion excess beyond 90.6 m^3/s (3200 ft^3/s) must not exceed 56.6 m^3/s-years (2,000 ft^3/s-years) during the first 39 years.

The modifications also stated that the U.S. Army Corps of Engineers (USACE) was charged with supervising, directing, and periodically auditing the diversion measurements and associated calculations. Accounting procedures have evolved over the years as new monitoring methods were developed and terms in the water budget were refined.

There are now three major components in the accounting for the Lake Michigan diversion:

- Municipal water supply taken from Lake Michigan;
- Stormwater runoff diverted from the Lake Michigan watershed through the river and canal system into the Illinois River watershed; and
- Water from Lake Michigan that directly enters the river and canal system in the greater Chicago area.

This last component consists of three parts:

- Direct diversions for navigational make-up and discretionary purposes made at the Chicago River, O'Brien, and Wilmette Controlling Works;
- Leakage that occurs at the Chicago River Controlling Works, Thomas J. O'Brien Lock and Dam, and Wilmette Pump Station and Sluice Gate; and
- Water required operating the Chicago Harbor Lock and the Thomas J. O'Brien Lock.

An assessment of the relative contributions for the three major components from 1996 through 1999 (Table 1) shows that municipal water supply pumping accounted for about 57% of the total diversion, more than twice as much as stormwater runoff.

A recent report from the United States Army Corps of Engineers (USACE, 2001) includes data that reveal the peak running average, 98.7 m^3/s (3487 ft^3/s), occurred in 1993 (Figure 3). That same year, the cumulative diversion excess reached a maximum of 105 m^3/s-year, or 16% above the limit. Since that time, the volume of water diverted has decreased substantially. The 2001 cumulative deficit was about 53 m^3/s-year. Major reasons for the decrease in the amount of water diverted include the recent relatively low water level of Lake Michigan (lower hydraulic head), repairs to lock gates (reduced leaks), and the City of Chicago water main repair program (reduced leaks). Espy et al. (2004) apparently assumed that those trends would continue and predicted the cumulative deficit would shrink to zero by the end of the 2004 accounting year.

Table 1. Fractional distribution of the Lake Michigan diversion and the total for accounting years 1996 – 1999 (Espey et al., 2004).

	1996	**1997**	**1998**	**1999**
Municipal supply	0.586	0.567	0.535	0.579
Stormwater runoff	0.290	0.276	0.256	0.274
Direct diversions	0.124	0.157	0.209	0.147
Total (m^3/s)	86.1	79.7	85.7	78.5

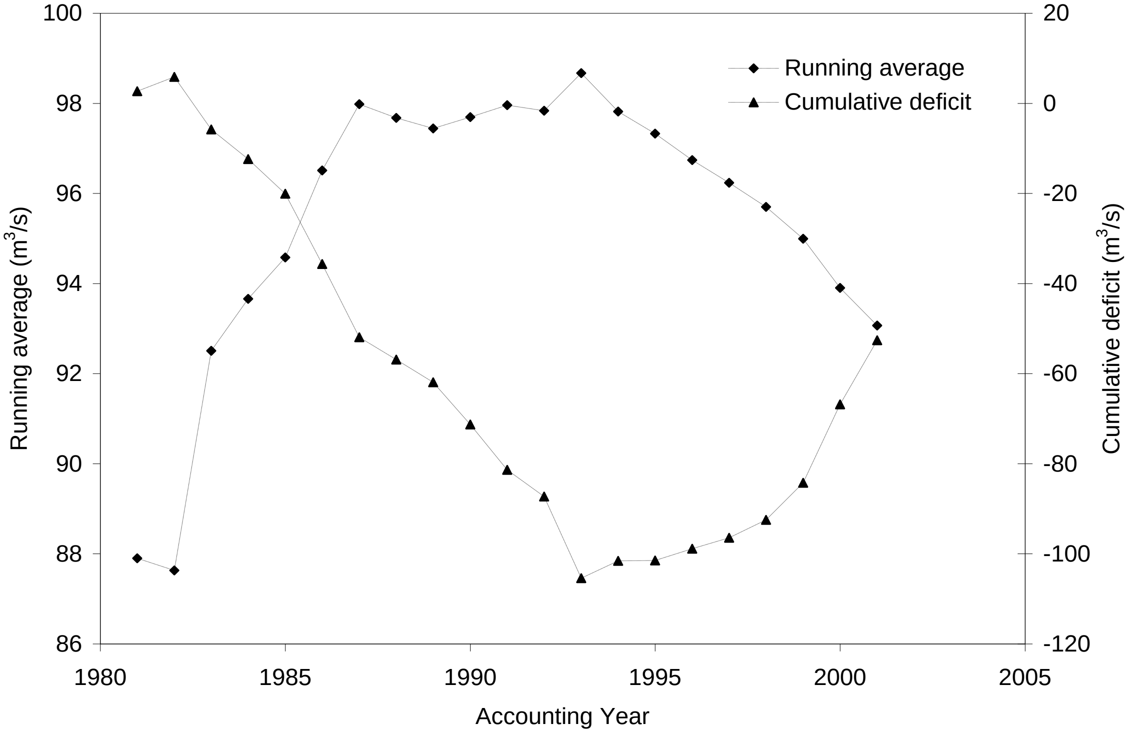

Figure 3. Running average and cumulative deficit for the Lake Michigan diversion since 1980. Data from USACE (2001).

The water main repair program is important because, as noted in Table 1, conventional municipal water use makes up most of the diversion. Based on data provided by Espy et al. (2004), from 1990 through 2001 treatment facilities pumped, treated, and distributed an average of 45 m^3/s (1,605 ft^3/s) to serve commercial and industrial needs and the domestic needs of about five million people in the City of Chicago and 124 nearby suburbs. Allowing for consumptive uses, about 90% of that water (41 m^3/s or 1445 ft^3/s) was returned to regional wastewater treatment facilities.

The regional wastewater treatment utility, the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) operates seven wastewater treatment plants (Table 2) with a total capacity of about 7.6×10^6 m^3/d (2 billion gallons per day or BGD). The average amount of water treated is 5.3×10^6 m^3/d (1.4 BGD). Treated effluent from these facilities is discharged to surface waters in the Chicago area (Table 2).

In addition to treated effluent, these surface waters can include: overflows from combined sewer systems; stormwater; base-flow and storm runoff from tributary watersheds; and cooling water from utilities and private buildings. Finally, as noted above, the North Shore Channel, the Chicago River, the Cal-Sag Channel, and the Chicago Sanitary and Ship Canal also carry navigation and discretionary diversion flows from the Lake Michigan watershed to the Illinois River watershed.

The Chicago River Controlling Works (CRCW), located at the mouth of the Chicago River, regulates the exchange of water between Lake Michigan and the Chicago River. The O'Brien Lock and Dam regulates the flow of Lake Michigan waters down the Calumet Sag Channel. The Lockport Lock and Dam controls the water level in the Chicago Sanitary and Ship Canal (CSSC).

Table 2. Receiving stream and flow for MWRDGC treatment plants (MWRDGC, 2006).

		Design Flow		**2005 Mean**		
Facility	**Receiving stream**	**10^3 m^3/d**	**MGD**	**10^3 m^3/d**	**MGD**	**Fraction**
Stickney	Chicago Sanitary and Ship Canal	4542.0	1200.0	2426.2	641	0.55
Calumet	Cal-Sag Channel	1339.9	354.0	847.8	224	0.19
North Side	North Shore Channel	1260.4	333.0	885.7	234	0.20
James C. Kirie	Higgins Creek	272.5	72.0	96.1	25.4	0.02
John E. Egan	Salt Creek	113.6	30.0	88.6	23.4	0.02
Hanover Park	West Branch DuPage River	45.4	12.0	29.1	7.7	<0.01
Lemont	Des Plaines River	8.7	2.3	10.2	2.7	<0.01
	Total	7579.8	2002.6	4383.8	1158.2	

The Lockport powerhouse is also used to generate electricity. MWRDGC receives credit from Commonwealth Edison for the power generated at this hydroelectric facility.

In summary, the Lake Michigan diversion at Chicago is limited by U.S. Supreme Court decree to a 40-year running average of 90.6 m^3/s (3200 ft^3/s). The largest single contribution to this diversion is the public water supply, at an average rate of 45 m^3/s (1,605 ft^3/s).

Exactly how all of that public water supply is used is not well known. One estimate of public water supply uses can be obtained from information presented by the United States Geological Survey (USGS). Every five years since 1950 the USGS summarizes water use data from all the states. Data for each county are available. Recent data suggest that the distribution of the public water supply in Cook County, IL (where Chicago is located) is unusual (Table 3). Relative to the rest of Illinois or to the rest of the U.S., domestic and industrial uses in the Chicago area are a smaller fraction of the total. Furthermore, although recent water mains repair efforts have probably improved the situation, the fraction of the water supply attributed to public uses and distribution system losses in Cook County has been more than twice the national average.

In the Chicago area (and through most of the U.S.) high quality water is used in applications such as commercial/industrial cooling, flushing toilets, or irrigation where the needs could be met with water that does not have to meet the stringent standards established for drinking water. For example, the U.S. EPA (1992) states that flushing toilets account for about 41% of domestic water use.

Table 3. Estimated fractional public water supply distribution for Cook County, IL, and mean values for all of Illinois and all of the U.S. in 1995 (Solley et al., 1998). The report for 2005 has not been released yet, and the report for 2000 (Hutson et al., 2004) does not include a similar breakdown for public water supplies.

Use category	Cook County, IL	IL mean	U.S. mean
Domestic	0.41	0.51	0.56
Commercial	0.19	0.24	0.17
Industrial	0.03	0.06	0.12
Thermoelectric	< 0.01	<0.01	<0.01
Public uses and losses	0.37	0.18	0.15

Water Resources Management Summary

The Great Lakes and especially Lake Michigan have been a valuable resource for the City of Chicago and northeastern Illinois since at least the middle of the 19th Century. A series of engineering projects in the early 20th century created canals and channels that linked the Great Lakes to the Illinois River watershed. The subsequent diversion of water from Lake Michigan raised concerns. Other states around the Great Lakes became concerned that diversion of water from Lake Michigan could lower the water level, leading to water supply, navigation, and recreation problems. In response to these concerns, the Supreme Court issued a decree that regulates the amount of diversion to Illinois. A large fraction of that diversion is for the public water supply, which provides potable water for domestic, commercial, and industrial applications in the Chicago area. For those applications that do not demand high quality potable water, treated wastewater could be reused. Although wastewater reuse is common in arid regions, it is a relatively unusual practice in the Midwest.

In the remainder of this report we examine incentives and barriers to municipal wastewater reuse in the Chicago area. The next section continues the description of water resources management, with a more detailed look at how water quantity and quality can influence wastewater reuse. To help organize the information, the issues are divided so that subsequent sections address regulations, policy, risk, and economics. These divisions are not precise. The categories overlap, especially in the area of economics.

Quantity and Quality Considerations

Although treated effluent can be appropriate for a wide variety of applications, the feasibility of a specific application depends on factors such as water quality, costs, and potential human health risks. In this section, we examine how water is used throughout the United States, contrast those applications with water use in Cook County, and look for reuse opportunities in Cook County. Industrial water use and park, forest preserve, and golf course irrigation are likely reuse opportunities. Because water quality is an important issue, we also examine the relative water quality of municipal water and treated effluent. Some of this information will be used in subsequent sections that address human health risks and economics.

Water Use across the United States and in Cook County

Every five years since 1950, the United States Geological Survey (USGS) reports on water use across the United States. Their most recent reports are for 1995 (Solley et al., 1998) and 2000 (Hutson et al., 2004). They provide data for water use in each state with detail at the county level. Between the 1995 report and the 2000 report the format of the reports changed slightly. Solley et al. (1998) estimate how the public water supply is distributed among various types of users such as commercial, industrial, and domestic. In contrast, Hutson et al. (2004) estimate the public water supply, but they do not describe the distribution. Total water use across the U.S. in 2000 was about 1.54×10^9 m^3/d (408 billion gallons per day or BGD). About 48 % of that was cooling water for thermoelectric power plants (7.4×10^8 m^3/d or 195 BGD); 33% was for irrigation (5.2×10^8 m^3/d or 137 BGD); 11% was withdrawn for public water supplies (1.63×10^8 m^3/d or 43 BGD); 5% was self-supply for industry (7.57×10^7 m^3/d or 20 BGD) - "self-supply" is in addition to the water industry takes from the public supply; and the remainder ($< 4.9\times10^7$ m^3/d or 13 BGD) was self-supply for domestic, livestock, agriculture, and mining (Figure 4).

Estimated total water use in Cook County in 2000 was 6.58×10^6 m^3/d (1.74 BGD), but the distribution was different from the national average (Figure 4). Water withdrawn for the public supply is the largest application, followed by cooling water for thermoelectric plants. Irrigation, which accounts for a substantial fraction of water use at the national level, is not an important water use for Cook County.

The thermoelectric facilities in Cook County are coal-fired power plants owned and operated by Midwest Generation, a subsidiary of Edison International (Edison International, 2005). The Crawford station, with two generators and a total capacity of 542 net MW, takes cooling water from the Chicago Sanitary and Ship Canal. The Fisk station (one generator with a capacity of 326 net MW) draws cooling water from the South Branch of the Chicago River.

According to the USGS (Solley et al., 1998), in 1995 the cooling water withdrawn for these thermoelectric plants averaged 1.55×10^6 m^3/d (409.88 MGD), which includes 2.65×10^3 m^3/d (0.7 MGD) from the public supply and 1.55×10^6 m^3/d (409.18 MGD) self-supply from the Chicago Area Waterways. Of this total, only 1.5% (2.33×10^4 m^3/d or 6.15 MGD) was for consumptive use. Most of the water was returned to the surface water sources (albeit at an

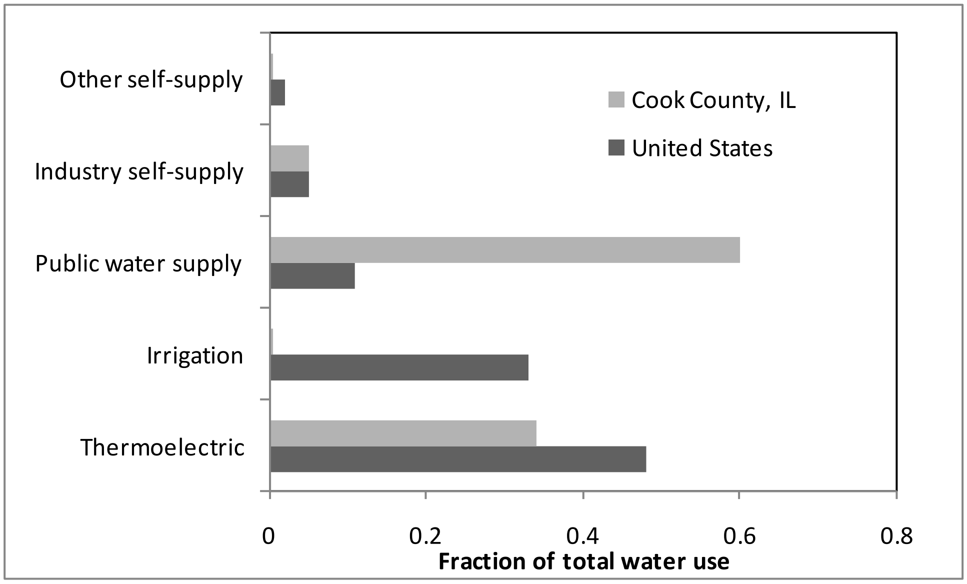

Figure 4. Estimated distribution of water use comparing Cook County, IL and the U.S. average in 2000 (Hutson et al., 2004).

elevated temperature). As noted above, in their USGS report for 2000 water use, Hutson et al. (2004) broke from the previous reporting format and no longer provided detailed information on distribution from the public supply. They did report, however, that self-supply (again from the Chicago Area Waterways) averaged 2.26×10^6 m^3/d (598 MGD). Interestingly, Dziegielewski et al. (2005) took a different perspective and, using much of the same data, concluded that water withdrawal for thermoelectric facilities in Cook County was 3.78×10^6 m^3/d (999 MGD) in 2000, or more than 60% larger than the value reported by the USGS (Table 4).

These data suggest that recent thermoelectric cooling water withdrawal in Cook County was at least 2.26×10^6 m^3/d (598 MGD) and as much as 3.78×10^6 m^3/d (1,000 MGD). Because this water comes from the Chicago Area Waterways and because most of that water is treated effluent, this application is an example of unplanned or incidental reuse. Water delivered from the public supply (about 2.65×10^3 m^3/d or 0.7 MGD in 1995) was mostly used for boiler water makeup. With proper pretreatment, it would be possible to substitute treated effluent for this application.

When looking for additional opportunities for wastewater reuse, a priority should be to find where municipal water is used in applications that do not require high quality water. According to USGS estimates (Solley et al., 1998), in 1995 the public water supply in Cook County was about 4.29×10^6 m^3/d (1134 MGD). Most of the supply was split between domestic applications and public uses and losses (Figure 5), with about 19% (8.3×10^5 m^3/d or 220 MGD) going to commercial applications and 3% (1.4×10^5 m^3/d or 37 MGD) going to industry.

Table 4. Estimates of water withdrawal for thermoelectric cooling facilities in Cook County, IL.

Cooling water (10^6 m^3/d)	**Source**	**Reference**
1.55	Public + self-supply	Solley et al. (1998)
2.26	Self-supply	Hutson et al. (2004)
3.78	Self-supply	Dziegielewski et al. (2005)

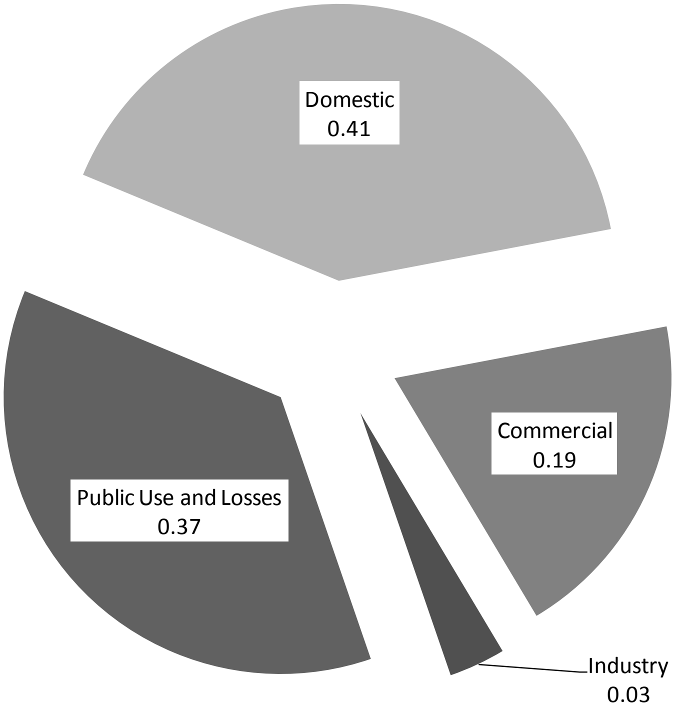

Figure 5. Fractional allocation of the 4.29×10^6 m^3/d (1134 MGD) public water supply in Cook County in 1995 (Solley et al., 1998).

As noted previously, the USGS estimates of water use in Cook County in 2000 (Huston et al., 2004) do not attempt such a detailed description of the public water supply allocation. They do report that in 2000 the public water supply was about 3.94×10^6 m^3/d (1043 MGD). If the same fractional allocation applied, there were about 7.5×10^5 m^3/d (198 MGD) going to commercial applications and 1.2×10^5 m^3/d (31 MGD) going to industry.

Water quality requirements depend on the application, but all of that water from the public supply to commerce and industry does not have to meet the same high standard as the public water supply. For example, the U.S. EPA (2004) noted that treated wastewater has been successfully used for industrial cooling water, boiler make-up water, and some process waters. According to Liaw and Chen (2004) the Taiwan government, which is concerned about looming water shortages, is encouraging industry in Taiwan to get 75% of their water supply from reuse by 2010. In the absence of a detailed audit to determine what fraction of the current commercial and industrial water supply could be replaced with treated wastewater, we suggest a conservative estimate that 25% of commercial and industrial water use in Cook County, or from 2.1×10^5 to 2.9×10^5 m^3/d (55 to 77 MGD), could be treated wastewater.

Commercial and industrial reuse applications would decrease the hydraulic loading to surface waters that receive treated effluent. Any applications that are currently self-supplying (withdrawing water from surface- or ground-water sources but not from the public supply) would also see a decreased demand on the total regional water supply. Finally, for these applications that rely on the public water supply, there would also be decreased demand on the public water supply. Water quality is one important factor that determines the suitability of treated effluent for many applications.

Water Quality

Part of the feasibility evaluation for a water reuse application is to assess potential impacts associated with water quality. There are potential human health risks, which are primarily associated with microbial pathogens and a variety of chemical contaminants. There are also potential ecosystem risks, which are associated with nutrient loading and a variety of chemical contaminants. Finally, water quality can have effects on the distribution system or the application equipment through processes such as corrosion or fouling (biological growth, mechanical plugging, or chemical precipitation).

During the feasibility evaluation, it is important to keep in mind that the potential impacts could be positive or negative. Furthermore, there will be trade-offs to consider where both positive and negative impacts can occur at the same time. For example, the reuse guidelines presented above recommend chlorination for most reuse applications as a way to decrease human health risks. Chlorine, however, reacts with organic matter to form a family of chlorination by-products that are potential carcinogens. In addition, chlorine can accelerate corrosion reactions in water distribution systems.

For each potential reuse application, the assessment should begin by considering differences in water quality characteristics between the current water supply and the treated effluent. As noted above, there are industrial, commercial, and domestic users in Cook County that are self-supplying. They obtain water from surface or groundwater sources. For most users in the Chicago area, however, the appropriate comparison is between the public water supply and the MWRDGC treated effluent.

One aspect of water quality that changes during use is water temperature. For most of the year, the temperature of treated effluent is greater than ambient air temperatures in Chicago (Figure 6). Temperature has an effect on reaction equilibrium and on reaction kinetics.

The effect of temperature on reaction equilibrium depends on thermodynamics. If the molar enthalpy of reaction is positive, equilibrium will shift in favor of more product formation. The reaction of calcium with carbonate to form solid calcite is an example of one such reaction that is relevant to wastewater reuse. An equilibrium analysis indicates that at the higher temperatures associated with treated effluent, we should expect more calcite to precipitate. In contrast, the dissolution of gaseous oxygen is an example of a reaction that has a negative molar enthalpy of reaction. As a result, relative to its value in cold water, the saturation concentration of dissolved oxygen in warmer water is lower. The thermodynamic analysis reveals only if a reaction can happen, it does not indicate how long it takes for that reaction to happen.

A kinetic analysis provides information on reaction rates. Reaction rates increase with increasing temperature. Relative to ambient temperatures (and public water supply temperatures), treated wastewater effluent is usually warmer, so reaction rates will be faster when treated effluent is present. Faster reaction rates could be detrimental or beneficial depending on the reaction and how much faster it is.

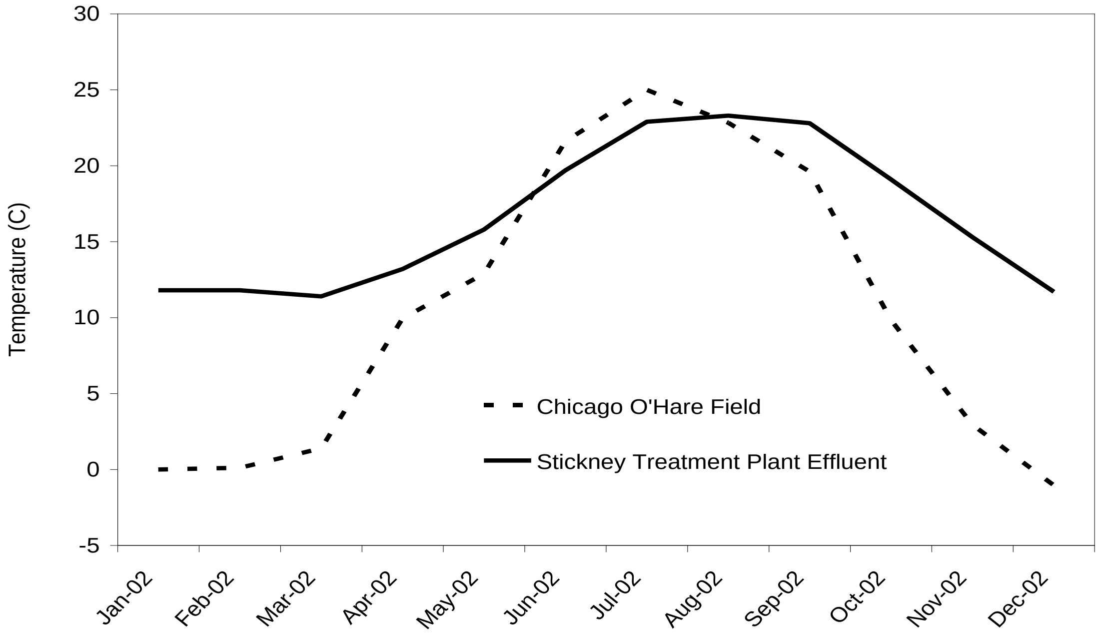

Figure 6. Average monthly temperature at Chicago's O'Hare Field and for the treated effluent from the MWRDGC Stickney facility in 2002.

For example, if corrosion rates are substantially faster, there could be higher maintenance costs associated with converting an application to treated effluent. Similarly, faster biological growth might lead to enhanced bio-fouling in distribution systems. Alternatively, faster degradation reactions (biological or abiological) could decrease concentrations of contaminants of concern.

The important water quality characteristic comparison for this study is between MWRDGC treated effluent and the City of Chicago municipal public water supply (Table 5).
Data in the table for municipal water are from the South Water Purification Plant, one of the two water purification plants that supply municipal water to the City of Chicago. These data are averaged values from quarterly data for November 2001 and February, May, and August 2002. Treated wastewater data are from the Stickney wastewater treatment plant, which processes over 50% of the wastewater treated by MWRDGC. These data are averaged values from 2002.

Table 5. Comparison of Chicago municipal water supply (South Water Purification Plant, values from November 2001 and February, May, and August 2002) and treated effluent (Stickney facility, values from 2002) major physical and chemical water quality parameters.

Parameter	**Unit**	**Municipal water**			**Treated wastewater**		
		Minimum	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**
Temperature	°C	6	13.3	24	8.9	16.6	25.3
Turbidity	N.T.U.	0.1	0.13	0.15	-	-	-
pH		7.4	7.6	7.7	6.1	6.8	7.4
Dissolved Oxygen	mg/L	-	-	-	6.3	8.5	11
BOD_5	mg/L	-	-	-	<2	<6	20
Total Solids	mg/L	182	202	220	369	676	2994
Total Dissolved Solids	mg/L	157	163	179	366	671	2978
Hardness	mg as $CaCO_3$/L	131	138.3	144	151	228	331
Total Alkalinity	mg as $CaCO_3$/L	103	104	105	56	125	313
Calcium	mg/L	31.3	33.1	35.2	38.9	57.2	80.4
Magnesium	mg/L	10.9	11.1	11.4	13.0	20.8	31.6
Sodium	mg/L	6.5	7.2	8.2	-	92[a]	-
Potassium	mg/L	1.4	1.4	1.5	-	18[a]	-
Total Kjeldahl Nitrogen	mg N/L	<0.1	0.1	1.2	0.79	2.06	6.05
Ammonia	mg N/L	-	<0.01	-	0.02	<0.50	3.94
Nitrite	mg N/L	-	<0.01	-	0.01	0.21	1.72
Nitrate	mg N/L	0.25	0.27	0.34	2.3	8.36	14.49
Total Phosphorus	mg/L	0.98	1.16	1.33	0.09	1.35	3.61
Chloride	mg/L	12	12.7	15.4	75	154.4	651.1
Fluoride	mg/L	0.99	1.03	1.17	0.47	0.94	1.38
Sulfate	mg/L	25.4	26.1	26.9	47.9	84.0	112.4

[a] Estimated from a charge balance assuming Na/K remains the same as in the municipal water.

The data have more visual impact in figures that show characteristics with relatively minor changes (Figure 7) and those that have more substantial changes (Figure 8). Fluoride is the only constituent that shows a decrease (about 10%) in concentration through municipal use and wastewater treatment. Phosphorus and total alkalinity increase by about 20%, and the major ions contributing to hardness (calcium and magnesium) increase about 70%. According to the U.S. EPA (2004), dissolved inorganic solids concentrations in water typically increase by 150 to 500 mg/L following domestic use.

The increase in the mean values for total dissolved solids in Chicago is slightly above this range. Constituents with the greatest increases in concentration are nitrogen compounds (20 to 30 times) and chloride, potassium, and sodium (12 times). In the absence of data on potassium and sodium concentrations in the treated effluent, values shown here were estimated from a charge balance, assuming the sodium-to-potassium ratio is the same as in the municipal water. Based on the mean concentrations, total solids and total dissolved solids increase by factors of three and four, respectively. The range in these values, however, is large so the increase could be as much as a factor of ten. The mean pH value decreases from 7.6 to 6.8 (hydrogen ion activity increases by a factor of 6.3).

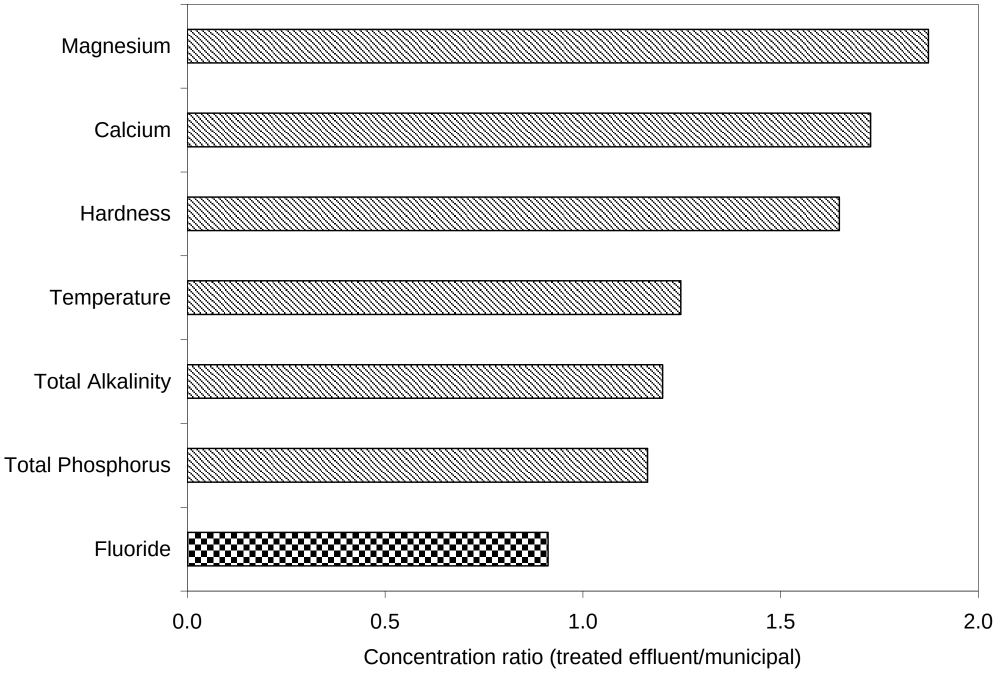

Figure 7. Decreased (checkered pattern) to slightly increased water quality parameters from Table 5, showing ratio of treated effluent to municipal mean values.

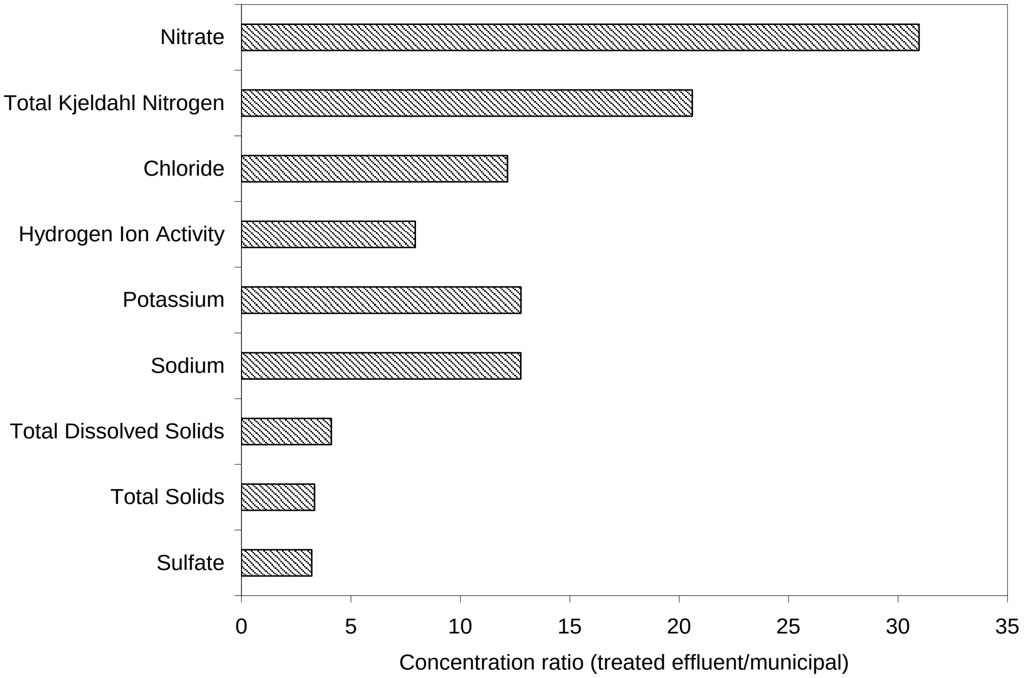

Figure 8. Substantially increased water quality parameters from Table 5 showing the ratio of treated effluent to municipal mean values. Hydrogen ion activity was based on the pH; potassium and sodium were estimated from the charge balance.

In addition to the water quality parameters noted above, there may be concern about a variety of constituents that are likely present in water at much lower concentrations. For example, trace elements can have cumulative effects on soil structure, plants, and groundwater quality (Kopec et al., 1993). Rowe and Abdel-Magid (1995) recommended maximum concentrations of trace elements in irrigation water; for those compounds where monitoring data are available, the effluent from the Stickney facility is well within these recommendations (Table 6).

Relative to their concentrations in the public water supply, concentrations of organic compounds also increase in treated effluent. From a bulk perspective, these changes can be quantified by measuring the total organic carbon (TOC) content. The TOC in the distribution system is about 1.5 mg C/L (City of Chicago, 2005). Starting in 2006, the MWRDGC began reporting TOC values for treatment plant effluent (MWRDGC, 2007a; 2007b). The mean concentration was 5 mg C/L with a standard deviation of 1 mg C/L (13 samples).

This level of TOC suggests a source of readily degradable organic carbon for biofilm growth, which could present problems for a secondary distribution system. Such a carbon source (known as assimilable organic carbon or AOC) in concert with readily available nutrients can lead to accelerated growth of biofilms (U.S. EPA, 2002b).

Table 6. Recommended maximum concentrations for trace elements in irrigation water (Rowe and Abdel-Magid, 1995) and concentrations reported for treated effluent (2002 mean values) from the Stickney facility.

Element	Concentration (mg/L)	
	Recommended Maximum	Stickney Effluent
Aluminum	5.0	N/A
Arsenic	0.10	<0.017
Beryllium	0.10	<0.0003
Cadmium	0.01	<0.0009
Cobalt	0.05	N/A
Chromium	0.10	<0.011
Copper	0.20	<0.016
Iron	5.0	0.18
Lithium	2.5	N/A
Manganese	0.20	<0.0124
Molybdenum	0.01	N/A
Nickel	0.20	<0.01
Lead	5.0	<0.023
Selenium	0.02	<0.024
Titanium	N/A	<0.039
Vanadium	0.10	N/A
Zinc	2.0	<0.039

Potential problems associated with biofilm growth in distribution systems include increased corrosion, higher disinfection resistance, and taste and odor problems. Furthermore, biofilms can accumulate nutrients and provide a favorable environment for pathogen growth.

In addition to the concerns about TOC, there is growing concern about trace organic compounds in municipal wastewater and the fates of those compounds and their by-products during and after wastewater treatment (Daughton and Ternes, 1999; Kolpin et al., 2002). The District monitors for a variety of organic priority pollutants at various stages of the treatment process. In 2006, the reported concentrations for all these priority pollutants were below the MWRDGC detection limits. In addition to these priority pollutants, there is an array of pharmaceuticals and biogenic hormones. In his letter to the MWRDGC Board, Lanyon (2006) described the District's current and planned activities related to these types of compounds. Briefly, in response to concerns about these compounds the District is collaborating with several investigators (including U.S. EPA) on a comprehensive assessment of the presence of these compounds in raw wastewater, different phases of the treatment process, biosolids, and treated effluent. Data from these studies are currently being collected and evaluated.

Finally, concerns about microbial pathogens in water are addressed by regulations that deal with drinking water quality (Federal Safe Drinking Water Act) and by regulations that deal with discharges to surface waters (Federal Clean Water Act). Illinois drinking water regulations for microbial pathogens are based on tests for total coliform, fecal coliform, and *E. coli* bacteria (IEPA, 2001). These organisms are used as an indication that other, potentially more harmful bacteria might be present. A supplier is in compliance with the standard if no more than 5% of the samples collected during one month (40 minimum samples) are positive for total coliform. In addition, there are concerns about other potential disease-causing organisms including *Cryptosporidium*, viruses, *Giardia lamblia*, and *Legionella*. These concerns, however, are addressed not by monitoring but by requiring specific treatment technologies for the water treatment facility.

Discharges to surface waters are not direct drinking water applications. Because the human health risks are lower, the standards for microbial pathogens are more lenient. For example, year-round protected waters in the State of Illinois, must meet a fecal coliform standard of 2000 cfu/100 mL (IAC Title 35 Subtitle C Chapter 2 Section 378.201). Seasonally protected waters must meet a fecal coliform standard of 200 cfu/100 mL from May through October. Treated effluent that is discharged to general use waters in Illinois should not exceed 400 cfu/100 mL (IAC Title 35 Subtitle C Chapter 2 Section 304.121). The Stickney plant is one of the four MWRDGC facilities that discharge to Chicago waterways currently designated as unprotected waters. These waters have no standards for fecal coliform. In the absence of a standard, the effluent is not chlorinated and the fecal coliform concentrations in effluent from the Stickney plant range from 2000 to 17,575 cfu/100 mL, with a geometric mean of 9802 cfu/100 mL. As a result, the microbial quality of treated effluent varies with the designation of the receiving water and in some cases the quality is higher in summer than it is in winter. Data for coliform concentrations are presented in the upcoming section on human health risks.

Water Quality Summary

Materials that are added to water through domestic, commercial, and industrial activities will alter water quality. Concentrations of most substances will increase. The change in water quality can have an effect on human health and ecosystem risks and on the performance of the distribution system and the application or process equipment (infrastructure risks). These effects could be beneficial or detrimental, so they need to be considered on a case-by-case basis. In general:

- Higher nutrient concentrations and the higher concentration of dissolved organic carbon can promote the growth of biofilms, which can enhance corrosion and pathogen development.

- Treated wastewater contains an array of organic priority pollutants. Monitoring data indicate that the concentrations of these substances are below the detection limit.

- Treated wastewater contains an array of contaminants of concern such as antibiotics, personal care products, and endocrine disruptors. MWRDGC is presently engaged in a study to determine concentrations of these compounds.

- Higher water temperatures of treated effluent will alter reaction equilibrium. The thermodynamics of specific reactions must be evaluated on a case-by-case basis to determine if reactants or products will be favored for each reaction.

- Higher water temperatures also imply faster reaction rates, but the effects may or may not be detrimental.

- Treated wastewater effluent can include an array of microbial pathogens. Concentrations of these organisms, most of which are not monitored on a regular basis, will vary depending on the discharge permit and the disinfection requirements.

Guidelines and Regulations that Influence Water Reuse in the Chicago Metropolitan Area

In this section, the term *regulations* refers to existing rules that are enforceable by governmental agencies, whereas *guidelines* are suggestions (perhaps from the same government agencies) that are not enforceable. Regulations can be incentives or barriers for wastewater reuse. For example, some regulations directly address the concept of reusing treated wastewater by specifying water quality, monitoring, or limits to the applications. Other regulations, which were not intended to address wastewater reuse, can still affect it. One example is regulations on disinfection. Finally, because wastewater reuse in this part of the country is not widespread, experience with these applications and regulations can be helpful. Most of this experience in Illinois comes from outside the Chicago region.

Federal Regulations

The U.S. EPA addresses risks associated with water quality through two regulatory programs. The Safe Drinking Water Act (SDWA) applies to source waters and finished drinking water. The Clean Water Act (CWA) applies to surface waters that are used for aquatic food source uses, recreation, or drinking water.

Promulgated in 1974, the Safe Drinking Water Act (as amended in 1986 and 1996) was designed to protect drinking water quality from source to tap. Under SDWA the U.S. EPA sets National Primary Drinking Water Regulations that include process requirements for contaminant removal or maximum contaminant levels for specific contaminants. The U.S. EPA considers health risks, costs, and technology in setting these regulations. The primary regulations include standards for 87 contaminants (7 microbiological, 4 disinfection by-products, 3 disinfectants, 16 inorganic substances, 53 organic substances, and 4 radionuclides) that can be found in drinking water. There are also Secondary Drinking Water Regulations (non-enforceable guidelines) for 15 substances that can have aesthetic or cosmetic effects (U.S. EPA, 2009).

In the Clean Water Act, water quality standards define the goals for a body of water by designating its uses, setting criteria to protect those uses, and establishing provisions to protect water quality from pollutants. A water quality standard consists of four basic elements:

- Designated uses of the water body;
- Water quality criteria to protect human health and aquatic life;
- An anti-degradation policy to maintain and protect existing uses and high quality waters; and
- General policies addressing implementation issues.

Designated uses of a water body include activities such as water supply, agriculture, aquatic life, and recreation.

Under the Clean Water Act, the U.S. EPA (2006a) developed recommended water quality criteria describing 120 priority pollutants and 47 non-priority pollutants. In addition, there are criteria for 23 pollutants associated with organoleptic effects, which means that these substances can render edible aquatic life or water unpalatable (but not toxic) to humans. These are “recommended” criteria that states should consider when developing their regulations.

To be consistent with water quality standards, individual states must also develop a three-tiered anti-degradation program. Tier 1, which applies to all surface waters, addresses existing uses and the water quality conditions that are needed to support those uses. Tier 2 is designed to protect and maintain water bodies where the current conditions exceed those required to support the designated uses. Tier 3 addresses waters classified as outstanding national resource waters, which includes ecologically unique, important, or sensitive waters. With the exception of certain temporary changes, the purpose of Tier 3 is to ensure that water quality of such resources is not diminished.

The Clean Water Act (CWA) exists to restore the biological, chemical, and physical integrity of the nation's surface waterways (the act does not directly address groundwater). The Act has a list of specific goals and policies including (U.S. EPA, 2008):

- Discharge of pollutants into the navigable waters was to be eliminated by 1985;
- Water quality that provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water was to be achieved by July 1, 1983;
- Discharge of toxic pollutants in toxic amounts is prohibited;
- Federal financial assistance will be provided to construct publicly owned waste treatment works;
- Area-wide treatment management planning processes will be developed and implemented to assure adequate control of sources of pollutants in each State; and
- Programs to control non-point sources of pollution will be developed and implemented.

Part of the Clean Water Act is a water quality-based control program that includes the National Pollution Discharge Elimination System (NPDES), which grants permits to point-source dischargers. U.S. EPA water quality standards are comprised of four elements:

- Designated uses for the water body, such as recreation, water supply, or aquatic life;
- Water quality criteria to protect those designated uses;
- Anti-degradation policy for existing high quality waters; and
- General implementation policies for issues such as low flow conditions and mixing zones.

Subject to approval by the U.S. EPA, individual states can adopt implementation policies that influence water quality standards. Examples of such policies include low-flow, mixing zone, and variance policies.

The federal regulations described above apply throughout the United States and could provide incentives or barriers to water reuse. In contrast, the Supreme Court decree that limits the Illinois diversion is an example of a federal regulation that specifically addresses water use in NE Illinois. Furthermore, that decree could provide a substantial incentive for water reuse.

U.S. EPA Guidelines for Water Reuse

There are no regulations at the federal level for water reuse in the United States. The U.S. EPA published *Guidelines for Water Reuse* in 1992 (U.S. EPA, 1992) and they revised those guidelines in 2004 (U.S. EPA, 2004). That document specifically states that the U.S. EPA does not propose "…standards for water reuse in this publication or any other [publication]" (underlined in the original document). Recognizing the growing importance of water reuse, the U.S. EPA developed their guidelines to support utilities and regulatory agencies in their water reclamation efforts.

The U.S. EPA identifies the following reuse categories:

- **Unrestricted urban reuse**. These applications do not have any restrictions on public access. Examples include irrigation of parks, playgrounds, school yards, and residences; toilet flushing, air conditioning, fire protection, construction, ornamental fountains, and aesthetic impoundments.

- **Restricted urban reuse**. Public access to these areas can be controlled. Examples include golf courses, cemeteries, and highway medians.

- **Agricultural reuse on food crops**. In these applications, water is used to irrigate crops that are for direct human consumption. The applications can be further divided into crops that are processed or consumed raw.

- **Agricultural reuse on non-food crops**. Applications include irrigation of fodder, fiber, and seed crops; pasture land; commercial nurseries; and sod farms.

- **Unrestricted recreational reuse**. Treated effluent is retained in an impoundment and there are no limitations on body-contact water recreation activities.

- **Restricted recreational reuse**. Treated effluent is retained in an impoundment where recreation is limited to non-contact activities such as fishing and boating.

- **Environmental reuse**. In these applications reclaimed water is used to augment stream flows or create or enhance wetlands.

- **Industrial reuse**. Industrial processes such as cooling water make-up, boiler-feed water, process water, and equipment cleaning are part of this category.

- **Groundwater recharge**. The application is aquifer recharge through infiltration basins, percolation ponds, or injection wells. The important concept is that the aquifer is not a source of drinking water.

- **Indirect potable reuse**. Treated wastewater is returned to a groundwater or surface water source with the knowledge that the source is a supply of potable water.

The U.S. EPA provides treatment and water quality guidelines for each of these reuse categories (Table 7).

Table 7. U.S. EPA (2004) guidelines for treatment and water quality prior to wastewater reuse.

Type of Reuse	Treatment	Reclaimed water quality
Urban reuse: Landscape irrigation, vehicle washing, toilet flushing, fire protection, commercial air conditioners, and other uses with similar access or exposure to the water	Secondary, filtration, disinfection	pH: 6 to 9 BOD: ≤ 10 mg/L Turbidity: ≤ 2 NTU Fecal coliform: < 200 / 100 mL Cl_2 residual: ≥ 1 mg/L
Restricted access irrigation	Secondary, disinfection	pH: 6 to 9 BOD: ≤ 30 mg/L TSS: ≤ 30 mg/L Fecal coliform: No detectable Cl_2 residual: ≥ 1 mg/L
Agricultural reuse: Food crops not commercially processed	Secondary, filtration, disinfection	pH: 6 to 9 BOD: ≤ 10 mg/L Turbidity: ≤ 2 NTU Fecal coliform: < 200 / 100 mL Cl_2 residual: ≥ 1 mg/L
Agricultural reuse: Food crops commercially processed	Secondary, disinfection	pH: 6 to 9 BOD: ≤ 30 mg/L TSS: ≤ 30 mg/L Fecal coliform: No detectable Cl_2 residual: ≥ 1 mg/L
Agricultural reuse: Non-Food crops, pasture for milking animals, fodder, fiber and seed crops	Secondary, disinfection	pH: 6 to 9 BOD: ≤ 30 mg/L TSS: ≤ 30 mg/L Fecal coliform: ≤ 200 /100 mL Cl_2 residual: ≥ 1 mg/L
Recreational impoundments	Secondary, filtration, disinfection	pH: 6 to 9 BOD: ≤ 10 mg/L Turbidity: ≤ 2 NTU Fecal coliform: < 200 / 100 mL Cl_2 residual: ≥ 1 mg/L

Table 7 continued. U.S. EPA (2004) guidelines for treatment and water quality prior to wastewater reuse.

Type of Reuse	Treatment	Reclaimed water quality
Landscape impoundments where public contact with reclaimed water is not allowed	Secondary, disinfection	pH: 6 to 9 BOD: ≤ 30 mg/L TSS: ≤ 30 mg/L Fecal coliform: ≤ 200 /100 mL Cl_2 residual: ≥ 1 mg/L
Construction use: Soil compaction, dust control, washing aggregate, making concrete	Secondary, disinfection	pH: 6 to 9 BOD: ≤ 30 mg/L TSS: ≤ 30 mg/L Fecal coliform: ≤ 200 /100 mL Cl_2 residual: ≥ 1 mg/L
Industrial reuse: Once-through cooling	Secondary, disinfection	pH: 6 to 9 BOD: ≤ 30 mg/L TSS: ≤ 30 mg/L Fecal coliform: ≤ 200 /100 mL Cl_2 residual: ≥ 1 mg/L
Industrial reuse: Recirculating cooling towers	Secondary, disinfection	pH: Variable, depends on cycles BOD: ≤ 30 mg/L TSS: ≤ 30 mg/L Fecal coliform: ≤ 200 /100 mL Cl_2 residual: ≥ 1 mg/L
Environmental reuse: Wetlands, marshes, stream augmentation	Secondary, disinfection	Variable, but not to exceed: BOD: ≤ 30 mg/L TSS: ≤ 30 mg/L Fecal coliform: ≤ 200 /100 mL
Groundwater recharge: Not for public water supply	Site-specific and use-dependent	Site-specific and use-dependent
Indirect potable reuse: Groundwater recharge by spreading into potable aquifers	Secondary, filtration, disinfection, may need advanced wastewater treatment	Water should meet drinking water standards after percolation through the vadose zone.
Indirect potable reuse: Groundwater recharge by injection into potable aquifers	Secondary, filtration, disinfection, may need advanced wastewater treatment	pH: 6.5 to 8.5 Turbidity: ≤ 2 NTU TOC: ≤ 3 mg/L Fecal coliform: No detectable Cl_2 residual: ≥ 1 mg/L TOX: < 0.2 mg/L Meet drinking water standards
Indirect potable reuse: Augmentation of surface water supplies	Secondary, filtration, disinfection, advanced wastewater treatment	pH: 6.5 to 8.5 Turbidity: ≤ 2 NTU TOC: ≤ 3 mg/L Fecal coliform: No detectable Cl_2 residual: ≥ 1 mg/L Meet drinking water standards

Summary observations from these guidelines include:

- The U.S. EPA follows a tiered approach. The recommended level of treatment increases with increasing human exposure.

- Except for groundwater recharge that is not to augment a public water supply and groundwater recharge through spreading, the U.S. EPA recommends disinfection for every type of reuse.
- Except for groundwater recharge that is not to augment a public water supply, groundwater recharge through spreading, and environmental reuse (such as wetlands), the U.S. EPA recommends that treated effluent intended for reuse should include residual chlorine.
- Only reuse waters that are intended to augment potable water supplies need to meet drinking water standards.

Interestingly, surface water discharge of treated wastewater is not included in the list of reuse categories. As noted by Maxwell (2001), the return of treated wastewater to surface waters – which are often used as a source of drinking water – is a widespread and acceptable practice. The U.S. EPA (2004) uses the term *surface water discharge* when treated wastewater is returned to surface waters primarily for disposal purposes.

As a result, federal policy regarding wastewater reuse seems to fall into a gap between the Clean Water Act and the Safe Drinking Water Act. For example, in their water reuse guidelines, the U.S. EPA (2004) notes that, "NPDES permits for these discharges are intended to make the rivers 'fishable and swimmable' and generally do not reflect potable water requirements downstream". Furthermore, the U.S. EPA apparently recognizes that drinking water standards may not provide sufficient protection. In the water reuse guidelines (U.S. EPA, 2004), they also note that, "Monitoring should include inorganic and organic compounds or classes of compounds, that are known or suspected to be toxic, carcinogenic, teratogenic, or mutagenic and are not included in the drinking water standards."

When surface water subsequently serves as a potable water supply, the practice is known as unplanned indirect potable reuse. If the same treated wastewater were discharged to surface waters with the intent to augment stream flow (Environmental reuse) or with the knowledge that a downstream community uses the stream as a potable water supply source (Indirect potable reuse), the application would be identified as a beneficial use. These distinctions leave the impression that facilities governed by the NPDES permit system could be unaware of what happens downstream from their outfall.

In the absence of federal regulations that specifically address water reuse, many states have developed their own regulations.

State Guidelines and Regulations

Evidence of the growing awareness of the need to address water reuse can be seen as the number of states with guidelines or regulations increased from 1992 to 2003 (Table 8). Typically, regulations and guidelines include recommendations for treatment and water quality requirements for specific reuse categories, as well as recommendations for water quality monitoring and setback distances for public access and potable water supply wells. Comments with the guidelines address the need for site-specific assessments for issues such as dechlorination, worker exposure, grazing animals, and additional treatment. States with extensive regulations or guidelines include Arizona, California, Colorado, Florida, Hawaii, Nevada, New Jersey, Oregon, Texas, Utah, and Washington. According to the U.S. EPA inventory, Illinois has reuse regulations that apply to the following reuse categories:

- Unrestricted urban reuse;
- Restricted urban reuse;
- Agricultural reuse on food crops; and
- Agricultural reuse on non-food crops.

These and other Illinois regulations that affect water reuse are described in the next section.

Table 8. Number of States with regulations or guidelines for reuse applications identified by U.S. EPA (U.S. EPA, 1992; 2004).

Type of reuse	Number of States with reuse guidelines or regulations	
	1992	2003
Unrestricted Urban	22	28
Irrigation	22	28
Toilet Flushing	3	10
Fire Protection	2	9
Construction	4	9
Landscape Impoundment	7	11
Street Cleaning	1	6
Restricted Urban	27	34
Agricultural (Food Crops)	19	21
Agricultural (Non-food Crops)	35	40
Unrestricted Recreational	5	7
Restricted Recreational	7	9
Environmental (Wetlands)	3	3
Industrial	6	9
Groundwater Recharge (Non-potable Aquifer)	0	5
Indirect Potable Reuse	0	5

Illinois State Regulations that affect Water Reuse

The Illinois regulations noted in the U.S. EPA inventory directly address water reuse in the state. There are, however, additional state regulations that can indirectly affect water reuse. All of these regulations are part of the Illinois Administrative Code (IAC). The IAC can be accessed through a web site maintained by the Illinois Pollution Control Board www.ipcb.state.il.us.

Illinois Environmental Protection Agency

The Illinois wastewater reuse regulation referred to in the U.S. EPA (2004) guidelines appears in Subtitle C Water Pollution, Chapter II Environmental Protection Agency, as Part 372 entitled "Illinois Design Standards for Slow Rate Land Application of Treated Wastewater" (ILPCB, 2002). This part includes design standards and permit application requirements for what is known as a "non-discharging" wastewater treatment system. The term "non-discharging" refers to the fact that effluent from these systems is applied to land and not discharged to surface waters. As a result, these systems are not required to obtain permits under the National Pollution Discharge Elimination System (NPDES) program. Under the category of unrestricted urban use, two treatment processes are mentioned: A two-cell lagoon system with tertiary sand filtration and disinfection, and a mechanical secondary treatment process with disinfection. The regulations address the following issues:

- **Storage requirements**. Two options are presented. The so-called "rational design" approach must include capacity for the wettest year from a 20-year cycle. The alternative approach is to provide 120-days of storage for areas south of Interstate 70 or 150-days of storage for areas north of Interstate 70.

- **Loading rates**. Loading or application rates are based on the limiting factor from material balance calculations for water, nitrogen, phosphorus, and biochemical oxygen demand.

- **Groundwater monitoring**. There must be one monitoring well up gradient, two monitoring wells down gradient, and additional wells if there are any potable water supply wells within 100 feet. Monitoring must include nitrate, ammonia, chlorides, sulfate, pH, total dissolved solids, total fecal coliform, and phosphate.

- **Setback distances**. Residential property must be at least 200 feet removed from the application area.

The same two treatment processes are addressed under the category of restricted urban use. Specific regulations are identical for storage requirements, loading rates, and groundwater monitoring, but there are more restrictions on the setback distances.

- **Setback distances**. No buffer is required if during the application and drying time the area is closed to the public. No buffer is required to irrigate a golf course between dusk and dawn. If there is a fence at least 40-inches high, residential property need be only 25 feet removed from the application area.

Regulations for applications to agricultural non-food crops are nearly identical to the regulations for restricted urban use. One exception is that the requirement for disinfection is waived. The other difference is that in the absence of a fence that is at least 40-inches high, residential property must be at least 200 feet removed from the application area.

The U.S. EPA does not identify specific Illinois regulations for application of treated wastewater for unrestricted recreational reuse, restricted recreational reuse, augmentation flow to wetlands, industrial reuse, groundwater recharge, or indirect potable reuse. In fact, Part 372 of the Illinois Administrative Code (ILPCB, 2002) specifically states that for systems approved for slow-rate land application:

> “Treated wastewater shall not be applied or discharged to wetlands, streams, waterways or other surface waters.”

If a system is approved for slow-rate land application, therefore, it seems that augmentation flow for wetlands, marshes, or streams would not be allowed for that system.

Other parts of IAC Title 35 can indirectly affect water reuse. For example, Subtitle C deals with water pollution and Chapter 1 includes appropriate standards set by the Illinois Pollution Control Board. Chapter 1, Part 302 addresses water quality standards that apply throughout the state, and Part 303 address water use designations and site specific water quality standards. Beginning with the lowest quality water the four general water quality standards are:

- **Secondary contact and indigenous aquatic life standards**. These standards apply only to waters specifically designated in Part 303, which include the Chicago Sanitary and Ship Canal, the Calumet-Sag Channel, the South Branch of the Chicago River, the North Branch of the Chicago River from its confluence with the North Shore Channel to its confluence with the South Branch, and the Des Plaines River from its confluence with the Chicago Sanitary and Ship Canal to the Interstate 55 bridge. According to Section 303.442, the Chicago River is not required to meet the public and food processing water supply standards (below). Standards for specific chemical constituents are not as stringent as they are for other waters. For example, there is no standard for fecal coliform and, therefore, no disinfection requirement.

- **General use water quality standards.** The purpose of these standards is to ensure the aesthetic quality of the water and protect water for a variety of uses including secondary contact use and most industrial uses, agricultural use, aquatic life, and wildlife. If the physical configuration permits it, these waters are also protected for primary contact uses. These standards address dissolved oxygen; pH; radioactivity; phosphorus; fecal coliform; and offensive conditions such as color, floating debris, and algal growth. There are also numeric standards for specific chemical constituents. In some cases these include acute standards, chronic standards, and human health standards.

- **Public and food processing water supply standards**. These standards must be met in all designated waters at any point at which water is withdrawn for treatment and distribution as a potable supply or for food processing. Cumulative with the general use standards, the water supply standards typically include more stringent limits (lower concentrations) and more constituents. Part of this standard (Section 302.303) deals with finished water. When standard water treatment processes are applied to these waters, the product should be potable water.

- **Lake Michigan Basin water quality standards**. The standards are set in Part 302 and the basin is defined in part 303. According to the code, the North Shore Channel and the Chicago River are not part of the Lake Michigan Basin.

These designated water quality standards can indirectly influence water reuse because the required degree of wastewater treatment depends on the standards established for the receiving stream. From the perspective of water reuse, one of the most important parts of wastewater treatment is disinfection. In addition to these standards, IAC Title 35 Subtitle C Chapter 2 Part 378 addresses effluent disinfection requirements and identifies three types of surface waters. Any waters that are likely to encourage primary contact (any water use that involves significant risk of ingesting enough water to pose a human health hazard) must not exceed the 200 fecal coliform per 100 mL standard from May through October. These waters are known as “seasonally protected waters”. There are also “year-round protected waters”, where the fecal coliform standard is less stringent (2,000 organisms per 100 mL) but the standard applies throughout the year. This category pertains to any intake point in waters used for public and food processing supply. The third type of water identified in this section, “unprotected waters” are not subject to a fecal coliform standard. These waters must have one or more of the following characteristics:

- Adjacent land use that discourages primary contact activity;
- Physical obstacles that prevent primary contact or limit access; or
- Waters with no deep pools during the summer or waters with an average depth that does not exceed two feet.

Identification of these unprotected waters is based on a survey to determine which of these characteristics applies.

As a result of these standards, three of the MWRDGC treatment plants (Kirie, Egan, and Hanover Park) have more sophisticated (tertiary) treatment facilities. From May through October, these three plants operate chlorination processes that are designed to help them comply with the fecal coliform component of the general use water quality standard. In contrast, the other four treatment plants (Stickney, Calumet, North Side, and Lemont) have two-stage, activated sludge processes and are not required to chlorinate their effluent.

In addition to specific water quality standards, the code includes the following language about toxic substances (IAC Section 302.210):

> “Waters of the State shall be free from any substances or combination of substances in concentrations toxic or harmful to human health, or to animal, plant or aquatic life.”

This statement is immediately followed by:

> "Individual chemical substances or parameters for which numeric standards are specified in this Subpart are not subject to this Section."

Part 302 also includes the anti-degradation standard. The purpose of this standard is:

> "…to protect existing uses of all waters of the State of Illinois, maintain the quality of waters with quality that is better than water quality standards, and prevent unnecessary deterioration of waters of the State."

The requirement for a facility-specific anti-degradation review does not apply in general to current NPDES permits. An anti-degradation review is required when new pollutant loadings or hydrological modifications require a new, renewed, or modified NPDES permit. A review is also required if improved monitoring data, new analytical testing methods, new or revised technology, or water-quality based effluent limits result in a change in the permit limits.

The anti-degradation standard is another example of a regulation that could have a significant effect on water reuse although it does not directly address the issue. As efforts grow to protect and improve surface water quality, there could be more political, regulatory, and economic pressures for wastewater reuse rather than wastewater discharge.

Illinois Department of Public Health

IAC Title 77 deals with public health and Chapter I specifically addresses the Department of Public Health. Subchapter r covers water and sewage. Part 890 includes the Illinois Plumbing Code. Parts of the code describe the need for air gaps and backflow preventers where potable water supply lines might connect with distribution systems that carry non-potable water, such as might occur in a fire protection system. Hydrants can be used with non-potable water if they are clearly labeled and isolated from the potable water supply. Section 890.1120 describes the color code for distribution systems carrying non-potable water; such systems must be clearly marked with yellow paint.

Illinois Department of Natural Resources

Title 17 of the Illinois Administrative Code deals with conservation issues. Chapter I includes the administrative rules for the Illinois Department of Natural Resources (IDNR). Subchapter h covers water resources and Part 3704 addresses regulation of public waters. The appendix to that section identifies the Chicago area waterways as public bodies of water that are open to public use. Any construction that interferes with the ability of the public to use public bodies of water requires a permit from the IDNR. Commercial or industrial applications that use water from the Chicago area waterways (predominantly a reuse application) would presumably be subject to this requirement.

Section 3730.304 specifies criteria that IDNR will consider in determining water allocation. After July 1, 1977, anyone using water from Lake Michigan that is subject to allocation must have a valid allocation permit from the IDNR. Section 3730.307 notes that a conservation plan is a condition of receiving an allocation, but it does not specifically mention the concept of water reuse.

IDNR set priorities for allocation based on categories of water users. The highest priority (Category I) includes residential, commercial, or industrial users for whom Lake Michigan provides the most economical supply. That same high priority is given to meeting navigation and dilution needs in the Sanitary and Ship Canal. Category II users are those residential, commercial, or industrial users who could reduce their demand on regional aquifers by using Lake Michigan water. Category II also requires dilution waters to meet water quality standards in the Sanitary and Ship Canal (apparently in contrast to the dual needs of navigation and dilution for Category I.) Category III applies to any users who do not fall in to either of the above categories.

Interestingly, the IDNR Lake Michigan allocation scheme does not address the water quality requirements of the users. For example, residential, commercial, and industrial users are lumped together as high priority users despite the fact that there is a wide range of water quality requirements among those users.

City of Chicago Ordinances

The City of Chicago does not have ordinances that specifically address water reuse. As with the state regulations, however, several ordinances can have an effect on water reuse. For example, Title 11 of the Municipal Code of the City of Chicago addresses Utilities and Environmental Protection (ALPC, 2010). Chapter 8, which deals with Water Supply and Distribution Systems, clearly spells out that the city intends to rely on Lake Michigan as its source for potable water:

> "No groundwater well, cistern or other groundwater collection device installed after May 14, 1997, may be used to supply any potable water supply system, except at points of withdrawal by the City of Chicago or by a unit of local government pursuant to intergovernmental agreement with the City of Chicago."

Groundwater recharge with treated wastewater would still be possible but the city would have to be involved if the groundwater were to be used as a source of potable water.

Section 11-12-100 addresses efficient water use. The commissioner has the ability to cut-off the water supply and charge the user for the wasted water.

Section 11-12-210 describes water meters, which are required for all new buildings and any new services on existing buildings. Metered consumers are charged a uniform rate for water use. Rates per 3.785 m^3 (1,000 gal) were $1.25, $1.29, and $1.33 during 2003, 2004, and 2005, respectively. The rates remained at the 2005 level for 2006 and 2007. In the absence of water use meters, rates are based on the dimensions of the building and the number and types of fixtures in the building.

The cost of water in the City of Chicago is low relative to the rest of Illinois (and much of the rest of the county). Dziegelwski et al. (2004) conducted a survey of water supply costs for Illinois communities in 2003. The most common approach to pricing community water was a uniform rate structure (constant cost per volume). The costs ranged from $0.20 to

$20.60 per 3.785 m^3 (1,000 gallons); the average cost was $3.39 per 3.785 m^3 (1,000 gallons). In parts of the country where treated wastewater reuse is practiced, the variety of rate structures makes it difficult to compare prices but the cost of reclaimed water ranges from 0.5 to 1.0 times the cost of potable water (U.S. EPA, 2004). In the upcoming section on economics, we will see how the relatively low cost of water in the City of Chicago could be a disincentive for water reuse.

Village of Richmond Water Reuse Ordinance

The Village of Richmond is located about 100 km (60 miles) northwest of Chicago. The Village drafted the first water reuse ordinance in Illinois. The purposes of the ordinance were to preserve groundwater and to protect water quality in the North Branch of Nippersink Creek. Information provided in this section was adopted from a version of the ordinance that was available at the Village of Richmond web site (www.richmpond-il.com) in 2005. Since that time, the ordinance was removed from the village web site, so in the following paragraphs we describe the ordinance in the past tense. Background information on how the ordinance came about can be found in the section on case studies.

The ordinance described specific instances where municipal water supply users would be required to use municipal treated wastewater. Reuse water was defined as water processed through a tertiary treatment facility and disinfected. That water must meet Illinois Environmental Protection Agency (IEPA) permitting criteria and public health standards for a non-potable water supply.

The ordinance applied only to applicable users, defined both by location and use category. For example, municipal water supply users in the section of the Village south of South Street must use treated wastewater for new developments or buildings or substantial improvement to existing buildings. This requirement applied to all public users, commercial users, industrial users, agricultural users, and new residential developments if the development was equal to or greater than ten acres. The ordinance did not apply to single family residential lots.

Applicable Users: The ordinance applied to new developments or buildings or substantial improvement to existing buildings by the following municipal water supply users south of South Street.

- All public users;
- All commercial users;
- All industrial users;
- All agricultural users; and
- All new residential developments users equal to or greater than ten acres.

Mandated Water Reuse: Applicable users listed above must use reuse water for:

- Landscape watering except in playgrounds frequented by children ten years of age or under;

- Landscape water features except in playgrounds frequented by children ten years of age or under;
- Industrial cooling water;
- Commercial, industrial, and public facilities toilet flushing;
- Commercial car wash facilities; and
- Commercial, industrial, and public boiler feed water.

Language in the ordinance encouraged water reuse in general. For example, industries were encouraged to use reuse water for non-potable industrial processes. However, they were required to submit an evaluation of a proposed reuse water system for all non-potable industrial processes. In addition to the mandated and encouraged water reuse, applications may include, but were not limited to, construction use water, commercial use, enhancement of wildlife habitat, and recreation impoundments. These applications were considered for approval by the Village on a case-by-case basis.

Some applications were mandated while others were recommended. For all applicable users, the following were mandated:

- Landscape watering except in playgrounds frequented by children ten years of age or under;
- Landscape water features except in playgrounds frequented by children ten years of age or under;
- Industrial cooling water;
- Toilet flushing at commercial, industrial, and public facilities;
- Commercial car wash facilities; and
- Commercial, industrial, and public boiler feed water.

The Village encouraged other industrial users to consider treated effluent for appropriate non-potable industrial processes. These applications would be considered on a case-by-case basis. The ordinance specifically mentioned water for construction practices, commercial uses, enhancement of wildlife habitat, and recreation impoundments.

Permits were required. The permits would become effective after facility completion, testing, inspection, and final approval. Each permit must describe the application and the amount of water expected to be used. The ordinance stated that the Village would make a good faith effort to meet the supply expectations, but there could be times when the supply was limited. The ordinance also stated that when drought conditions limit uses for the potable water supply, those limitations would not apply to the reuse applications.

Regulations Summary

Federal government programs regulate discharges to surface waters and protect drinking water supplies from source waters to the supply tap, but they do not regulate water reuse. The U.S. EPA does provide water reuse guidelines, which address human health risks by recommending higher levels of treatment for increased human exposure. Except for groundwater recharge by spreading effluent on the land surface, the U.S. EPA recommends disinfection for every reuse application.

The number of states with guidelines or regulations for water reuse applications is increasing. However, Illinois has few regulations that directly address water reuse. IEPA has design standards for systems that apply treated wastewater to land. IDPH plumbing code describes labeling and isolation requirements for systems that carry non-potable water.

Water quality standards in Illinois can indirectly discourage water reuse, especially in the Chicago Metropolitan area. Much of the Chicago Area Waterways is by definition relatively low quality water, and therefore exempt from effluent disinfection requirements.

In response to the Supreme Court decree that limits the amount of water that Illinois diverts from Lake Michigan, IDNR developed water allocation criteria. Those criteria, however, do not mention water reuse as a conservation practice. Furthermore, the allocation rules place the same priority on domestic supply as they do on navigation and dilution.

The City of Chicago has banned new groundwater wells for public supply since 1997. If future demands for municipal water in this region continue to grow, the supply could be constrained by the Supreme Court's diversion limit. If so, the City of Chicago will need to consider alternative water resources, such as treated municipal wastewater from MWRDGC's facilities.

The Village of Richmond's planned water reuse ordinance could be a boost to water reuse in N.E. Illinois. It provides an example of how a local community can implement water reuse in the absence of federal regulations.

The Safe Drinking Water Act and the Clean Water Act are examples of federal programs that involve regulations and policy. Although they are not regulations, the U.S. EPA water reuse guidelines are presented in this section because they provide a good introduction to the regulations. In addition to these federal programs there are also regional policies that affect water reuse.

Regional Policy

This section covers several different levels of non-federal policy that can influence water reuse. These levels include the state, the regional planning authority, the city, and local utility policies.

State Policy

There do not appear to be any Illinois state policies that specifically address the concept of water reuse. There are, however, state programs that could affect water reuse. For example, the mission of the IEPA Bureau of Water is to:

- Ensure that Illinois' rivers, streams, and lakes will support all uses for which they are designated, including protection of aquatic life, recreation and drinking water supplies;
- Ensure that every Illinois Public Water system will provide water that is consistently safe to drink; and
- Protect Illinois' groundwater resource for designated drinking water and other beneficial uses.

To achieve this mission and as required by the Federal Water Pollution Control Act Amendments of 1972, Illinois has a Water Quality Management (WQM) plan. Developed in 1982, the plan coordinates IEPA's water quality management efforts, which cover 83 counties, with the water quality management plans of three regional planning agencies, which cover the remaining 19 counties. The overall State WQM plan incorporates the above four management plans with all approved wastewater treatment facilities plans and all wastewater National Pollutant Discharge Elimination System (NPDES) Permits (excluding industrial process, thermal, and non-contact cooling water NPDES permits). The WQM Plan helps to safeguard state and federal investments in pollution control facilities. It is supposed to assure sound economical and environmental decision making. The Plan addresses control of pollution sources, maintenance of stream use and water quality standards, protection of groundwater resources, and control of hydrographic modifications. Consistent with the approach of the original Clean Water Act, the Plan is implemented by focusing on water treatment districts called Facility Planning Areas (FPAs).

In 2003, IEPA assembled a diverse group of stakeholders into a Basin-Wide Management Advisory Group (B-MAG) to review how the agency plans for and protects water quality. In contrast with the FPA approach, which frequently led to local disputes about who would control development, B-MAG recommended a watershed-based approach to address ecosystem concerns, water quality problems, development, and economic growth. The FPA approach remains in place while IEPA tests a watershed-based approach in specific watersheds.

CMAP Policy

The Chicago Metropolitan Agency for Planning (CMAP) is the comprehensive land-use planning and regional growth management agency for six counties in NE Illinois.

CMAP is charged with administering the FPA approach in those counties. Evolved from the 1957 legislation by the Illinois General Assembly known as the Northeastern Illinois Planning Act, part of their charge is to recommend plans that address water supply and sewage disposal in the region and ensure they are consistent with the federally approved Illinois Water Quality Management Plan. The original name for the agency, the Northeastern Illinois Planning Commission or NIPC, remains in use. Many of the citations in this section refer to that original name.

As an aid in their task of reviewing wastewater facility plans, CMAP has a *Water Quality Management Plan Amendment Process and Procedures Manual* (NIPC, 1997), which provides an overview of the review process and the criteria the commission uses to evaluate applications. The manual lists the components of a comprehensive facility plan, including an assessment of the water supply implications, analysis of alternative discharge locations to minimize water quality impacts, and an analysis of regional treatment alternatives. The manual also notes that a "…recommended alternative is to evaluate a no-discharge system, such as land application." Furthermore, when considering this alternative, the "…cost differential should be weighed against predicted water quality and stream use impacts."

The publication *Protecting Nature in Your Community: A Guidebook for Preserving and Enhancing Biodiversity* (NIPC, 2000) included a chapter on Improved Wastewater Management. In that chapter NIPC notes that "Treatment plant effluent should be utilized as a resource and not simply viewed as a waste product." To promote wastewater reuse, NIPC suggests that wastewater reuse can be an inexpensive approach to reducing the potential adverse impacts of wastewater discharges to surface waters. One option they mention is using treated wastewater for flushing toilets. Another option is irrigation or land application of treated wastewater. They note that the area needed for a land application process depends on soil slope and permeability. Furthermore, land application can be part of a multi-objective management approach that also addresses benefits such as recreation, habitat, and stormwater management.

CMAP is also a member of the Southern Lake Michigan Regional Water Supply Consortium. The Consortium includes a variety of stakeholders from SE Wisconsin, NE Illinois, and NW Indiana who share a common mission to promote a comprehensive, regional approach to sustainable water supply planning and management. The Consortium provides another opportunity to integrate water reuse into planning.

Water Reuse Policy in Chicago

The City of Chicago describes strategies for water resource management in *Chicago's Water Agenda 2003* (City of Chicago, 2003). In that agenda, Mayor Richard M. Daley acknowledges water as a vital resource that should be protected, conserved, and managed wisely. The agenda addresses water conservation, water quality protection, stormwater management, and outreach.

Highlights of the program include:

Chicago Parks. The Chicago Park District is taking the following steps to address conservation issues:

- Ensure that there are on/off controls on all new drinking fountains;
- Upgrade 53 swimming pools so they safely re-circulate water;
- Install splash fountains that re-circulate water; and
- Disconnect Park District downspouts from the sewer system so that stormwater can be used for irrigation and groundwater recharge.

Public places. The City is installing water saving plumbing fixtures in City buildings. The City will also:

- Examine the building code for opportunities for more efficient fixtures, such as dual flush toilets and waterless urinals;
- Explore opportunities for gray water systems for flush toilets or to irrigate landscaping around public buildings; and
- Reduce the need for landscape watering by planting native species that are drought tolerant.

Industries. The Chicago Department of Environment Industrial Energy Efficiency Program can provide energy-and-process audits for interested large industrial energy users. That program also features interest-free loans that can be used to implement recommendations from the audit. Audits of 12 Chicago businesses have already identified nearly 4.92×10^5 m^3/y (130 million gallons per year) in water savings.

Residential use. Most residential water customers pay a flat rate for water use, regardless of the amount of water used. To promote responsible water use, the Department of Water Management is developing a plan to install water meters for all residential water users.

Replacement of water mains. The Department of Water Management instituted a five-year, $620 million capital improvement program, and part of that effort is directed to replacing old leaking water mains. In addition, the Department is helping other municipalities examine their distribution systems for leaks. The improvements in Chicago alone will save an estimated 4.54×10^5 m^3/y (120 million gallons) of water each day.

The MWRDGC

The mission statement of the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC, also known as "The District") is:

> "The District will protect the health and safety of the public in its service area, protect the quality of the water supply source (Lake Michigan), improve the quality of water in watercourses in its service area, protect businesses and homes from flood damages, and manage water as a vital resource for its service area."

Most of the mission statement addresses water quality issues, but the last line also describes the need to "…manage water as a vital resource…" Water reuse could be part of that management effort, and the MWRDGC is the regional entity with the most experience in water reuse. They have a history of water reuse both internally and in cooperation with industrial and commercial applications. A more detailed description of their reuse experience can be found in the upcoming section on case studies.

Regional Policy Summary

Most regional policy does not explicitly address the concept of wastewater reuse. The state of Illinois has opportunities, CMAP has a written policy, the City of Chicago has a written policy, MWRDGC has the most experience, but there is little incentive to promote wastewater reuse.

Human Health and Ecosystem Risks

Kolpin et al. (2002) examined samples collected from 139 streams in 30 states for 95 organic wastewater contaminants (OWCs) and found that many of the compounds that are important in commercial, industrial, and domestic activities can make their way into the environment after passing through wastewater treatment plants. They also noted that although many of these household chemical and pharmaceutical compounds were designed specifically to stimulate a physiological response in animals, plants, or humans, little is known about the fate and transport of these compounds in the environment. They cited several specific concerns including potential increased incidences of cancer, abnormal physiological processes and reproductive impairment, and development of antibiotic-resistant bacteria. For example, in their critical review of the existing literature on estrogens, Khanal et al. (2006) observed that there is evidence aquatic species such as minnows, turtles, and trout can be sexually inhibited or reversed when exposed to natural estrogens at concentrations as low as several tens of ng/L.

Faced with these kinds of uncertainty, the U.S. EPA (2006a) uses risk assessment as a regulatory tool because it provides "…a qualitative or quantitative evaluation of the risk posed to human health and the environment by the actual or potential presence of pollutants." In general, human health and ecosystem risks can be associated with inorganic and organic substances, and microbial pathogens that are present in wastewater. Recently, the U.S. EPA (2006b) reported that microbial contaminants (bacteria, viruses, and protozoa) and disinfection by-products are among the most important health risk management challenges facing the drinking water supply industry.

Similar methods are applied to assess ecosystem risks. The U.S. EPA Region V office identified nutrient loadings as one of the most common causes of water quality impairment in the Region (U.S. EPA, 2006a). Nutrient (phosphorus and nitrogen) loading to surface waters can stimulate excess algal growth. Algal blooms can block sunlight from reaching submerged aquatic vegetation. In addition, algal blooms can lead to substantial fluctuations in dissolved oxygen concentrations as algal populations shift between photosynthesis in the day and respiration during darkness. Finally, when algal blooms die the oxygen demand created from microbial degradation of the algae can lead to anoxic conditions in the water column. The combined effect of these stressors on the ecosystem can substantially reduce biological diversity and overall ecosystem health. Problems associated with excess nutrient loading are not limited to local symptoms. The hypoxia problem in the Gulf of Mexico is probably related to excess nutrient loads to the Mississippi River watershed (USGS, 2006). Furthermore, algal blooms can create taste and odor problems in drinking water and some species of algae produce toxins that can lead to neurological and respiratory problems. In these and other cases ecosystem and human health risks can overlap.

Wastewater reuse presents an opportunity to alter current practice and change the types and degrees of risk. Relative to the risks associated with current wastewater management, wastewater reuse could increase or decrease human health and ecosystem risks. This section includes a review of results from water reuse applications and an assessment about how reuse could alter the risks associated with wastewater management.

Potential Human Health Risks associated with Reuse

Human exposure to recycled water will vary with the reuse application. In general, human health risks should be lower where water is reused in closed-loop industrial processes and more risks should be expected when water is used for irrigation or groundwater recharge. Most of the existing literature on contaminant fate and transport associated with wastewater reuse stems from studies of recharge applications.

Percolation or infiltration of treated wastewater provides an opportunity for additional water treatment (a polishing step) as the treated effluent percolates into the subsurface. A concern associated with this process is that contaminants present in the treated wastewater could degrade groundwater quality. For example, Barber et al. (1998) described their assessment of the groundwater recharge that has been operating near the Otis Air Force Base in Massachusetts since 1936. The authors concluded that organic compounds that are only slowly degraded can lead to groundwater contamination problems when effluent is used to recharge a low-carbon, permeable aquifer.

In response to the increasing awareness of potential water resource shortages, the National Research Council constituted a Committee on Groundwater Recharge to assess problems that could be associated with using treated wastewater effluent to recharge groundwater aquifers (NRC, 1994). The committee reported that the primary health risk concerns were associated with synthetic organic chemicals, disinfection by-products, and pathogenic organisms. They also noted that the soil aquifer treatment that occurs during recharge can be an effective way to remove these contaminants, but cautioned that the operating conditions that are optimum for removal of one contaminant may not be optimum for another contaminant. The committee observed that health implications associated with using reclaimed water for recharge had been studied at several sites, including direct potable reuse in Denver, and indirect potable reuse in San Diego, Tampa, and Orange County, CA. No significant effects from infectious disease agents or chemical toxicants were reported from any of these studies. The authors cautioned that uncertainties remained, especially with regard to long-term exposure to these compounds.

More recently, Fox et al. (2001) summarized results from studies conducted by the National Center for Sustainable Water Supply evaluating soil aquifer treatment processes for reclaiming treated wastewater. They reported that the greatest concerns were associated with residual organic material, nitrogen, and pathogenic microorganisms. Removal of dissolved organic carbon (DOC) during recharge was a function of the concentration of readily degradable carbon in the wastewater after pre-treatment. Surprisingly, after relatively short-term treatment (30-d), DOC removal apparently was well-correlated with the concentration of natural organic matter in the drinking water supply. Although much of the DOC removal happened within 3-m of the surface, removal continued over longer time scales.

A large part of the concern about residual organic materials stems from the fact that most reuse applications recommend chlorination, which can lead to the formation of disinfection by-products. Fox et al. (2001) reported that the trihalomethane formation potential during recharge, when normalized to the DOC concentration, could not be distinguished from the formation potential of the drinking water source. They concluded that the reactivity of the DOC was not changed through the treatment process.

Fox et al. (2001) also noted that when total nitrogen concentrations in treated wastewater exceeded 10 mg as N/L the fate of these nitrogen compounds in the subsurface could be of concern. Based on their tests, when nitrate was the dominant form of nitrogen at least half of the applied nitrogen could be removed if the oxygen demand of the recharge water was sufficient to create anoxic conditions, provided there was an adequate supply of biodegradable carbon to promote nitrogen reduction. The authors also believed that ammonia could be removed through nitrification provided there were sufficient wetting and drying cycles.

Results related to microbial pathogens were inconclusive. As would be expected, when effluent that had tertiary treatment (filtration and extended chlorination) was used for recharge, detection of bacterial indicators and viruses was less than it was at a site that was recharged with chlorinated secondary effluent. In some cases, the authors believed the results suggested background contamination and in other cases the use of reclaimed water had no significant microbial impact. Their summary suggests that soil aquifer treatment can be effective at removing microbes, but the results depend on the level of pretreatment and specific soil characteristics of the site.

According to Fox et al. (2001), although DOC removal was faster under aerobic conditions, the concentration of refractory organic compounds after 30-d was not a function of the redox conditions. Redox conditions also apparently had no significant effect on pathogen removal. As noted above, however, groundwater redox conditions did have an effect on nitrification. Alternating wetting and drying cycles can be used to control formation of clogging layers, which can reduce infiltration rates. Management of these cycles can also play an important role for nitrification.

Lenheer et al. (2001) examined chlorine reactivity of organic compounds during recharge. Their study site was the Montebello Forebay recharge basin in Los Angeles County. They reported that DOC precursors of disinfection byproducts in reclaimed water were not rapidly removed by soil aquifer treatment. Most of the DOC in infiltrated reclaimed water was fulvic acid derived from wastewater treatment and natural fulvic acid in the water supply.

The Montebello Forebay recharge site in Los Angeles County, CA, could be one of the most thoroughly studied groundwater recharge sites in the world. The USGS (Schroeder, 2003) recently published a summary from several years of study at that site. They reported that surfactant metabolites traveled several miles through the subsurface and were detectable almost 30 years after they were introduced. Interestingly, relative to natural organic carbon in most surface water sources, the trihalomethane formation potential of organic carbon in recycled water was lower. The authors concluded that results from their work clearly demonstrated that organic carbon and nitrogen could be substantially removed from treated effluent during soil aquifer treatment. They cautioned, however, that they were unable to answer the question of long-term sustainability and to what extent removal was due to temporary storage on the soils.

Since that summary report was released, Anders et al. (2004) followed up with a report on their studies of virus transport associated with groundwater recharge at the Montebello Forebay. They concluded that during recharge with treated wastewater viruses were rapidly removed from the water and that adsorption, not inactivation, was primarily responsible for virus removal. Furthermore, they suggested that it should be possible to design a public health management plan that would maintain favorable conditions for virus attachment and removal and maximize the amount of treated wastewater used for recharge.

Overall, these results are consistent with conclusions from the earlier NRC (1994) study that concluded artificial recharge was a viable option in a comprehensive total water resource management program. Furthermore, they suggest that with pretreatment and post-treatment appropriate for the source and site, treated effluent could be used as a source for artificial recharge of groundwater aquifers.

In the studies summarized above, the focus was on recharge and subsequent human exposure through groundwater. Other wastewater reuse applications, however, can present different exposure pathways. Blumenthal et al. (2000) recognized these differences when they combined epidemiological studies with a quantitative risk assessment model to come up with guidelines for agricultural applications involving treated wastewater. The authors pointed out that risks vary depending on the irrigation method. Spray or sprinkler irrigation lead to the greatest health risks from irrigated crops. Risks to field workers are greatest when flood or furrow irrigation is used. As a result, they recommended fecal coliform limits ranging from 10^{-3} per 100 mL for restricted irrigation sites down to 10^{-5} per 100 mL for unrestricted irrigation, flooding irrigation, or for sites where children might be exposed. At the time of their study, the authors believed that there was not sufficient evidence to demonstrate a need for separate specific pretreatment guideline limits to protect against viruses or parasitic protozoa.

How to define “proper pretreatment” is an important and challenging question to answer. For example, the U.S. EPA guidelines reviewed above recommend chlorination prior to most reuse applications. The reasoning behind such a recommendation can be seen by considering data describing fecal coliform concentrations in the effluent from the John E. Egan wastewater treatment facility. Effluent from the Egan facility is subject to chlorination requirements from May through October each year. The effect of this regulation clearly shows up in the effluent fecal coliform concentrations, which exhibit seasonal cycles from less than 10 organisms per 100 mL during the chlorination period to more than 10,000 organisms per 100 mL through the winter months (Figure 9). Chlorination, however, also promotes the formation of potentially carcinogenic chlorinated organic compounds.

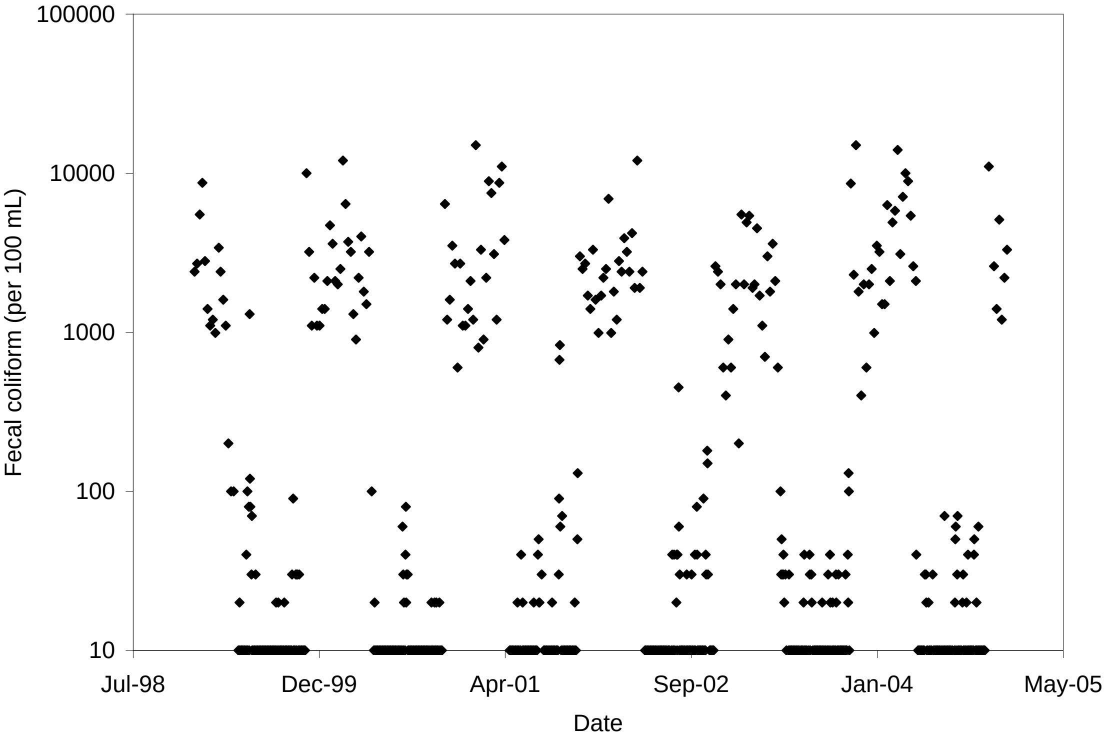

Figure 9. Fecal coliform concentrations in the effluent from the John E. Egan wastewater treatment plant from 1999 through 2004. Data come from the MWRDGC web site.

Human Health and Ecosystem Risk Summary

In summary, the greatest human health risks from groundwater recharge are probably associated with nitrogen, dissolved organic carbon (DOC), and microbial pathogens. Existing studies suggest that when the recharge site is designed and managed properly (appropriate loading with alternating wetting and drying cycles) total nitrogen concentrations can be lowered to acceptable levels. DOC concentrations can also be reduced and, relative to nitrogen removal, the duration of the wetting and drying cycles is not as critical. In terms of specific DOC fractions, the trihalomethane formation potential is apparently no worse than it is in the source water, and many of the compounds believed to be responsible for endocrine-disrupting activity are either biodegradable or strongly adsorbed onto aquifer solids. The fate of microbial pathogens is not as clear, perhaps because of background contamination problems and perhaps because of the variety of different organisms with different behavior. As noted by the U.S. EPA (2004) however, "…there have not been any confirmed cases of infectious disease resulting from the use of properly treated reclaimed water in the U.S."

Different applications and treatment processes can lead to different risks, so an important part of the decision making process is to acknowledge and weigh these risks. Another important part of the decision making process is the economic analysis, which is covered in the next section.

Economics

The seven MWRDGC wastewater treatment facilities provide different levels of treatment. In some cases the level of treatment changes on a seasonal basis. For example, the James C. Kirie, John E. Egan, and Hanover Park facilities (representing about 5% of the MWRDGC effluent) have tertiary treatment processes and, prior to discharge from May to October, the treated wastewater from these facilities is chlorinated. In contrast, treated effluent from the Stickney, North Side, Lemont, and Calumet facilities is not chlorinated. However, Knight and Sokol (1991) reported that the Stickney effluent that is reused on site is specifically chlorinated.

Therefore, to make treated effluent available throughout the Chicago area there will be additional costs associated with a distribution system and – for 95% of the effluent – costs for additional treatment. This section includes estimates of capital costs for disinfection, pumping, and pipeline installation, as well as associated O&M costs. Some specific applications could require additional treatment and those additional costs must be added to the estimates presented here. Chlorination dosage, for example, which varies depending on chlorine demand, wastewater characteristics, and discharge requirements, usually ranges from 5 to 20 mg/L (U.S. EPA, 1999). Some wastewater characteristics, especially TSS and nitrite concentrations, can have a substantial effect on the chlorine dose (Table 9).

Table 9. Wastewater characteristics that affect the chlorination process (U.S. EPA, 1999).

Characteristic	Effect on Chlorine Disinfection
Ammonia	Forms chloramines when combined with chlorine
BOD	Degree of interference depends on functional groups and chemical structures
Hardness, Iron, Nitrate	Minor effect, if any
Nitrite	Reduces effectiveness of chlorine; results in THMs
pH	Affects distribution between hypochlorous acid and hypochlorite ions and among the various chloramine species
Total Suspended Solids	Shields embedded bacteria and chlorine demand

Chlorination Costs

Based on U.S. EPA water reuse guidelines and the water reuse regulations of other states, it seems likely that once the State of Illinois approves large-scale water reuse in the Chicago area they will require chlorination. Qasim (1999) introduced equations for estimating capital costs and O&M costs for chlorination systems. He suggested that the equations were applicable for a design flow ranging from 3.79×10^{3} to 1.9×10^{5} m^{3}/d (1 to 50 MGD) with a dosage of 10 mg chlorine/L and 30 minutes contact time at average flow. Qasim (1999) also suggested that the expected service life for the chlorination system should be about 15 years.

The equation presented by Qasim for capital costs (adapted here for flowrate expressed as m^{3}/d) is:

$$CC_{chlorine}\ (1996\ \$) = 795\ Q^{0.598}$$

In this expression, $CC_{chlorine}$ is the capital cost and Q is the average design flow through the facility (m^{3}/d). Construction costs include chlorine storage and handling building and facilities, chlorinators, injector, and plug-flow contact chamber. Land cost, external piping, electrical, instrumentation, site work, contingency, engineering and construction supervision, and miscellaneous structures are not included. Assuming an average annual inflation rate of 2.5% over the past 11 years the 2007 cost is:

$$CC_{chlorine}\ (2007\ \$) = 1.04\times10^{3}\ Q^{0.598}$$

The equation presented by Qasim for annual operation and maintenance costs (adapted for m^{3}/d) is:

$$O\&M_{chlorine}\ (1996\ \$) = 2.4813\times10^{4} + 2.36\ Q - 10^{-6}\ Q^{2}$$

Operation and maintenance costs include labor costs for operation, preventive maintenance, and minor repairs; materials costs include replacement parts and major repair work; chemical costs; and electrical power costs. Applying the same inflation rate, 2007 costs are:

$$O\&M_{chlorine}\ (2007\ \$) = 3.26\times10^{4} + 3.10\ Q - 1.31\times10^{-6}\ Q^{2}$$

Pump Stations

Gummerman et al. (1979) presented a capital cost equation for water supply pump stations. More recently Qasim (1999) presented both capital and O&M cost equations for low lift pump stations suitable for sewage lifting, normally at TDH less than 3.05 m (10 ft). In this study, we adapted the capital cost equation from Gummerman et al. (Table 10) and the O&M cost equation by Qasim. The cost equations used in this study are listed in Table 11.

Table 10. Pump station capital cost estimates from Gummerman et al. (1979). The total dynamic head for both flow ranges is $9.1 \le \text{TDH (m)} \le 30.5$. The adjustment to 2007 is based on an annual average inflation rate of 4.14% from 1978 to 2007.

Design flow (10^3 m^3/d)	Cost (1978 \$)	Cost (2007 \$)
$3.8 \le Q \le 37.9$	$CC_{pump} = 449.9\ H^{0.22}\ Q^{0.44}$	$CC_{pump} = 1.46\times10^3\ H^{0.22}\ Q^{0.44}$
$37.9 \le Q \le 378.5$	$CC_{pump} = 11.26\ H^{0.37}\ Q^{0.76}$	$CC_{pump} = 36.51\ H^{0.37}\ Q^{0.76}$

Assuming H = 30.5 m, the current costs for the low and high design flow cases are respectively:

$$CC_{pump}(2007\ \$)\ 3.10\times10^3\ Q^{0.44} \qquad\qquad CC_{pump}(2007\$) = 129.3\ Q^{0.76}$$

The O&M estimate by Qasim (1999) is for a low-lift pump stations with TDH = 3.05 m (10 ft) and a 15 year service life. Operation costs include labor, preventive maintenance, and minor repairs; materials costs include replacement parts, major repair work, and electrical power costs. The original equation (Q expressed as m^3/d) is:

$$O\&M_{pump}\ (1996\ \$) = 18{,}526 + 0.80\ Q$$

Qasim suggested that for TDH other than 3.05 m (10 ft), the equation could be used by substituting an effective flow (Q_E) in place of Q:

$$Q_E = Q_{Design} \times \frac{TDH_{Design}}{3.05}$$

In this study, we assume TDH = 30.5 m (100 ft) for the reuse distribution system, so $Q_E = 10$ Q. The O&M equation above becomes:

$$O\&M_{pump}\ (1996\ \$) = 18{,}526 + 8\ Q$$

Finally, based on an annual inflation rate of 2.5 % (from 1996 to 2007), the cost equation used in this study is:

$$O\&M_{pump}\ (2007\ \$) = 24{,}308 + 10.50\ Q$$

Distribution

Paintall (2004) observed that a reasonable cost range for pipeline installation in the Chicago area is from \$246 to \$656 per meter (\$75 to \$200 per foot). The low-end cost applies to relatively open areas while the high-end cost applies to developed areas that have utility lines already in place. This estimate is based on the concept that pipe diameter has little effect on the costs in urban settings where it is necessary to work around existing utilities and replace streets and sidewalks. Because the focus of this study is on the Chicago metropolitan area, we assume a cost of $500 per meter for pipeline installation capital costs, or:

$$CC_{pipe}\ (2007\ \$) = 5\times10^{5}\ L$$

In this expression L is the length of pipeline (km).

To estimate total annual costs capital costs were amortized using the following equation:

$$A=P\left[\frac{i(1+i)^{n}}{(1+i)^{n}-1}\right]\Rightarrow\frac{A}{P}=\frac{i(1+i)^{n}}{(1+i)^{n}-1}$$

In this equation, A is the annual payment, P is the total capital cost (2007 $), i is the interest rate, and n is the amortization period. The quantity (A/P), the capital recovery factor, is a convenient way to determine A for a given P value. For this study, we assume a 15-year life (n = 15) and a 10% annual interest rate (i = 0.10), so the capital recovery factor = 0.13147.

It is also helpful to normalize the costs to the volumetric flow. That conversion is:

$$\frac{\left(\$/\text{year}\right)}{\left(10^{3}\text{m}^{3}/\text{d}\right)}\times\frac{1}{365}\frac{\text{d}}{\text{year}}=\frac{\$}{10^{3}\text{m}^{3}}$$

Table 11. Summary of cost equations used in this study. Capital costs are expressed as 2007 $, O&M costs are 2007 $/year, Q is in m^{3}/d, and L is in km. We assume TDH = 30.5 m (100 ft) for the pumping equations. Original sources for these equations are described in the text. Equations that are a function of Q are valid in the range 3800 ≤ Q (m^{3}/d) ≤ 190,000 (1 to 50 MGD).

Process	Equation
Pipeline	
Capital cost	$CC_{pipe} = 5\times10^{5}\ L$
Chlorination	
Capital cost	$CC_{chlorine} = 1.04\times10^{3}\ Q^{0.598}$
O&M cost	$O\&M_{chlorine} = 3.26\times10^{4} + 3.10\ Q - 1.31\times10^{-6}\ Q^{2}$
Pumping (3,800 ≤ Q ≤ 37,900)	
Capital cost	$CC_{pumping} = 3.10\times10^{3}\ Q^{0.44}$
O&M cost	$O\&M_{pumping} = 24{,}308 + 10.50\ Q$
Pumping (37,900 ≤ Q ≤ 378,500)	
Capital cost	$CC_{pumping} = 129.3\ Q^{0.76}$
O&M cost	$O\&M_{pumping} = 24{,}308 + 10.50\ Q$

The normalized costs for pump stations and chlorination systems decrease rapidly with increasing flowrate up to about 20×10^3 m^3/d (5.3 MGD) (Figure 10). Further increases in the size of these systems provide little economy of scale so that costs start to become asymptotic above 50×10^3 m^3/d (13 MGD). The relative contributions to the total cost are pump station O&M > chlorination O&M > pump station or chlorination capital costs.

Capital costs for pipeline installation depend on the length of the pipeline and those costs are not readily incorporated into Figure 10. An alternative approach is to consider specific distribution system pipeline length and examine how much the pipeline costs contribute to the total cost. Results from such an analysis (Figure 11) indicate that pipeline installation costs typically contribute a substantial fraction to the total cost (except for large flows and short distances).

Total (including pipeline installation) reuse water supply costs expressed as a function of flowrate and pipeline distance still exhibit an economy of scale. Costs decrease with increasing flowrate up to about 20×10^3 m^3/d (5 MGD) (Figure 12). Costs approach an asymptote at greater flowrates, reaching values that range from about \$66 to \$132 per m^3 (\$0.25 to \$0.50 per 10^3 gallons).

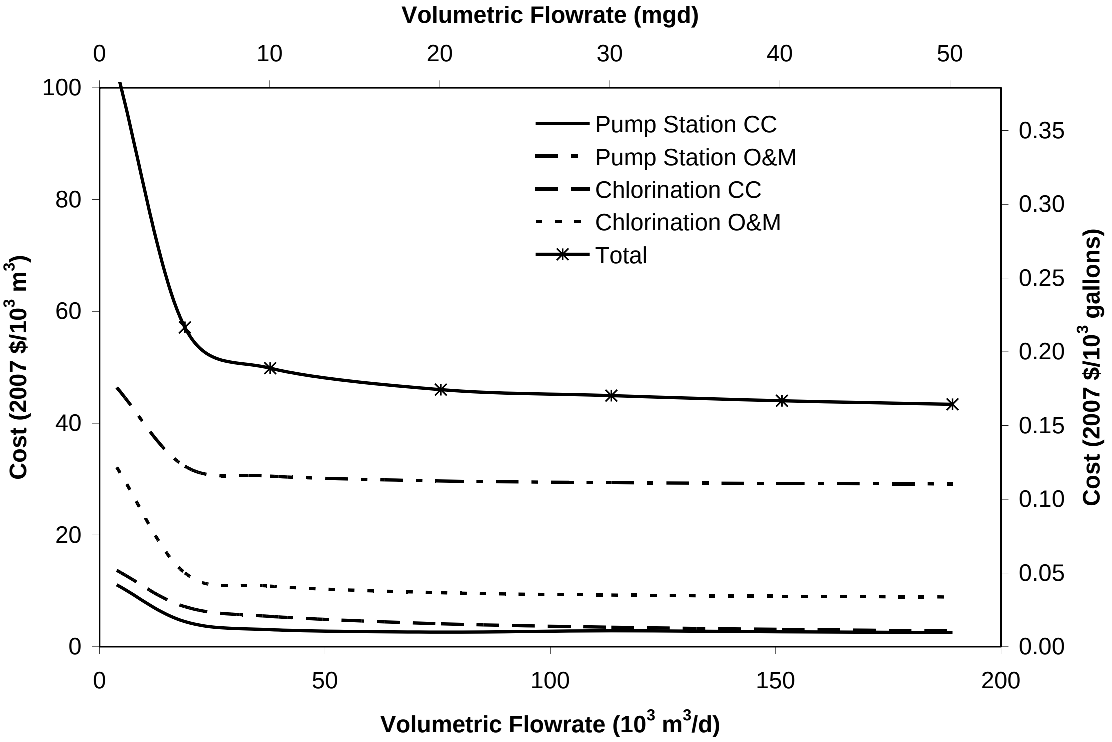

Figure 10. Capital and O&M costs for pump stations and chlorination and total costs as a function of the volumetric flowrate.

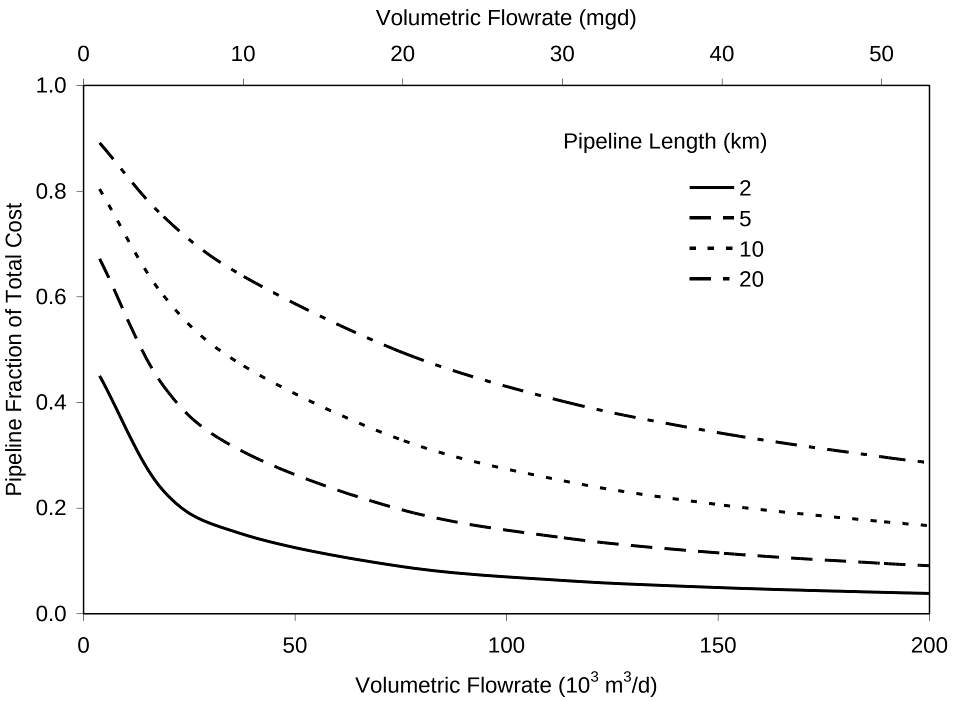

Figure 11. Fraction of total system cost attributed to capital cost for pipeline installation as a function of volumetric flowrate and pipeline length.

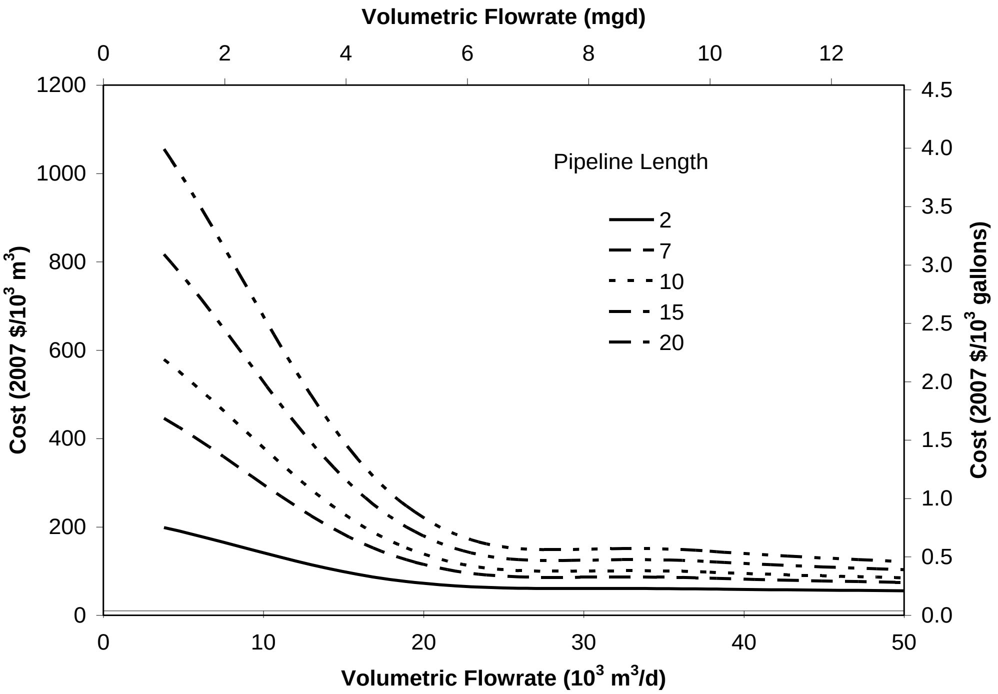

Figure 12. Supply costs based on capital costs (pipeline, pump station, and chlorination) and O&M (pump station and chlorination) as a function of flowrate and total pipeline length.

Capital costs associated with installing a secondary distribution systems are a large part of the system cost, so it is worthwhile considering how those capital costs could be reduced. For example, directional drilling techniques may lower the overall cost. Alternatively, planning to "piggy-back" installation of a second distribution line with other sidewalk or street repairs could result in substantial savings.

In addition to the direct costs associated with installing and operating a nonpotable water distribution system, there is lost revenue associated with water reuse in the Chicago area. The MWRDGC owns and operates the Lockport hydroelectric facility and earns energy credits in the amount of about $\$3\times10^6$ each year by selling power to ComEd, the local utility (MWRDGC, 2006). The facility generates about 60×10^6 kWh per year so the value of these credits is \$0.05/kWh. Wastewater reuse would mean a reduction in these credits proportional to the reduction in flow through the powerhouse. Durgunoglu and Singh (1992) provided a correlation between total flow at Lockport and flow through the powerhouse. Assuming an average total flow of 7.8×10^6 m^3/d (3,200 cfs or 2.07×10^9 gallons/d), flow through the powerhouse would be 7.1×10^6 m^3/d (2888 cfs or 1.87×10^9 gallons/d), and the normalized value is about $\$1/10^3$ m^3 ($\$0.00379/10^3$ gallons) revenue lost as a result of wastewater reuse.

According to Knight and Sokol (1991) the MWRDGC has had formal water reuse agreements with industries withdrawing water from either the Calumet-Sag Channel or the Main Branch. The MWRDGC user fees for withdrawing water from the Chicago Area Waterways are designed to compensate for the loss of revenue from the Lockport hydroelectric facility. Assuming an average annual inflation rate of 2.5%, the current value of these water reuse agreements probably ranges from \$0.45 to \$1.85 expressed as 2007 $\$/10^3$ m^3 (0.0017 to 0.0072 $\$/10^3$ gallons). This amount is considerably less than the U.S. EPA (2004) reported typical user fees for urban water reuse systems, which ranges from \$40 to \$240 per 10^3 m^3 (0.15 to 0.91 $\$/10^3$ gallons).

Economics Summary

Capital costs associated with installing a secondary nonpotable water distribution system are the largest single expense for a water reuse project in the Chicago area. Other important costs are operation and maintenance costs for the pump station and chlorination system and, to a lesser extent, the capital costs for those same systems. Projected supply costs (cost per volume delivered) decrease as the total volume of water supplied increases. The economy of scale effect is greatest up to about 20×10^3 m^3/d (5 MGD). At this rate, the projected costs for a nonpotable water supply - about \$50 to \$200 per 10^3 m^3 (\$0.19 to \$0.75 per 10^3 gallons) - are in good agreement with typical costs reported by the U.S. EPA. Unfortunately, the cost of municipal water in the City of Chicago (about \$350 per 10^3 m^3 or \$1.33 per 10^3 gallons in 2007) means that water reuse systems in the Chicago area must be large before they become cost competitive.

Specific Case Studies

This section includes three examples of past or potential water reuse applications in the Chicago area. Each case includes a description of how regulatory, policy, technical, risk, and economic issues have or are likely to affect the application.

The Village of Richmond

Background

The Village of Richmond, located 100 km (60 miles) northwest of Chicago, Illinois, has a population of around 1,100 residents. This case study describes the path they took in planning for wastewater reuse, and how regulations, public policy, risk, technical, and economic issues influenced that path. Although each issue is presented in a separate subsection below, these issues are clearly intertwined with each other. Much of the background information presented in this section was adopted from a presentation by Kabbes (2003). Recent updates on water reuse at the Village of Richmond come from information provided by Hartnett (2007) and village staff.

Regulatory issues

Appropriate state regulations and the draft Village of Richmond water reuse ordinance were presented in a previous section. The focus here is on regulations that played a role in moving the Village to consider water reuse: The NPDES permit program and the Illinois anti-degradation standard (IAC Section 302).

The NPDES permit program played a role because the Village of Richmond had an aging municipal wastewater treatment facility that was built in the 1920s. The facility was no longer able to meet the permit requirement for ammonia discharge. As a result, the Village was moved to consider their options for a new wastewater treatment plant.

Once the Village of Richmond starting planning for a new treatment plant, the Illinois anti-degradation standard played a role because they had to demonstrate that there was no unnecessary degradation of the waters of the state. Property that was available for the new facility was on the southern edge of the Village adjacent to the North Branch of the Nippersink Creek. A tributary watershed to the Fox River, Nippersink Creek is one of the highest quality streams in Northern Illinois (Nippersink Creek Watershed Planning Committee, 2005). Based on assessments of trophic composition, fish species richness and composition, and fish condition and abundance, IDNR designated parts of the North Branch of Nippersink Creek as a unique aquatic resource (Class A stream). The reach of the Nippersink Creek adjacent to this property, the conventional choice for the treated effluent discharge from the treatment plant, contained a high quality mussel bed. Concerned about the potential risk that the effluent could present to the mussel bed, the Village elected to install a pipeline to deliver the effluent to another point in the creek.

Although regulations were not the only factors involved, it seems likely that in the absence of the NPDES program and the anti-degradation standard, wastewater reuse would not have been considered.

Policy issues

With their decision to pipe the effluent to another reach of the creek, the Village of Richmond also made a policy decision. They decided to consider wastewater reuse as a way to minimize the volume of treated effluent returned to the creek. To help implement that policy decision, the administration appreciated the importance of having diverse input from engaged stakeholders, so they formed a team to work on the first water reuse ordinance in Illinois. The ordinance development team included the IEPA, NIPC (now CMAP), Sierra Club, Friends of Nippersink Creek, McHenry County Conservation District, McHenry County Defenders, the local school district, and other stakeholders. Part of their research included a critical review of existing water reuse ordinances from communities in Arizona, California, Florida, and other areas. One of their objectives was to maximize water reuse, so they proposed making reuse mandatory for new developments and new facilities, and even public schools were included. The product of their efforts was the draft reuse ordinance that we summarized in the previous section on regulations.

By regional standards, the decision by the Village of Richmond to consider wastewater reuse and draft a reuse ordinance is unique. As part of this study, we attempted to trace the evolution of that decision. The critical components seemed to be an informed and proactive Village administration, input from environmental groups, and consultants that were willing to consider creative engineering.

Risk issues

Planning for wastewater reuse in the Village of Richmond did not involve direct risk assessment studies. The planning team, however, did review information from other communities that had reuse systems in place. They also ensured that their approach was consistent with IEPA and Illinois Department of Public Health requirements. These efforts are reflected in the draft water reuse ordinance. For example, the ordinance calls for color-coded lines, signage, and cross-connection prevention measures. In addition, irrigation applications are subject to time restrictions, they must use directed spray systems, and irrigation rates cannot exceed the infiltration rate of the soil.

Technical issues

Technical issues did not play a major role in water reuse planning for the Village of Richmond. Their new wastewater treatment facility will enable them to comply with discharge regulations and provide water with a quality that is acceptable for many applications.

The draft ordinance does mention the design of reuse facilities for specific users must be certified by an engineer registered with the State of Illinois. Part of that design will be to consider water pressure requirements, which will be determined by the Village and will probably be lower than the supply pressure for the potable water system. If the service pressure provided by the Village is not adequate for an application, the user's design will need to include a booster pump. Alternatively, if the service pressure is too high, the design will need to include a pressure regulator. Individual users will need to determine water quality requirements for an application and provide for any pretreatment needs.

According to the draft ordinance, the design should also consider the need to protect any reuse water storage facilities against erosion, overland runoff, and other impacts associated with a 100-year frequency, 24-hour duration storm event. In addition, reuse water storage facilities must be lined to protect the groundwater.

Economic issues

The economic feasibility of each reuse application will be determined by many of the issues noted above. The language of the draft ordinance indicates that the Village expects the user fees will include tap-on and connection fees, meter and service line charges, and a guarantee deposit. According to the ordinance, the costs "…shall be determined by the Village Board … at the time of a water reuse building permit is issued by the Village." Because there are no reuse applications at the time this report is being written, it is not possible to provide specific costs. The current (summer of 2007) water rate structure for the Village of Richmond is $5.869 per 1,000 gallons for the first 5,000 gallons, and $2.934 per 1,000 gallons subsequently. Although this kind of decreasing rate structure does not discourage water use, it does leave room for a competitively priced nonpotable water supply.

Recent update

Many of the potential reuse applications described in the draft reuse ordinance may never occur. Current plans call for treated wastewater to be pumped to a multipurpose holding pond adjacent to Nippersink Creek (Hartnett, 2007). The pond will serve as a storage and equilibration basin for treated effluent prior to delivery to the creek through an overflow weir. The pond is also a water feature and a holding pond for irrigation water for the golf course. From April through October each year most of the effluent could be used to irrigate the golf course. From November through March the effluent would be discharged to the North Branch Nippersink Creek.

Conclusion

Despite the time, effort, and cost that went into planning for water reuse in the Village of Richmond, as of the summer of 2007 it is not clear that the original vision will ever be realized. It is a curious result because the planning steps apparently made substantial progress toward removing at least some of the conventional barriers to water reuse. For example, when the Village decided to build a pipeline to deliver effluent to a different reach of Nippersink Creek, a substantial part of the costs associated with reuse were already accounted for. Furthermore, the fact that their planning task force was a diverse group of stakeholders suggests that they had overcome the hurdle associated with public acceptance. Finally, their reuse concept and draft ordinance had the approval the appropriate state agencies.

It may be that the concept of water reuse across many segments of one community is too new of an idea in NE Illinois or it may be that the idea of mandatory reuse makes people uncomfortable. The pieces are in place. It may be that water reuse will become more common in the Village of Richmond in the future.

Chicago Area Golf Courses

Snow (2001) estimated that more than 1,000 golf courses across the United States used treated effluent for irrigation and pointed out that in some arid regions irrigation with treated effluent is required. More recently the U.S. EPA (2004) issued a more conservative estimate that there were more than 300 golf courses in the United States irrigated with treated effluent. Clearly there is a substantial range in these estimates, but the important point is that golf course irrigation with treated effluent has been practiced at least in some parts of the country.

Golf course irrigation with treated effluent in the Chicago area dates back to at least 1982. According to Knight and Sokol (1991), that was when the Elk Grove Village Park District began using treated effluent from the MWRDGC John E. Egan plant (tertiary treatment) to irrigate a driving range and a golf course. The golf course is about 0.8 km (0.5 miles) from the treatment plant. Water is provided through an existing force main that runs adjacent to the golf course. The Park District paid for some minor modifications to make it easier to access the water. The Park District also pays for pumping based on electricity rates. From April to November the Park District uses about 1.89×10^4 m^3 (5×10^6 gallons). In this section we consider the potential for additional golf course irrigation in the Chicago area.

Technical issues

According to an on-line golf course directory there are 109 golf courses in Cook County (Golfable.com, 2006). Although the directory does not provide the area of each course, there is enough information to determine there are 1,868 golf course holes in Cook County. Luke Cella, Executive Director of the Midwest Association of Golf Course Superintendents, suggested that an 18-hole golf course covers about 4.86×10^5 m^2 (120 acres) (Cella, 2004). Based on those numbers the total golf course area in Cook County is about 5.04×10^7 m^2 (12,453 acres).

Irrigation rates for golf courses depend on course characteristics such as soil type, weather, slope, and irrigation efficiency. The Massachusetts Department of Environmental Protection (MDEP, 2000) prepared a golf course water use policy and as part of their planning process they surveyed a variety of turf experts and golf course architects about irrigation rates. They concluded that during a typical dry season, water requirements for a golf course range from 1.0 to 3.8 cm per week (0.4 to 1.5 inches per week). According to the Illinois State Climatologist, from 1998 through 2005 summer quarter precipitation at O'Hare Field averaged 2.39 cm (0.94 inches) per week (ISC, 2006). These data suggest that irrigation requirements could range from 0 to 1.4 cm (0.55 inch) per week. Golf courses could probably be designed and managed for sustained higher irrigation rates, but these values suggest the amount of treated effluent that could be used for golf course irrigation in Cook County ranges from about 7.2×10^3 m^3 per day to 108×10^3 m^3 per day (2 to 29 MGD) during the growing season (Table 12).

Water quality can also play an important role in golf course irrigation. Harivandi (2004) suggests that the most important water quality parameters to consider for turf grass irrigation are total dissolved solids (TDS), sodium (Na) content, the sodium adsorption ratio (SAR), chloride (Cl) content, boron (B) content, total carbonate content, and pH. When compared to mean values for the treated effluent from the Stickney plant (Table 13), TDS, sodium, the sodium adsorption ratio, and chloride are in concentrations that present moderate concerns. The degree of concern depends on irrigation schedules, the type of turf grass, and the soil characteristics. These are management issues that can be resolved on a case-by-case basis by, for example, altering irrigation patterns, using heartier turf grass species, using soil amendments, or blending effluent with higher quality water. In general the water quality does not present a barrier to golf course irrigation.

Table 12. Irrigation rates translated into volumetric flowrates for Chicago area golf courses, assuming a total area of 5.04×10^7 m^2 (12,453 acres).

Amount per week		Volume per day	
cm	inches	10^3 m^3/d	MGD
0.1	0.04	7.2	1.9
0.5	0.2	36	9.5
1.0	0.39	72	19
1.5	0.59	108	29

Table 13. Golf course turf grass can be sensitive to these water quality parameters (Harivandi, 2004). Concentrations for the Stickney effluent are mean values from 2005. Concentrations are expressed as mg/L; SAR and pH are dimensionless.

Parameter	Moderate concern	Stickney Effluent
TDS	450 – 2000	671
Na^+	> 70	92*
SAR	3 - 9	3.7*
Cl^-	70 - 355	154
HCO_3^-	90 – 500	76
pH	6.5 – 8.4	6.8

*Sodium concentration (also part of the SAR) estimated assuming Na/K ratio remains the same as in Chicago municipal water.

Policy issues

In cooperation with environmental organizations the United States Golf Association (USGA, 1996) developed an extensive set of principles to guide golf course design, construction, maintenance, and operations. Some of the principles specifically encourage water reuse:

> "Water reuse strategies for irrigation should be utilized when economically feasible and environmentally and agronomically acceptable. It is important that recycled water meets applicable health and environmental standards and that special consideration be given to water quality issues and adequate buffer zones. Water reuse may not be feasible on some sites that drain into high quality wetlands or sensitive surface waters. Suitable soils, climatic conditions, groundwater hydrology, vegetative cover, adequate storage for treated effluent and other factors will all influence the feasibility of water reuse."
>
> "Consider converting to effluent irrigation systems when available, economically feasible and agronomically and environmentally acceptable."

In addition to this policy statement from the USGA, public policy could have an effect on golf course irrigation. For example, the *Water Agenda 2003* (City of Chicago, 2003) specifically mentions that the City of Chicago will explore the use of gray water for landscape irrigation. On the same page of the *Agenda* there is a brief summary of how the Chicago Park District is actively addressing water conservation. Although those two activities are not correlated in the *Agenda*, there is clearly opportunity for reuse on the Park District golf courses.

Regulatory issues

There are no federal regulations that directly address the use of treated wastewater for golf course irrigation, and we are not aware of any local or regional regulations. At the state level, the "Illinois Design Standards for Slow Rate Land Application of Treated Wastewater" (Subtitle C Water Pollution, Chapter II Environmental Protection Agency, Part 372) should apply. The regulations address storage requirements, loading rates, groundwater monitoring, and setback distances. These issues were described in more detail in the previous section on state regulations. Golf courses fall under the category of restricted urban use. According to those regulations there is no set back distance if the irrigated area is closed to the public during the application and drying time, and no set back distance is required for golf courses were irrigation occurs between dusk and dawn.

Risk issues

Assuming that the above IEPA regulation applies to golf course irrigation, public exposure will be limited and groundwater monitoring will be required. USGA researchers (Kopec et al., 1993) point out that risks to wildlife are minimal and human health risks can be minimized; their greatest concerns appear to be related to the potential risks to the turf grass.

Economic issues

It is difficult to develop general cost estimates for using treated effluent for golf course irrigation because costs probably vary substantially from case-to-case. For example, the location relative to the source of treated effluent is important due to the cost of a secondary distribution system pipeline. Storage will be required, but it might be available with ponds or lakes on the golf course. Additional potential costs include those associated with equipment modification, groundwater monitoring, soil and turf grass monitoring, and turf management. If an irrigation system is to be added specifically for reuse, that cost ranges from \$14,820 to \$24,700 per hectare (\$6,000 to \$10,000 per acre) (Clark, 2007; American National Sprinkler and Lighting, 2003). Kopec et al. (1993) note that the benefits associated with the use of treated effluent for golf course irrigation include having a dependable (drought-resistant) water source and a supplementary source of nutrients.

The MWRDGC

In this section we review Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) experience with treated wastewater reuse within their facilities. Much of the information presented here comes from the water reuse assessment conducted by Knight and Sokol (1991). Based on conversations with Lanyon (2005) and other MWRDGC employees, the reuse numbers from that 1991 report are a good estimate of current practice. Although this section will focus on internal reuse, according to Knight and Sokol there is approximately an equal amount of water managed through external reuse applications that include industries and park districts.

Technical issues

The MWRDGC treats an average of 5.3×10^6 m^3/d (1.4 BGD) through seven wastewater treatment facilities. Total wastewater reuse at the MWRDGC is about 40×10^3 m^3/s (11 MGD). Relative to average plant discharge, reuse at individual plants ranges from as little as 0.1% at the North Side facility to over 10% at Hanover Park (Table 14).

Table 14. Estimated treated wastewater reuse within MWRDGC plants. Original reuse volumes come from the study by Knight and Sokol (1991); Lanyon (2005) suggested these data still apply. Facility discharge data are from the MWRDGC website.

	2006 total discharge		**Estimated reuse**		
Facility	**10^3 m^3/d**	**MGD**	**10^3 m^3/d**	**MGD**	**Reuse (%)**
Stickney	2759	729	30.20	7.99	1.1
Calumet	1071	283	2.12	0.56	0.2
North Side	946	250	0.98	0.26	0.1
James C. Kirie	133	8.9	1.17	0.31	0.3
John E. Egan	99	26	3.70	0.98	3.8
Hanover Park	34	8.9	3.59	0.95	10.7
Lemont	9.7	2.5	<0.04	< 0.01	<0.4
Total	5053	1335	41.77	11.05	0.8

The MWRDGC experience demonstrates that treated effluent can be reused for a variety of applications. Knight and Sokol (1991) documented 11 different reuse applications among the treatment plants (Figure 13). Not all of these applications, however, are practiced at every plant. For example, cooling water, which accounts for almost 40% of total reuse, is used in chillers, blowers, air compressors, ozone generators, and pump motors. All of the cooling water demand, however, comes from three facilities: the Stickney; North Side; and James C. Kirie plants. The second highest demand for treated wastewater (about 30%) is for pump seals, where water is used to affect a complete seal around the drive shaft that enters the volute of the pump. Treated effluent is used for pump seals at all of the District plants.

Knight and Sokol (1991) reported that the MWRDGC experienced problems with some applications when they use treated effluent. In some cases equipment was plugged or clogged due to higher suspended solids concentrations. They suspect that scaling (precipitation) also caused problems with some nozzles and lines. Biological growth (biofilms on surfaces or algal particles) also created fouling or handling problems, but these issues apparently occurred only when there was no chlorination.

Two advantages continue to drive the wastewater reuse program and the MWRDGC. One is that relative to the municipal water supply, the reuse water is available at a higher and reliable pressure. Knight and Sokol (1991) observed that the pressure of the municipal supply could be increased at the point of use, but doing so would increase the cost. The major incentive for wastewater reuse is the cost savings.

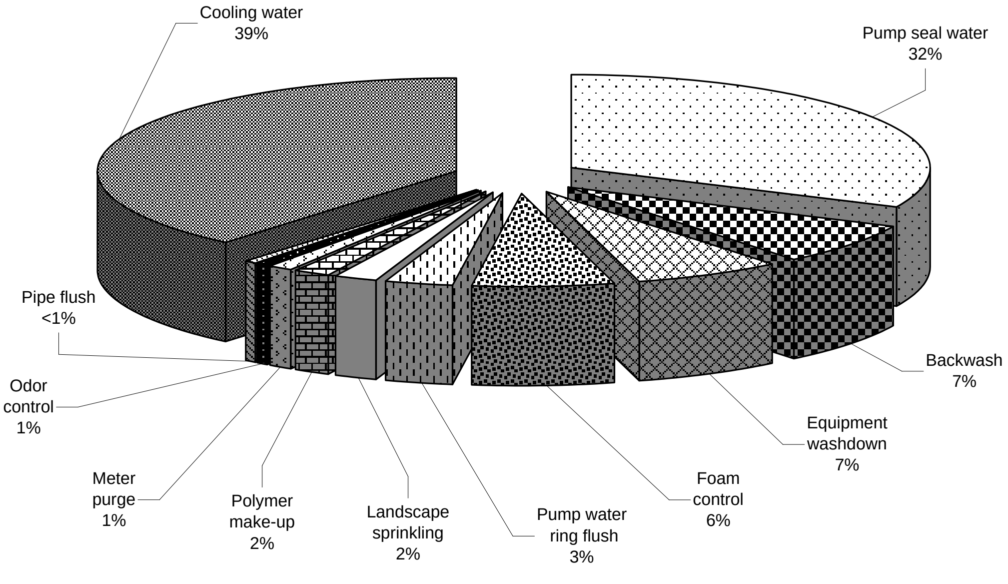

Figure 13. Wastewater reuse applications at the MWRDGC facilities (Knight and Sokol, 1991).

Economic issues

Knight and Sokol (1991) briefly describe reuse costs, including capital costs for pumps as well as operation and maintenance costs. Based on an average annual use of 1.53×10^7 m^3 (4.05×10^9 gallons) they estimate the annual cost associated with wastewater reuse would be $225,366 (1990 $). At that time the equivalent volume of municipal water would cost about $4,978,583, representing a savings of more than $4.5 M per year.

The amount saved is probably overstated, because the estimate apparently did not consider costs for worker training or chlorination, or the lost revenue due to the smaller volume of water at the Lockport hydroelectric facility, but these differences are minor. A more important issue is the fact that this economic assessment is unique to the MWRDGC. Because they enjoy such a close proximity to the source, among potential users only the MWRDGC can avoid the cost of a secondary distribution system.

Regulatory issues

There are no federal, state, or municipal regulations that directly address wastewater reuse within the MWRDGC.

Policy issues

Knight and Sokol (1991) reported that in the absence of applicable state or federal regulations concerning wastewater reuse, the MWRDGC has developed an internal reuse policy. The original policy, formulated in the early 1980s, mandated chlorination prior to reuse and straining for effluent from plants that have only secondary treatment. It also prescribed specific applications including fire protection, washdown, cooling, and irrigation. Since that time the policy has evolved to allow for many more applications. The basic approach at the time of the article was that treated effluent should be used in an application if the use did not cause harm and if reuse was cost effective relative to the use of municipal water.

Risk issues

Wastewater reuse within the MWRDGC presents minimal public exposure. The applications involve trained professionals who are familiar with wastewater. Furthermore, the MWRDGC policy requires chlorination prior to reuse (even at those facilities that are not required to chlorinate prior to discharge).

Conclusion

MWRDGC experience demonstrates that treated municipal wastewater can be successfully used in a wide variety of applications where nonpotable water is appropriate. These applications include cooling water, pump seal water, equipment cleaning, and irrigation. The District relies on trained personnel to minimize human exposure. They have also learned about potential problems with scale formation and biofilm growth and how to minimize those problems. Relative to other potential users, the District enjoys the benefits of being close to the source of treated effluent and they have employees who are familiar with the process. A major motivation for water reuse at the MWRDGC is that it saves money.

Summary and Conclusions

The Lake Michigan diversion at Chicago is limited by U.S. Supreme Court decree to a 40-year running average of 90.6 m^3/s (3200 ft^3/s). The largest single contribution to this diversion is the public water supply, at an average rate of 45 m^3/s (1,605 ft^3/s). Stormwater runoff that is not returned to Lake Michigan is about 27% of the total and direct diversion accounts for about 16%.

About 41% of the public supply is used for domestic purposes, 19% is used for commercial purposes, and 3% is used by industry. The USGS attributes about 37% of the public supply to public uses and losses. The City of Chicago has made substantial progress in recent years to minimize the losses. Although the public water supply meets federal regulations for drinking water, much of the water is used in applications such as commercial/industrial cooling, flushing toilets, or irrigation where the needs could be met with lower quality water.

A more efficient approach to managing local water resources is to reuse treated wastewater for those applications where nonpotable water is appropriate. The Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) owns and operates seven wastewater treatment facilities to reclaim municipal wastewater in the Chicago region. The current practice is to treat wastewater to satisfy federal water quality standards and then discharge that treated effluent to surface waters that ultimately connect with the Illinois River watershed. MWRDGC has reused treated effluent in a variety of applications within their facilities, but there is little reuse outside of the MWRDGC.

Major factors that influence the likelihood of reuse in the Chicago area include:

- There are no federal regulations that directly apply to wastewater reuse and Illinois regulations only directly address wastewater reuse for irrigation. The absence of regulatory guidance creates an uncertainty that could inhibit potential providers and consumers from considering reuse.

- Much of the Chicago Area Waterways is currently defined as relatively low quality water. Current regulations do not require disinfection before treated effluent is discharged to those surface waters. Federal guidelines, however, recommend disinfection prior to most reuse applications. The cost of added disinfection facilities could discourage reuse.

- Most regional policy does not directly address the concept of wastewater reuse. Local authorities could take a more active role to promote reuse.

- Relative to the municipal water supply, treated wastewater is different. It contains a wide variety of dissolved and suspended constituents and it has a higher temperature. The net effect of reusing treated wastewater could increase or decrease the risks associated with human health, ecosystems, and infrastructure, and that uncertainty makes it more difficult to change the current approach toward more reuse.

- Capital costs associated with installing a secondary nonpotable water distribution system can be a large fraction of the total cost of water reuse. Planning for efficient installation (identifying clusters of users, scheduling installation to occur with other infrastructure maintenance) could help reduce these costs.

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