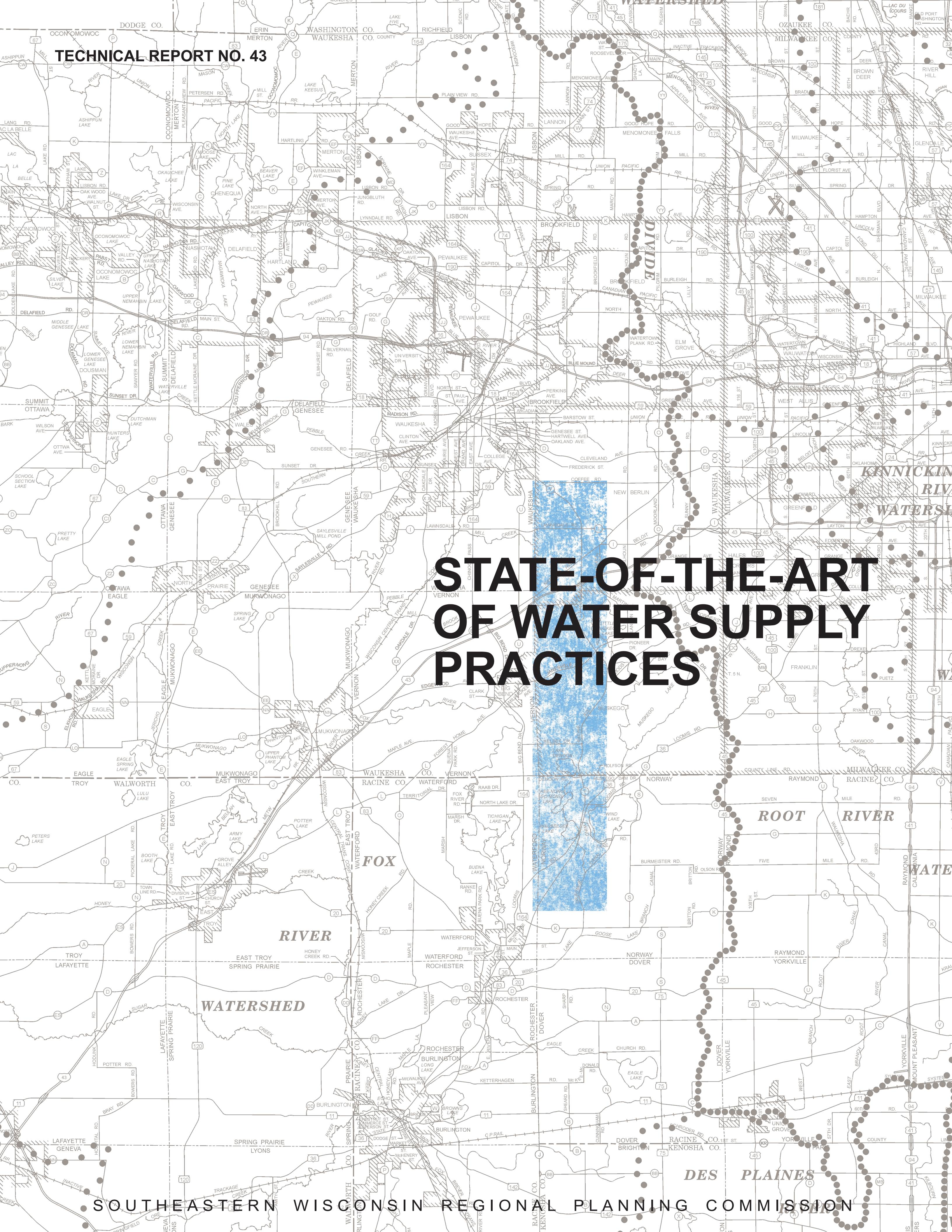

TECHNICAL REPORT NO. 43

STATE-OF-THE-ART OF WATER SUPPLY PRACTICES

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

STAFF FOR THE STATE-OF-THE-ART OF WATER SUPPLY PRACTICES REPORT

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

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The assistance provided by the State of Colorado Geological Survey in the development of Chapter VI, "Artificial Groundwater Recharge and Management," is gratefully acknowledged.

Special acknowledgment is due to Mr. Raymond Grzys, former Director of Utilities, City of New Berlin; Mr. Roger C. Johnson, former Manager, North Shore Water Commission; and Mr. Patrick T. Marchese, representative of the Public Policy Forum, for their contributions as former members of the Advisory Committee.

TECHNICAL REPORT
NUMBER 43

STATE-OF-THE-ART OF WATER SUPPLY PRACTICES

Prepared by

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July 2007

Inside Region $15.00
Outside Region $30.00

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July 11, 2007

STATEMENT OF THE EXECUTIVE DIRECTOR

In 2005, the Regional Planning Commission undertook the preparation of a regional water supply plan. The plan is to be completed in 2008. The planning effort included the preparation of two technical reports that provide an important foundation for the actual system plan preparation effort, concluding with a regional water supply plan recommended plan to be presented in a Commission planning report. This report constitutes the second of the two technical reports, the first, published in 2007, having dealt with water law.

The formulation of sound alternative and recommended water supply system plans designed to meet water supply planning objectives requires, among other things, definitive knowledge of the state-of-the-art of the technologies involved in water supply practices. This is particularly important given the significance of emerging water quality issues, the geographic limitations within the Region on the use of surface water as a source of supply, and the growing need for the application of practical water conservation measures. This report presents the results of a review of the current state-of-the-art of water supply source development; water treatment, transmission, and storage; and water conservation and reuse. The information presented includes descriptions and applicability of the water supply practices, together with information on attendant capital, operation, and maintenance costs.

The inventory of the state-of-the-art water supply practices was prepared by the consulting engineering firm Ruekert & Mielke, Inc., working in cooperation with the Commission staff. The work of the consulting engineering firm and Commission staff was overseen by a Water Supply Planning Advisory Committee created by the Commission to guide the planning effort. The membership of the Committee is listed on the inside of the front cover of this report.

The state-of-the-art of water supply practices report is intended to serve as a technical foundation for the development of alternative and recommended water supply plans under the regional water supply planning program. The report is also intended to be a useful resource for public officials, water utility engineers and managers, and others involved in, or having interest in, water supply within the Region.

Respectfully Submitted,

Philip C. Evenson

Philip C. Evenson

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Ruekert·Mielke
engineering solutions for a working world

April 23, 2007

Mr. Philip C. Evenson
Executive Director
Southeastern Wisconsin Regional Planning Commission
P.O. Box 1607
Waukesha, WI 53187-1607

Re: SEWRPC Technical Report No. 43,
State of the Art of Water Supply Practices

Dear Mr. Evenson:

We are pleased to submit our final report entitled "State of the Art of Water Supply Practices". We believe the information contained in this report will be important for the regional and local planning of our future water supplies in southeastern Wisconsin.

I would like to acknowledge the professional contributions to this document from Steven H. Schultz, P.E. and John R. Jansen, P.G., Ph.D. who were responsible for this report.

Should you have any questions during your review of this document, please do not hesitate to call us.

Very truly yours,

RUEKERT/MIELKE

William J. Mielke

William J. Mielke, P.E., R.L.S
President, CEO

WJM:jkc

cc: File

|8009049 Regional Water Supply Plan > 101 State of Art Study > Reports|Evenson-20070423-State of the Art Water Supply Practices.doc

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Chapter I

INTRODUCTION

GENERAL

This report presents the results of a review of the current and probable future state-of-the-art practices in water supply source development, water treatment, water transmission, water storage, and water conservation and reuse. It incorporates information related to these areas that is required for the technically sound development of alternative water supply plans and the selection of a recommended plan under the regional water supply system planning program for southeastern Wisconsin. Particular attention has been given to emerging technologies, such as aquifer storage and recovery, groundwater recharge, radionuclide removal, and water conservation and reuse. The report includes information on pertinent unit costs over the range of facility system capacities, which may be expected to be considered in the water supply planning process. Pertinent factors other than costs that may be involved in water supply management measures are also examined, such as system demand and hydraulics, quantity of supply, water quality, conservation impacts, and current capacity considerations.

STUDY AREA

The aforementioned treatment processes, small area systems, groundwater recharge systems, water conservation programs, and objectives and standards have been developed for application for the southeastern Wisconsin Region. The Region consists of the counties of Kenosha, Milwaukee, Ozaukee, Racine, Walworth, Washington, and Waukesha (see Map 1). Exclusive of Lake Michigan, these seven counties have a total area of about 2,689 square miles, or about 5 percent of the total area of Wisconsin. These counties, however, account for about 35 percent of the total population of the State, about 36 percent of all jobs in the State, and about 38 percent of the total tangible wealth of the State as measured by equalized real property value. Exclusive of school and other special-purpose districts, the study area contains 154 local units of government.

SCOPE

The specific scope of the review included the following elements:

1. A summary of the existing public and private water supply systems, pertinent water sources, and the treatment, management, and conservation measures occurring in the Region, as reported in more detail in Chapter III of SEWRPC Planning Report No. 52, *A Regional Water Supply Plan for Southeastern Wisconsin*. This includes both surface water and groundwater supply systems.

2. Description and evaluation of municipal and private water treatment processes applicable to the water supply sources used within the Region.

3. For each of the surface water and groundwater treatment processes considered, development of:

    a. Descriptions of the processes and applications;
    b. Data on contaminant removal applicability;
    c. Information on the reliability, economic life, and other pertinent noncost evaluation factors;
    d. Major issues and constraints on the use of the process based upon technical and legal considerations; and
    e. Cost data for construction and operation and maintenance costs.

4. Identification of small area and individual water supply system components and the water usage and treatment requirements of such systems.

5. For groundwater supply, identification of the following:

    a. The current state of artificial recharge systems and the associated design, source water, operations, and hydrogeologic factors;
    b. Evaluation of relevant case histories; and
    c. Descriptions of groundwater source development methods and water budgets.

6. Evaluation and description of current water conservation techniques, including:

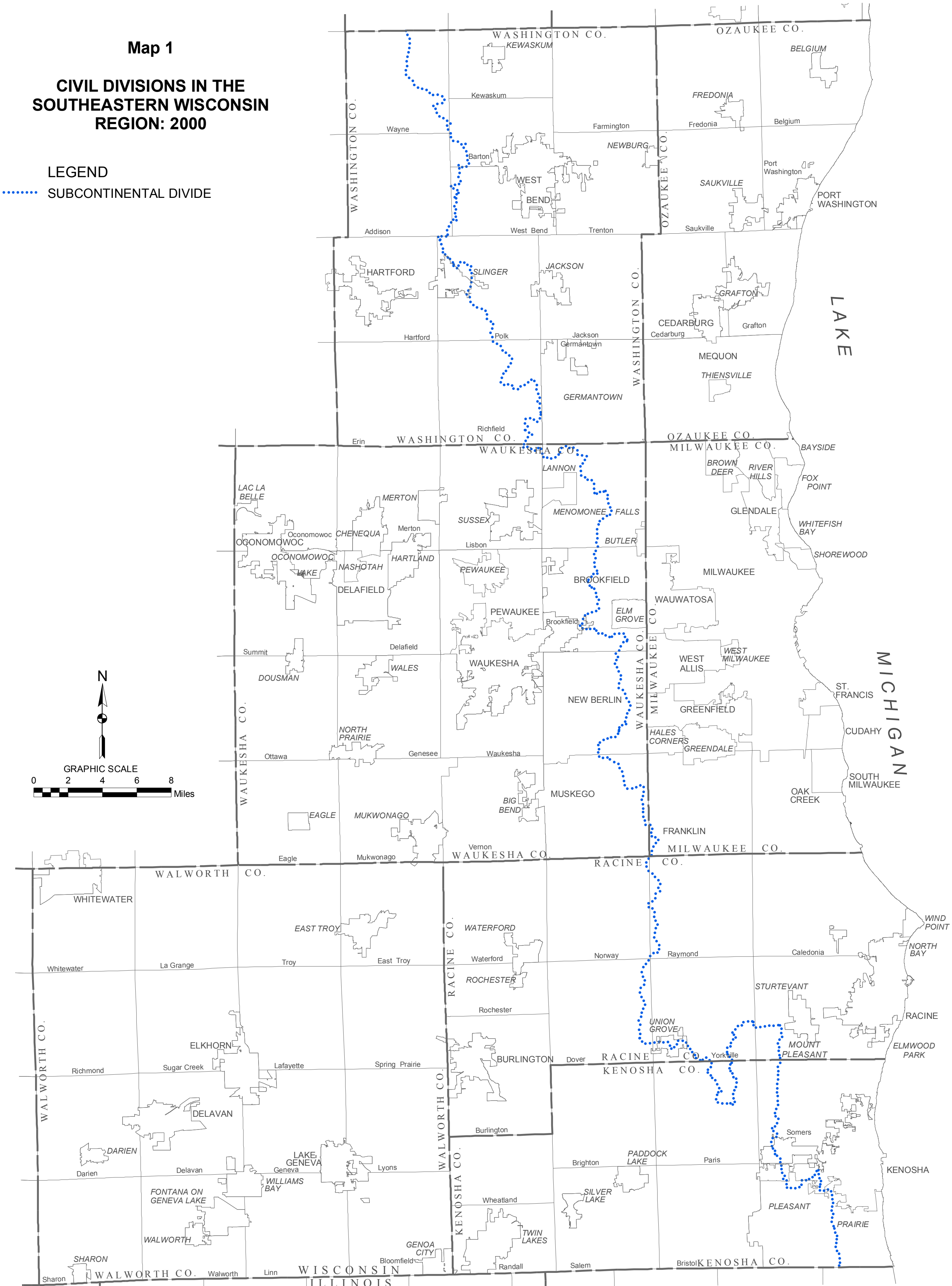
    a. Public water conservation measures;
    b. Private water conservation measures;
    c. Water reuse and reclamation; and
    d. Potential reductions in water use and subsequent impacts that may be expected from conservation programs.

7. Provision of pertinent engineering planning and design standards for:

    a. Water use and water demand data by use category;
    b. Water supply facilities;
    c. Water storage facilities;
    d. Water transmission and distribution facilities; and
    e. Groundwater recharge systems.

Map 1

CIVIL DIVISIONS IN THE SOUTHEASTERN WISCONSIN REGION: 2000



Source: SEWRPC.

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Chapter II

INVENTORY OF EXISTING WATER SUPPLY SYSTEMS

Information on the existing public and private water supply systems within the seven-county Southeastern Wisconsin Region is presented in summary form to provide background for the documentation of water supply management measures and practices that are viable for components of alternative and recommended water supply plans. The inventory also summarizes collated data on water use and on both groundwater and surface water sources of supply. In addition, areas of existing urban development not currently served by public water supply facilities were identified. A detailed account of existing public and private water supply systems is also provided in Chapter III of SEWRPC Planning Report No. 52, *A Regional Water Supply Plan for Southeastern Wisconsin*.

WATER SUPPLY SOURCES

Water resources, consisting of the surface waters in the lakes and streams of the Region, and of the groundwater aquifers underlying the Region, together with associated wetlands and floodlands, form important elements of the natural resource base of the Southeastern Wisconsin Region. Lake Michigan is a major source of water for municipal and industrial users in the most intensely developed areas of the Region lying east of the subcontinental divide. The underlying groundwater aquifers constitute a major source of supply for domestic, municipal, and other water users in areas of the Region lying west of the subcontinental divide, as well as for some areas of the Region lying east of the subcontinental divide, primarily in Ozaukee and Washington Counties. Understanding the interaction of the surface water and groundwater resources of the Region is essential to sound water supply system planning. The surface and groundwater of the Region are interrelated components of, in effect, a single hydrologic system. The groundwater resources of the Region are hydraulically connected to the surface water resources inasmuch as the former provide the base flow of streams, and the water levels of wetlands and inland lakes. The development and use of groundwater supply sources—such as wells for municipal or irrigation purposes—will have impacts on the surface water system. Thus, the analyses of existing conditions, and the description and evaluation of water supply management measures and practices and the use of those measures in developing alternative and recommended water supply plans under the regional water supply system planning program must recognize the existence of such impacts.

The groundwater aquifers of southeastern Wisconsin extend to depths in excess of 1,500 feet in the eastern parts of the Region. The aquifer systems underlying southeastern Wisconsin can be divided into two types: the shallow unconfined water table aquifers, and the deep semi-confined or confined aquifers. Water table conditions generally prevail in the sand and gravel deposits and Silurian dolomite aquifer above the Maquoketa Formation and in the Galena-Platteville aquifer west of the Maquoketa Formation. These aquifers are interconnected and are commonly referred to collectively as the "shallow aquifer." These shallow aquifers provide water for most private domestic wells and some municipal wells within the Region. In the deep sandstone aquifer beneath the Maquoketa Formation, the water was historically under artesian pressure. Deep high-capacity wells in the eastern part of the Region extract millions of gallons per day from the sandstone aquifer, creating a decline in water pressure within this aquifer that extends throughout most of the Region, except into the northern parts of Washington and Ozaukee Counties and the western part of Waukesha and Walworth Counties. Heavy pumping of the high-capacity wells has caused the gradual, steady decline in the artesian pressure and a reversal of the predevelopment, upward flow of groundwater. Recharge to the aquifers underlying the Region is derived almost entirely from precipitation. Much of the groundwater in the shallow aquifer originates from precipitation that has fallen and infiltrated within a radius of about 20 or more miles from where it is found in the aquifer. The deeper sandstone aquifer is recharged by downward leakage of water through the Maquoketa Formation from the overlying aquifers or by infiltration of precipitation beyond the western edge of the Region where the sandstone aquifer is not overlain by the Maquoketa Formation and is unconfined.

The chemical composition of groundwater largely depends on the composition and physical properties of the soil and rock formations it has been in contact with, the residence time of the water, and the antecedent water quality. The chemical composition of groundwater in the Region is primarily a result of its movement through, and the interaction with, Pleistocene unconsolidated materials and Paleozoic rock formations. The latter contain large amounts of dolomite—$CaMg(CO_3)_2$—that is dissolved by water passing through the rock formations. The current quality of groundwater in both the shallow and deep aquifers underlying the Region is generally good and suitable for most uses, although localized water quality problems occur in some areas. One exception to this is the concentration of radium exceeding drinking water standards which occurs in portions of the deep sandstone aquifer underlying the Region. Another exception is the presence of naturally occurring arsenic in a limited number of municipal and private water supplies.

Nearly all of the surface water supply in the Region is from Lake Michigan, with some use of other surface waters for limited purposes. These include a few instances of water use from the Milwaukee River for intermittent recharge of the groundwater associated with building foundation maintenance, for cooling of buildings primarily in the central business district of Milwaukee, and for thermoelectric-power generation purposes. In addition, other surface waters are intermittently used for such purposes as irrigation of agricultural lands or golf courses and for ski-hill snowmaking.

Lake Michigan provides a high-quality source of supply for public water supply systems. The water taken from offshore deep water intakes is amenable to treatment by conventional methods, such as chemical addition, flocculation, sedimentation, and filtration and disinfection. Finished water utilizing these processes typically meets, and generally exceeds, Federal and State drinking water quality requirements. Some of the utilities have installed tertiary-level treatment units, such as microfiltration and ozonation in order to safeguard against micro-organisms, such as *Cryptosporidium* and *Giardia*.

WATER SUPPLY SYSTEMS

Existing Municipal Water Supply Systems

In 2005, 78 municipal water supply utility systems provided water to about 423 square miles of service area, or about 16 percent of the area of the Southeastern Wisconsin Region. These systems served a population of about 1.60 million persons, or about 81 percent of the residential population in the Region. Forty-eight of the water supply systems rely on groundwater as a source of supply. Twenty-eight of the water supply systems rely on Lake Michigan as the source of supply which is provided by nine water treatment plants, with 16 intakes. Two of the systems use both groundwater and surface water in different portions of their service area. Selected characteristics of the existing municipal water utilities which served the Region in 2005 are presented in Table 1.

In 2005, the total storage capacity for the 78 municipal water systems operating in the Region was approximately 296 million gallons, divided among the 255 storage facilities, as listed in Table 1. Based on Wisconsin Public Service Commission annual reports for the year 2005, approximately 261 million gallons per day of water were pumped for use in the 78 municipal systems concerned (see Table 1). As shown on Table 2, the water use totaled about 193 mgd for residential, commercial, industrial, institutional, or other urban uses, with the remaining 68 mgd of total pumpage being used for purposes, such as water production and system maintenance, or being unaccounted-for water. Overall, about 90 mgd, or about 47 percent of total municipal water used, was for single-

Table 1

SELECTED CHARACTERISTICS OF EXISTING MUNICIPAL WATER SUPPLY SYSTEMS WITHIN THE SOUTHEASTERN WISCONSIN REGION: 2005

County	Number of Utilities	Estimated Area Served (square miles)	Estimated Population Served[a]	Source of Supply[b]	Number of Wells	Total Well Pumpage Capacity (mgd)	Number of Surface Water Treatment Plants	Number of Lake Water Intakes	Surface Treatment Plant Capacity (mgd)	Number of Storage Facilities	Total Storage Capacity (gallons x 1,000)	2005 Annual Average Pumpage (mgd)	2005 Maximum Daily Pumpage (mgd)
Kenosha.........	6	34.2	116,900	G, S, SP	4	2.1	1	2, plus 1 emergency	42	17	31,760	17.6	28.0
Milwaukee.......	14	195.9	920,800	S, SP	- -	- -	6	8	432	45	167,092	160.8	248.4
Ozaukee.........	7	17.7	49,200	G, S, SP	20	17.6	1	2	4	23	6,311	6.7	11.8
Racine	12	38.3	147,000	G, S, SP	12	14.2	1	3	40	23	20,554	29.7	48.5
Walworth.........	16	22.2	61,800	G	44	35.2	- -	- -	- -	38	13,500	8.4	17.1
Washington.....	7	21.8	73,400	G	32	9.8	- -	- -	- -	26	10,040	8.2	14.1
Waukesha.......	16	87.9	234,200	G, SP	93	73.4	- -	- -	- -	83	45,789	29.3	54.3
Total	78	418.0	1,603,300	- -	201	152.3	9	15, plus 1 emergency	518	255	295,046	260.7	422.2

[a]*Population based upon Wisconsin Department of Natural Resources data base adjusted to 2005 Wisconsin Department of Administration Civil Division estimates and SEWRPC data, where appropriate.*

[b]*The following abbreviations are used:*

G = Groundwater
S = Surface Water (Lake Michigan)
SP = Surface Water Purchased (Lake Michigan)

Source: Wisconsin Department of Natural Resources, Public Service Commission of Wisconsin, water utilities, and SEWRPC.

Table 2

SUMMARY OF MUNICIPAL WATER USE IN THE SOUTHEASTERN WISCONSIN REGION: 2000, 2004, AND 2005

	Average Annual Water Uses										
	Residential Water Use[a]			Industrial Water Use		Commercial, Institutional, and Multi-Family Residential[a]			Total Municipal Water Use[b]		
Year	Total[c] (gallons per day X 1,000)	Per Person[d] (gallons per capita per day)	Per Acre[d] (gallons per acre per day)	Total[c] (gallons per day X 1,000)	Per Acre (gallons per acre per day)	Total[c] (gallons per day X 1,000)	Per Acre (gallons per acre per day)	Other Municipal[e] Water Uses (gallons per day X 1,000)	Total[c] (gallons per day X 1,000)	Per Person[f] (gallons per capita per day)	Percent Unaccounted-for Water[g]
2000	85,391	68	910	50,889	4,010	53,595	1,054	10,077	199,952	128	10
2004[h]	85,027	67	873	39,761	3,049	49,959	959	10,866	185,612	117	12
2005[I]	89,904	70	916	39,731	3,003	51,055	964	11,874	192,564	120	11

[a]*Residential category includes population associated with single-family and two-family housing units, plus some larger multi-family housing where individual water meters are used for each unit. Other multi-family units are included in the commercial water use category.*

[b]*Includes all water specifically accounted for.*

[c]*As reported in annual reports submitted to the Public Service Commission of Wisconsin.*

[d]*Reported residential water use excludes that associated with multiple-unit dwellings where a single meter which serves three or more housing units. That water use is classified as commercial under the Public Service Commission of Wisconsin reporting system. The unit water uses presented on a per capita and per acre basis were calculated by adjusting the population and residential land area to be consistent with this reporting procedure.*

[e]*Includes uses for fire protection services, sales to public authorities, sales to irrigation customers and interdepartmental sales.*

[f]*Estimated based upon total residential population served.*

[g]*Water not specifically accounted for as a percent of total pumpage.*

[h]*2004 land use was approximated by increasing the 2000 land use amounts by the increase in population from 2000 to 2004 for the individual communities served.*

[I]*2005 land use was approximated by increasing the 2000 land use amounts by the increase in population from 2000 to 2005 for the individual communities served.*

Source: Public Service Commission of Wisconsin and SEWRPC.

and two-family housing units residential purposes; about 51 mgd, or about 26 percent, for commercial and multi-family residential, and institutional uses; and about 40 mgd, or about 21 percent, was for industrial uses. The remaining 12 mgd, or about 6 percent, was used for other municipal purposes. Based upon the population served and reported water use, residential water consumption within the 78 water supply systems was approximately 70 gallons per person per day in 2005. When accounting for all municipal water uses, the average water consumption was about 120 gallons per person per day. In 2005, the amount of water which was unaccounted for by County ranged from 8 to 13 percent, with an average of 11 percent of the water pumped for the utilities. This, unaccounted-for water was not included in the computed per capita consumption rates. It should be noted that the residential water use reported by the water utilities excludes that associated with the use of water by multiple-unit dwelling units with a single meter serving three or more units. Those uses are included with commercial water uses. Thus, the calculation of the water uses on a per capita and per acre basis for the residential and commercial categories were made by adjusting the population and acreage considered under these categories to reflect this reporting requirement.

The total water used in the 78 municipal utility systems in 2005 was about 4 percent less than used in 2000 and about 4 percent more than used in 2004. The decrease between 2000 and 2005 was due largely to a decrease of about 22 percent in industrial water use. The increase from 2004 to 2005 was due largely to an increase in residential water use of 6 percent. In this regard, it is noted that 2005 was a relatively dry year during the growing season.

With regard to water conservation measures, many of the utilities are working to improve efficiency and minimize water losses in their systems. Such measures include meter testing for accuracy, leak detection programs, and repair of water main breaks and leaks. In addition, nearly all of the water supply utilities within southeastern Wisconsin have water metering in place, and have billing systems based upon usage, and all of the water supply systems are governed by the State plumbing code which limits flow rates and volumes for plumbing fixtures.

Self-Supplied Private Water Supply Systems
In 2005, there were 169 existing privately owned water, self-supplied, systems operating in the Southeastern Wisconsin Region which provide water supply services to primarily residential land uses, such as subdivisions, apartment or condominium developments, and mobile home parks, and to some institutional uses. Such systems are generally categorized by the Wisconsin Department of Natural Resources as "other than municipal, community systems." These systems serve a residential population of about 29,800 persons, or about 1.5 percent of the 2005 Region resident population. These systems are served by 312 wells and appurtenant equipment.

In 2005, there were 108 existing privately owned, self-supplied, water systems operating in the Region which provide water for industrial land uses. These systems all utilize groundwater as a source of supply through 186 wells and appurtenant equipment.

In 2005, there were 941 existing privately owned, self-supplied, water systems operating in the Region which provide water for commercial land uses. These systems all utilized groundwater as a source of supply through 1,008 wells and appurtenant equipment.

In 2005, there were 593 existing privately owned, self-supplied, water systems operating in the Region which provided water for institutional and recreational land uses. These systems all utilized groundwater as a source of supply through 835 wells and appurtenant equipment.

In 2005, there were 54 existing privately owned, self-supplied, water systems operating in the Region which provided water for irrigation and other purposes for agricultural land uses. These systems all use groundwater as a source of supply through 111 wells and appurtenant equipment.

In 2005, there were 96 existing privately owned, self-supplied, water systems operating in the Region which provided irrigation water for land uses other than agricultural uses, such as golf courses. All of these systems utilize groundwater as a source of supply through 150 wells and appurtenant equipment.

In 2005, there were six existing privately owned, self-supplied, water systems operating in the Region which provided cooling water for thermoelectric-power-generation facilities. These facilities include the Pleasant Prairie Power Plant, a coal-based generating facility, and the Paris Generating Station, a combustion turbine generating facility, both in Kenosha County; the coal-based Valley Power Plant and the Oak Creek Power Plant, both in Milwaukee County; the Port Washington Power Plant, a facility being converted in 2006, from a coal to an intermittent-load natural gas facility in Ozaukee County; and the Germantown combustion turbine gas-fired, intermittent-use facility in Washington County. Combined, these facilities were reported to use nearly two billion gallons of water per day in 2000. Most of that water is utilized by the Valley Power Plant, the Oak Creek Power Plant, and the Port Washington Power Plant, all of which utilize Lake Michigan water for once-through cooling systems. These systems typically return over 99 percent of the cooling water used back to the Lake. The Pleasant Prairie Power Plant is located five miles away from Lake Michigan, where a closed-loop system with large cooling towers is used. The amount of water used is reported to be about 11 million gallons per day, the majority which is make-up water for the cooling tower system. We Energies reports that nearly 75 percent of the water used at that plant is evaporated to the atmosphere. The two small peaking combustion turbine power plants in the Village of Germantown and the Town of Paris use limited amounts of well water for nitrogen oxide control and cooling on an intermittent-use basis.

Existing Self-Supplied Residential Water Systems
As of the year 2005, there were about 347,000 persons, or about 17 percent of the total resident year 2005 population of the Region, served by private domestic wells. Assuming an average use of 65 gallons per capita per day, the private domestic well within the Region would withdraw about 23 million gallons per day from the shallow groundwater aquifer. The value of 65 gallons per capita per day was selected to represent average water use in residential areas served by private wells. This value is somewhat less than the regional average of 67 to 70 gallons per capita per day for residential use in areas served by municipal systems. The lower value is expected because residential water use in areas served by private wells are expected to be somewhat lower than in areas

served by municipal systems because of concerns with local water supply capacity and with onsite sewage disposal systems. In addition, some outdoor water use demands are expected to be less in areas served by private wells.

It is estimated that 37 percent of the households served by private domestic wells are served by public sanitary sewer systems. Thus, the water withdrawn from the groundwater system for about 37 percent of the private domestic wells, or about 8.5 million gallons per day, was discharged to the surface water system as treated sanitary sewage. The majority (approximately 90 percent) of the remaining 63 percent of the water withdrawn by private wells, or about 13.0 million gallons per day, was returned to the groundwater aquifer via onsite sewage disposal systems.

Chapter III

SURFACE WATER TREATMENT TECHNOLOGIES

INTRODUCTION

Varying measures and levels of treatment can be considered for the processing of surface water for water supply purposes. This chapter presents process descriptions and cost data for those surface water treatment technologies that are considered appropriate for consideration in water supply planning for the Southeastern Wisconsin Region. For each technology, a process description including its intended treatment or other purposes, as well as data on unit costs in terms of capital and operation and maintenance, are provided as appropriate. At the end of the chapter, a summary section is included which provides a typical treatment train configuration, level of treatment, and cost for use in system level planning studies.

SURFACE WATER AND GROUNDWATER TREATMENT TECHNOLOGY APPLICABILITY

There are a number of treatment technologies that are applicable, or partially applicable, to both surface water and groundwater processing. Chapter IV of this report includes a description of and costs for groundwater treatment technologies. Those treatment technologies included in Chapter IV which are also considered applicable, or potentially applicable, to surface water systems include the following:

- Adsorption;
- Ion Exchange; and
- Point-of-Use Treatment.

For purposes of this chapter on surface water treatment technologies, the process descriptions and costs for these above noted technologies are referenced to Chapter IV.

SOURCES OF COST DATA

The cost of treatment technologies for drinking water is highly variable depending on source water quality. In 1979 the U.S. Environmental Protection Agency (USEPA) published data collected from water treatment facility contractors, engineers, and equipment vendors nationwide. The USEPA surveyed over 70 firms for cost estimates on nearly 100 unit processes popular at the time. The results were expressed in the form of cost curves for 72 treatment technologies commonly used for water treatment.[1] The values contained in the document, when adjusted for appropriate cost inflation, are remarkably accurate when compared to estimated current construction costs. Unfortunately, several new technologies currently used for treatment were not included in the 1979 document.

During the mid 1990s the U.S. Department of the Interior, Bureau of Reclamation (USBOR) developed a spreadsheet that utilizes the 1979 USEPA publication values and updates the values using the *Engineering News Record* (ENR) construction cost index, ENR building cost index, and several other ENR indexes or cost values. In addition, this spreadsheet includes sections for several technologies developed between 1979 and the mid 1990s.[2] This spreadsheet was utilized extensively to estimate December 2005 costs for the technologies considered in this report. These costs were compared to known local facility costs where available. Typically, costs noted are from this USBOR source unless otherwise identified. Cost curves, based upon the spreadsheet, are contained in Appendix A.

INTAKE PROTECTION AND PRETREATMENT

Process Description

Surface water intakes must be designed to reduce intake of unwanted materials, including larger solids, fish and other animals. Typically, elimination of larger solids and animals is accomplished through screening. In some cases these screens may need to be mechanized to remove large solids for disposal at a landfill. In cold weather climates, intake screens must be designed to resist the formation of frazil ice or crystalline ice formed below the surface by the movement of ice in flowing water. This normally is accomplished by designing the intake screen size to assure low velocities within the surface water supply. The provision of more than one intake screen allows for the use of a clear screen while a blocked, or partially blocked, screen is cleared of ice. Mechanical intake screens are most typically installed at the shoreline, rather than at the inlets of the intakes. Figure 1 illustrates a typical intake screen.

Some animal species become a nuisance at water intakes because of their affinity for the conditions that exist at the water intake. One such species that has gained notoriety is the zebra mussel (*Dreissena polymorpha*). Left uncontrolled, zebra mussel shells can block entire intake pipes over time. Zebra mussel control is typically done through velocity control or through periodic chemical treatment to remove the mussels. Utilizing a variety of pipe sizes and several intake pipes allows flexibility to maintain sufficient velocity to inhibit zebra mussel attachment. More recently, the quagga mussel (*Dreissena bugensis*) has been found in Lake Michigan (1997) and may become a problem similar to the zebra mussel. The quagga mussels are active year-round, while zebra mussels are dormant in the winter. Thus, year-round chemical controls may be needed for the quagga mussel. Intakes with limited control over velocity use biocides, often oxidizers such as potassium permanganate, to eliminate the mussels. Chemical treatment is typically done intermittently as a preventative maintenance activity.

In many cases organic materials—either man-made or natural—in the water supply need to be removed prior to filtration and disinfection in order to enhance filtration and reduce disinfection byproducts in the finished water.[3] One of the most common methods to eliminate byproduct precursors is to oxidize the precursors prior to filtration to enhance the amount removed during filtration. Common oxidation chemicals used are ozone, permanganate,

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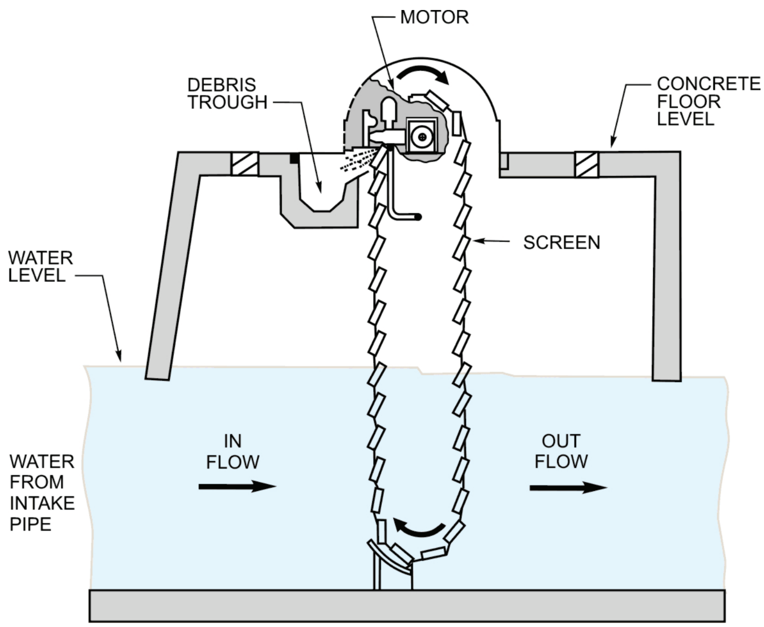
[1]*Robert C. Cumerman, Russell L. Culp, and Sigurd P. Hensen,* Estimating Water Treatment Costs - Volume 2 - Cost Curves Applicable to 1 to 200 MGD Treatment Plants*, USEPA, Cincinnati, OH, August 1979, pp. 1-5.*

[2]*Michelle Chapman Wilbert, John Pellegrino, Jennifer Scott, and Qian Zhang,* Water Treatment Estimation Routine (WaTER) User Manual*, U.S. Department of the Interior, Bureau of Reclamation, Denver, CO, August, 1999, pp. 1-2.*

[3]*American Water Works Association and American Society of Civil Engineer, American Water Works Association,* Water Treatment Plant Design, Third Edition*, McGraw-Hill, Inc., New York, New York, 1998, p. 50.*

Figure 1

TYPICAL THROUGH FLOW INTAKE MECHANICAL SCREEN



Source: MACMET INDIA LIMITED and SEWRPC.

and chlorine. Chemical addition is typically done as close to the raw water intake as possible to allow sufficient mixing and reaction time prior to sedimentation or filtration. The chemical injection point is often located within the facility grounds for safety and health reasons, but may be at the raw water intake.

In some areas blue-green algae (*Cyanobacteria*) have become a concern in surface waters. Some species of this algae contain toxins that are released into water when the bacterial cells rupture. Blue green algae also create taste and odor problems in water. Fortunately, the conditions favorable to the growth of *Cyanobacteria*,[4] small stagnant waterbodies, are not generally chosen as drinking water supplies. The blue-green alga, *Cylindrospermopsis*, is an invasive type of algae that is now present in major inland lakes in Wisconsin. This alga is difficult to detect and releases toxins continuously. These toxins are toxic to animals and humans, making this type of algae a particularly undesired invasive species. The algae have not yet been reported as an issue in Lake Michigan.

Costs
The costs associated with screening and preliminary chemical addition are not documented in the USEPA 1979 publication, nor are they included in the USBOR spreadsheet updated in the late 1990s.

Investigation indicates that the incremental cost of adding screening to intake pipes that are typically relatively long is minimal, as is installing chemical feed pipes to intakes, when compared to other unit costs. December 2005 costs for an actual installation were under $0.04 per gallon per day (gpd) of capacity, installed costs. For systems-level planning purposes, it is recommended that $0.05 per gpd capacity be used for both screening and chemical addition.

Operation and maintenance costs for intake structures are also low relative to other facility processes. Documentation of such costs is limited, apparently because such tasks are intermittent and are accounted for under other activities. Accordingly, estimates of operation and maintenance costs for screening and related demand control herein are accounted for as part of miscellaneous costs.

WATER TREATMENT PLANT INTAKES

Description
Water intakes are designed and located to draw water from an area within the source that is as free of contaminants as possible. In some cases this can be a sophisticated structure designed so that the water can be drawn from several levels. Typically, for Lake Michigan water, the intakes need to be located far from shore and

[4]*National Institutes of Health*, Blue-Green Algae*, Available at:* http://ntp-server.niehs.nih.gov/index.cfm *Accessed: 4/19/2006.*

can be placed near the bottom of the lake. The intake structures for the surface water treatment facilities in southeastern Wisconsin vary considerably in design. Some intake structures are simple pipes formed into one or more intake ports, while others have concrete or steel structures to prevent sediment and other material from entering the intake. Water treatment plant intake pipelines in southeastern Wisconsin range in length from 2,500 feet to 11,800 feet, with an average of just over 5,000 feet. The intakes reach lake water depths of 25 to 55 feet and range in size from 16 inches to 144 inches in diameter.

Costs
As indicated earlier, the cost of intake structures and screens is not documented well in literature. The cost of the intake pipeline and structure for Lake Michigan water treatment plants is considerable. Due to the underwater work and the need for specialized marine equipment, the cost for intake pipeline construction is typically 2.5 to 4.0 times the cost of similar land projects.[5] The Milwaukee Water Works extended one of its water intakes in 1996 at a cost of $0.15 per gpd of treatment plant capacity and about $0.06 per gpd of actual intake capacity (December 2005 value). The latter cost is considered relatively low because of the large economy of scale achieved when constructing a 144-inch-diameter pipeline. In 1994, a study[6] was done which resulted in the publication of a formula for the estimation of submerged intake pipeline construction costs based upon pipe material, diameter, and pipe length. When the recent Lake Michigan intake construction project costs are compared to the results of this formula, the cost differences are within an acceptable accuracy range. The costs in 2005 dollars for intake pipelines is estimated by this formula to range from $4.2 million for a 24-inch-diameter intake to $8.0 million for a 48-inch-diameter intake extending one mile into the lake. For a hypothetical 30 mgd water treatment plant with a 6,000-foot-long, 36-inch-diameter intake pipeline and intake structure, the estimated cost of the intake is $7.0 million, or an average of $0.23 per gpd of capacity. For planning purposes, it is recommended that an average value of $0.25 per gpd of capacity be used for intake pipeline and intake structure construction.

As indicated earlier, the annual operations and maintenance costs for intakes are minimal and typically are not accounted for separately by facilities.

RAW WATER PUMPING

Process Description
Typically the source water level is at a lower elevation than the treatment facility, which requires raw water pumping to allow gravity flow through treatment processes. Occasionally a reservoir or other source can be located at a higher elevation to allow for complete gravity feed throughout the treatment facility. Raw water pumps are typically low head centrifugal pumps located at or near the shoreline of the source surface waterbody.

Costs
When the USEPA 1979 values are adjusted to December 2005 values using the USBOR spreadsheet, an estimated construction cost of $0.70 per gpd capacity is obtained for a 1.0 million gallon per day (mgd) facility. The spreadsheet utilizes current electrical costs and estimated dynamic head values to determine operation and maintenance costs for a facility. The estimated operation and maintenance costs obtained for a 1.0 mgd facility is $690 per million gallons (MG) pumped. For planning purposes, it is recommended that a cost of $0.70 per gpd capacity be used for the former value and $600 per MG pumped for the latter value.

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[5]*ASCE and AWWA,* Water Treatment Plant Design*, Second Edition, 1990.*

[6]*Thomas M. Walski, Janet S. Condra, and Ken Cable, "Procedure for Estimating Surface-Water Intake Cost,"* Journal of Environmental Engineering*, Vol. 110, No. 2, March/April 1984, pp. 381-391.*

COAGULATION-FLOCCULATION-SEDIMENTATION

Process Description
Sedimentation processes were among the first to be utilized for drinking water treatment.[7] The process of sedimentation is relatively simple—allowing water to stand in, or slowly flow through, a tank under quiescent conditions for particles to settle. Early research identified the physical characteristics that enhanced settling.[8] Many of these principles continue to be applied today in the form of specially designed settling chambers. Settling chambers utilizing such embellishments as tube settlers and inclined plate separators are commonplace in any treatment process utilizing settling as part of the treatment train.[9] Figure 2 shows an inclined plate separator system. Upflow clarification is utilized to enhance settling by bringing influent upward through the settling zone to force smaller solids within the influent to contact higher concentrated solids.[10] Relatively small improvements in clarifier design appear to continue to advance settling characteristics. Many manufacturers have patented such improvements. Today, sedimentation is typically used to remove flocculated solids—primarily organic materials—prior to filtration.

The combined process of coagulation—the neutralization of charges through chemical addition—and flocculation—that is, the coming together of smaller particles into larger particles or flocs—is an area of continual improvement. Coagulants are often added to enhance coagulation and flocculation prior to sedimentation. Coagulation often occurs in flash mixers that provide rather rapid mixing followed by flocculation in a very slowly agitated zone. A typical in-line flash mixer is illustrated in Figure 3. After flocculation water flows to a clarification zone where flocculated particles settle and are removed.[11]

Coagulants such as aluminum and iron salts have been utilized for many years both for solids removal, as well as softening of water.[12] Today organic polymers can be utilized that are often specific for the type of particle desired for removal from water. In an effort to move away from chemical addition the ballasted flocculation system has been developed. With the ballasted flocculation system, microsand (a fine quartz sand) is added to the water to serve as the nucleus of the flocculating particle. Given the higher density of sand, the particle settles much more easily and quickly than a chemically flocculated particle. After mixing and flocculation within a sludge zone at the lower areas of the clarifier, the water is passed through an area of inclined plates in order to pass on to the next treatment step.[13] The detention time within such units appears to be relatively low and can lead to more compact treatment units and less land area required for such units.[14]

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[7]*American Water Works Association (AWWA),* Water Quality and Treatment-A Handbook for Community Water Supplies-4th Edition*, McGraw-Hill, Inc., New York, New York, 1990, p. 367.*

[8]*AWWA (1990), p. 368.*

[9]*AWWA (1990), p. 386.*

[10]*GC3 Specialty Chemicals, Inc., Clarification Text, Available at www.gc3.com/techdb/manual/clartext.htm, (accessed December 30, 2005).*

[11]*American Water Works Association (AWWA)/American Society of Civil Engineers (ASCE),* Water Treatment Plant Design-3rd Edition*, The McGraw-Hill Companies, Inc., New York, New York, 1998, pp. 87-89.*

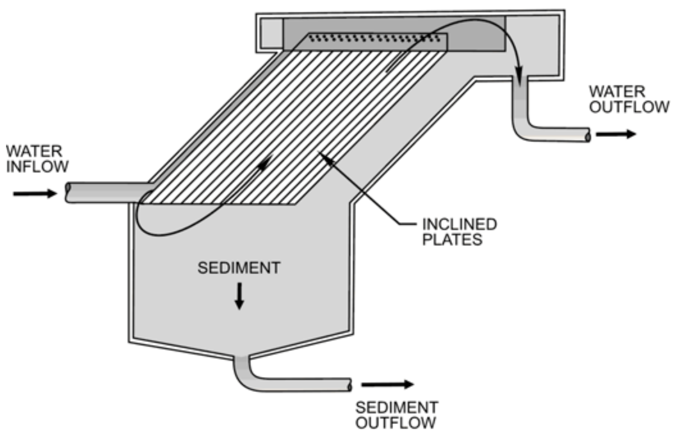
[12]*AWWA (1990), p. 271.*

[13]*Products-Actiflo for Drinking Water and Wastewater Treatment, available from: www.krugerusa.com/pages/products/actiflo.htm, (accessed December 30, 2005).*

[14]*City of Melbourne, Florida, Melbourne Drinking Water, available from: www.melbournefl.org/watercon/lwplant.htm, (accessed December 29, 2005).*

Figure 2

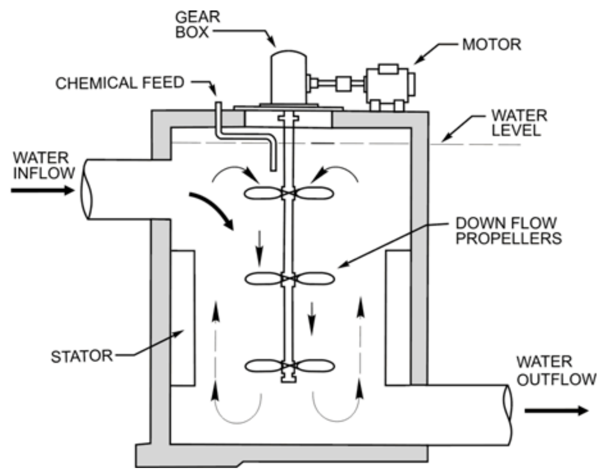
INCLINED PLATE SEPARATORS FOR SOLIDS SEPARATION AND TURBIDITY REDUCTION



Source: U.S. Environmental Protection Agency and SEWRPC.

Figure 3

TYPICAL FLASH MIXER



Source: American Water Works Association and SEWRPC.

Many manufacturers of treatment technologies have concentrated development in recent years on enhancing coagulation and flocculation with no sedimentation prior to filtration—a process commonly known as direct filtration. While not in widespread use in southeastern Wisconsin, the process has been used with success in other areas. Given the level of treatment needed under the surface water treatment rule[15] and the disinfection byproducts rule,[16] having a filter of some sort for final solids removal guarantees compliance when compared to the sedimentation process.[17] The addition of chemicals to enhance coagulation and flocculation can significantly improve the effectiveness of filtration units.[18]

Costs

The cost of constructing coagulation, flocculation, and sedimentation facilities is highly dependent on local conditions, especially raw water quality and existing facilities.[19] However, sedimentation is required for treating Lake Michigan water with gravity filtration processes. In addition, many facilities have eliminated or reduced sedimentation in favor of filtration. The USEPA 1979 costs adjusted to December 2005 values for a coagulation-flocculation-sedimentation facility approximates $0.49 per gpd of design capacity. For planning purposes it is recommended that a cost of $0.70 per gpd of design capacity be used. This figure varies significantly for design flows under 1.0 mgd and should not be applied to smaller facilities. For smaller facilities, site-specific cost analyses are needed.

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[15]*A USEPA rule provided for under the 1996 amendments to the Safe Drinking Water Act designed to reduce illness linked to pathogenic microorganisms in drinking water and to ensure that water systems maintain microbial protection.*

[16]*A USEPA rule provided for under the 1996 amendments to the Safe Drinking Water Act designed to reduce potential cancer and reproductive and developmental health risks from disinfection by-products in drinking water, which can form when disinfectants are used to control microbial pathogens.*

[17]*AWWA (1990), p. 506.*

[18]*AWWA (1990), p. 507.*

[19]*AWWA (1990), p. 449.*

The operation and maintenance costs for coagulation-flocculation-sedimentation facilities can be significant. Chemical mixing and addition for coagulation can be labor intensive, depending on specific chemicals and chosen mixing equipment. USEPA 1979 values adjusted to December 2005 values by the USBOR spreadsheet indicate a cost of between $90 and $180 per MG of treated water in a 1.0 mgd facility, depending upon the type of chemicals used and specific design of clarification. For planning purposes, it is recommended that a cost of $150 per MG of water treated be used.

FILTRATION

Introduction

The institution and modification by the USEPA of its surface water treatment regulations has forced many previously unfiltered water supplies to develop filtration facilities in recent years. The rules are written to encourage filtration of surface water supplies by requiring that significant programs and procedures be in place if filtration is to be avoided.[20] The original regulations targeted the removal of gross solids and pathogenic organisms, while the current emphasis is on the removal of organic materials to prevent the formation of disinfection byproducts after filtration.[21] Filtration is commonly divided into three categories: gravity filtration, pressure filtration, and membrane filtration.

Gravity Filtration

Process Description

Slow Sand Filtration

The intent of the filtration of drinking water was originally to remove nuisance materials, as well as to reduce pathogens and hence reduce disinfection requirements. A simple and inexpensive way to do so was to allow water to percolate slowly through sand and to collect the water afterwards. This process mimicked the natural process of water movement and clarification within soil, and is relatively effective at removing contaminants. Slow sand filtration utilizes smaller and less-uniform-sized sand, as compared to sand used in rapid sand filtration, in which the hydraulic application rate is relatively low.[22] For these reasons, the labor required for maintenance—including cleaning of the "schmutzdecke," or collected solids—and the land area necessary for filters is relatively high. Few slow sand filtration facilities have been built in recent years, especially for systems treating significant flows of water.[23]

Rapid Sand Filtration

Rapid sand filtration has largely replaced slow sand filtration over the past 100 years. Rapid sand filters utilize sand of a larger and more consistent grain size than slow sand filtration. This creates larger void spaces within the filter bed with an associated higher flow-through rate. Filtration occurs through the mechanism of particles within the water stream becoming attached to the sand throughout the entire depth of the sand bed. In order to increase the ability of materials to be trapped, coagulants are added and flocculation is almost always encouraged prior to rapid sand filtration.[24] Rapid sand filters can be designed with a higher hydraulic application rate—up to 13 gpm

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[20] *U.S. Environmental Protection Agency,* 40 CFR Ch. 1 (7-1-02 Edition).

[21] *U.S. Environmental Protection Agency,* Rule Fact Sheet - Long Term 2 Enhanced Surface Water Treatment Rule*, EPA 815-F-05-002 December 2005.*

[22] *Oasis Design,* Slow Sand Filtration*, June 1991.*

[23] *American Water Works Association and American Society of Civil Engineer, American Water Works Association,* Water Treatment Plant Design, Third Edition*, McGraw-Hill, Inc., New York, New York, 1998, p. 193.*

[24] *American Water Works Association and American Society of Civil Engineer, American Water Works Association,* Water Treatment Plant Design, Third Edition*, McGraw-Hill, Inc., New York, New York, 1998, p. 154.*

per square foot of filter area—so the land area required for rapid sand filters is less.[25] Rapid sand filters must be backwashed on a regular basis, which is generally done on a schedule determined by a number of factors including gallons treated, head loss through the filter, filtered water quality, and time since the last backwash. The treatment and disposal of the backwash water is a major consideration during site selection and designing of rapid sand filtration facilities. Backwash water may be treated on site or stored temporarily for discharge into sewers for treatment at the local wastewater treatment facility. Rapid sand filtration backwash cycles often incorporate an air scour for added agitation of the filter bed and increased cleansing action. A typical rapid sand filter is shown in Figure 4.

Dual-Media (or multi-media) Filtration

The term dual-media filtration has a variety of meanings, some based upon proprietary issues and others simply based upon the descriptive nature of the term. The general concept common among most filters identified as dual media is that more than one material is utilized within the filter bed. The advantages of utilizing a material as a filter media, which can physically, electro-chemically, or through some other means, improve removal of contaminants, is self evident. Unfortunately, the differences in density and other characteristics between the two materials make backwashing technologically challenging. Recent advancements are overcoming these challenges as man-made resins and resin coatings are developed which can perform contaminant removal. The most common types of medias used in dual-media filters are sand and manganese greensand—the mineral glauconite within the same filter bed—that increases the removal of iron from water. Filter media of sand and anthracite are also commonly used for simple filtration. Research with proprietary dual-media filters within the New York City water supply system indicate promise for increased removal of disinfection byproduct precursors, as well as removal of pathogens, such as *Cryptosporidium* and *Giardia*.[26] Granulated activated carbon is commonly combined with sand filtration to enhance organic substance removals.

Micro Screens

Self-cleaning micro screens are becoming popular for prefiltration prior to other processes, such as membrane processes. Micro screens are typically designed to eliminate solids larger than a specific size. Often micro screens are sized at 500 microns, but can be supplied in a variety of sizes. Micro screens are typically of the wedgewire design to prevent clogging. Screens self clean by being shaped in such a way that the inflow forces the screenings toward the waste disposal area. Alternatively, the screens may be cylindrical and operated in a rotary fashion. Micro screens can be configured to screen raw water or water at other stages of treatment.

Costs

The construction of typical—not including granular activated carbon—gravity filtration based on USEPA 1979 costs adjusted to December 2005 values by the USBOR spreadsheet are estimated to be $0.43 per gpd of capacity for a 1.0 mgd facility. This estimation is exclusive of engineering, administration, legal, and contingency costs. It is, therefore, recommended that, for planning purposes, a constructed cost of $0.60 per gpd capacity be used for facilities with a capacity of 1.0 mgd. Smaller facilities do not typically use gravity filtration.

Gravity filtration facilities utilizing granular activated carbon are significantly more costly to construct. The USBOR cost estimation spreadsheet estimates the cost of construction at $4.10 per gpd capacity for a 1.0 mgd facility. Much of the additional cost—that is, cost above that of other gravity filters—is the cost of carbon regeneration facilities. For planning purposes, it is recommended that a cost of $5.50 per gpd capacity for new gravity granular activated carbon facilities for facilities with a capacity of 1.0 mgd.

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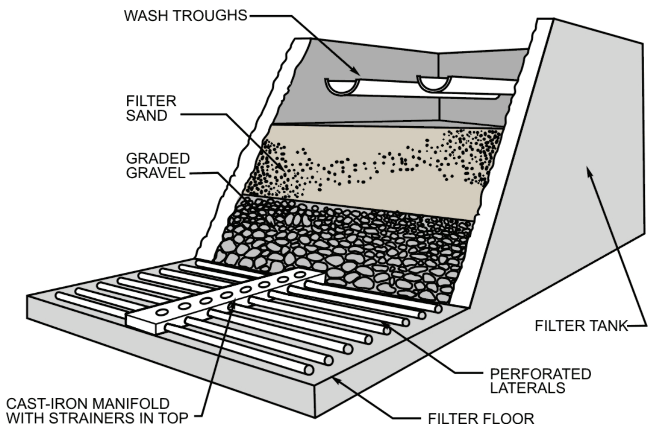
[25]*American Water Works Association,* Water Quality and Treatment, A Handbook of Community Water Supplies, Fourth Edition*, Copyright 1990, by McGraw-Hill, Inc., New York, New York, p. 476.*

[26]*National Academy Press, "Watershed Management for Potable Supply: Assessing the New York City Strategy," www.nap.edu, 2000, p. 25.*

Figure 4

TYPICAL RAPID SAND FILTER



Source: American Water Works Association and SEWRPC.

The cost to construct micro screen facilities was not included in the 1979 USEPA cost estimates, nor was it included in the USBOR spreadsheet. Several references that list costs for membrane processes do not include costs for pre-screening processes. It is known that some facilities have chosen micro screens over pre-screening with sand filtration, and, therefore, the cost to construct must be less than sand filtration, at least in some cases. Therefore, it is recommended to use the estimated cost for sand filtration facilities—without their backwash facilities—for systemwide planning purposes. This cost is $0.40 per gpd capacity for facilities with a capacity of 1.0 mgd.

Operation and maintenance costs for gravity filtration—other than granular activated carbon filters—are estimated to be $80 per MG treated based on the USEPA 1979 figures adjusted by the USBOR spreadsheet to December 2005 values. When activated carbon gravity filters are utilized, the above estimates increase by a factor of over 10; to about $1,000 per MG treated. For planning purposes, it is recommended that values of $80 and $1,000 per MG treated be used for traditional gravity filtration and activated carbon filtration, respectively, for facilities with a 1.0 mgd capacity. The cost of operation and maintenance of micro screens is not documented in literature. It appears, intuitively, to be very low compared to other filtration processes. Therefore it is recommended to use $80 per MG treated for systemwide planning purposes. Treatment of backwash water is also an important factor in operation and maintenance costs as noted in the subsequent section.

Treatment of Wastes

Rapid sand filters produce significant amounts of backwash water that must be treated and/or disposed of. Treatment is often performed on site with drying beds and disposal of the residuals at a sanitary landfill. It is also common to utilize a municipal wastewater treatment facility for backwash treatment. In either case, the method to handle backwash waste must be considered and accounted for. Such backwash can be overwhelming for some wastewater treatment facilities. Because of their nature, activated carbon filters do not require as much consideration for waste disposal.

The cost of the treatment of wastes is most dependent on the charges applied by the local wastewater collection and treatment utility. In most cases charges for nonresidential wastewater treatment is based upon the type and concentration of waste constituents in the wastewater, as well as the quantity of wastewater generated. If wastewater characterization finds that backwash water from a drinking water treatment facility contains constituents that may not be treated at the wastewater treatment facility or may disrupt the proper operation of such facilities, pretreatment may be required before discharge. Any specific planning must take into account the site pretreatment that may be required and specific costs of backwash water treatment and/or disposal.

The specific costs for the disposal of backwash water or concentrate generated by transport to wastewater treatment facilities varies from $3.30 per 1,000 gallons to $6.00 per 1,000 gallons. For planning purposes it is recommended that $5.00 per 1,000 gallons of wastewater generated be used. The quantity of wastewater generated is a process specific quantity and must be determined on a site-specific basis during facility design. Typically, the amount of backwash generated by gravity sand filtration is less than 5 percent of the water flow.

Pressure Filtration

Process Description

Pressure Sand Filters

Generally, the above filters are thought of as open top filters with flow through the filter bed by gravity. In larger drinking water treatment facilities, this is the most common layout for such filters. As systems get smaller, and depending upon the media required for specific contaminants removal, filter media may be placed into a pressurized tank with distribution and collection mechanisms at the inlet and outlet, respectively. Tanks are typically cylindrical and may be oriented horizontally or vertically. The most common example of such tanks are those used for softening of water using ion exchange media for small community and commercial entities.

Pre-Coat Filtration (diatomaceous earth filters)

With pre-coat filtration, a coating of fine material is applied to a septum or porous plate. This fine material—often the silica deposits of microscopic shells of diatoms—provides a thin layer of filtering material that can filter out particles down to 1.0 micron in diameter. The finer the grade of diatomaceous earth utilized, the finer the particles that can be filtered.[27] Utilizing finer materials also requires increased backwashing of the filter and increased operation and maintenance costs for pre-coating. The backwash from pre-coat filters not only contains the filtered solids, but also includes the pre-coat material that must be treated and disposed of.

Costs

Pressure filters are typically provided as a "skid-pack" that is delivered to the site ready to be plumbed into a facility. Based on 1979 values as estimated by the USEPA and converted to December 2005 values using the methods employed by the USBOR spreadsheet, the construction cost of a 500,000 gpd pressure filtration facility would be $0.80 gpd capacity. For facilities smaller than 0.5 mgd capacity, the cost per gallon of treatment capacity increases significantly. It is recommended that a cost of $1.50 per gpd capacity be used for planning purposes for facilities with capacities between 0.25 mgd and 1.0 mgd.

Operation and maintenance costs for pressure filtration facilities were identified in the 1979 USEPA study. When these figures are adjusted to December 2005 values for labor and energy rates, the cost is approximately $265 per MG treated based upon a facility with an average daily flow of 0.4 mgd. There is a high degree of variability between manufactured units. For planning purposes, it is recommended that a cost of $300 per MG treated for pressure filtration units be used.

Pressure filtration units that utilize media other than sand—such as granulated activated carbon—may have construction, operation, and maintenance costs significantly higher and must be priced on a site-specific basis.

Backwash Treatment

Similar to gravity sand filters, pressure sand filters must be backwashed and the backwash water must be treated. Most pressure filters are associated with smaller facilities and utilize municipal wastewater treatment facilities for backwash treatment. In the case of pre-coat filters the diatomaceous earth is removed as part of the backwash and must be treated. Such backwash can be a relatively high hydraulic and pollutant load to the wastewater treatment facility in a small community. Backwash quantities may be as high as 10 percent of treated water flows for some proprietary systems.

Pressure Membrane Processes

Process Description

The concept of utilizing membranes to filter contaminants out of water is one that has been considered since the principle of osmosis was discovered in animal cells. Water generally moves across many animal cells membranes relatively easily from areas of low contaminant concentration to areas of high concentration. If this osmotic

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[27] *American Water Works Association and American Society of Civil Engineer, American Water Works Association,* Water Treatment Plant Design, Third Edition*, McGraw-Hill, Inc., New York, New York, 1998, p. 207.*

pressure can be overcome, the water will move in the opposite direction and the water passing through the membrane will be free of all contaminants that will not pass through the membrane with the water. Reverse osmosis was the first membrane process to gain notoriety. To overcome the osmotic pressure, water is placed under high pressure against the membrane and then collected after passing through the membrane. In order to keep the pores of the membrane open, the water to be filtered needs to be passed along the membrane to keep contaminants in suspension. This leads to much of the water entering the unit being discharged as waste.

Recent improvements in recirculation mechanisms, as well as membrane materials have lead to reduced waste brine flow, reduced pressures necessary to force water through the membrane, and reduced construction, operation and maintenance costs of membrane filtration technologies. Systems can be developed for removal of a specific contaminant at the ion, molecular, or particle level. The size of material to be removed determines the relationship between the pressure and membrane required. The typical terms used to describe levels of membrane filtration are shown in Table 3.

As can be observed in Table 3, the smaller the pore size—and the smaller the attendant size of the contaminant particles removed—the higher the pressure necessary to pass water through the membrane. Selection of membrane material is critical to efficient operation of membrane treatment systems designed to remove specific contaminants. Submerged membrane filtration utilizes hollow membranes under a slight negative pressure submerged in a process tank to remove contaminants.

Low-Pressure Membrane Filtration

Recent developments in membrane material technology and membrane cleaning systems have lowered the pressures necessary for effective membrane treatment. The membranes used for low-pressure systems are in low-pressure cartridges or typically hollow fiber membranes that are suspended in modules within a process tank. This tank may be an existing tank, such as a filter box or clarifier, or may be constructed specifically for this purpose. A slight vacuum is applied to the interior of the hollow fiber membranes that causes water to flow into the membrane filter, which is then pumped to further treatment and/or distribution. The exteriors of membranes are typically cleaned with a combination of water spray and air scouring. Typical pressure membrane systems are illustrated in Figures 5 and 6.

Other Membrane Processes

Electrodialysis (ED) is a membrane process that utilizes the ability of certain membranes to allow the passage of certain charged particles. In the ED process, the charged particles within the water move through the membrane as opposed to the pressure membrane processes described above, where the water moves through the membrane. As such, particles without a charge are not removed from the water stream. The force that causes particle movement within the ED process is direct current electricity that causes two electrodes to be charged—one positively and one negatively. Positively charged particles are drawn towards the negatively charged electrode, and negatively charged particles are drawn towards the positively charged electrode. Membranes are utilized which allow particles to move only part way towards their destination electrode. Ultimately, there will be alternating areas separated by membranes that are either devoid of charged particles or highly concentrated with charged particles.[28]

One large disadvantage of the ED process is that a charged particle will travel through a membrane that will pass particles of its charge and continue to move towards the oppositely charged electrode until it encounters a membrane that will not allow it to pass. This causes solids buildup on the membrane that hinders the passage of the opposite charged particles through the membrane. In order to solve this problem, the electrodialysis reversal (EDR) process was developed. In the EDR process the treatment unit reverses the electrodes, as well as the

[28]*Mia Lafontaine, Rachel D'Souza, Omer Fereig, and Derek Tse,* Turning Sea Water into Drinking Water: Electrodialysis, *Available at: http://cape.uwaterloo.ca/che100projects/sea/intro.html. January 3, 2006.*

Table 3

COMPARISON OF PRESSURE MEMBRANE PROCESSES

Classification	Typical Pressure Range	Typical Pore Size (microns)	Typical Level of Removal
Reverse Osmosis...........	100->1000 psi	0.0001-0.002	Ions
Nano Filtration................	50-150 psi	0.001-0.005	Divalent ions/simple molecules
Ultra Filtration.................	7-100 psi	0.005-0.1	Larger molecules/viruses
Micro Filtration	5-45 psi	0.075-3.0	Particles/algae/bacteria

Source: Modified from AWWA, 1990, p. 336.

finished and raw water channels on a regular schedule—typically several times each hour.[29] By doing so, the particle buildup on membranes is reduced and membrane life is extended significantly. Figure 7 shows a graphic representation of the EDR process.

As inferred earlier, the ED and EDR processes can be utilized to remove any charged particles in a water stream. These processes are commonly used in desalination facilities.

Treatment of Waste

All membrane processes will produce a highly concentrated waste stream that must be dealt with prior to returning the waste stream to the environment. In some cases the concentration of the contaminant can be very high, and there may be a mixture of several contaminants. This can lead to problems in waste disposal if treating water that contains chemicals classified as hazardous waste and/or radioactive waste are being removed. In such situations specific regulations may apply. The amount of concentrate generated by membrane processes is typically up to 30 percent compared with the waste stream from microfiltration systems which is typically 20 percent or less.

Costs

Costs of all water treatment technologies are difficult to predict because the final cost of facilities is highly dependant on source water quality. This is especially true of filtration facilities. Unfortunately, many technologies, including most membrane technologies, used today are not found in the USEPA 1979 document, and other sources must be relied upon. Given the short time that many new technologies have been in use, there are limited amounts of data available and the data have not been standardized as to what is included and what has not been included.

Membrane filtration of surface water sources may be expected to become commonplace in the future because of the ability to treat multiple contaminants. Elarde and Bergman[30] have published cost curves for membrane filtration facilities in recent years. The construction and installed equipment curves are reproduced in Appendix A. It is worth noting that, for facilities above 5.0 mgd capacity, the curves are relatively flat and a value of $2.00 per gpd of capacity could be used comfortably. For planning purposes, a cost of $2.60 per gpd of capacity is recommended.

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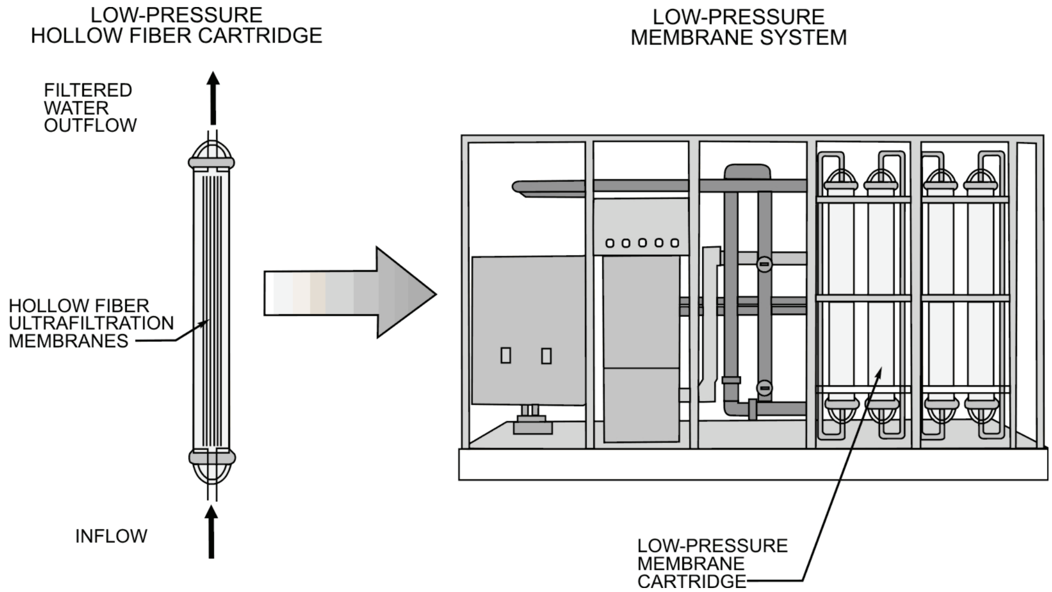
[29]*American Water Works Association and American Society of Civil Engineer, American Water Works Association,* Water Treatment Plant Design, Third Edition*, McGraw-Hill, Inc., New York, New York, 1998, p. 337.*

[30]*American Water Works Association (AWWA),* Membrane Practices for Water Treatment*, 2001, p. 8-13.*

Figure 5

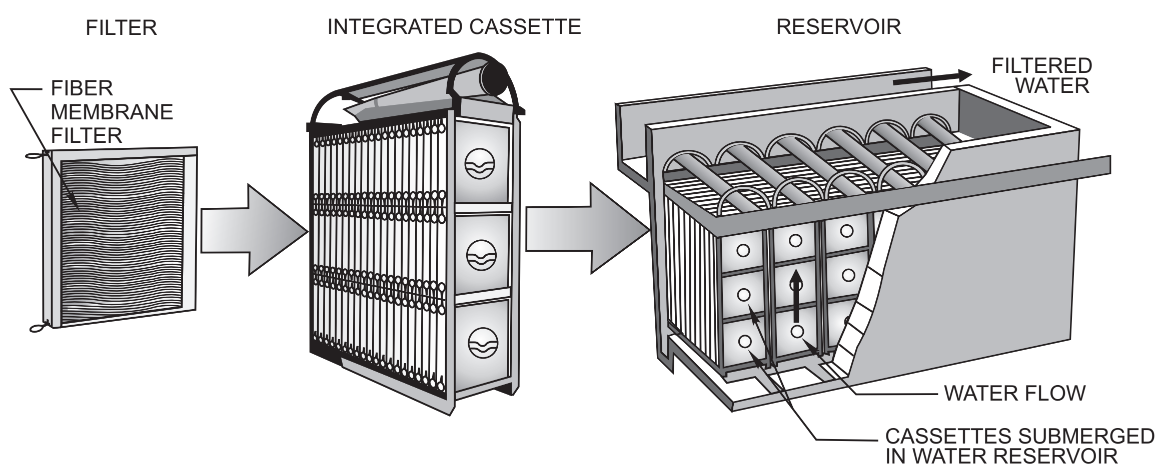
TYPICAL LOW-PRESSURE MEMBRANE SYSTEM



Source: Watersolve International, LLC, and SEWRPC.

Figure 6

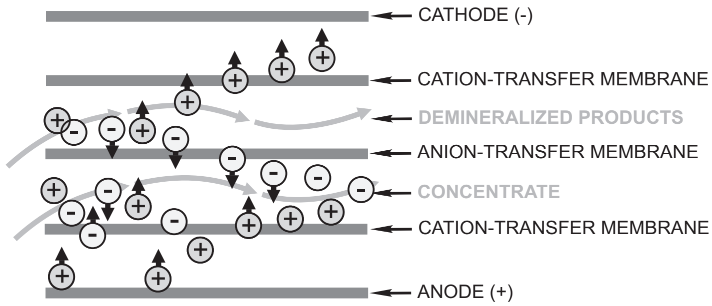
TYPICAL SUBMERGED LOW-PRESSURE MEMBRANE SYSTEM



Source: ZENON and SEWRPC.

Figure 7

TYPICAL ELECTRODIALYSIS REVERSAL (EDR) SCHEMATIC



Source: EDR Schematic, GE Water and Process Technologies, and SEWRPC.

Operation and maintenance costs are similarly difficult to estimate. As with construction and equipment costs, operation and maintenance costs are relatively stable for facilities above 5.0 mgd in size, at just under $400 per MG of finished water. Given the uncertainty associated with this value due to small sample size and the date of data collection, it is recommended that an operation and maintenance value of $300 per MG of finished water be utilized when planning for membrane facilities larger than 5.0 mgd. Operation and maintenance costs increase rapidly on a unit basis as the plant capacity decreases, with facilities producing 1.0 mgd to be approximately $600 per MG and facilities producing 0.1 mgd to be approximately $1,800. These estimates include waste treatment costs.

FILTRATION AVOIDANCE

Process Description

At the time that the surface water treatment regulations were promulgated by the U.S. Environmental Protection Agency, provisions were placed within the rules to allow surface water supplies to avoid the filtration requirements if they met certain guidelines. Generally these provisions require that the source water must be of exceptional quality, and that the water provider must assure that the quality of the source water is protected from contamination. Specifically the regulations require that within the watershed of the surface water supply source the water supplier must:[31]

1. Characterize the hydrology of the watershed, as well as the classification of the land ownership;
2. Identify watershed characteristics and activities that may adversely affect the source water quality;
3. Monitor the occurrences of activities that may adversely affect source water quality; and
4. Must demonstrate the ability to control all human activities within the watershed.

In addition there are specific water quality parameters that must be met to continue filtration avoidance. To meet the requirements listed above, water suppliers typically utilize the following best available technologies identified by the USEPA:[32]

1. Land acquisition;
2. Agricultural and forest land management practices through the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS);
3. Wastewater management of onsite, decentralized/cluster, and community treatment systems;
4. Institution of construction codes and inspection;

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[31]*U.S. Environmental Protection Agency,* 40 CFR Ch. 1 (7-1-02 Edition).

[32]Ibid.

5. Shoreline development codes; and

6. Activity regulations for users of the waterbody and the watershed.

Bodies of water in southeastern Wisconsin are typically not of sufficient quality to allow for filtration avoidance to be an option, and—given the initiation of the recently USEPA-approved disinfection byproducts rules—an exception would be highly unlikely. Filtration avoidance is not currently permitted under Wisconsin Department of Natural Resources (WDNR) regulations. Even though filtration is required, the protection of source water from contamination should be an important component of any comprehensive water supply plan in order to minimize treatment requirements and the risk to public health.

Costs
The costs of filtration avoidance are significant. Purchasing land surrounding water sources is costly and often not politically possible within a community. The ongoing costs of technical and security personnel to control human impacts on water sources would be very high. As noted earlier, several large-sized cities, such as New York and Boston, have determined that the cost of treatment facilities outweighs the cost of filtration avoidance. The systems serving such cities, however, typically have well established source water protection programs in place.

DISINFECTION

Introduction
Water treatment plant operators have practiced disinfection—the killing or inactivation of pathogenic organisms—since the early 1900s. In the United States the disinfectant of choice has been chlorine, whereas systems in Europe have most commonly utilized ozone.[33] While chlorination of drinking water supplies has come under scrutiny in recent years, few would argue that disinfection using chlorine has not significantly reduced the evidence of waterborne diseases in the United States. Methods of disinfection include:

- Chlorine;
- Chlorine dioxide;
- Chloramines;
- Ozone;
- Ultraviolet light; and
- Filtration.

All of these methods are in common use in the United States, with chlorination being the more common method.

Process Description
Chlorination
Chlorine can be added to water treatment systems as pure chlorine gas, as liquid sodium hypochlorite, or as a powdered calcium hypochlorite. While the greatest efficiency is gained by using gaseous chlorine, health and safety factors associated with handling gaseous chlorine have caused many water treatment facilities to move to other disinfection processes. One distinct advantage of using chlorine—as opposed to nonchlorine-based disinfection processes—is that a residual concentration can be maintained and measured throughout the distribution system. Maintaining the residual increases the confidence of the efficiency of the disinfection by

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[33]*American Water Works Association,* Water Quality and Treatment, A Handbook of Community Water Supplies, Fourth Edition*, Copyright 1990, by McGraw-Hill, Inc., New York, New York, p. 880.*

providing for disinfection within the distribution network. The efficiency of disinfection can be accomplished either by measuring the inactivation of organisms, such as *Cryptosporidium* or fecal coliforms, or by measuring the chlorine residual in the water. The USEPA surface water treatment regulations require use of both measurements to assure continual disinfection. There is a great deal of concern surrounding disinfection byproducts. The possibility exists that these byproducts may be carcinogens. The USEPA has promulgated a disinfection byproducts rule to address this issue.

Chlorine Dioxide

Chlorine dioxide appears to form disinfection byproducts that are less likely to be carcinogens in drinking water and, therefore, has gained in interest as a disinfectant in recent years. Chlorine dioxide cannot be stored or transported because it is unstable and must be produced onsite. It is produced when chlorine—either in gaseous or in solution form—is passed through sodium chlorite. While chlorine dioxide is beneficial because it lessens the potential long-term adverse health effect of disinfection byproducts, the safety hazards entailed in handling chlorine are not eliminated. However, elevated levels of chlorine or chlorine byproducts are acute contaminants.

Chloramination

Chloramination is a process that also reduces the amount and, most importantly, type of disinfection byproducts formed in drinking water. This process is not typically effective as a primary disinfecting process, but is effective as a secondary disinfection process. By injecting ammonia into water at approximately the same time as chlorine, chloramines are formed which are very effective at disinfection in drinking water. Similar to the case with chlorine dioxide addition, the disinfection byproduct problem is abated to some degree, but the safety issues of dealing with chlorine are still a concern. In addition, ammonia storage and additional equipment must be located onsite, and these constitute an added safety concern.

Ozonation

The disinfection effects of adding ozone (O_3) to water have been known since approximately the same time as chlorine (the early 1900s). In central and eastern Europe ozone became the preferred method of disinfection, while in most of the rest of the world chlorination became the most common method used.[34] Unlike chlorine, which must be manufactured offsite and transported to the site to be used, ozone is typically generated onsite. This is done by passing air—or occasionally oxygen—through an electrical field that converts the oxygen (O_2) in the air to O_3. Ozone appears to form fewer and less detrimental disinfection byproducts than chlorine-based disinfection. Ozone also oxidizes other contaminants in the water, making them easier to remove. A disadvantage of ozone is that it reverts to oxygen (O_2) shortly after leaving the ozone generator. Given this fact, ozone residual for further disinfection and measurement of disinfection efficiency cannot be maintained. In addition, the off-gas from an ozone contactor must be controlled to assure that relatively high concentrations of ozone are not released to the atmosphere. This is typically done by reinjecting the off-gas into the water stream, and/or by thermal destruction. In addition, if air is used to produce ozone, the water and nitrogen gas in the air can produce unwanted compounds—such as nitric acid—that must be controlled.

Disinfection with Ultraviolet Light

When pathogens in water are exposed to light of the wavelength in the range of 100 nanometers (nm) to 300 nm—within the range commonly known as the ultraviolet range—there are significant changes in the deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) of living organisms, and those organisms are rendered unable to reproduce and in many cases die. Low-pressure mercury lights which emit light in the wavelength of approximately 254 nm have been used extensively over the last decade to disinfect water and, to a greater extent, wastewater. Recent advancements in medium-pressure, high-intensity lamps allow production of ultraviolet light in a more varied range of wavelengths, with an associated increase in the effectiveness of the light to render

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[34] *UNEP International Environmental Technology Centre,* Source Book of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean*, 1997.*

potential pathogens harmless.[35] The largest single advantage of disinfection with ultraviolet light is that there are no disinfection byproducts formed during the disinfection process. The major disadvantage is that, like ozone, there is no residual in the water exiting an ultraviolet disinfection unit. Ultraviolet light is easily inhibited when passing through water and therefore the turbidity of water to be disinfected must be low.

Filtration

Filtration of drinking water supplies removes significant quantities of pathogenic organisms. While not all pathogens can be removed through filtration, the amount removed is considered in the design of water treatment facilities. As described later in this chapter, the multi-barrier-toolbox approach assigns credits for various filtration processes in relation to disinfection.

Multi-Barrier Approach

The need to find methods that provide effective disinfection with little or no disinfection byproduct production has led to the use of the term "multi-barrier" disinfection. The desirable characteristics of disinfection methods include:

- Inactivation of pathogenic organisms;
- Reduction in disinfection byproducts; and
- Maintenance of a residual in the distribution network.

In order to meet these characteristics, treatment trains have been developed that improve disinfection in multiple steps of water treatment. For example, ozone may be added to perform preliminary disinfection and oxidize organic materials that are disinfection byproduct precursors for removal in sand filters, followed by chlorine addition immediately before the distribution network so that a disinfectant residual may be maintained. Another common train for the disinfection of sand filtered effluent is to use ultraviolet light, followed by the addition of chlorine to maintain a residual. Not only does a multi-barrier approach allow several contaminants to be removed, but it will also increase the total number of pathogens removed, which will reduce the possibility of pathogen ingestion by water users. Multi-barrier techniques may be expected to become more prevalent in the future and will need to be matched to source water quality to effectively meet water treatment goals.[36]

Cost

As with all water treatment technologies, the cost of disinfecting water is highly dependent upon source water quality. Estimating the costs entailed is complex when the need to reduce disinfection byproducts is considered. In adjusting the USEPA 1979 costs for chlorine disinfection construction and operation and maintenance using the USBOR spreadsheet, costs are adjusted not only to current indices for construction and labor, but for the current cost of chlorine as well. Construction costs, when adjusted to December 2005 dollars, are estimated at $0.03 per gpd capacity. This includes only a minimal amount for ancillary costs. It is, therefore, recommended that $0.04 per gpd capacity be used for planning purposes. Operation and maintenance costs are estimated at $30 per MG treated. Both of these costs are based on a 1.0 mgd facility and are generally applicable to larger facilities.

Chloramination adds a second chemical feed system—in addition to the chlorination feed system—to feed ammonia into the flow stream. Doing so more than doubles the costs because of the more complex feed mechanism and the higher expense associated with the use of ammonia. The 1979 USEPA costs adjusted using the USBOR spreadsheet indicate a cost of construction of $0.07 per gpd capacity and operation and maintenance

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[35] *Water Environment Research Foundation,* Comparison of UV Irradiation to Chlorination: Guidance for Achieving Optimal UV Performance Disinfection*, 1995.*

[36] *John C. Crittenden, R. Trussell, S.W. Hand, Kerry Howe, and G. Tchobanoglous,* Water Treatment: Principles and Design, Second Edition*, (MWH, John Wiley & Sons, Inc.) 2005, pp. 227-228.*

costs at $90 per MG treated for a 1.0 mgd facility. It is recommended that for planning purposes a construction cost of $0.09 per gpd capacity, and an operation and maintenance cost of $100 per MG treated, be utilized for facilities over 1.0 mgd.

Ozonation costs are commonly quoted in the literature and in marketing materials as being four to eight times higher than chlorination costs. The USEPA construction costs, when adjusted using the USBOR spreadsheet, indicate significantly higher costs than given in the literature, at $0.60 per gpd capacity. Operation and maintenance costs are $30 per MG treated. The Milwaukee waterworks added ozonation to their treatment facilities in 1998 at a cost of approximately $0.20 per gpd capacity (December 2005 value). Given the limited information concerning the inclusions in Milwaukee's data and the scale of the project, the aforementioned cost data are not appropriate for use in systemwide planning purposes. The Green Bay Water Utility also added ozonation to their treatment facilities in 1998 at a cost of $0.85 per gpd capacity, including engineering and contingencies. Considering the difference in construction cost between the USEPA estimated costs and the Green Bay Water Utility data, it is recommended that for planning purposes a construction cost of $0.60 per gpd capacity be used. It is also recommended that a cost of $30 per MG treated to estimate operation and maintenance costs for ozonation facilities for planning purposes.

Ultraviolet light disinfection was not included in the USEPA 1979 cost study. Ultraviolet light system technology is rapidly developing because of the low amount of disinfection byproducts formed in its use. Cost estimates obtained in early 2006 for flows between 1.0 and 1.5 mgd indicated installed costs between $0.20 per gpd capacity and $0.86 per gpd capacity. The high estimate appears to be aberrant in its facility layout and, therefore, an installed cost of $0.40 per gpd capacity is recommended for use in planning. Operation and maintenance costs are primarily driven by electrical power costs, bulb replacement frequency and cost, and labor associated with bulb maintenance, including cleaning and replacement. Figures presented in a 1995 Water Environment Research Foundation Report, adjusted to December 2005 values, ranged from $38 per MG treated to $207 per MG treated dependent upon facility layout and bulb configuration. One manufacturer estimates operation and maintenance costs at $188 per MG treated in early 2006. It is recommended to use a cost of $200 per MG treated for planning purposes.

MISCELLANEOUS CHEMICAL TREATMENT

Process Description

Often chemicals other than those previously described need to be added to drinking water systems. Such additives typically are driven by unique characteristics of source water quality, or by unique characteristics desired in the treated water. Examples include items such as corrosive sources of water that need to be treated to prevent lead and copper leaching from distribution system piping, or fluoridation of water for dental health reasons based on community decisions to do so.

Fluoridation

Fluoridation of drinking water is an option that can be undertaken to reduce the incidence of dental cavities. The use of fluoridation for this purpose is controversial, with valid questions being raised regarding the cost-effectiveness of the provision of fluoridation through the water supply, as opposed to the provision of fluoridation through individual dental care. In addition, the availability of fluoride in products, such as toothpaste and certain food products, make it difficult to limit the amounts of fluoride ingested to amounts considered healthy, particularly in children. Another consideration in evaluating the option of the provision of fluoridation through the water supply is social in nature, and relates to the concern that some residents may not have access to individual dental care and other sources of fluoride due to economic status. With regard to the option of providing fluoridation of water supplies, it should be noted that the American Dental Association, the American Medical Association, the Centers for Disease Control and Prevention, the U.S. Public Health Service, and the World Health Organization recognize the public health benefits of drinking water fluoridation.

Chemicals added are sodium fluoride, sodium silicofluoride, or fluosilicic acid, formally referred as hydro-fluorosilic acid. Of the chemicals available, fluosilicic acid is most commonly used within southeastern

Wisconsin. Fluosilicic acid is provided in liquid form, and a chemical feed pump delivers the acid into the water prior to distribution at a dosage not to exceed 1.2 parts per million (ppm) of fluoride ion.

Corrosion Inhibitors

Corrosion control programs are often put into place to control lead and/or copper in drinking water. These metals most commonly find their way into drinking water after leaching from distribution systems and building plumbing piping materials. Through corrosion control, excessive lead or copper levels in drinking water systems can typically be controlled. Chemicals added are typically aimed at pH and/or alkalinity adjustment, or consist of the addition of silicate or phosphate inhibitors. While the chemical methods differ significantly, the end result is the deposition of a thin, noncorrosive layer on piping materials that prevents lead and/or copper leaching into the water. The most common chemicals being added in southeastern Wisconsin are silicate-based or phosphate-based inhibitors. These chemicals are provided in liquid form, and a chemical feed pump is used to meter their flow into finished water.

Cost

Construction costs for chemical addition are typically low, with some variability due to the specific storage needs of some chemicals. Estimated construction costs based on 1979 USEPA costs adjusted to December 2005 values with the USBOR spreadsheet are typically under $0.10 per gpd design capacity for most chemicals. This value includes a rather generous allotment for building construction and site work, which is sometimes unnecessary. For planning purposes, it is recommended that $0.13 per gpd capacity be utilized to estimate costs of constructing chemical feed systems not specifically listed elsewhere.

Operating and maintenance costs are driven by chemical costs and labor associated with maintaining chemical feed equipment. Both of these items are dependent upon the chemicals to be fed and, therefore, operation and maintenance costs must be determined for specific situations.

TREATED WATER PUMPING

Process Description

Ultimately, the treated surface water must be pumped into the distribution system for delivery to users. Typically in southeastern Wisconsin, the distribution system contains water towers that provide storage and pressure throughout the system. In some areas water is pumped into transmission mains to relatively distant areas where lift pumps provide the pressure necessary for distribution and use. The type of pump utilized will be dependent on the flow and pressure needed in a given situation.

Costs

The costs of treated water pumping facilities will generally be similar to those of raw water pumping. The operation and maintenance costs are linked most closely to the discharge pressure—water storage elevation—of the pump. These costs are highly variable and are situation-specific.

EMERGING AND UNREGULATED CONTAMINANTS

Introduction

Historically, attention to chemical contaminants related to water supply has been focused on conventional priority contaminants. It is important to recognize that these chemicals are not the only ones entering the surface waters and groundwater systems. Recent attention has been focused on several groups of chemicals that have been detected in surface water and groundwater and that may pose risks to human health and to aquatic life. Examples of these include pharmaceuticals and personal care products and endocrine disrupting chemicals. In addition to these chemicals, there are a number of contaminants that are currently not subject to any proposed or promulgated Federal or State drinking water regulations; are known or anticipated to occur in public drinking water systems; and which may require future regulation. As of May 2006, there were nine microbial and 42 chemical contaminants on the U.S. Environmental Protection Agency listing of drinking water contaminants that are candidates for regulation.

Pharmaceuticals and personal care products and endocrine disrupting chemicals may be expected to become of increasing concern as the ability to measure these compounds in water improves. Pharmaceuticals and personal care products consist of both prescription and nonprescription medicines that are discharged to the environment through use in human or veterinary medicine. Pharmaceuticals may be discharged through human or animal excreta, disposal of unused or outdated medicines, or directly from washing of the skin after use. Endocrine disrupting chemicals are those that affect the hormonal composition of humans or animals when exposure occurs. These chemicals include natural and synthetic hormones, pesticides, certain compounds used in the plastics industry, and other industrial byproducts. The endocrine disrupting chemicals may be a chemical directly released into the environment, a biological metabolite discharged from human or animal activity, or a chemical that is changed after environmental exposure. The most common link between all these chemicals is their link to human activity, either through direct discharge from humans or through intentional or unintentional discharge to the environment. It is important to recognize that municipal and onsite wastewater treatment and disposal systems are not specifically designed to remove these chemicals and the removal efficiencies are poorly understood. In addition, the fate of the chemicals in the environment is also not well understood.

The detection limits for pharmaceuticals and personal care products and endocrine disrupting chemicals in water are being lowered as advancements are made in analytical techniques. Limited ability to measure low concentrations in the past has resulted in minimal information on the effects of these chemicals in the environment on animals and humans. Today it is known that these chemicals are present in the environment and have been detected in drinking water.

Pharmaceuticals and personal care products and endocrine disrupting chemicals enter the drinking water source through a number of routes. Given the link to human activities, the most prevalent and well-documented route is through discharges of municipal and onsite wastewater treatment facilities. Other sources include both agricultural and urban runoff, as well as industrial discharges. Due to the nature of the discharges as they are currently understood, surface water sources are more susceptible to contamination from these chemicals than groundwater sources. However, the linkage of these chemicals through onsite wastewater disposal systems and the groundwater has also been documented.

Pharmaceuticals and Personal Care Products and
Endocrine Disrupting Chemicals Removal from Water

Given the currently limited understanding of the magnitude of the pharmaceuticals, personal care products, and endocrine disrupting chemicals problem in water, there is no single technology readily available to address the problem. Chemicals in this group are varied and attendant specific treatment technologies may be as varied. As research progresses the elimination of the discharge of these chemicals into the environment appears to be the best method to prevent the presence of the substances in drinking water. Treatment of these chemicals when present in higher concentrations—as for example, in wastewater discharges—may be more effective than doing so at the drinking water source. Treatment prior to discharge into the environment also limits environmental exposure of aquatic and other animals.[37]

Most existing surface water treatment technologies remove some level of pharmaceuticals, personal care products, and endocrine disrupting chemicals. Coagulation and flocculation are not particularly effective on most of the substances concerned and therefore, sedimentation and filtration are typically not very effective in their removal. The chemicals involved are typically synthetic organic compounds, and the treatments for such compounds set forth in Chapter IV under the groundwater treatment technologies may be effective. Granular activated carbon can be effective in the removal of these chemicals, but release of the chemicals in large concentrations from the

[37] *USGS Fact Sheet FS-027-02,* Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, *June 2002.*

carbon appears to occur if regeneration of the carbon is not performed in a timely fashion.[38] Oxidation appears to be very effective in deactivating the chemicals involved, although little is, as yet, known about the effects of the compounds formed. Ozone appears to be the most effective oxidant for these contaminants. Chlorine and its derivatives are relatively ineffective, and ultraviolet irradiation has almost no effect. Oxidation appears to improve the removal of pharmaceuticals, personal care products, and endocrine disrupting chemicals by sand filtration. Reverse osmosis is effective at removing these chemicals directly, but its use is costly. Other membrane processes appear to be effective after oxidation of the chemicals concerned in the source water. The treatment technology selected will need to be specific for the compounds existing in the source water, and multiple treatment technologies may be needed, depending upon the specific chemicals to be removed.

DESALINATION

The vast quantity of seawater found on earth makes it a natural source to be considered for seashore communities, as well as for seagoing vessels and sea-based operations. Original desalination processes utilized the evaporation and condensation of water—either through heating of water or through lowering of vapor pressure—to extract fresh water from seawater. Current technology typically utilized to produce drinking water from seawater utilizes the membrane processes of electrodialysis-electrodialysis reversal, or reverse osmosis. While there is no necessity to produce drinking water from seawater in southeastern Wisconsin, the shortage of fresh water in much of the world located near seawater sources will have an impact on treatment systems in this geographic area. As technologies are refined to remove salt from water, those technologies may be useful for removal of similar contaminants in surface waters, such as those present in southeastern Wisconsin. As improved removal processes are realized in other parts of the world, it may be possible to utilize those processes in facilities locally.

PACKAGED/MODULAR TREATMENT SYSTEMS

Many technology vendors have assembled their technology into pre-engineered systems capable of treating specific flow ranges. Generally, such systems are utilized for smaller water treatment facilities with flows of up to 500,000 gallons per day. Such systems typically use technologies described elsewhere within this report to perform treatment, having those technologies assembled into a unit or module that can be delivered to the site, ready to be plumbed into the system. Such systems are not described separately herein; instead, description of specific technologies is left to other sections of this report.

AUXILIARY FACILITIES AND REQUIREMENTS

Surface water treatment facilities include a number of auxiliary facilities and required programs, such as system security, laboratory facilities, and maintenance facilities. The costs for these facilities and requirements are recommended to be covered by adding a 20 percent factor to the capital cost and operation and maintenance costs for an entire new treatment plant. For treatment unit costs for additions to existing plants, a 10 percent factor is recommended to be used.

Water System Security

After the terrorist attacks on New York and Washington, D.C., of September 11th, 2001, the Public Health Security and Bioterrorism Preparedness and Response Act—Public Law 107-188—was adopted. Title IV of the act requires that all drinking water treatment facilities serving a population of more than 3,300 persons prepare an emergency response plan based upon a vulnerability assessment. While it is not the intent of this report to identify all of the steps required under the Act, it is important to note that water supply is a critical component of the Nation's infrastructure and that it must be maintained. An essential part of the maintenance of this infrastructure is emergency planning. Aspects of the emergency planning process may impact treatment processes selected on any local system. The basis for all emergency planning is an accurate vulnerability assessment done on the entire

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[38] *American Chemical Society, Environmental Science & Technology Online News, Keeping Drugs Out of Drinking Water, 2006.*

water supply and delivery system. Highly vulnerable parts of systems may require redundant systems that may increase construction and/or operation and maintenance costs significantly.

Laboratory Facilities
Surface water treatment facilities require extensive water quality monitoring for compliance with regulatory requirements, as well as process control. Laboratories must be provided in new facilities and, in all likelihood, will need to be expanded in existing facilities to be upgraded. Laboratory space within facilities can be expensive because of the special utility services, such as exhaust, needed for some testing. Costs for laboratory facilities is not necessarily proportional to the amount of water treated and may require careful consideration when planning facilities.

Maintenance Facilities
Most water treatment facilities perform many of the maintenance activities on the operations within house as opposed to contracting out maintenance operations. Given this fact, maintenance facilities must contain sufficient space and tooling to repair process equipment. In addition, a sufficient parts inventory for specialized equipment must be maintained to assure that effective repairs can be made in a timely manner. Given the size of most process equipment, large spaces with heavy lifting equipment are generally needed. While costs of such space can be significantly lower than other more specialized areas, the cost of constructing such spaces must be considered.

Online Monitoring and Supervisory Control and Data Acquisition Systems
Improvements in technology for online monitoring of water quality along with computer networking and software systems have provided for significantly improved efficiencies in water treatment. Such systems allow for nearly real-time adjustment of operational parameters such as chemical feed rates, backwash or cleaning frequencies, pumping rates, and disinfection control. Data from online monitors can be used by computerized controls to automatically adjust operational parameters or notify operators of anomalies in water quality. Online monitoring and supervisory control and data acquisition (SCADA) systems are often designed as part of the treatment system when installed, but must be considered separately, as well to assure integration with other pertinent systems, particularly remote systems.

Miscellaneous Operations, Controls, and Office Space
Sufficient space must be provided within a treatment facility for offices, conference rooms, control rooms, rest rooms, and shower facilities. While such spaces are intuitively required, they are noted specifically for planning purposes as well.

SUMMARY

The use of surface water as the source of drinking water presents unique challenges from technological and regulatory points of view. When surface water is utilized as the source of supply, the USEPA surface water treatment regulations require filtration prior to use in most areas, including southeastern Wisconsin. Newly instituted regulations to control disinfection byproducts place a particularly heavy burden on technologies to treat surface source waters. Several surface water source treatment facilities in southeastern Wisconsin are at the forefront of the technologies that will be used in the future. These include those serving the largest local communities—the cities of Milwaukee, Racine, and Kenosha.

Multi-Barrier/Toolbox Approach
The U.S. Environmental Protection Agency promulgated the Long-Term 2 Enhanced Surface Water Treatment Rule in early 2006 to reduce illness associated with *Cryptosporidium* and other disease–causing microorganisms in drinking water. In conjunction with the publication of this regulation, the Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual was published in draft form. This guidance manual promotes a multi-barrier approach to *Cryptosporidium* removal based upon the quality of the source water. The source water quality places the water treatment facility into a category, or "bin," numbered 1-4. Bin 1 requires no further treatment, while Bins 2, 3 and 4 require treatment to reduce *Cryptosporidium* levels by 4.0, 5.0, or 5.5 log levels, respectively. Traditional treatment technologies are assigned an amount of reduction for each bin. For instance,

direct filtration is allotted a log reduction of 2.5 for Bin 4. Since Bin 4 water requires a reduction of 5.5 log for *Cryptosporidium* oocyst removal, a treatment facility using direct filtration for treatment of Bin 4 water would need to add a treatment unit or units proven to reduce *Cryptosporidium* oocysts by 3-log levels. This 3-log reduction could be accomplished by adding traditional treatment trains—which have log removal credits assigned—or by adding alternative filtration technologies—which must be tested by the technology vendor and verified by the State for their log removal credits. Treatment facilities with source water quality in Bins 3 or 4 must use at least one of several listed technologies to meet 1.0 log of their credits. Source water protection programs provide for 0.5 log reduction of oocysts in the regulations.

Given the above guidelines that are supported by the regulations of the long-term 2 enhanced surface water treatment rule, it appears that this "toolbox" approach will be the method used to select surface water treatment technologies in the future. Lake Michigan water could be expected to be of quality that would place it in Bin 4, which requires that treatment reduce *Cryptosporidium* oocyst by 5.5 log levels. To attain this level of reduction it is expected that membrane filtration will be required in the future. Therefore, the typical treatment train provided below includes membrane filtration.

Typical Treatment Train

In order to meet the USEPA surface water treatment regulations and the USEPA disinfection byproduct regulations, both of which have been recently enacted, any newly constructed treatment facility will probably have to utilize several new technologies that would not have been considered a decade ago.

Treatment trains may include methods to oxidize organics—disinfection byproduct precursors—in raw water prior to filtration. Rapid sand filtration will be followed by membrane filtration if the rapid sand filtration is currently in place or may be replaced by membrane filtration if a completely new facility is being considered. Disinfection may be accomplished by ozone addition or ultraviolet light, followed by chlorine addition for residual control. A typical treatment train for a surface water treatment facility is shown in Figure 8.

Costs

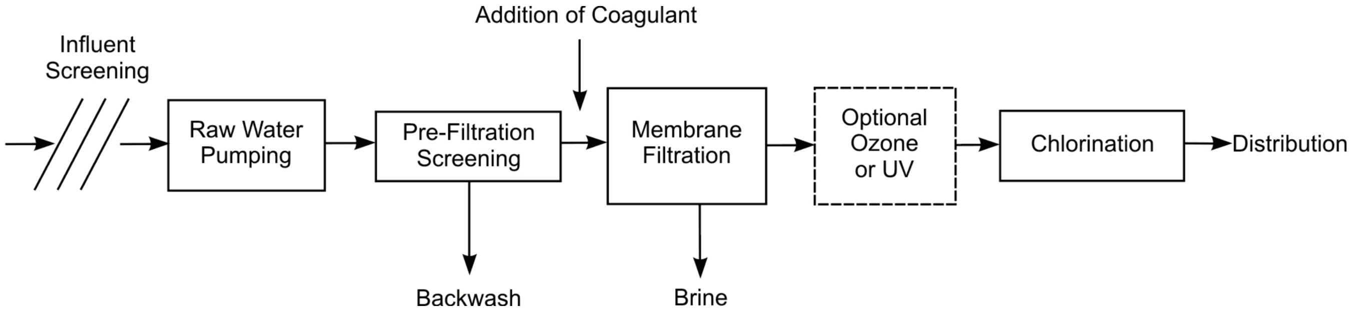
The cost of surface water treatment facilities is highly variable and dependent upon such factors as source water quality, size of treatment facility, and treatment processes selected. Table 4 summarizes the unit process construction and operation and maintenance costs presented elsewhere in this chapter.

Table 5 identifies the capital costs for constructing a facility comprised of the identified typical treatment train at various flow rates. The cost of constructing the treatment train identified varies between $3.61 per gpd capacity for a 100 mgd facility and $7.62 per gpd capacity for a 0.5 mgd facility.

Operation and maintenance costs are reported to, and summarized by, the Wisconsin Public Service Commission (PSC). These costs varied from $302 per MG delivered to $2,884 per MG delivered, with an average of $1,255 per MG delivered for the eight surface water treatment utilities in the Southeastern Wisconsin Region in 2004. The PSC classifies expenses into many subcategories, but the subcategories are not based upon treatment technologies. According to information available from the Wisconsin Department of Natural Resources, all facilities have coagulation-flocculation facilities followed by filtration. There appears to be no correlation between operation and maintenance costs and the number of treatment processes involved. For planning purposes, the value of $1,500 per MG treated is suggested for the treatment train identified.

Figure 8

TYPICAL SURFACE WATER TREATMENT TRAIN



Source: Ruekert & Mielke, Inc., and SEWRPC.

Table 4

UNIT PROCESS COSTS FOR TYPICAL WATER TREATMENT[a]

Units	Unit Prices (dollars per gpd capacity)		Unit Prices (dollars per MG treated)	
	Calculated Construction Costs	Recommended Capital Cost for Planning[b]	Calculated Operation and Maintenance Cost	Recommended Operation and Maintenance Cost for Planning
Intake	$0.23	$0.25	N/A	N/A
Raw Water Pumping	0.70	0.70	$ 600	$ 600
Coagulation/Flocculation/Sedimentation	0.49	0.70	90-180	150
Gravity Filtration (nonGAC)	0.43	0.60	80	80
Micro Screens	N/A	0.40	N/A	60
Granular Activated Carbon	4.10	5.50	1,000	1,000
Pressure Filter (skid pack)[c]	0.80	1.50	265	300
Membrane Filtration[d]	2.00	2.60	400	300
Chlorination	0.03	0.04	30	30
Chloramination	0.09	0.09	90	100
Ozonation	0.36-0.85	0.60	30	30
Ultraviolet Light	0.20-0.86	0.40	38-207	200
Chemical Addition	<0.10	0.13	N/A	N/A

[a]Based on a 1.0 mgd facility unless otherwise noted.

[b]Including administration, engineering, legal, and contingency.

[c]Based on 500,000 gpd facility.

[d]Based on a 5.0 mgd facility.

Source: Ruekert & Mielke, Inc.

Table 5

CAPITAL COSTS FOR VARIOUS SIZE TREATMENT FACILITIES

Unit Process	Estimated Capital Costs (dollars per gpd capacity)			
	0.5 mgd	1.0 mgd	10 mgd	100 mgd
Intake	$0.35	$0.25	$0.25	$0.20
Raw Water Pumping	0.80	0.70	0.60	0.55
Micro Screen Pre-Filtration	0.60	0.40	0.30	0.30
Membrane Filtration	5.00	4.00	2.00	2.00
Chlorination	0.07	0.04	0.01	0.01
Distribution Pumping	0.80	0.70	0.60	0.55
Total	$7.62	$6.09	$3.76	$3.61

Source: Ruekert & Mielke, Inc.

Chapter IV

GROUNDWATER WITHDRAWAL AND TREATMENT TECHNOLOGIES

INTRODUCTION

Existing State and Federal regulations governing groundwater treatment and delivery are organized primarily by contaminants to be treated as opposed to the level of treatment required as is done with surface water treatment. Surface water treatment technologies were organized by components generally used in treatment trains designed to treat Lake Michigan water for a variety of constituents and purposes. Groundwater treatment technologies are typically more directly related to specific contaminants or problem conditions. Therefore, this chapter initially presents a description of wells and well pumping, and then presents the major contaminants or problem conditions typically considered with respect to groundwater sources. For each contaminant, a review is presented of the technologies that are commonly used to remove those contaminants or treat the problem conditions. Since there is a great deal of commonality in the technologies used for contaminant removal, the technologies and their costs are described after all contaminants, problem conditions, and viable methods of removal are described.

GROUNDWATER AND SURFACE WATER TREATMENT TECHNOLOGY APPLICABILITY

There are a number of treatment technologies that are applicable, or partially applicable, to both surface water and groundwater processing. Chapter III of this report included descriptions and costs of surface water treatment technologies. Those treatment technologies included in Chapter III which are also considered applicable, or potentially applicable, to groundwater systems include the following:

- Coagulation and Filtration;
- Gravity Filtration;
- Pressure Filtration;
- Membrane Filtration;
- Manganese Oxide (green sand) Filtration;
- Granular Activated Carbon;
- Activated Alumina;

- Reverse Osmosis;
- Disinfection;
- Desalination;
- Fluoridation; and
- Corrosion Inhibition.

In addition to the treatment technologies noted above, Chapter III also presents information on finished water pumping systems that is also applicable to groundwater-supplied systems. For purposes of this chapter on groundwater treatment technologies, the process descriptions and costs for the abovenoted technologies are referenced to those given in Chapter III, where applicable. In addition, Chapter III includes a section on miscellaneous surface water supply systems which are also applicable to groundwater supply systems, including laboratory facilities, security, monitoring, and maintenance and operations facilities.

COST ESTIMATION DATA SOURCES

Cost data for groundwater withdrawal and treatment technologies were obtained from multiple sources. These sources included: AWWA Research Foundation report[1] on arsenic removal technologies; the 1979 U.S. Environmental Protection Agency (USEPA) data report[2] described in Chapter III; Ruekert & Mielke, Inc., project file data; quotations from equipment suppliers; and local municipalities. These data were updated to December 2005 costs using the *Engineering News Record* cost indices. As available, local project data from water utilities in the Region were used as a second source for data obtained from the above sources, with adjustments being made to reflect the localized costs, where appropriate. Cost curves developed based upon those sources are included in Appendix A.

GROUNDWATER WELLS AND PUMPING

Introduction

The majority of the municipal and other public water supply systems in the Region use groundwater as the source of supply for the system. Water is typically pumped from wells using turbine pumps. These pumps provide water delivery to the system, pump water through treatment processes, transmit water through transmission and distribution mains and through building connections, provide system pressure, and deliver water to storage structures. Generally, each well must have its own pump. The groundwater is obtained from wells completed in three distinct, but interrelated, water bearing geologic formations or aquifers. A brief description of the groundwater geology of the area is provided below.

Process Description

Water Well Geology

The first of the three aquifers consists of the unconsolidated sand and gravel layers that lie on top of the bedrock. The extent and thickness of these layers do not provide significant groundwater yields in all areas. Sand and gravel deposits suitable for use as aquifers for municipal wells are difficult to locate. The thickness of the underlying unconsolidated material varies through the area. Wells finished in the sand and gravel formations have a wide range of capacity, from 10 to 2,000 gallons per minute or more. Since this aquifer is closest to the ground

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[1]*Gary Amy, Hsiao-Wen Chen, Aleksandra Drizo, Urs vo,* Adsorbent Treatment Technologies for Arsenic Removal*, ISBN I-58321-399-6, AWWA Research Foundation, 2005.*

[2]*Robert C. Cumerman, Russell L. Culp, and Sigurd P. Hensen,* Estimating Water Treatment Costs - Volume 2 - Cost Curves Applicable to 1 to 200 MGD Treatment Plants, *USEPA, Cincinnati, OH, August 1979, pp. 1-5.*

surface, it is most susceptible to contamination from surface sources. Proper well siting and construction and wellhead protection can, however, minimize the potential for contamination.

The next lowest aquifer consists of dolomitic bedrock known locally as the "Silurian dolomite." The Silurian dolomite is the aquifer from which many domestic wells in the area obtain water. This aquifer is also used as a source for some municipal wells in portions of the area. The Silurian dolomite contains numerous fractures, voids, and bedding plane enlargements that act as open conduits for groundwater migration. Groundwater can flow through these open conduits rapidly, both horizontally and vertically, without any significant filtration. As a result, any contamination that enters the aquifer can be transported hundreds to thousands of feet without attenuation. The distribution of the fractures and voids is highly variable, making it difficult to predict the primary pathways of groundwater migration. When viewed on a large-scale, the general pattern of groundwater flow resembles the typical uniform flow pattern of uniform porous aquifers. On a smaller scale, however, discrete flow paths exist which cause groundwater to flow at higher rates and in different directions. Therefore, while it is possible to describe the average groundwater flow pattern in this aquifer on a regional basis, it is usually not possible to describe the actual groundwater flow pattern to a particular well.

The next lowest aquifer is the sandstone aquifer. The sandstone aquifer of southeastern Wisconsin consists of interbedded sandstone, dolomite and shale units of Ordovician to Cambrian age. Over much of the Region, the aquifer is separated from the two shallower aquifers previously described by a regional aquitard that consists of the Maquoketa formation and the underlying Galena-Platteville dolomite. This confining unit restricts the vertical migration of water between the upper aquifers and the sandstone aquifer. The Maquoketa formation generally consists of an interbedded dolomite and shale unit. The Wisconsin Department of Natural Resources (WDNR) is concerned about contaminant transport from the upper dolomite to the sandstone aquifer. For this reason, it does not allow new wells to be drilled that are open to both aquifers. The Maquoketa aquitard pinches out approximately ten miles west of the City of Waukesha. The area where the confining unit is absent comprises the major recharge area for the sandstone aquifer. Precambrian granite and quartzite deposits lie immediately beneath the sandstone aquifer. These units are essentially impermeable and serve as the base of the sandstone aquifer.

The sandstone aquifer is the primary source for industrial and municipal wells in most of eastern Wisconsin. Approximately 30 municipal water systems and 200 industries obtain at least some of their water from wells in the sandstone aquifer in southeastern Wisconsin. In 1995 the sandstone aquifer supplied approximately 95 percent of municipal pumpage in Waukesha County. With the exception of a well-documented zone of brackish water[3] located immediately adjacent to the Lake Michigan shoreline, the water in the aquifer has historically been fresh and suitable for most potable uses.

A large discontinuity, known as the Waukesha fault, traverses the City of Waukesha and extends tens of miles to the northeast and southwest. On the northwestern side of the fault, the Precambrian surface is within approximately 1,200 feet of the ground surface. On the southeastern side of the fault the total thickness of the aquifer is unknown, but the Precambrian surface is estimated to be at least 3,000 feet deep. No wells in Wisconsin are known to penetrate the full thickness of the aquifer on the down side of the Waukesha fault.

While the sandstone aquifer is the major source of groundwater for the region, it is not well understood. Most wells are drilled to a depth where adequate water quantity is obtained and terminated. As a result, few wells penetrate the full thickness of the aquifer, making the thickness of the aquifer poorly known in several areas. In some cases it is possible to estimate the elevation of the base of the aquifer by triangulation from surrounding wells. However, ridges of quartzite and mounds of granite are present that rise above the surrounding Precambrian surface. These features are poorly known or unmapped in many places and can cause the sandstone to be thinner than expected and the yield of a well to be less than projected.

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[3] *R.W. Ryling, "A Preliminary Study of the Distribution of Saline Water in the Bedrock Aquifers of Eastern Wisconsin," Wisconsin Geological and Natural History Survey Information Circular 5, 1961.*

Unexpected mounds on the Precambrian surface have resulted in sandstone wells terminating shallower than expected in at least two cases in Waukesha County over the last few years. In 1996 the Village of Pewaukee drilled a sandstone well to the top of granite. The depth to the granite was estimated at 1,200 feet based on surrounding well logs. Unfortunately, the well encountered an unmapped quartzite ridge at 790 feet. Due to the reduced thickness of the Mount Simon sandstone, the well only produces about 600 gpm instead of the project capacity of 1,000 to 1,200 gpm. In 1995, the Village of Delafield drilled a sandstone well. Quartzite was encountered at 1,225 feet instead of approximately 1,500 feet as projected from previously available regional data.

Well Fields

Most public water systems rely on more than one well to supply their needed quantity of water. When more than a single well serves a system, the group of wells can be termed a well field. In areas where geology permits such as where there is a highly permeable deposit of sand and gravel, multiple, closely spaced wells may comprise the well field. In a fracture dolomite aquifer, wells may be spaced randomly on separate fracture trends and the well field would reflect this random placement. In a confined aquifer, such as the sandstone in the eastern portion of the area, the well field generally has wells spaced about one-half mile apart to avoid mutual interference.

Typical High-Capacity Well Design and Construction

Well design and construction of water wells is largely dependent upon the aquifer used as a source of supply, the local geology, the well depth, and the hydraulic properties of the aquifer. Generally, wells finished in the sand and gravel aquifer will have a stainless steel screen installed in water bearing formations, and wells finished in rock (dolomite or sandstone) will have open holes.

A typical shallow sand and gravel well will be designed to include a smaller diameter test well (eight or 10 inches) and a larger final production well. The test well is a temporary well constructed to gain information on aquifer properties from geologic samples and test pumping. That information is then used to locate and size the final casing and screen for the production well. A slotted stainless steel screen is installed in geologically favorable areas of the well and a string of continuous steel casing pipe is welded above, and sometime below or between, screened intervals in the well. A gravel pack consisting of known size particles of silica-based rock, gravel, or sand may be placed in screened intervals of the well, or the well may be finished in the local geology and have a "natural pack." The well is typically grouted and developed using mechanical or chemical energy to increase the output of the well by creating free flow to the screened areas of the well.

Dolomite and sandstone wells are generally completed with open drill holes into the bedrock aquifer. A larger drill hole is constructed from the surface into competent rock in the aquifer and a casing is grouted in place. A lower drill hole is then constructed into the rock of the aquifer to either a predetermined depth or to the bottom of the aquifer. Multiple aquifer wells are not allowed in Wisconsin.

Typical Pumping Equipment

The size and configuration of water well pumping equipment can vary significantly with well capacity, depth, and water pumping level. Generally, the shallower the well and the lower the output of the well, the lower the required size of the pump and motor. If a well has a high capacity and is a deep sandstone well, required pump and motor sizes can be quite large. In southeastern Wisconsin, well pump sizes range from 100 GPM to over 2,000 GPM. Horsepower requirements can range from 10 Hp up to 800 Hp. The higher horsepower units require larger electric services and voltages. For pump setting depths of about 600 feet or less, vertical turbine lineshaft pumps are predominant. In deeper settings, submersible pumps and motors are sometimes installed due to well alignment, prelubrication, and other problems.

Costs

Costs for wells were derived from review of thirteen wells constructed over the last three years in southeastern Wisconsin, including two deep sandstone wells, two dolomite wells, and nine sand and gravel wells. Actual bids were reviewed and updated to December 2005 using ENR cost indices as previously described.

Costs for installation of pumps and construction of associated buildings are very similar to the costs discussed in Chapter III for water pumping. The operation and maintenance costs for pumping water are directly related to the flow and pressure needed to be delivered by the pumps. In the case of groundwater sources, the depth to water is an important factor in determining the pressure required to be delivered by the pump. Given this fact, operation and maintenance costs are related to the depth of the well concerned.

Well construction costs vary from about $60,000 for a shallow sand and gravel well 54 feet deep to $270,000 for a deep sandstone well about 1,200 feet deep, based upon recent bid data. The capital cost of a typical well pump station with only necessary appurtenances is expected to be $250,000 to $500,000. Cost curves developed utilizing these sources are included in Appendix A. Included are curves for well construction cost based upon well depth and operation and maintenance costs including replacement costs based upon well pumping levels.

CONVENTIONAL GROUNDWATER TREATMENT NEEDS

Groundwater is typically treated for a number of contaminants and to enhance its quality. The treatments used are intended to: remove hardness-causing minerals, such as calcium and magnesium; remove iron and manganese; and provide corrosion control.

The principle constituents of water that contribute to the property of hardness are calcium and magnesium. These constituents have no known health hazard effects on humans at the concentrations that occur naturally in groundwater. However, the water with a high hardness level can interfere in the many uses of water. While there is no Federal or State standard for hardness, a level of hardness in water of less than 100 milligrams per liter (mg/l) as calcium carbonate is generally not objectionable. Most of the groundwater in the Region exceeds this level. The main water quality problem caused by excessive hardness of water is formation of insoluble residues when the water comes in contact with soap or is heated.

Maximum concentrations of iron and manganese specified in the WDNR secondary drinking water standards are 0.30 mg/l and 0.05 mg/l, respectively. Neither constituent poses a health hazard at the concentrations that occur naturally in groundwater, but both can cause a variety of aesthetic problems, such as objectionable taste, staining of laundry and plumbing fixtures, and encrustation and clogging of well screens and distribution systems. An iron or manganese concentration greater than 200 micrograms per liter (μg/l) is objectionable for many industrial uses of water.

In order to treat groundwater to achieve the treatment objective noted above, the following processes are potentially applicable: phosphate sequestering, ion exchange, manganese oxide filtration, and iron pressure or gravity filtration. In addition, water users with groundwater as a source of supply incur water-softening costs that are not typically expected when using surface water as a source of supply.

ARSENIC TREATMENT

Introduction

Arsenic has become a contaminant of concern in recent years due to its linkages with human health issues. The potential health effects associated with long-term chronic exposure to arsenic in drinking water include the possible increase in the risks of certain types of cancer. In addition, arsenic has been reported to affect the vascular system in humans and has been associated with diabetes. The USEPA reduced the maximum contaminant level (MCL) standard for arsenic to 10 μg/l as of January 23, 2006.[4] According to the WDNR records, 265 of the 936 samples taken for arsenic testing over the six-year period from January 1, 2000 through December 31, 2005, by the 2031 public water supply systems located within the Southeastern Wisconsin Region

[4]*U.S. Environmental Protection Agency,* Arsenic and Clarifications to Compliance and New Source Monitoring Rule; A Quick Reference Guide*, 66FR 6976, January 2001.*

had arsenic contents of 50 percent or more of the MCL. One or more of these 265 samples were reported by 15 of the 50 water utilities in the Region using groundwater as a source of supply. Arsenic may be removed from water through a number of technologies:[5]

- Nontreatment Options;
- Adsorption;
- Ion Exchange;
- Coagulation and Filtration;
- Oxidation and Filtration;
- Electrodialysis Reversal;
- pH Adjustment (lime softening);
- Activated Alumina (see Chapter III);
- Reverse Osmosis (see Chapter III);
- Finding a New Water Source; and
- Well Reconstruction (see nontreatment options).

Adsorption
Arsenic typically occurs as a charged ion in water. Therefore, several medias have been developed, the particles of which can adsorb arsenic and can then be trapped within a filter. Filter media materials that have been proven to be effective in the adsorption of arsenic include modified activated alumina, titanium based oxides, zirconium based oxides, and iron based oxides.

Each of these media has slight advantages and disadvantages over the others, and the potential application must be evaluated on a case-specific basis. Each can be processed to varying particle sizes, a factor important in determining the effectiveness of the filters concerned. The filters are typically pressure filters configured for upflow operation. Three or more filter tanks are used so that one can be serviced, one can be in operation, and the third can be in series operation in case of breakthrough and contamination of the tank in operation. All of these materials may be regenerated to a certain degree, but will eventually lose their effectiveness. When effectiveness is lost, disposal of the media may be a challenge due to potential classification as a hazardous material.

Ion Exchange
Ion exchange is most commonly known for its use in water softening. Water is passed through a bed of resin, and the contaminant to be removed is electro-chemically bound to the resin. In the process, ions that are bound to the resin are released into the water stream. In order for the charge of the arsenic to be sufficient for removal, the arsenic must be in the form of arsenate—known as arsenic (V)—which is the form most normally found in groundwater. Arsenite—known as arsenic (III)—can be converted to arsenic (V) through oxidation. Arsenic speciation tests are needed to determine which form of arsenic is present. Similar to a home water softener, the ion exchange resin can be regenerated with a solution of a salt. The backwash water will contain a relatively high concentration of arsenic and must be properly disposed of. Ion exchange resins are often not selective, and other

[5]*U.S. Environmental Protection Agency,* Treatment Technologies for Arsenic Removal*, November 2005.*

ions will interfere with the removal process. Sulfates have a significant negative affect on arsenic removal by the ion exchange process. Sulfates will become bound to the resin adsorption sites, thereby preventing the site from being utilized for arsenic adsorption. High sulfates in water to be treated for arsenic removal by ion exchange must have the sulfates removed prior to treatment or regeneration must occur more often.

Coagulation and Filtration
Arsenic (V) will often coagulate with other compounds in the water stream. Coagulants are typically aluminum or ferric salts. The treatment process will typically contain an oxidation step—to convert arsenic (III) to arsenic (V)—followed by coagulant addition, flocculation, and filtration. Micro-filtration can be used if gross solids are removed either before coagulation or before micro-filtration.

Oxidation and Filtration
Water that is high in iron and also contains arsenic when oxidized will form a precipitate that is filterable. There must be an iron to arsenic mass ratio of at least 20 to one for the oxidation process to be effective. In addition, the oxidation of both materials must occur simultaneously, which will not occur when air is added as the oxidant. Typically manganese oxide (green sand), permanganate, or chlorine is used as the oxidant.

Electrodialysis Reversal
The electrodialysis reversal process, as previously described in Chapter III, may be utilized to remove arsenic. Specialized membranes can be utilized for arsenic removal. At the current time the electrodialysis reversal process is generally more costly than other processes for removing arsenic, but may be very viable if other contaminants present are also to be removed.

Finding a New Source of Water and Well Reconstruction
As is the case with most contaminants, arsenic in groundwater is typically found in limited areas of the aquifer. Utilizing wells not in the contaminated aquifer or performing well reconstruction may sometimes be used to eliminate contaminated water from entering the well.

pH Adjustment (lime softening)
Often, arsenic in water can be precipitated out of solution if the pH of the water is adjusted. In most cases this is a benefit of removing hardness from water, which may be used if the amount of arsenic to be removed is relatively low.

RADIONUCLIDE TREATMENT

Introduction
The USEPA has determined that long-term consumption of radium in drinking water does pose a significant risk of bone cancer for the people exposed. Near the end of the year 2000 USEPA promulgated a final radionuclide rule, consisting of a complex group of regulations specifying how drinking water suppliers are to monitor and control radionuclides in drinking water systems.[6] The objective of the rule is to bring all community water systems into compliance with the radionuclide standards that were established. Samples to be analyzed for radium-226, radium-228, uranium, and gross alpha particles need to be collected during four consecutive calendar quarters and tested prior to the end of calendar year 2007. In addition, vulnerability assessments need to be done for beta particles and photon activity. If radionuclides are found—or the water system was found to be vulnerable—the mitigative measures must be instituted and quarterly tests performed until four consecutive samples indicate that the mitigative measures are successful at bringing the elevated radionuclide levels below the MCLs. Systems that are vulnerable include those utilizing the sandstone aquifer in southeastern Wisconsin. Elevated levels of beta particles and photon activity in drinking water are normally associated with man-made activities. This has not been an issue in Wisconsin. The MCLs concerned are set forth in Table 6.

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[6]*U.S. Environmental Protection Agency,* A Regulator Guide to the Management of Radioactive Residuals from Drinking Water Treatment Technologies*, EPA 816-R-05-004, July 2005.*

Table 6

RADIONUCLIDES MCLS: 2006

Combined Radium-226 and 228	5 pCi/L
Gross Alpha Particle Activity (excluding radon and uranium)	15 pCi/L
Beta Particle and Photon Radioactivity	4 mrem/year
Uranium	30 μg/L

Source: U.S. Environmental Protection Agency.

According to the WDNR records, there where 113 samples taken over the six-year period from January 1, 2000 through December 31, 2005, by municipal and "other than municipal, community" water supply systems located within the Southeastern Wisconsin Region that had radionuclide levels exceeding the MCLs. One or more of these 113 samples were reported by 13 of the 50 municipal water utilities and by nine of the approximately 200 "other than municipal, community" water supply systems in the Region using groundwater as a source of supply.

Best Available Technologies

Since the rule took effect in 2000, the USEPA has identified best available technologies, as well as small system compliance technologies,[7] for treatment of water that exceeds the MCLs for radionuclides.[8] Compliance technologies are listed in Table 7, which identifies the technologies considered to be the best available for both large and small systems, as well as the type of radionuclide contamination each can remove.

It is important to note that the only technology that can be applied to all radionuclide contaminants and is recommended for use on all sizes of systems is reverse osmosis. However, during 2006, the first reverse osmosis water treatment plant was being designed for construction in Wisconsin. Other treatment options recommended for systems of typical size in southeastern Wisconsin are ion exchange, lime softening, and coagulation/filtration. All three of these technologies are limited in the type of radionuclide controlled.[9] Currently, communities in the region are installing or testing systems using ion exchange, adsorption onto a selective resin, hydrous manganese oxide filtration, and others. Proprietary systems are being developed which combine certain aspects of several treatment technologies, such as ion exchange resins that are disposed of as opposed to being regenerated.

Some of the processes used to remove radionuclides can be relatively labor intensive from an operations perspective. Others have limited labor requirements, but require contractual arrangements for media replacement and disposal. In addition, the residuals produced in the process of removal may require disposal as a radioactive waste. The WDNR has provided radioactive waste disposal requirements and guidance.

Nontreatment Options

Given the limited number of technologies that are effective and efficient in removing radionuclides, the costs of those technologies when applied on a large-scale and other factors, nontreatment options are generally considered as preferred for the control of radionuclides. Investigation of new sources and blending with low radionuclide content sources are sometimes viable options. Connecting to neighboring systems to obtain water for blending

[7]*Best Available Technologies (BATs) are the best technologies, treatment techniques, or other means than the USEPA Administrator determines to be available after examination for efficacy under field conditions, and not solely under laboratory conditions, taking cost into consideration. Small System Compliance Technologies (SSCTs) are technologies that have been Federally approved for systems serving fewer than 10,000 persons to use in complying with regulations.*

[8]*U.S. Environmental Protection Agency,* Radionuclides in Drinking Water: A Small Entity Compliance Guide*, EPA 815-R-02-001, February 2002.*

[9]*U.S. Environmental Protection Agency,* Radionuclides Rule: A Quick Reference Guide*, Vol. 65, No. 236, December 7, 2000.*

Table 7

APPLICABILITY OF BEST AVAILABLE TECHNOLOGIES (BAT) AND SMALL SYSTEM RADIONUCLIDE COMPLIANCE TECHNOLOGIES (SSCT)[a]

Treatment Technology	Designation BAT and/or SSCT?	Customers Served (SSCTs only)	Appropriate for Systems Serving Greater than 10,000 Customers	Treatment Capabilities				Source Water Considerations	Operator Skill Required
				Radium (Ra)	Uranium (U)	Gross Alpha (G)	Beta/p boton (B)		
Ion Exchange	BAT & SSCT	25-10,000	Yes	√	√		√	All ground waters	Intermediate
Point of Use (POU) Ion Exchange	SSCT	25-10,000	No	√	√		√	All ground waters	Basic
Reverse Osmosis (RO)	BAT & SSCT	25-10,000 (Ra, G, B)[b] 501-10,000 (U)[b]	Yes	√	√	√	√	Surface waters usually requiring pre-filtration	Advanced
POU RO	SSCT	25-10,000	No	√	√	√	√	Surface waters usually requiring pre-filtration	Basic
Lime Softening	BAT & SSCT	25-10,000 (Ra) 501-10,000 (U)	Yes	√	√			All waters	Advanced
Manganese Oxide (green sand) Filtration	SSCT	25-10,000	No	√				Typically ground waters	Basic
Co-precipitation with Barium Sulfate	SSCT	25-10,000	No	√				Ground waters with suitable water quality	Intermediate to advanced
Electrodialysis/ Electrodialysis Reversal	SSCT	25-10,000	No	√				All ground waters	Basic to intermediate
Pre-Formed Hydrous Manganese Oxide Filtration	SSCT	25-10,000	No	√				All ground waters	Intermediate
Activated Alumina	SSCT	25-10,000	No		√			All ground waters	Advanced
Coagulation/Filtration	BAT & SSCT	25-10,000	Yes		√			Wide range of water qualities	Advanced

[a]*U.S. Environmental Protection Agency,* Radionuclides Rule: A Quick Reference Guide*, Vol. 65, No. 236, December 7, 2000.*

[b]*R = Radium-226 and 228; G = Gross Alpha; B = Beta Particles; and U = Uranium.*

Source: Modified from USEPA, December 2000.

deserves consideration. In a limited number of cases radium and gross alpha levels have also been reduced to below the MCLs by isolating portions of the well bore which produce high levels of radionuclides or selectively stimulating intervals of the well bore that produce low levels of the contaminant. If there are treatment technologies currently in place, the optimization of those technologies may reduce radionuclide content to a level below the MCL.

Hydrous Manganese Oxide (HMO) Filtration

HMO filtration uses conventional treatment processes for iron and manganese removal from well water. It has long been recognized that a limited amount of radium may be removed as a consequence of iron-manganese treatment processes, as a result of sorption to the metal oxides produced. Sorption is the adhesion of a molecule to the surface of a solid. Removals have generally been observed to increase in the presence of increasing manganous ion and have been attributed primarily to the sorption of radium to hydrous manganese oxides (HMOs) and not to iron oxides, which appear to have a much lower radium sorption potential under typical water treatment conditions.

The sorptive capacity depends on the conditions under which the HMOs are formed, the chemicals used to form them, and the chemistry of the water being treated. Sorption will also depend on the pH and the presence of competing ions such as calcium and barium, which are expected to reduce sorption of radium.

Sorption to freshly precipitated HMOs has been specifically exploited to remove radium from water. High dosages of HMOs have been used to remove very high concentrations of radium from effluents associated with uranium mining and from drinking water. A number of Wisconsin water systems are planning to use this process for radium removal. There are some proprietary processes that utilize the general concepts of the HMO treatment processes.

Ion Selective Adsorbent Technologies

One proprietary technology that uses adsorption for the removal of radium has been successfully pilot tested in Wisconsin. This process typically utilizes an up-flow contactor containing a proprietary granular media, which is selective in adsorbing radium compounds in the water. The radium is adsorbed to the media and radium levels in the drinking water are, thereby, reduced. Radium levels are typically reduced to well below the maximum contaminant level (MCL) of 5.0 Pico curies (pCi) per liter allowed by U.S. Environmental Protection Agency and Wisconsin State Standards. Other companies have proposed the use of similar adsorption technologies for use in drinking water treatment within the State.

In the pilot tested process, the water to be treated flows sequentially through two vessels containing the adsorption media. The media adsorption capacity is initially exhausted where the raw water enters the upstream vessel. As more water is treated, media exhaustion extends progressively through this vessel. When all of the media in the upstream vessel is exhausted, as determined by calculation or by testing for the adsorpted radium, the media in the upstream vessel is removed. The media in the downstream vessel is moved to the upstream vessel and the exhausted media in the upstream vessel is replaced with new media.

A second proprietary technology was pilot tested in Wisconsin at two sites in southeastern Wisconsin. The process uses a proprietary manufactured adsorbent media that is selective in removing radium and barium compounds in the water in a manner similar to the adsorptive granular media. The pilot tests were submitted to the WDNR for review and approval. The WDNR correspondence indicates the test results were positive and that further testing would be required of the completed units. The pilot testing company of record no longer represents this process. The process differs from the system described above, in that instead of operating in the vertical upflow mode, the water flows downward through two vessels in series. The media is loaded at a higher rate than the granular media operating in an upflow mode. When the removal capacity of the initial vessel is exhausted, the second vessel becomes the first and new media is added to the second vessel.

The initial plans were to load this media to a higher radioactivity level that would require landfilling in a site licensed to take the levels of Technically Enhanced Naturally Occurring Radioactive Material (TENORM) that would be created. Initial plans were for disposal of the media by the vendor. The media is still available; however, it is not known if the process has been purchased or offered by another vendor serving the Region. The proprietary company that provides the media typically handles removal and disposal of the media. Disposal is typically done at a licensed disposal facility. In most cases, the media disposal is accomplished as part of a service contract with the proprietary company. One advantage of this procedure is that the facility operating personnel do not need to handle waste material high in radionuclides. The costs for these technologies are typically the cost associated with the vessels and backwash equipment. Costs of the media and exchange of the media are typically incurred under a service contract with the company providing the media.

SYNTHETIC ORGANIC COMPOUNDS (PESTICIDES-HERBICIDES) TREATMENT

Introduction
The prevalence of synthetic organic compounds (SOCs) in common use, such as pesticides and herbicides, creates concern for their removal from drinking water. There are a large number of synthetic organic chemicals that can potentially affect groundwater supplies for which the WDNR had established MCLs for drinking water. These chemicals are largely associated with pesticides and herbicides. However, they are also used in a variety of manufacturing and commercial processes. The potential human health affects of these chemicals at levels exceeding the MCLs in drinking water are varied and are largely of a long-term, chronic nature, often including increased risks of cancer, among others.

Thirty SOCs are identified with MCLs in Section NR 809.20(1) of the *Wisconsin Administrative Code*. According to WDNR records, 51 samples taken over the six-year period from January 1, 2000 and December 31, 2005, by public water supply systems located in the Southeastern Wisconsin Region exceeded the detectable limit. The 51 samples represented 44 of the approximately 250 water supply systems in the Region. Four of the samples representing 44 water supply systems approached or exceeded the MCL.

Best Available Technologies
The best available technologies for the removal of the SOCs mentioned above are identified in the *Wisconsin Administrative Code*. These technologies are listed in Table 8.[10]

Chapter NR 809 of the *Wisconsin Administrative Code* identifies granular activated carbon as the most broadly applied technology to remove SOCs. The current literature also most often refers to granular activated carbon as the most appropriate technology to remove SOCs. There are, however, some short-chain and long-chain organics that are not adsorbed by this process. Granular activated carbon is typically incorporated into pressure or gravity filters to act as an adsorbent. The adsorbent sites on the activated granules will eventually become exhausted and the activated carbon will need to be regenerated, which is commonly done by a thermal process.

Membrane Processes
Membranes have been developed for the removal of SOCs from water. Reverse osmosis, nanofiltration, and electrodialysis reversal are most commonly utilized in such processes. All of these processes are expensive to install and operate and create a waste stream that is relatively difficult to manage.[11] The waste brine will be high in the organic compounds being removed, and treatment of waste onsite may not be possible. Similarly, local regulations may limit discharge to local sanitary sewers.

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[10]*Wisconsin Department of Natural Resources, Chapter NR 809 of the* Wisconsin Administrative Code*, No. 593, May 2005.*

[11]*National Drinking Water Clearinghouse, Tech Brief,* Organic Removal*, August 1997.*

Table 8

BEST AVAILABLE TECHNOLOGIES FOR SYNTHETIC ORGANIC COMPOUND TREATMENT: 2006

Technology	Appropriate to Be Used on:
Granular Activated Carbon	All listed contaminants except glyphosate (roundup)
Packed Tower Aeration	Dibromochloropropane, di(2-ethylexyl)adipate, ethylene dibromide, and hexachlorocyclopentadiene
Oxidation	Glyphosate(roundup)
Other treatment processes	Accepted upon demonstration

Source: Wisconsin Administrative Code *NR 809.20(2).*

Nontreatment Options

Similar to radionuclides, wells contaminated with synthetic organic compounds are often abandoned in favor of other sources that are not contaminated. Occasionally, source blending may be used to reduce contaminant levels below the MCL, but the stigma of SOCs and the low MCLs required often limit the application of blending.

INORGANIC NITROGEN COMPOUND REMOVAL (NITRATES AND NITRITE) TREATMENT

Introduction

Inorganic nitrogen compounds enter water supplies through a number of routes. The most notable is from agricultural runoff, although sources, such as wastewater treatment systems, urban runoff, and atmospheric deposition, are also significant contributors. Nitrate and nitrite are typically considered a groundwater contamination issue in shallow aquifers, but can also affect surface water supplies.[12] Human health standards for nitrate nitrogen are based primarily on the role of nitrate-nitrogen in causing a temporary, but potentially serious, blood disorder called "methemoglobinemia" in infants. High nitrate-nitrogen concentrations can also affect the health of livestock, but livestock can generally tolerate higher nitrate-nitrogen concentrations in water than the 10 mg/l MCL for human consumption.

According to WDNR records, 206 samples taken over the six-year period from January 1, 2000 to December 31, 2005, by 65 of the approximately 250 municipal and "other than municipal, community" water suppliers in the Southeastern Wisconsin Region reported exceedences of the MCL for either nitrate-nitrogen or nitrate and nitrite-nitrogen. Most of the exceedences were for samples that exceeded the MCL for nitrate-nitrogen. Many of the exceedences were reported twice since a sample exceeding the MCL of 10 mg/l for nitrate-nitrogen will also exceed the MCL of 10 mg/l for nitrate and nitrite combined.

Best Available Technologies

Section NR 809.11(4)a of the *Wisconsin Administrative Code* identifies the following best available technologies for removal of nitrate and nitrite: ion exchange; reverse osmosis; and electrodialysis/electrodialysis reversal (for nitrate only).

Nontreatment Options

All of the above described best available treatment technologies are relatively costly, especially given the fact that many communities utilizing groundwater sources presently do so with little or no treatment prior to distribution. For this reason, many communities—and particularly smaller communities—consider no-treatment options, such as source blending or well abandonment, if source wells test positive for nitrates and/or nitrites.

[12] *U.S. Environmental Protection Agency,* Technical Factsheet On: NITRATE/NITRITE, *Available at: www.epa.gov/safewater/dwh/t-ioc/nitrates.html, Accessed December 30, 2005*

Biological Treatment

Some research has been done in recent years to treat water through biological means utilizing denitrifying bacteria. While such treatment has been successfully used in wastewater treatment, its use in drinking water treatment does not appear practical in the near future.[13] Biological nitrogen removal requires addition of micro- and macro-nutrients to enhance bacterial growth. These nutrients, if not balanced correctly, can lead to water quality problems.

NONTREATMENT OPTIONS

New Source Development

Ultimately, any treatment alternative must be evaluated on the basis of a number of factors, including economic factors. Typically, alternative scenarios include options that involve utilizing the source under new operational parameters, or abandoning the existing source in favor of a source that does not contain the contaminant of concern. Blending water from the source concerned with water from new sources can sometimes be used to reduce the concentration of contaminants below the maximum contaminant level (MCL). Treatment of a portion of the noncompliant flow stream, and subsequent remixing with untreated water can also be used to reduce the concentration below the MCL. Public perceptions may play a role in decisions to treat water from the source, or develop a new source. Education of the public can help to assure that decisions are based on sound science, engineering, and public health practices.

Source Redevelopment

The concentration of most contaminants varies within an aquifer. If the contaminant is from a point source, the contamination often varies with distance from the source. Some contaminants are derived from naturally occurring minerals within the aquifer matrix. The distribution of these contaminants is often related to the oxidation state of the groundwater, which typically varies with depth within an aquifer. When the distribution of a contaminant is varied within an aquifer, the concentration can often be reduced by changing the construction of a well to selectively produce water with lower concentrations. When the zones are separated by a confining unit, it is often possible to achieve a significant and permanent reduction in contaminant levels. Several wells in southeastern Wisconsin have been selectively reconstructed to avoid treatment for several different types of contaminants. Where possible, this option has the advantages of lower costs, but also reduces significant disposal issues related to most treatment processes.

Wells have been reconstructed to reduce total dissolved solids concentrations (Waukesha Water Utility Well No. 9 and City of New Berlin Well No. 8), radium and gross alpha (City of Pewaukee Well Nos. 9 and 10), nitrate (City of Orfordville, Wisconsin, Well No. 3), barium (City of Sycamore, Illinois, Well No. 4), among other contaminants. Typically, the distribution of water quality and water production along a well bore is measured using packer tests, or more commonly, geophysical well logging and down hole water sampling. The measurements must be made while pumping the well at a similar rate to the desired capacity. The variation in water quality and production rate is used to identify high concentration zones; to isolate low concentration zones that can be selectively stimulated; and to predict the water quality and capacity of the well in its reconstructed state. It is generally necessary to extend any seals in the well across a confining unit to avoid vertical migration within the formation. It is possible to calculate the transmissivity and head of the major hydraulic zones of a well if down hole flow measurements are made under two different stable pumping conditions.

Well reconstruction is generally more practical for wells completed across multiple aquifers, such as many deep sandstone aquifer wells. Sealing off zones is usually accomplished by hanging casing or packers within the well bore or by backfilling the lower portion of the well. Selective stimulation is usually performed by shooting selected zones with depth specific rehabilitation tools such as the Airburst™ or Bore Blast™ tools. In some cases, sealing off the high-concentration zones reduces the capacity of the well to the point where the reconstruction is

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[13] *American Society for Microbiology,* Removal of Nitrate from Groundwater by Cyanobacteria: Quantitative Assessment of Factors Influencing Nitrate Uptake*, 2000.*

not feasible. In some wells, such as wells completed in uniform sand and gravel aquifers, it is not possible to vertically isolate a portion of the aquifer. In fracture-controlled aquifers, such as the Silurian dolomite, it is difficult to predict if zones can be isolated without a packer test. The process of reconstructing wells to reduce contamination may result in reduced well capacity.

TREATMENT TECHNOLOGY PROCESS DESCRIPTIONS AND COSTS

Introduction

The previous sections identified process technologies that are appropriate for controlling specific regulated contaminants. This section describes in greater detail the technologies not previously described in Chapter III, together with the associated costs. Technologies noted earlier in this chapter that have been previously described in Chapter III include:

- Coagulation and Filtration;
- Electrodialysis Reversal;
- Reverse Osmosis;
- Specialized Filtration Processes;
- Green Sand Filtration (discussed in dual media filtration);
- Granular Activated Carbon; and
- Activated Alumina.

Technologies that will be described in this section of the chapter are:

- Adsorption;
- Ion Exchange;
- Hardness Removal Systems Using pH Adjustment;
- Hydrous Manganese Oxide Filtration;
- Packed Tower Aeration; and
- Point of Use Treatment.

Co-precipitation with barium sulfate is not typically used on a systemwide basis. It is only effective on radium, is not considered a best available technology, and is not efficient for systems serving populations over 10,000. For these reasons, it is not described further in this report.

Adsorption

Process Description

Adsorption is the process of capturing contaminants through the attraction of that contaminant to a filter media particle. As previously noted, this process can be used for treatment of arsenic, but may also be used for any charged ion contaminant. Technically, processes, such as granular activated carbon and ion exchange, are sorption processes. Typically, however, the processes considered in the adsorption category do not include granular activated carbon or ion exchange because of the ability to regenerate those processes. Generally, the adsorbents included in this section are utilized once and then disposed of, typically, at a landfill. Thus, the ongoing operations and maintenance costs include replacement of the filter media and not costs associated with regeneration of the filter bed.

The adsorbent materials are typically housed in a pressure vessel that assures passage of the water to be treated through the filter media and avoids short-circuiting within the filter bed. Adsorbent media can be used in gravity flow arrangements for larger flow treatment systems. In the case of surface water treatment, any gross solids need to be removed prior to processing in the adsorbent bed.

The adsorbent process is, typically, a one-pass process, with systems laid out in such a way that units are in series. When break-through of the contaminant is found between units, the feed location is moved and the first treatment unit is emptied and refilled with new adsorbent. With such a scenario, at least three treatment units must be available for use.

The variety of adsorbents available is growing rapidly. As indicated earlier in this chapter, proven adsorbents are generally oxides of metal, typically titanium, zirconium, or iron oxides. These oxides have an affinity for the positively charged arsenic ion and trap the arsenic within the media bed. The AWWA Research Foundation, in partnership with the USEPA, has surveyed vendors of such adsorbents. Of the 35 adsorbents identified, 21 are classified as experimental.

As of early 2005, the adsorbents that are currently available and meet the National Sanitation Standard 61 for drinking water treatment are:[14]

- US Filter Granular Ferric Hydroxide (STD 61 approval pending);
- Iron Oxide Coated Diatomite;
- Aqua Bind (alumina modified with manganese oxide);
- Macrolite (ferric salt STD 61 approval pending, addition prior to ceramic media);
- Sulfur Modified Iron; and
- Modified Zeolite.

Costs

The AWWA Research Foundation, in conjunction with the University of Colorado at Boulder and Malcolm Pirnie, Inc., has developed an arsenic adsorbent design and costing procedure that estimates capital, as well as operation and maintenance, costs for adsorption removal of arsenic from drinking water. This procedure can be used to estimate costs meeting Association for the Advancement of Cost Engineering (AACE) Class 4 to 5 estimates. These cost classes are recommended for use in system-level planning and, generally, provide estimates with an accuracy range of minus 30 percent to plus 50 percent. When this model is used to estimate the cost for a 1.0 million gallons per day (mgd) facility, the capital costs vary between $0.96 per gallon of treatment capacity to $2.00 per gpd of treatment capacity, depending upon adsorbent selected. For planning purposes it is recommended that a cost of $1.36 per gpd of treatment capacity be used. Operation and maintenance costs will vary between $353 per million gallons (MG) treated and $1,192 per MG treated, again depending upon the media selected. For planning purposes, it is recommended that a cost of $1,000 per MG treated be used. The above operation and maintenance costs include the replacement of media as needed.

It is also recommended that the aforereferenced model used to generate these costs be utilized for planning purposes. The variation between the annualized costs associated with various adsorbents can lead to an adsorbent

[14] *U.S. Environmental Protection Agency,* Adsorbent Treatment Technologies for Arsenic Removal*, 2005.*

having a significantly lower net present value when neither construction costs nor operation and maintenance costs are the lowest of all adsorbents.

Ion Exchange

Process Description

As previously noted, ion exchange can be used for treatment of arsenic, radionuclides, synthetic organic, and nitrogen compounds, as well as for hardness causing minerals. Ion exchange traditionally utilized zeolite—a porous mineral that may be man-made or natural—to adsorb charged particles from a water stream. Currently, there are a large number of resins that have replaced zeolites for most uses. The most widespread use for the ion exchange process is in the removal of hardness causing minerals—calcium and magnesium compounds—from water. Ion exchange treatment units are typically pressure vessels filled with an adsorbing resin. Once all adsorption sites have been utilized in a resin bed, the resin must be regenerated. Regeneration is typically done with an automated sequencing valve that draws a salt brine into the resin bed. The resin bed is then rinsed briefly to remove the brine prior to putting the ion exchange unit back in service. Again, the most typical brine used is sodium chloride for resins that remove hardness minerals. Resins and brines that remove cations—positively charged ions—are more common and less expensive than those for anions—negatively charged ions. Typical home water softeners that remove calcium and magnesium are cationic resins and, therefore, are less expensive to purchase. Resins to remove radionuclides are anionic and are significantly more expensive. The waste created with an ion exchange system not only contains the contaminant in question, but also is very high in salt concentration. Special consideration must be given to the treatment of ion exchange waste.[15] This waste will be high in the salt brine used for regeneration. Since chlorides are commonly the salt source, the chlorides may pass through wastewater treatment facilities and increase the chlorides in the effluent. In addition, the target contaminant will also be in high concentration and may be controlled by regulations.

Costs

As with all water treatment processes, the source water quality has a large impact on the construction costs of ion exchange treatment. Regeneration frequency is not only dependent upon contaminant concentration, but also similar ion concentration that will also be removed. The largest impact on costs is the charge of the target ion. Anionic resins are typically three to five times more expensive than cationic resins. For planning purposes, it is recommended that a cost of $0.20 per gpd of treatment capacity be used as a cost estimate for cationic ion exchange. The previously noted factors may be applied to this estimate to determine the costs of anionic resins. Operation and maintenance costs will vary depending on the type of resin used. For planning purposes, it is recommended that a cost of $1,700 per million gallons (MG) treated be used.

Hardness Removal through pH Adjustment

Process Description

Hardness is typically caused by calcium and magnesium compounds dissolved in water. Excessive hardness in water may cause deposits on pipes, increased use of soap products, and premature failure of water appliances. The reduction of hardness is not typically a regulatory issue, but one of customer preference. In addition, there are several regulated substances, such as radionuclides and arsenic, that can be removed through pH adjustment and precipitation. The process of hardness removal through pH adjustment is often called lime softening, but several chemicals may be used to raise the pH, including hydrated lime $(CaCOH)_2$, quicklime (CaO), soda ash (Na_2 CO_1), or caustic soda (2NaOH). The chemicals are added to increase the pH to above 10 for calcium removal or 11 for magnesium removal. After mixing, the precipitate is allowed to settle in a clarifier and clear water is drawn off for downstream treatment or use. Sludge is produced that consists of the added chemical in addition to the precipitated calcium and magnesium. This sludge may be treated on site and disposed of by land application on agricultural fields or may be discharged to a wastewater treatment facility. Lime softening sludge is very difficult for most wastewater treatment facilities to treat and a treat ability assessment must be performed during design of any water treatment facility.

[15] *Anthony M. Wachinski, PhD. P.E., AWWA,* Ion Exchange Treatment for Water*, 2006.*

Costs

The cost of pH adjustment softening typically make it suitable for use in moderate- to large-size systems—those having flows above 500,000 gallons per day (gpd). The 1979 USEPA construction costs, when adjusted by the USBOR spreadsheet indicate a cost of $0.62 per gpd capacity for chemical addition and clarification facilities. Operations and maintenance costs are estimated at $240 per MG treated. It is recommended for systemwide planning purposes that $0.85 per gpd capacity is used to estimate construction costs and $250 per MG of treated water be used for estimating operations and maintenance costs.

Hydrous Manganese Oxide Filtration

Process Description

In 1992, the American Water Works Research Foundation (AWWARF) sponsored a study by Dr. Richard Valentine of the University of Iowa. The study examined the effectiveness of using hydrous manganese oxides (HMOs) to reduce radium concentrations in drinking water. The study included bench scale laboratory work and pilot studies at two different full-scale plant installations.

The AWWARF study examined the effectiveness of feeding a mixture of potassium permanganate ($KMnO_4$) and manganous sulfate ($MnSO_4$) prior to filtration. The mixture of the two chemicals forms negatively charged slurry. Through a sorption process, the negatively charged slurry attracts and sorbs the positively charged radium that is present in the raw water. The reaction is similar to the ion exchange softening process. The particulate slurry is then captured in a granular media filter. Radium removal efficiencies of 60 to 80 percent were found to be typical.

The raw water quality plays a role in the effectiveness of the HMO process. If soluble iron is present in the raw water, an oxidant, such as chlorine or potassium permanganate, is fed prior to the addition of the HMOs. The purpose of the oxidant is to oxidize the soluble iron to an insoluble state. Soluble iron has a tendency to interfere and reduce the effectiveness of the HMO process. Oxidation methods, such as pressure or gravity aeration, are acceptable alternatives to chemical oxidation. Other ions that may affect the HMO process include cations that are similar to radium, such as calcium, magnesium, and barium. Moderate calcium and magnesium hardness concentrations in groundwater have a minimal impact on the HMO process. Barium has a more distinct affect on the HMO process at increasing concentrations.

The HMO process produces wastewater that must be disposed of. The waste stream from an HMO process is similar to common iron and manganese removal waste from a filtration system. Like iron and manganese applications, the filters remove the particulate from the raw water. Based on time, breakthrough, or head loss, the filters are backwashed to remove the accumulated solids. The backwash water is supplied at a sufficient rate to expand the filter media and allow the solids to be removed from the filter bed. The waste produced in the backwash process is generally sent to the municipal wastewater treatment plant. For small communities or waste systems that are negatively affected by a large volume of waste, a backwash holding tank can be used. Flow from the backwash holding tank is metered into a sanitary sewer over a period of time to reduce the load on the wastewater treatment plant.

Costs

As with most new technologies, HMO filtration is not included in the 1979 USEPA publication or in the USBOR spreadsheet. In lieu of this information, the approximate estimated costs for HMO filtration at an actual well in southeastern Wisconsin are known. This facility is designed to treat slightly less than 1.0 MGD. The estimated cost for installation of the treatment system, including pilot testing, was $869,000, or approximately $0.90 per gpd capacity. Operations and maintenance for this facility are estimated to be $130 per MG treated. For systemwide planning purposes it is recommended to use $1.10 per gpd capacity and $150 per MG treated to account for the actual date of estimation being uncertain.

Packed Tower Aeration

Process Description

Packed tower aeration is typically utilized to remove organic substances. A variety of synthetic organic compounds (SOC) or volatile organic compounds (VOC) can be removed with packed tower aeration. Packed tower aeration units are typically columnar in shape and filled with a manufactured media. The shape of the media and its size varies in accordance with the surface area desired. Water to be treated is distributed over the top of the media column, and air is forced through the media bed from the bottom. Organics are removed from the water as it passes through the column through a combination of volatilization, direct oxidation, and biological oxidation by bacteria that develop on the media. Depending upon the organic material to be removed, packed tower aeration can be very effective at organic removal.[16] One advantage of packed tower aeration is that there are few residuals to dispose of. If biological growth becomes excessive, the tower may need occasional treatment with a biocide, and the treatment water would be metered into the sanitary sewer.

Costs
The costs for packed tower aeration treatment systems were not included in the USEPA publication in 1979, nor were they included in the USBOR spreadsheet update. Such systems are relatively unusual to find, with less then 10 serving municipal water supply systems in southeastern Wisconsin. Vendor cost information is not readily or easily useable because the amount of costs incurred for ancillary items is not clear.

In a presentation made at the University of Wisconsin-Madison, Department of Engineering Professional Development course, in May 2006, Dr. Steven Duranceau, P.E., of Boyle Engineering Corporation provided cost curves for several different treatment scenarios, including treatment for the removal of hydrogen sulfide with packed tower aeration. These cost curves are presented in Appendix A.

When the values for a one MGD treatment facility are adjusted to December 2005 values and the costs for engineering, legal, contingencies, and administration are added, it is recommended that a construction cost of $0.31 per gpd capacity be used for planning purposes. Similarly, a time adjusted cost of $690 per MG treated is recommended for operations and maintenance costs.

Point of Use Treatment
Point of Use (POU) treatment is a philosophy of utilizing any treatment technology mentioned in this report or available to individuals and applying that technology at the point of use. The point of use is sometimes interpreted literally and treatment units are located on the tap or under the sink. More often POU means that the treatment unit is located in the same building as the user, generally a treatment unit that serves one home. POU is typically not the most cost-effective method of treating contaminants that need to be removed from all water delivered to customer for regulatory reasons. In fact, POU treatment is not allowed except for the smallest public systems. POU devices are commonly utilized for homes or businesses served by private wells or to remove nuisance contaminants, such as hardness, which are not regulated and not considered health risks. Occasionally, POU devices are purchased by a water utility for a contaminant affecting a small geographic area on a temporary or permanent basis. One such application is currently being considered in the Madison area for the removal of manganese. POU treatment is covered in Chapter V.

Treatment of Wastes
Most of the treatment systems discussed in this chapter produce a backwash water or filtrate that must be treated. Other processes produce a filter media that must be disposed of and/or treated. In some cases, both waste streams are produced. The cost of treatment and/or disposal of these waste streams are highly site-specific. These costs must be determined during the planning process for any given site and the contaminants to be removed at that site.

SUMMARY

This chapter has addressed the contaminants and described the treatment technologies available for groundwater supply systems. Unlike surface water, the treatment of groundwater is determined by the specific contaminant

[16]*American Water Works Association,* Water Quality and Treatment, A Handbook of Community Water Supplies*, Fourth Edition*, *Copyright 1990, by McGraw-Hill, Inc., New York, New York.*

Table 9

ESTIMATED COSTS OF GROUNDWATER TREATMENT TECHNOLOGIES (USD, DECEMBER 2005)

Treatment Technology	Can Be Effectively Used to Treat	Estimated Capital Costs (dollars per gpd capacity)	Estimated Operations and Maintenance Cost (dollars per MGD treated)
Adsorption	A	$1.36	$1,000
Ion Exchange (cationic)	A, N, R	0.20	1,700
Coagulation Filtration	A, R	0.60	80
pH Adjustment	A	0.85	250
Granular Activated Carbon	SOC	5.50	1,000
Packed Tower Aeration	SOC	0.31	690
Membrane Processes	N, R	2.60	300
Hydrous Manganese Oxide Filtration	R	1.10	150

NOTE: The following abbreviations were used:

A = Arsenic
SOC = Synthetic Organic Carbon
N = Nitrogen Treatment
R = Radionuclide Treatment

Source: Ruekert & Mielke, Inc.

present in the source water, rather than being specified directly in regulations. The contaminants of concern in groundwater are identified with maximum contaminant levels (MCLs)and treatment must occur when the MCL is exceeded. The method of treatment is more often an issue of consumer preference than of regulatory need.

This chapter addressed some of the more common contaminants and related problems found in groundwater sources, including hardness, arsenic, radionuclide, synthetic organic compounds, and nitrogen. Treatment technologies commonly used for groundwater sources were described and estimated costs of treatment were presented. Unlike surface water treatment technologies, there are no “typical” treatment trains, because the treatment requirements for groundwater systems vary depending upon the contaminants present, from no treatment to very extensive treatment trains to remove multiple contaminants.

Table 9 summarizes estimated costs associated with the treatment technologies described in this chapter.

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Chapter V

SMALL AREA AND INDIVIDUAL WATER SUPPLY SYSTEMS

INTRODUCTION

The regional land use plan[1] recommends that new sub-urban density[2] residential development be restricted to that which is already committed through approved subdivision plats and certified survey maps. In this respect, the plan envisions that the amount of new sub-urban density residential land within the southeastern Wisconsin Region would increase by about nine square miles, or by about 31 percent, between 2000 and 2035. This would accommodate about 3,400 households, or about 2 percent of the projected increase in households within the Region between 2000 and 2035. No additional sub-urban density residential land beyond the amount already committed is recommended. The development of land at sub-urban densities of 0.2 to 0.6 dwelling unit per acre, typically, precludes the use of centralized sanitary sewer and water supply services. In addition, there were in 2000 about 126,000 households within the Region that were using private individual, or other than municipal community wells as a source of water supply. In areas where public water supply systems are not available, other options, such as onsite wells or private water systems, are typically used to serve residential, commercial, industrial, and agricultural water needs. Such residential, commercial, and other nonresidential land uses served were estimated to have a net groundwater withdrawal of about 18 million gallons per day (mgd) of groundwater in 2000. Of this total, about 4.5 mgd is estimated to be the net withdrawal and not returned to the groundwater system in areas served by onsite sewage disposal systems. About 13.5 mgd is estimated to be withdrawn in areas served by private water supply systems, but contributed to public sanitary sewer systems. Almost all the latter amount of pumped water is lost to the local aquifer.[3]

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[1]*SEWRPC Planning Report No. 48,* A Regional Land Use Plan for Southeastern Wisconsin: 2035, June 2006.

[2]*The regional land use plan recognizes three densities of urban residential land use: high, medium, and low density; a sub-urban density; and a rural density. Sub-urban development can be characterized as development on residential lots having an area of 1.5 to 5.0 acres for dwelling units. The regional land use plan recommends that such development in unsewered areas be limited to that which is already committed. The plan envisions residential development at densities down to 1.5 acres per dwelling unit as urban, and as such, requiring centralized sanitary sewer and water supply services. Within that urban range, the plan further discourages development at the lower urban densities of 0.5 to 1.5 acres per dwelling, seeking to increase urban residential densities within the Region.*

[3]*D.S. Cherkauer,* Estimation of Domestic Pumping for Inclusion in the Region Groundwater Flow Model*, July 2006.*

Systems designed for small areas and individual water supplies can use groundwater, surface water, or a combination as the source of water supply. For instance, a golf course may have one or more wells to serve potable water needs and also use the wells to replenish nonpotable surface water sources used for irrigation. The size of the water supply system for these types of development varies and is dependant upon the availability of supply, local aquifer characteristics, development size, and type of water use.

Agricultural and other nonpotable water uses also affect the local water supply. The location and type of irrigation equipment can interact with other nearby water supply sources in hydrologically connected aquifers. Larger, high capacity wells used by industrial or commercial operations can have similar interactions.

This chapter presents descriptions and cost data for those small area and individual water supply systems considered appropriate for potable and nonpotable water uses in southeastern Wisconsin. Systems that do not reflect current use within the Region or a potential state-of-the-art practice within the Region, such as those used to treat rainwater or surface water for potable uses, are not presented in this chapter. Small area or individual water supply practices associated with rainwater capture, treatment, and nonpotable use are described briefly in this chapter and in more detail in Chapter VII, together with other water conservation practices.

RESIDENTIAL PRIVATE SYSTEMS

The predominant nonpublic type of water system in southeastern Wisconsin is the private, onsite water system consisting of an onsite well and appurtenances. Wells are generally finished in the first available aquifer that can provide eight to 10 gallons per minute.[4] Water quality in an individual aquifer may require treatment for removal of contaminants or objectionable tastes, odors, or physical characteristics, such as hardness. If objectionable water quality is encountered during drilling of a well, a homeowner or well driller may opt to continue to drill deeper to locate alternate supplies.

Supply Sources

Within southeastern Wisconsin, shallow aquifers provide most of the water for private domestic wells.[5] These aquifers consist of the shallow sand and gravel deposits and the Silurian dolomite. Water moves freely between these two aquifers and they are generally considered to comprise a single hydrologic unit.[6] There is considerable variability in the thickness of the shallow deposits across the Region. Western Racine, Kenosha, and Waukesha Counties, and Washington and Walworth Counties have significant sand and gravel deposits that support private wells. Eastern portions of the Region have somewhat less-extensive, more-localized sand and gravel deposits, but a more-extensive dolomite aquifer. In areas where the Silurian dolomite is underlain by the Maquoketa shale, the dolomite is the primary source for domestic wells. Isolated conditions throughout the Region may require well completion in the sandstone aquifer, or in extreme cases, consideration of the use of surface water, as a source of supply. Any such surface water-supplied systems would be subject to the plan review requirements of Chapter NR 812 of the *Wisconsin Administrative Code.* Currently, there are no known private domestic potable water supply systems using surface water in the Region.

Wells are constructed by driving a well point or by drilling. The simplest and least expensive construction is a driven well point. Hydraulic considerations generally limit well points to areas where the pumping level of the groundwater is less than 30 feet below ground surface, and generally to areas where it is in the 15 to 25 feet below ground surface range. Typically, these driven wells can be found around surface waterbodies.

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[4]*U.S. Environmental Protection Agency Water Supply Division,* Manual of Individual Water Supply Systems*, 1975, p. 17.*

[5]*Southeastern Wisconsin Regional Planning Commission and Wisconsin Geological and Natural History Survey, Technical Report No. 37,* Groundwater Resources of Southeastern Wisconsin*, June 2002, p. 73.*

[6]Ibid.

Drilled wells are, by far, the most common well construction in the Region. A variety of well drilling methods are used, including: cable tool, direct rotary, casing hammer, and other modern drilling techniques. While methods vary, costs are market driven and do not differ greatly between methods. Construction of individual systems is governed by Chapter NR 812 of the *Wisconsin Administrative Code,* entitled "Well Construction and Pump Installation." Typical costs for drilling and constructing a private domestic well in the Region are estimated to range from $18 to $25 per foot of well depth.

Surface water is generally used only for outside use and irrigation in riparian zones. Treatment requirements for potable use of surface waters and associated costs prevent most use of surface water as the primary onsite residential source of supply.

Residential Treatment Systems

The use of home water treatment facilities is generally at the discretion of the homeowner. Treatment can range from periodic well disinfection to reverse osmosis filtration. The most common types of treatment within the Region are designed to remove two constituents that impact water quality, iron and hardness. Homes and businesses may also use cartridge filtration systems, reverse osmosis units, and other point-of-use type treatment.

SMALL AREA AND COMMUNITY WATER SYSTEMS

In areas where public water supply systems are not available, smaller systems to serve a few homes, a subdivision, multi-family residences, and businesses may be used for water supply needs. If a water system serves "…7 or more homes, 10 or more duplexes, 10 or more mobile homes, 10 or more condominium units, or 10 or more apartments…," it is subject to the requirements of Chapter NR 811 of the *Wisconsin Administrative Code* entitled "Requirements For The Operation And Design Of Community Water Systems". If the system has 15 or more service connections, or serves an average of 25 people for more than 60 days per year, it is subject to Chapter NR 809 entitled "Safe Drinking Water." These code requirements are the same requirements that municipal systems must meet. Therefore, the cost associated with construction of supply, storage, and treatment systems for community water systems is considered to be similar to those used for public water systems, as described in Chapter IV.

COMMERCIAL AND INDUSTRIAL INDIVIDUAL SYSTEMS

Commercial and industrial development is usually located in areas served by public sanitary sewerage and water supply systems. Rural areas may contain industrial and commercial development served by private water supplies, but the size and extent of these types of development is generally limited. In calendar year 2000, private, self-supplied, water supply facilities serving commercial and industrial land uses provided a total of about 23 mgd.[7] These estimated quantities represent about 7 percent of total water withdrawals from the Region during the same period. For the purposes of this report, it is assumed the groundwater withdrawals are all governed under Chapter NR 812 of the *Wisconsin Administrative Code*. Well construction and pump installation costs vary by depth, production rate, and required water quality for the application concerned. Each industrial withdrawal and treatment facility must be evaluated on an individual basis to account for the wide range of variability.

Commercial and industrial development also tends to be located near areas served by public utilities and, in most cases, larger-scale developments would be served by municipal systems. In rural areas, developments, such as convenience stores, gas stations, and restaurants, use wells similar to those constructed for residential developments.

[7]*U.S. Geological Survey: Data Files for Estimated Use of Water in the United States, 2000, Available at http://water.usgs.gov/watuse/data/2000/wico2000.xls. Accessed June 20, 2006.*

AGRICULTURAL IRRIGATION AND OTHER SYSTEMS

In calendar year 2000, a total combined groundwater and surface water use for irrigation within the Region was estimated to be 7.4 mgd. This was just over 2 percent of the total water use within the Region.[8] Agricultural irrigation systems have evolved from a combination of open ditch, gated pipe, and center pivot sprinkler irrigation to predominantly center pivot sprinkler systems. Irrigation systems in the Region are typically provided water from high-capacity wells. These wells are constructed under the requirements of Chapter NR 812 of the *Wisconsin Administrative Code*. Construction costs for irrigation wells vary, depending upon the amount of water available, depth of well, and the aquifer the well is constructed in. Well construction costs are cited in Appendix A and range between $60 and $100 per vertical foot of well constructed, depending upon local conditions.[9]

As of 2002, there were about 550 dairy operations, with a total of about 47,000 milk cows, located in the Region. It is estimated that about 2.0 mgd are used within the Region to support these dairy operations. For the most part, all of this water is groundwater provided from domestic-type wells located on individual farms.[10]

ONSITE WASTEWATER DISPOSAL SYSTEMS CONSIDERATION

In areas served by onsite sewage disposal systems, a number of options are currently available for wastewater disposal based upon Wisconsin Department of Commerce regulations. All but one of these options, including conventional septic tank systems, mound systems, pressure distribution systems, and sand filter systems, rely on soil absorption systems for disposal of wastewater. Thus, most of the spent water is returned to the local aquifer. One option, the holding tank, does not provide for the return of the spent water to the local aquifer, since the spent water is stored, and then trucked to an offsite disposal facility—usually a public sewage treatment plant. The use of onsite sewage disposal systems, other than holding tanks, has a potential to impact groundwater quality, given that partially-treated wastewater is introduced below ground through soil absorption systems. Current State, county, and local programs and regulations are intended to minimize the potential for groundwater contamination of such systems. However, impacts on groundwater quality remain an important issue due to factors, such as the inadequate maintenance of some existing onsite sewage disposal systems; design and construction of older, existing systems; and the potential limitation in the effectiveness of the systems in minimizing contamination from emerging contaminants, such as viruses, pharmaceutical, personal care products, and toxic household chemicals.

There are a number of considerations that are usually taken into account when evaluating the use of onsite sewage disposal systems, including holding tanks for wastewater disposal. These considerations include, among others, the cost of installation and operation and maintenance, trucking impacts on roadways, groundwater quality, and homeowner maintenance. The impact of the loss of water from the local aquifer should also be considered in such an evaluation.

RAINWATER COLLECTION AND TREATMENT

Before the advent of municipal water treatment facilities, many people relied solely on the collection of rainwater for household and agricultural uses. Currently, some residents and businesses within the Region capture rainwater as a source of supply for maintenance of gardens and landscaping plantations. This section briefly describes

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[8]Ibid.

[9]*Telephone conversations with Sam's Well Drilling and Guthrie and Frye, June 22, 2006.*

[10]*Based upon regional data on operations and milk cows from* 2002 Census of Agricultural-County Data*, USDA National Agricultural Statistics Service; and* Groundwater Wisconsin's Buried Treasure*, Wisconsin Department of Natural Resources, April 2006, for water use data.*

rainwater collection and treatment systems, as such systems are, or could be, used for selected nonpotable uses as a component of individual water supply systems. Such systems are also described in Chapter VII, "Water Conservation," since the primary purpose of such systems is to reduce water uses supplied from other sources. In addition, the practices associated with rainwater infiltration enhancement are described in Chapter VI. Rainwater collection and treatment systems as presented in this chapter are considered viable only for nonpotable uses.

Most rainwater collection systems are designed to capture rainwater from the roofs of buildings. The water is then transported through gutters and other pipes into cisterns or tanks, where it is stored until needed. The water collected can be used for various nonpotable uses. A typical rainwater collection system may consist of the following:

- Collection area, usually the roof;
- Means of conveying the water, gutters, downspouts, and piping;
- Settling, initial flow diverters, and/or filtering device;
- Storage tank or cistern; and
- System to distribute the water as needed.

There are several options when it comes to selecting a storage container for the water. Most storage tanks or cisterns are constructed from concrete or fiberglass and can be located either above ground or below. Below ground systems will require a pumping system, as well as a piping system for water distribution.

All collected rainwater will contain some suspended solids and other contaminants which can be present, due to bird droppings, air pollution fallout, and other sources. Thus, care must be taken to prevent unintended human consumption of the water. Some systems have been designed to incorporate first flow diverters, or presettling facilities, to reduce the sediment and related contaminant content of the runoff. A residential rainwater collection and treatment system comprising a cistern, treatment system, pump, and piping for outdoor and limited selected indoor water use costs from $5,000 to $10,000.[11]

The simplest and most common technique for rainwater collection in the Region is the use of a rain barrel, with the collected water used for garden and landscape watering. This technique is described further in Chapter VII.

POINT-OF-USE AND POINT-OF-ENTRY WATER TREATMENT

Introduction
Individual dwellings or buildings have two options for the treatment of water once it enters the building. Point-of-entry treatment devices treat all, or most, of the water coming into a building, while point-of-use devices are typically designed to treat only that portion of water being used for consumptive drinking or cooking uses.

Regulatory Considerations
The Wisconsin Department of Natural Resources (WDNR) and the Wisconsin Department of Commerce (WDOC) have complimentary regulations for small individual water supply systems. In some cases, these regulations will result in situations where individual small system treatment is prohibited or impractical. In such situations, either a public water supply system is needed or the economics of providing a safe water source may preclude development. One of the major considerations associated with these regulations is the concern that lack of proper maintenance will make treatment ineffective in the long term. Even though homeowners have a prime vested interest in maintaining water treatment devices, they often do not provide routine maintenance, such as

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[11]*Drittari J. Krishna, Texans Water Development Board, www.twdb.state.tx.us.*

changing filters or media, and do not hire professional, qualified personnel to calibrate devices or take samples to verify proper operation. Such maintenance issues are of less concern with treatment units designed to remove hardness or iron, but are a significant concern when considering acute health contaminants.

The WDNR regulations, as set forth in Chapter NR 812 of the *Wisconsin Administrative Code*, require abandonment of wells contaminated with biological agents if batch chlorination treatments fail to eliminate the problem. Such regulations are designed to protect the groundwater resource from cross-contamination, as well as to protect the public health. In addition, the WDNR may require abandonment of a well if the well water is contaminated with a substance in exceedence of the State drinking water standards. As a matter of policy, the WDNR considers individual system treatment to be the solution of last resort for health-related contaminants. Treatment is typically approved for individual water systems only when obtaining a natural safe source of water is impractical. In many cases, a replacement well can be drilled into a different aquifer to avoid contamination. Examples are gasoline-contaminated wells that are replaced with deeper wells, or arsenic-contaminated wells that are replaced with shallower wells. In some cases, the WDNR will approve treatment, such as was done in Door County, Wisconsin, where bacteria-free water could not be obtained due to bedrock crevices, and where some restaurants and resorts were approved to install ultraviolet light treatment units. This approval was conditioned upon annual certification by a licensed plumber and monthly water monitoring.

The WDOC regulations require approval of all plumbing products, including treatment devices for small individual users. The WDOC maintains a listing of all water treatment devices that are approved systems, following manufacturer submittals of specifications and test data. The WDOC-approved treatment devices are listed on the "Plumbing Products Register," which is available on the Department's website.

Available Technologies

The type of devices that are currently available have different principals of operation, remove different types of contaminants, and have different efficiencies and anticipated service lives. Two types of devices are predominant: faucet-mounted and pitcher-style filters.[12] The faucet-mounted devices can be plumbed-in units before the faucet, faucet-attached units, or faucet-connected counter top units. Separate faucets are often provided for water to be consumed and allow the use of untreated water for washing and cleaning, thus reducing operating costs of the point-of-use unit.[13]

The primary point-of-use technologies are adsorptive media, ion exchange, granular activated carbon, and reverse osmosis. The primary point-of-entry technologies are granular activated carbon, ion exchange, and iron oxidation-filtration, which are all treatment processes that have been described in previous chapters. The processes are identical at the point-of-entry and point-of-use treatment levels, only on a much smaller scale. Table 10 provides a listing of promising technologies for point-of-entry and point-of-use treatment.

Point-of-Entry Devices

Traditionally point-of-entry devices have been used primarily to alter the aesthetic characteristics of the water supply. Treatment methods included softening using ion exchange, and iron removal using oxidation and filtration. In the last few decades, point-of-entry treatment has expanded to include membrane filtration, granular activated carbon, and aeration technologies. In some cases, specialty process or medias are required for removal of specific contaminants.

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[12]Research Report on Investigation of the Capability of Point-of-Use/Point-of-Entry Treatment Devices as a Means of Providing Water Security*, Office of Research and Development, National Homeland Security Research Center, U.S. Environmental Protection Agency, February 2006, p. ix.*

[13]Point-of-Use or Point-of-Entry Treatment Options for Small Drinking Water Systems*, U.S. Environmental Protection Agency, Office of Water, April 2006, p. 1-1.*

Table 10

PROMISING POINT-OF-ENTRY AND POINT-OF-USE TECHNOLOGIES

Technology	Removes					Notes
	Viruses	Bacteria	Cysts	Organic Compounds	Metals	
Solid Block Activated Carbon (SBAC)	No	Some	Yes	Most	Most	Limited removal capability for some pesticides; can remove methyl tertbutyl ether and selected disinfection byproducts; also removes chlorine
Granular Activated Carbon (GAC)	No	No	No	Most	Some	Limited removal capability for atrazine, aldicarb, and adachor; shows promise for removal of biotoxins; removes chlorine
Reverse Osmosis (RO)	Yes	Yes	Yes	Most	Most	Not effective at removing low molecular weight organic compounds; removes radionuclides
Ultraviolet (UV) Light	Most	Yes	Yes	No	No	Requires prefiltration; used alone or in combination with other technologies
Microfiltration (MF)	No	Yes	Yes	No	Some	Used as prefilters in combination with RO; metals depending upon the metal compound formed
Ultrafiltration (UF)	Some	Yes	Yes	Some	Some	Cannot remove low-weight (less than 100,000 daltons) organic compounds; metals depending upon the metal compound formed
Nanofiltration	Yes	Yes	Yes	Some	Some	Can be configured to remove arsenic; metals depending upon the metal compound formed
Adsorptive Media	No	No	No	Some	Some	Fluoride, arsenic, can be configured to reduce radium
Softening	No	No	No	No	Some	Calcium hardness, radium and uranium
Iron Removal	No	No	No	No	Some	Can promote bacterial growth

Source: Adapted from Research Report on Investigation of the Capability of Point-of-Use/Point-of-Entry Treatment Devices as a Means of Providing Water Security, Office of Research and Development, National Homeland Security Research Center, U.S. Environmental Protection Agency, February 2006.

Softeners

Water softeners have been used for treating water that is considered to be hard. Hard water is water that contains excessive amounts of dissolved calcium and magnesium. The more of these minerals dissolved in the water, the harder the water. Calcium and magnesium are not harmful to consume, but can have damaging affects to plumbing, plumbing fixtures, and other household investments. Most water softeners use ion exchange to remove calcium and magnesium minerals and to replace them with sodium. The unit, or the media, must typically be replaced every seven to 12 years. Typically, the entire unit is in need of replacement after this time period.

Membrane Filtration

Membrane filtration systems for home water treatment generally employ reverse osmosis filtration technology. Reverse osmosis decreases dissolved minerals in the water. It successfully treats water high in salt, hard water, and water with high mineral content. Reverse osmosis also is capable of filtering microorganisms, if properly maintained. The systems use high pressure to force water through a thin membrane with very fine pores. The membrane allows the water through, but not the minerals or microorganisms. The filtrate is then disposed of by discharge to the household drain system.

Point-of-Entry (POE) Treatment Costs

The costs associated with point-of-entry treatment are highly variable depending on the contaminants to be treated and their concentration. Economies of scale also tend to decrease costs in areas where a certain contaminant predominates because local suppliers and installers sell and install systems in higher quantity. Table 11 summarizes the cost of purchase and installation of typical point-of-entry treatment systems and the annual operation and maintenance costs. The annual costs vary considerably with water quality conditions. For example, water-softening costs are dependent upon the frequency of backwashing the softening media, which is dependent upon the hardness of the water.

Point-of-Use Devices

NSF International (NSF) is a nonprofit, independent organization that is the world leader in standards development related to public health, safety, and standards development, and is widely recognized for its scientific and technical expertise in the health and environmental sciences. The NSF Water Treatment Device Certification Program[14] provides product testing and evaluation of residential water treatment products. The technologies currently evaluated and the applicable standards are listed in Table 12.

Point-of-use systems typically treat water in batches and deliver water to a single tap, such as a kitchen sink faucet or an auxiliary faucet mounted next to the kitchen sink. The following listing provides brief explanations of different point-of-use systems, and issues to consider when determining which type of a system is best for a particular proposed application. The list is ordered from easiest installation and operation to more difficult or complex installation and operation, and is not meant as a recommended order of choice.

Personal Water Bottle	This type of product consists of a bottle and a filter. The filter may be integrated with the push/pull cap of the filter bottle or may be integrated with a straw.
Pour Through	In pour-through products, gravity causes water to drip through a filter into a pitcher, which is usually stored in the refrigerator. These products typically have a lower capacity—can filter fewer gallons—than other types of systems.
Faucet Mount	This type of filter is mounted on an existing kitchen sink faucet, usually replacing the aerator or installed immediately before the aerator. A diverter is usually used to direct water through the system when treated drinking water is desired.
Counter-Top Manual Fill	This system is usually placed on a counter and filled by pouring water into the system and activating it for a batch of water. A manual fill distiller is usually considered to be a counter-top manual fill.
Counter-Top Connected to Sink Faucet	This product is usually placed on a counter and connected by tubing to an existing kitchen sink faucet. The treated water dispenses out of a return tube from the kitchen faucet, or the treated water is dispensed from a spout on the system.
Plumbed-In	This type of system is usually installed under the sink and requires a permanent connection to an existing water pipe. The filter water is dispensed through the existing sink faucet.
Plumbed-In to Separate Tap	This product installs in the same manner as plumbed-in systems. However, the filter water is dispensed through an auxiliary faucet mounted next to the kitchen sink.

[14] *http://www.nsf.org/consumer/drinking_water, Accessed June 20, 2006.*

Table 11

CAPITAL AND OPERATION AND MAINTENANCE COSTS OF COMMON POINT-OF-ENTRY TREATMENT UNITS (2005 DOLLARS)

Treatment Technology	Estimated Capital Cost	Estimated Annual Operations and Maintenance Costs
Reverse Osmosis	$5,000-$20,000	$150-$250
Ultraviolet	$1,000	$100-$150
Cation Exchange (water softening)	$800-$3,300	$200-$500
Granular Activated Carbon and UV	$3,000	$200-$250

Source: Adapted from Research Report on Investigation of the Capability of Point-of-Use/Point-of-Entry Treatment Devices as a Means of Providing Water Security, *Office of Research and Development, National Homeland Security Research Center, U.S. Environmental Protection Agency, February 2006, p. ix. and Lahlou, Z. Michael, "Tech Brief: Point-of-Use/Point-of-Entry Systems,"* On Tap Magazine*, National Drinking Water Clearinghouse, Spring 2003.*

Table 12

CURRENT STANDARDS AND TECHNOLOGY FOR POINT-OF-USE TREATMENT

Technology	Description of Product Technology
Adsorption (NSF/ANSI 42 & 53)[a]	This is the physical process that occurs when liquids, gases, dissolved or suspended matter adhere to the surface of, or in the pores of, an adsorbent medium. Carbon filters use this technology to filter water
Softeners (NSF/ANSI 44)	Water softening devices covered by Standard 44 use a cation exchange resin, regenerated with sodium chloride or potassium chloride, to reduce the amount of hardness (calcium, magnesium) in the water. The hardness ions in the water are replaced with sodium or potassium ions
Ultraviolet Treatment (NSF/ANSI 55)	This treatment style uses ultraviolet light to disinfect water (Class A systems) or to reduce the amount of heterotrophic bacteria present in the water (Class B systems)
Reverse Osmosis (NSF/ANSI 58)	A process that reverses, by the application of pressure, the flow of water in a natural process of osmosis so that water passes from a more concentrated solution to a more dilute solution through a semi-permeable membrane. Most reverse osmosis systems incorporate pre- and post-filters along with the membrane itself
Distillers (NSF/ANSI 62)	These systems heat water to the boiling point and then collect the water vapor as it condenses, leaving many of the contaminants behind, particularly the heavy metals. Some contaminants that convert readily into gases, such as volatile organic chemicals, may be carried over with the water vapor

[a]NSF/ANSI refers to National Sanitation Foundation International, a private public health and safety company, and ANSI refers to the American National Standards Institute, an institute that coordinates private-sector standards setting in the United States.

Source: http://www.nsf.org/consumer/drinking_water, Accessed June 20, 2006.

Point-of-Use Treatment Costs

The U.S. Environmental Protection Agency (USEPA) is currently conducting a study of the cost of point-of-use and point-of-entry devices that will be released in late 2006. In a February 2006 research report on use of point-of-use and point-of-entry devices as security devices,[15] USEPA did develop cost tables for two scenarios of treatment: reactive and proactive. The reactive scenario is where contamination is discovered and a homeowner

[15]Research Report on Investigation of the Capability of Point-of-Use/Point-of-Entry Treatment Devices as a Means of Providing Water Security*, Office of Research and Development, National Homeland Security Research Center, U.S. Environmental Protection Agency, February 2006, p. ix.*

reacts to install treatment quickly. The proactive scenario is where homeowners install equipment initially or in anticipation of water quality problems. Tables 13 and 14 present these costs.

The use of point-of-use devices and the choice of which type to use is affected by the water quality at the treatment site. The removal efficiency of a device can be reduced by the presence of high levels of competing contaminants or fouling agents. Some of the leading causes of concern and competing ions are listed in Table 15.

Periodic maintenance is required for the devices to work properly and for continual removal of contaminants. Table 16 presents operation and maintenance recommendations for both point-of-entry and point-of-use devices. Poor maintenance of water treatment devices may contribute to a health hazard. Proper maintenance of private water treatment devices is important for the devices to function as intended and to reduce nuisance and public health-related contaminants. Reduced effectiveness due to lack of proper maintenance of devices may not be readily evident. In order to properly maintain small-scale, individual water systems, it is important to make sure the device is accompanied by adequate information on lifetime capacity, and clear instructions for operation and maintenance when purchased. This will facilitate the development of information on replacement and operation and maintenance schedules and costs. Some devices may need to be calibrated by a qualified technician. Periodic water sampling is important for systems that are designed to remove health-related contaminants.

WATER SUPPLY TESTING

Water that comes from a municipal system is regularly tested for contaminants regulated by Federal and State standards. It is also desirable to periodically have private, individual well water supplies periodically tested by a certified laboratory periodically to avoid risks. The Wisconsin Department of Natural Resources recommends an annual test of well water for bacteria. Wells should also be tested when any change in taste, odor, or appearance is noted. Water testing can also be useful in helping to select, operate, and maintain point-of-entry and point-of-use water treatment devices.

All of the counties in the Region, which have significant numbers of private wells, will assist individual homeowners in obtaining an analysis of their well water. Typical costs are $20 for testing for bacterial content and $10 for chemical testing for nitrate, fluoride, hardness, chlorine, and iron content for owner-collected samples. For county or commercial staff collected samples, costs will approximate $125 for bacterial testing and $135 for bacterial, plus chemical testing.

BOTTLED WATER

Use of commercially available bottled water may be a viable alternative to use of small, individual water treatment devices, particularly if needed for only limited uses or for a short period of time. In some cases, this option is used when a homeowner or business is pursuing a new source of water, or installing a point-of-use or point-of-entry water treatment device. Other homeowners or businesses may utilize bottled water on a permanent basis for selected purposes—most often direct consumption.

Bottled water is regulated as a food by the U.S. Food and Drug Administration (FDA). The FDA concerns itself mostly with sanitation and labeling, but is also responsible for ensuring that bottlers comply with Primary and Secondary Drinking Water Standards. However, only those bottlers operating in more than one state are regulated by the FDA. In Wisconsin, the Wisconsin Department of Agriculture, Trade, and Consumer Protection (WDATCP) regulates and inspects water bottling operations, and the Wisconsin Department of Natural Resources monitors the associated sources of supply.

The WDATCP, Division of Food Safety, is required by State law to annually sample bottled water produced in Wisconsin and to issue a report on the findings. In addition, bottling establishments must meet specific requirements for product sampling, analysis, recordkeeping, and reporting. At a minimum, bottling establishments must test for bacteria each month; nitrates every calendar quarter; volatile organics, pesticides, and inorganics

Table 13

COMPARATIVE POINT-OF-USE (POU) TREATMENT COSTS AT HOUSEHOLDS: REACTIVE SCENARIO

Treatment Technology	Initial Cost	Estimated Annual Operation and Maintenance Cost
RO POU without UV Disinfection	$400-$700	$150-$200
RO POU with UV Disinfection	$600-$900	$300-$350
RO/GAC–Faucet Mount	$50	$50
RO/GAC–Under the Sink	$300	$100-$150
Specialty media POU–Arsenic Removal	$300-$650	$100-$150
GAC POU without UV–faucet Mount	$10-$30	$10-$30
GAC POU without UV–Under the Sink	$500	$200-$300
GAC POU with UV–Under the Sink	$750	$350-$450
GAC POE with UV	$3,000	$600-$750
Rented RO POU without UV	- -	$200-$300

Source: Adapted from Research Report on Investigation of the Capability of Point-of-Use/Point-of-Entry Treatment Devices as a Means of Providing Water Security*, Office of Research and Development, National Homeland Security Research Center, U.S. Environmental Protection Agency, February 2006, pp .ix.*

Table 14

COMPARATIVE POINT-OF-USE (POU) TREATMENT COSTS AT HOUSEHOLDS: PROACTIVE SCENARIO

Treatment Technology	Initial Cost	Estimated Annual Operation and Maintenance Cost
RO POU	$200-$400	$150-$200
Rented RO POU	- -	$200-$300
Specialty Media POU	$150-$250	$100-$150
Pitcher Filters	$75	$75
GAC–Under the Sink	$100-$150	$200-$300
Rented GAC POU without UV	- -	$250-$300
Rented GAC POU with UV	- -	$350-$400

Source: Research Report on Investigation of the Capability of Point-of-Use/Point-of-Entry Treatment Devices as a Means of Providing Water Security*, Office of Research and Development, National Homeland Security Research Center, U.S. Environmental Protection Agency, February 2006, pp .ix.*

Table 15

WATER QUALITY PARAMETERS OF CONCERN FOR POINT-OF-USE (POU) AND POINT-OF-ENTRY (POE) TECHNOLOGIES

Technology	Water Quality Parameter of Concern	Issue
Ion Exchange	Iron, manganese, copper	Fouling, competing ions
Adsorptive Media	Silica, fluoride, phosphate, sulfate, dissolved iron and manganese	Interfering/competing ions
Reverse Osmosis	Hardness, iron, manganese	Fouling
Granular Activated Carbon	Organics, multiple SOCs or VOCs present	Competing ions
Aeration	Hardness, iron, manganese	Fouling, scaling

Source: Point-of-Use or Point-of-Entry Treatment Options for Small Drinking Water Systems*, U.S. Environmental Protection Agency, Office of Water, April 2006, pp. 1-1.*

Table 16

OPERATION AND MAINTENANCE RECOMMENDATIONS FOR VARIOUS POINT-OF-ENTRY (POE) AND POINT-OF-USE (POU) TREATMENT DEVICES

Treatment Technology	Operation and Maintenance Considerations
Adsorptive Media: Activated Alumina (AA) and Specialty Media	POU: Replacement of spent cartridges and particulate pre-filters (if used) POE: Periodic backwashing. Replacement of spent media and particulate pre-filters (if used). Maintenance and cleaning of storage tank (if used)
Aeration: Diffused Bubble or Shallow Tray	Only appropriate for POE Replacement of particulate pre-filters. Replacement of air filters for fan intake and for exhaust. Maintenance of fan, motors, and (re) pressurization pumps. Replacement of post-treatment (GAC polishing filters. Maintenance and cleaning of storage tank If UV is used for post-treatment disinfection, replacement of UV bulb and cleaning bulb housing. If ozonation is used for post-treatment disinfection, maintenance of ozonation element
Granular Activated Carbon (GAC)	POU: Replacement of spent cartridges and particulate pre-filters (if used) POE: Periodic backwashing. Replacement of spent media and particulate pre-filters (if used). Maintenance and cleaning of storage tank (if used). If UV is used for post-treatment disinfection, replacement of bulb and cleaning bulb housing. If ozonation is used for post-treatment disinfection, maintenance of ozonation element
Ion Exchange (IX): Anion Exchange (AX) and Cation Exchange (CX)	POU: Replacement of spent resin cartridges and particulate pre-filters (if used) POE: Regular regeneration and periodic backwashing. Replacement of salt used for resin regeneration. Replacement of lost or spent resin and replacement of particulate pre-filters. Maintenance and cleaning of storage tank (if used)
Reverse Osmosis (RO)	POU and POE: Replacement of exhausted membranes, particulate pre-filters, and pre- and post-treatment GAC filters. Maintenance and cleaning of storage tank. Maintenance of (re) pressurization pumps (if used)
Ultraviolet Light (UV)	POU and POE: Replacement of UV bulbs. Cleaning bulb housing

Source: Point-of-Use or Point-of-Entry Treatment Options for Small Drinking Water Systems, *U.S. Environmental Protection Agency, Office of Water, April 2006, p. 1-1.*

every third year; and radionuclides every five years. The bottling establishment must retain the results of microbiological analyses for one year, chemical analyses for six years, and radiological analyses for 10 years.

During the State fiscal year ending June 30, 2004, the Division of Food Safety analyzed 11 commercial bottled water samples, from 10 licensed establishments. These samples included water from both private wells and municipal water sources. The samples were analyzed for 26 possible substances that have aesthetic defects or are contaminants of public health concern. All of the samples analyzed in 2004 met current public health enforcement standards as set forth in Chapter NR 140 of the *Wisconsin Administrative Code*.

SUMMARY

This chapter has addressed the onsite provision and treatment of water for individual homes and businesses, industry, agriculture and dairy operations not served by public water supply systems. Further, this chapter has described the methods used for removal of aesthetic and health related contaminants at the point-of-entry to or point-of-use of an individual property and provides costs for the various options a home or business may employ to treat the individual water supply. No typical treatment train is described because the treatment of groundwater drawn from onsite wells varies depending on the contaminants present, from no treatment required to very expensive treatment trains to remove multiple contaminants.

Chapter VI

ARTIFICIAL GROUNDWATER RECHARGE AND MANAGEMENT

INTRODUCTION

Artificial recharge is defined as any engineered system designed to introduce and store water in an aquifer.[1] This chapter presents planning data for those artificial recharge technologies that are considered appropriate for application in water supply system planning for the Southeastern Wisconsin Region. Included for each technology are descriptions of the processes concerned, design considerations, source water and treatment considerations, and data on unit capital and operation and maintenance costs. In addition, information on monitoring requirements, regulatory issues, and selected case histories is provided. A summary section is provided that draws conclusions regarding the use of artificial recharge technologies with southeastern Wisconsin.

Land use development and associated stormwater management and wastewater disposal practices typically have impacts on groundwater and surface water hydrology. Such impacts typically include increases in runoff and reductions in infiltration of precipitation due to the development of impervious surfaces. When public sanitary sewerage systems are developed to support development, water supplies used may be exported from the source of supply areas as treated wastewater. These changes in the natural hydrology can be minimized by developing land in a manner that reduces the hydrologic impacts, such as conservation subdivision design. In addition, preservation of important recharge areas can reduce the impacts of development on the natural hydrology. In areas where development occurs on onsite sewage disposal systems, the export of spent groundwater is minimized. This chapter is not intended to present information on these management practices for maintaining the natural hydrology. Rather, the chapter is intended to focus on information related to artificial groundwater recharge technologies that can be considered to offset groundwater withdrawal and recharge losses and provide other benefits. The chapter includes information on selected stormwater management measures that are considered as a means of artificial surface infiltration technologies. However, the chapter does not present information on development practices, natural recharge area protection, and the use of onsite sewage disposal systems. Those practices are to be considered as part of the future conditions and alternative plan development elements of the regional water supply planning program.

Artificial recharge can be accomplished by a number of methods that can be broadly classified into the following categories:

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[1]*Ralf Topper, Peter E. Barkmann, David R. Bird, and Matthew A. Sares, Colorado Geological Survey Department of Natural Resources,* Artificial Recharge of Ground Water In Colorado - A Statewide Assessment*, 2004.*

- Surface infiltration, which uses infiltration basins, or impoundments, to percolate water into the ground;

- Subsurface infiltration, which uses vadose zone (unsaturated zone) wells or trenches to introduce water into the unsaturated zone below the ground surface to facilitate infiltration;

- Direct injection, including aquifer storage and recovery, which uses wells or other structures to inject water directly into an aquifer. The water is recovered by the same well in typical aquifer storage and recovery systems;

- Enhanced recharge, which uses man-made changes to the land surface to increase the amount of water recharged from natural sources;

- Riverbank filtration, including induced recharge, which uses well fields placed near surface waterbodies with the intention of inducing surface water into the aquifer to provide some or all of the water produced by the well field; and

- Water banking under which an aquifer is recharged by one of the foregoing methods with the intent of recovery of the water at some future, possibly undefined, timeframe.

Figure 9 illustrates several different types of groundwater recharge. The schematic block diagram illustrates examples of natural, enhanced, induced, and incidental recharge, and aquifer recharge by injection.

Nonaquifer underground storage is a related technology that uses underground voids such as mines or caverns to store water on a limited basis where suitable structures exist. These structures tend to have limited storage volumes and are only present in a few locations. As a result, underground nonaquifer storage methods are not described in this report.

Artificial recharge is distinguished from incidental recharge, which is defined as recharge that reaches an aquifer from human activities not designed specifically for recharge.[2] Incidental recharge includes septic tank leach fields, stormwater retention ponds, percolation from irrigation, leaking water, or wastewater facilities.

Artificial recharge is in use in at least 32 states and 26 countries.[3] Map 2 shows the distribution of artificial recharge projects in the United States by state, including all forms of artificial recharge. It has been used in one form or another in a few locations for centuries. Nomads in Turkmenistan and tribal communities in India have used hand-dug wells and trenches to direct recharge into shallow sand deposits for later recovery with shallow wells.[4] In the United States, the U.S. Geological Survey (USGS) has been involved in artificial recharge projects for over 100 years.[5]

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[2]*Herman Bouwer, "Artificial Recharge of Groundwater: Hydrogeology and Engineering,"* Hydrogeology Journal *Vol. 10, 2002, pp. 121-142.*

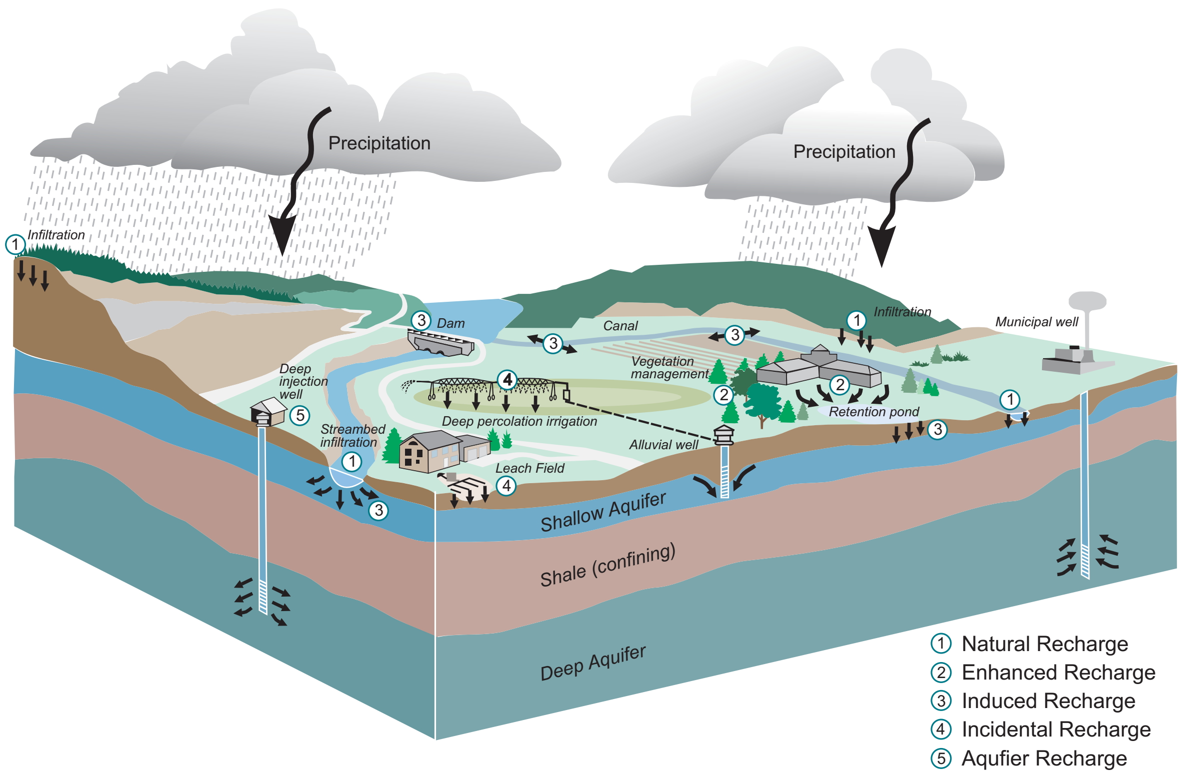
[3]*Ralf Topper,* et. al., op. cit.

[4]*R. David G. Pyne,* Groundwater Recharge and Wells A Guide to Aquifer Storage Recovery, *Lewis Publishers, 1995.*

[5]*E.P. Weeks,* A Historical Overview of Hydrological Studies of Artificial Recharge in the U.S. Geological Survey, *U.S. Geological Survey Open File Report 02-89, 2002.*

Figure 9

SCHEMATIC DIAGRAM OF GROUNDWATER RECHARGE METHODS



Source: Colorado Geological Survey Department of Natural Resources and SEWRPC.

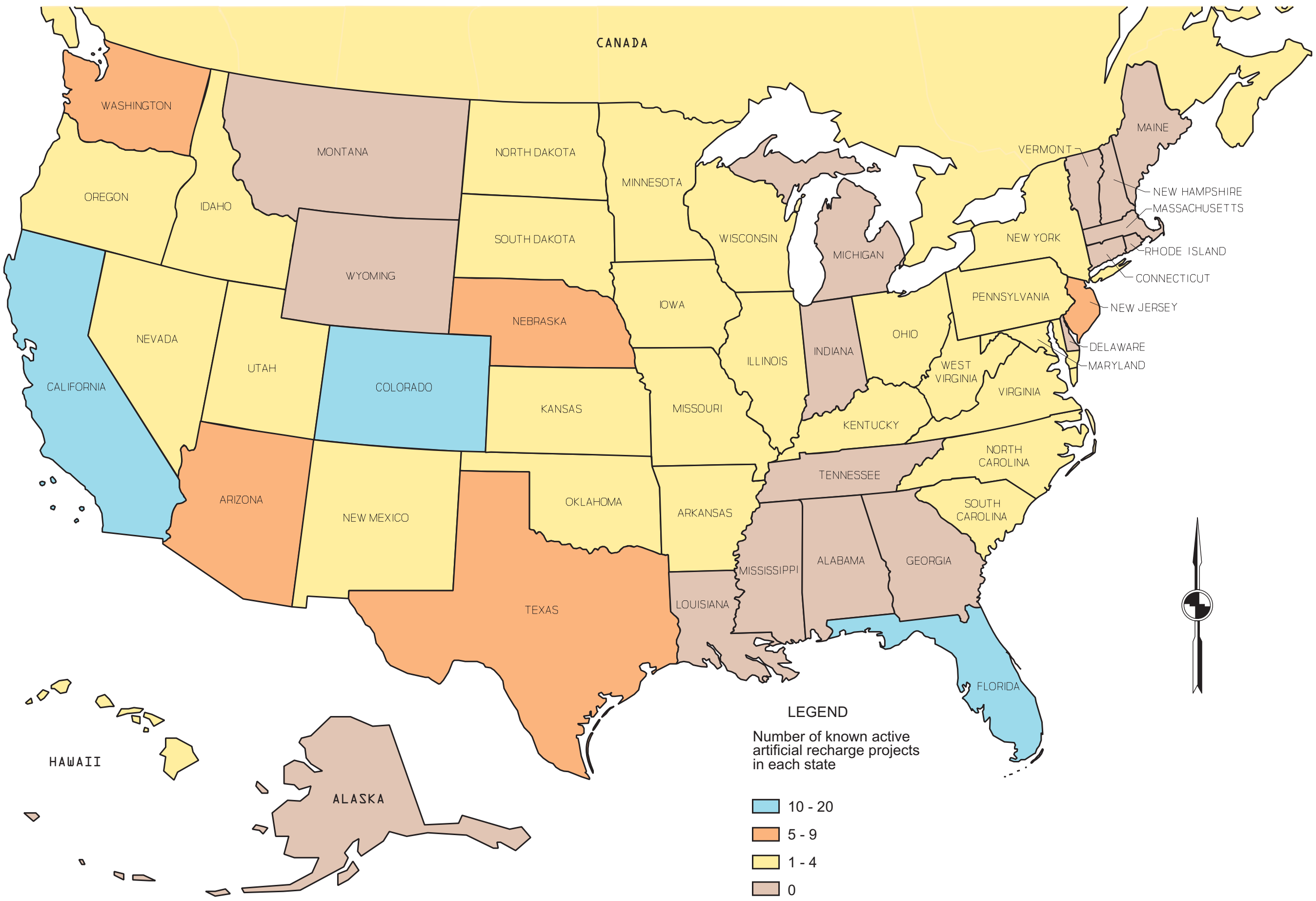
Most larger artificial recharge projects are located in the arid to semi-arid west or in areas where population growth or irrigation has stressed available water supplies such as in California, Arizona, Nevada, Florida, Kansas, Colorado, and New Jersey and New York. Artificial recharge systems range from small stormwater ponds intended to infiltrate runoff from small subdivisions to large recharge projects covering entire valleys, such as the project in Las Vegas, Nevada, that has a recovery capacity of 100 million gallons per day (mgd).[6]

Artificial recharge projects have been designed to accomplish many goals. These goals include:

- Water supply management to balance short-term or long-term imbalances in water supply;
- Meeting legal obligations, such as downstream flow requirements or interstate water agreements;
- Manage water quality by using the aquifer to improve water quality or temperature or to blend waters of different quality;
- Restoration or protection of aquifers by restoring groundwater levels, limiting compaction, or preventing salt water intrusion; and
- Environmental protection, such as restoring wetlands, enhancing habitat, or controlling the migration of contaminated groundwater.

Map 2

ARTIFICIAL RECHARGE IMPLEMENTATION SUMMARY



Note: Number of projects does not represent all Artificial Recharge projects in a state.

Source: Colorado Geological Survey Department of Natural Resources and SEWRPC.

Some of these goals are specific to western water law or western water compacts. Others are more related to arid and semiarid regions or coastal aquifers. For southeastern Wisconsin, the most likely objectives of a potential artificial recharge project would be to:

- Restore water levels in a partially depleted aquifer;
- Increase the sustainable yield of a well field;
- Supplement the base flow to a stream, wetland, spring, or lake;
- Manage stormwater to limit peak flows in streams;
- Moderate temperature changes in sensitive waterbodies such as trout streams;
- Offset down-gradient impacts caused by impermeable surfaces or well fields; or
- Protect groundwater quality.

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[6]*American Society of Civil Engineers,* Standard Guidelines for Artificial Recharge of Ground Water, *2001.*

Runoff from urban and some rural lands can contain contaminants that could be detrimental to groundwater quality. Furthermore, recharge of treated wastewater into aquifers has a potential for transmitting regulated and unregulated contaminants into the groundwater system. Care must be taken to avoid the potential contamination of aquifers from artificial recharge projects.

Artificial recharge projects typically take several years to develop and must consider a myriad of factors dealing with site conditions, project objectives, water quality, economics, and environmental issues. The American Society of Civil Engineers (ASCE)[7] has established a set of standard guidelines meant to help identify the important issues involved in an artificial recharge project and has established procedures to address these issues in an organized manner. The guidelines can be briefly summarized as follows:

- Phase I–Preliminary Activities, such as data collection, water resource evaluation, evaluation of potential sites, developing a conceptual plan, and environmental assessment and public involvement;

- Phase II–Field Investigation and Test Program, including infiltration tests, subsurface investigations, water quality testing, and environmental site assessments;

- Phase III–Design, including preliminary and final designs, groundwater modeling, pilot tests, economic analysis, environmental assessments, public involvement, and engineering reports;

- Phase IV–Construction and Start Up;

- Phase V–Operation, Maintenance, Project Review, and Project Modification; and

- Phase VI–Closure, including sampling for residual contamination and eliminating pathways for groundwater contamination.

This report and subsequent reports prepared for the regional water supply plan for southeastern Wisconsin will provide some of the elements required for a Phase I preliminary activities study. However, the provision of other elements of a Phase I study, and the subsequent phases, would require site-specific investigations after the location and objectives of any artificial recharge project are identified.

SOURCES OF COST DATA

Cost data for artificial recharge systems is difficult to find. Typical system costs are affected by many factors including site conditions, type of recharge system, water treatment processes, cost to acquire and transmit the source water, land costs, and regulatory standards. This report uses published cost data, where available, and information from several artificial recharge practitioners for additional data. The most relevant cost data came from artificial recharge projects in southeastern Wisconsin. Recent cost data was available for the Oak Creek aquifer storage and recovery system. Construction cost data has been used to estimate the cost of constructing a hypothetical artificial recharge system in southeastern Wisconsin that is similar to the Lake Geneva infiltration system using three different levels of treatment. Water treatment cost data from Chapter III of this report were used to compare data from the literature and calculate the cost of the hypothetical recharge system.

ARTIFICIAL RECHARGE TECHNOLOGIES PROCESS DESCRIPTIONS

Artificial recharge can be accomplished in several ways depending on the soils present in the unsaturated zone, the aquifer concerned, and the objectives of the project. Bouwer[8] provides an excellent summary of artificial

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[7]Ibid.

[8]*Herman Bouwer*, op. cit.

recharge practices. In general, artificial recharge can be accomplished by either surface or subsurface methods. Table 17 summarizes the common artificial recharge technologies together with attendant advantages and limitations.

Surface Infiltration Methods
Surface methods are generally preferred due to lower cost, greater simplicity, and lower operation and maintenance costs. Surface methods require sites with permeable soils, sufficient depth to the water table, suitable topography, no perching layers above the aquifer, and an aquifer that has sufficient permeability and lateral extent to accept the water without building a large groundwater mound that would impede further infiltration. Common surface infiltration methods include infiltration ponds and spreading basins, infiltration ditches, stream channels, closed depressions, including kettles, and land applications. Figure 10 illustrates common surface infiltration methods.

- Infiltration ponds and spreading basins are artificial depressions or diked structures that receive water and allow the water to recharge an aquifer through the bottom of the structure. Existing excavations, such as gravel pits or leaky reservoirs, are often used for recharge basins. Smaller structures are commonly called infiltration ponds or basins, larger structures are commonly called spreading basins.

- Infiltration ditches are linear structures, such as canals or ditches, which are designed to leak water through their bottoms to recharge an aquifer. Infiltration ditches can sometimes be built in areas where the topography or limits of available land preclude the use of infiltration ponds.

- Riverbank filtration is a method of using a well field near a surface waterbody to induce recharge from the surface waterbody to supplement all or some of the well field production. This technology can be viewed as a means of substituting surface water sources for a significant portion of a groundwater source of supply. Riverbank filtration systems can be developed using vertical wells along the edge of a river, lake, or reservoir in an aquifer that is hydraulically connected to the waterbody. The portion of the well production that comes from induced recharge is a function of the volume of recharge to the aquifer from other sources, the proximity of the well field to the waterbody, and the hydraulic connection of the aquifer to the waterbody. Horizontal wells may be used with screened intervals projected under the waterbody to maximize the amount of water derived from induced recharge. In many cases the permeability of the bottom of the waterbody is the most important limiting factor on the volume of recharge than can be induced. Over time, clogging can occur on the riverbed from siltation, geochemical precipitation, or biological growth.[9] Clogging is unavoidable and eventually leads to the need to abandon the riverbank filtration system. However, the rate of clogging can be limited by reducing infiltration velocities and by maintaining water quality in the surface waterbody involved.

  Riverbank filtration systems are common in Europe. Approximately 16 percent of the drinking water in Germany, 40 percent in Hungary, 48 percent in Finland, 50 percent in France, and 80 percent in Switzerland, is produced by riverbank filtration systems.[10] Such systems are less common in the

[9]*Jurgen Schubert,* Significance of Hydrologic Aspects on RFB Performance, *Slovakia Republic, 2004, Available at: www.soulstatic.com/NATORBF/papers/schubert/casehistory.pdf.*

[10]*Nathalie Tufenkji, Joseph N. Ryan, and Menachem Elimelech, "Bank Filtration,"* Environmental Science & Technology, *November 1, 2002.*

Table 17

COMPARISONS OF ARTIFICIAL RECHARGE TECHNOLOGIES

Technology	Description	Advantages	Limitations	Aquifer Suitability
Surface Infiltration (general comments apply to all technologies within this category)	- -	• Initial low capital construction cost • Maintenance can be simple and low cost • Low operation and maintenance costs • Can use untreated surface water • Can co-exist with recreation use or wildlife habitat	• Require near-surface aquifer • Require permeable soil profile/high vertical permeability • Require frequent maintenance to prevent clogging • Evaporation losses can be high • Vulnerable to surface contamination • Land availability and cost • May be incompatible with nearby land uses • Regulatory considerations	• Unconfined aquifers with surface exposure • Alluvium • Semi-consolidated sediments at outcrop • Highly fractured bedrock
Infiltration Ponds and Basins Spreading Basins	Engineered off-channel structures (rectilinear)	• Can adapt former gravel pits and quarries	• Can require large tracts of land	• Unconfined aquifers with surface exposure • Alluvium • Semi-consolidated sediments at outcrop • Highly fractured bedrock
Selected Stormwater Management Measures	Grassed swale drainage systems, including grassed roadway drainage ditches, bioretention basins, surface sand filters, and rain gardens	• Commonly used practices • Serve multiple purposes by reducing runoff rates and volumes and potentially reduces non-point source pollution	• Limited in areas with poorly drained soils • Requires water quality impact evaluation	• Unconfined aquifers with surface exposure • Alluvium
Leaky Ponds and Reservoirs	Allow existing structure to leak	• Can utilize existing structures	• Very site-specific	• Unconfined aquifers with surface exposure • Alluvium • Semi-consolidated sediments at outcrop • Highly fractured bedrock
Infiltration Ditches Ditch/Furrow	Engineered off-channel structures (linear)	• Adapt to irregular topography	• Very site-specific	• Unconfined aquifers with surface exposure • Alluvium • Semi-consolidated sediments at outcrop • Highly fractured bedrock

Table 17 (continued)

Technology	Description	Advantages	Limitations	Aquifer Suitability
Leaky Ditches	Allow existing structure to leak	• Utilize existing structure	• Very site-specific	• Unconfined aquifers with surface exposure • Alluvium • Semi-consolidated sediments at outcrop • Highly fractured bedrock
Dry Stream Channels	Divert flow into the natural channel of an ephemeral stream	• Utilize natural topographic feature	• Very site-specific • Environmental concerns	• Unconfined aquifers with surface exposure • Alluvium • Semi-consolidated sediments at outcrop • Highly fractured bedrock
Closed Depressions, Including Kettles	Use natural depressions that catch water in wet cycles	• Utilize natural topographic feature	• Very site-specific • Require soil modification to break-up/remove native low permeability soils	• Unconfined aquifers with surface exposure • Alluvium • Semi-consolidated sediments at outcrop • Highly fractured bedrock
Land Application	Surface irrigation at rates that exceed crop consumptive use	• Combine with agricultural or recreational land use • Generate revenue from crops or recreational fees	• Require large tracts of land	• Unconfined aquifers with surface exposure • Alluvium • Semi-consolidated sediments at outcrop • Highly fractured bedrock
Subsurface Infiltration (general comments apply to all technologies within this category)	- -	• Can be used where surface layers of low permeability preclude surface infiltration • Can co-exist with other surface urban uses such as parking lots and recreation facilities • Minimize evaporation losses	• Higher initial capital costs • Limited aerial extent • Difficult to clean/maintain • Dependent upon near-surface geology	• Unconfined aquifers • Alluvium • Semi-consolidated sediments at outcrop • Highly fractured bedrock
Infiltration Trenches	Perforated pipe embedded in a gravel-filled ditch	• Compatible with urban land uses	• Higher initial capital costs • Limited aerial extent • Difficult to clean/maintain • Dependent upon near-surface geology	• Unconfined aquifers • Alluvium • Semi-consolidated sediments at outcrop • Highly fractured bedrock

Table 17 (continued)

Technology	Description	Advantages	Limitations	Aquifer Suitability
Infiltration Galleries	Similar to trenches, except in arrays	• Can cover larger areas	• Higher initial capital costs • Limited aerial extent • Difficult to clean/maintain • Dependent upon near-surface geology	• Unconfined aquifers • Alluvium • Semi-consolidated sediments at outcrop • Highly fractured bedrock
Dry wells	Wells completed above the water table	• Can be used where space is limited	• Higher initial capital costs • Limited aerial extent • Difficult to clean/maintain • Dependent upon near-surface geology	• Unconfined aquifers • Alluvium • Semi-consolidated sediments at outcrop • Highly fractured bedrock
Infiltration Pits/Shafts	Large diameter bore or excavation to penetrate near-surface low-permeability soils	• Can be used where space is limited	• Higher initial capital costs • Limited aerial extent • Difficult to clean/maintain • Dependent upon near-surface geology	• Unconfined aquifers • Alluvium • Semi-consolidated sediments at outcrop • Highly fractured bedrock
Direct Injection (general comments apply to all technologies within this category)	- -	• Can be used where vertical permeability is limited • Occupy small surface areas • Can fit in with most land-use patterns • Can utilize existing water supply infrastructure	• Require pre-treatment to drinking water standards • Require tight control over source water quality • High capital costs, when existing infrastructure is not available • High energy requirements, high operation and maintenance costs • Require frequent pumping to remove clogging • Contamination from recharge would be difficult to remediate	• Unconfined aquifers with limited surface exposure • Confined aquifers • Deep alluvium • Sedimentary bedrock aquifers
Injection Wells/ASR Wells	Wells that are either used solely for injecting water (injection wells) or both injection and recovery (ASR wells)	• Can be used for deep aquifers • Low capital costs, when existing infrastructure is available	• High capital costs • Potential reactions between injected water and native formation or groundwater	• All of above • Abandoned mines • Karst, caverns

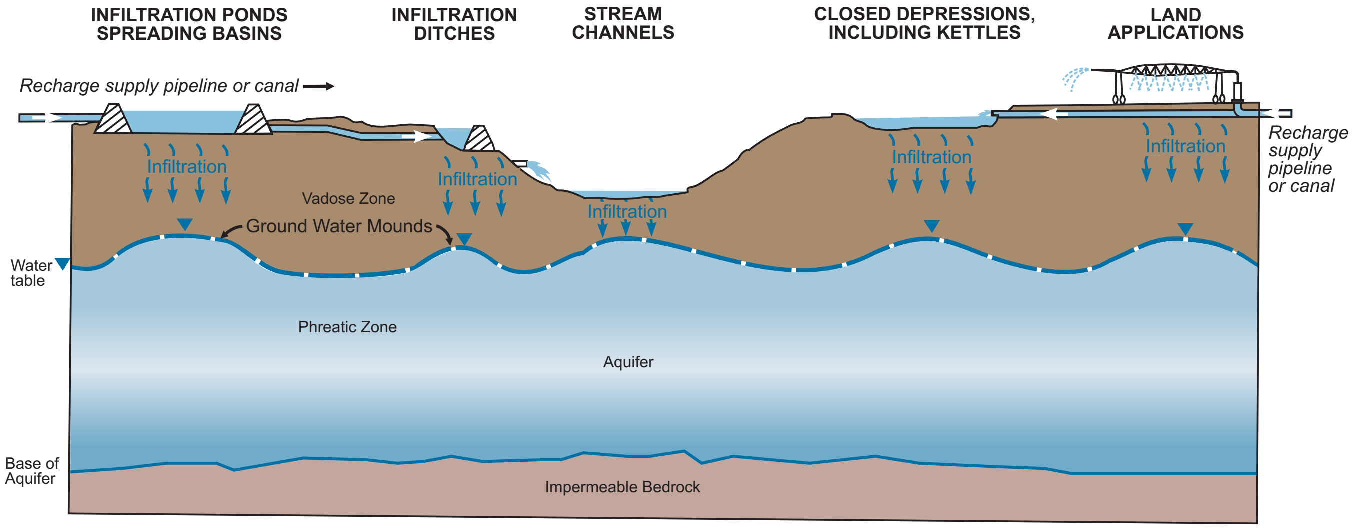
Table 17 (continued)

Technology	Description	Advantages	Limitations	Aquifer Suitability
River Bank Filtration and Induced Recharge (general comments apply to all technologies within this category)	Well or well field completed near or under a surface waterbody designed to induce surface water recharge	• Can increase the source of supply available • Reduces demand on groundwater • Provides significant improvement in source water quality	• Requires surplus surface water • Requires permeable connection between surface water and wells • Plugging of surface waterbed reduces yield over time • Higher level of treatment required than for most groundwater sources	• Shallow aquifers in direct connection with surface water
Radial Collection Wells (Raney well)	Large diameter collector well with horizontal radial bores	• High infiltration rates from a single point	• High initial capital costs	• Unconsolidated aquifers
Horizontal Wells	Small diameter well that deviates from vertical to horizontal with depth	• High infiltration rates from a single point	• High initial capital costs • Unproven technology	• All of above
Enhanced Recharge	Modification of land use or vegetation to increase recharge	• Low input and low maintenance	• Limited potential to increase recharge	• Unconfined aquifers
Other Artificial Recharge Technologies	- -	- -	- -	- -
Detention Dams, Dikes and Weirs	Engineered structures in the channel of a stream to catch natural flow and enhance natural recharge	• Low operation and maintenance costs	• Very site-specific • Environmental concerns	• Unconfined aquifers with surface exposure • Alluvium • Semi-consolidated sediments at outcrop • Highly fractured bedrock
Groundwater Dams	Structures in the aquifer that intercept or obstruct natural groundwater flow	• Do not necessarily require outside source of water • Low operation and maintenance costs • Low evaporation losses	• Site-specific and limited to shallow aquifers with small cross-sectional areas • High construction costs for larger, deeper aquifers	• Unconfined aquifers with surface exposure • Alluvium
Adits/Shafts/Natural Openings	Allow water to flow into cavern or mine using open shaft	• High recharge rates	• Vulnerability to contamination • Site-specific	• Abandoned coal and metal mines, caverns • Karst • Caverns

Source: Modified from Topper et. al.*, 2004.*

Figure 10

EXAMPLES OF SURFACE INFILTRATION TECHNOLOGIES



Source: Colorado Geological Survey Department of Natural Resources and SEWRPC.

United States, but the method is in use in several states, including Nebraska, Iowa, Ohio, Kentucky, Missouri, and Wyoming.[11,12,13,14,15]

Riverbank filtration is commonly used as a water treatment process to improve the water quality over what could be obtained from a surface water intake. Drawing the water through the riverbed and aquifer has been shown to reduce natural organic matter content with attendant reduced taste and odor issues, and to reduce disinfection byproduct issues. Riverbank filtration also breaks down organic contaminants, reduces levels of dissolved metals, stabilizes temperature, and reduces microbial pathogens, such as viruses, bacteria, protozoa, and cysts.[16] Removal rates for bacteria and viruses at

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[11]*William D. Gollinitz, Bruce L. Whitteberry, and Jeffrey A. Vogt, "Riverbank Filtration: Induced Infiltration and Groundwater Quality,"* Journal AWWA, *December 2004.*

[12]*S. Hubbs, and T. Caldwell, "Clogging in Louisville," presented at the NATO Advanced Research Workshop, Riverbank Filtration: Effect of Riverbed Clogging on Water Quality and System Capacity, Slovakia Republic, 2004.*

[13]*William D. Gollintz, Jennifer L. Clancy, Bruce L. Whitteberry, and Jeffrey A. Vogt, "RBF as Microbial Treatment Process,"* Journal AWWA, *December 2003.*

[14]*D. Schafer, "Use of Aquifer Testing and Groundwater Modeling to Evaluate Aquifer/River Hydraulics at Louisville Water Company, Louisville, Kentucky, USA," presented at the NATO Advanced Research Workshop, Riverbank Filtration: Effect of Riverbed Clogging on Water Quality and System Capacity, Slovakia Republic, 2004.*

[15]*D.L. Galloway, W.M. Alley, P.M. Barlow, T.E. Reilly, and P. Tucci,* Evolving Issues in Managing of Ground-Water Resources; Case Studies on the Role of Science, *U.S. Geological Survey Circular 1247, 2003.*

[16]*Carsten K. Schmidt, Frank Thomas Lange, Heinz-Jurgen Brauch, Wolfgang Kuhn,* Experiences with Riverbank Filtration and Infiltration in Germany, *2003.*

three such filtration sites in the Netherlands ranged from 3.1 to 7.8 log cycles.[17] A log cycle reduction represents a reduction by a factor of 10. For example, a two-log cycle reduction indicates a particular contaminant has been reduced to a level of 0.01 (1 percent) of its original concentration. Recent studies in the United States have demonstrated two to four log cycle reductions in *Cryptosporidium* or surrogates.[18,19] Riverbank filtration has been shown to be equally or more effective than conventional slow sand filtration in removing fecal coliform bacteria, cysts, turbidity, and dissolved organic carbon.[20] However, increases in the river stage can result in infiltration through previously unsaturated soils that may not have the same removal properties as the river bottom and break though of some contaminants can occur.[21] The U.S. Environmental Protection Agency offers a credit of 0.5 to 1.0-log reduction bank filtration credit for removal of *Cryptosporidium*, depending on the separation between the source and well for the amendments to the Safe Drinking Water Act, known as the Long Term 2 Enhanced Surface Water Treatment Rule.[22]

Figure 10 displays examples of surface infiltration technologies. Water for recharge is applied at the surface above an unconfined aquifer in man-made or natural depressions to infiltrate down to the underlying water table, ultimately causing the water table to rise. This application requires high vertical permeabilities and the absence of impeding layers.

- Stream channels can be used as infiltration ditches providing the configuration of the water table allows the stream to infiltrate water into the ground, such as a losing stream reach or a perched stream channel.

- Shallow closed depressions, including kettles, can be effective groundwater recharge features that act as recharge basins. The effectiveness of these features may be limited by the soil permeability and other characteristics.

- Land application includes a variety of methods where water is applied to the land surface. Recharge can occur if the application rate exceeds the evapotranspiration rate of the area. Common land application methods include crop irrigation and some wastewater disposal systems that use irrigation methods.

- Rain gardens are small recharge basins typically constructed to recharge stormwater from a home or commercial building. These are small-scale structures that are usually constructed on a voluntary basis by private landowners. Although rain gardens are worthy efforts that should be encouraged, such gardens would need to be constructed on a large number of sites in favorable locations to make any significant contribution to groundwater recharge at an urbanized area or regional scale.

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[17] *Nathalie Tufenkji,* et. al., op. cit.

[18] *William D. Gollinitz,* et. al., *December 2004,* op. cit.

[19] *William D. Gollinitz, Jennifer L. Clancy, J. Brock Mcewen, and Stephen C. Garner, "Riverbank Filtration for IESWTR Compliance,"* Journal AWWA, *December 2005.*

[20] *V. Partinoudi, M.R. Collins, A.B. Margolin, L.K. Brannaka,* Assessment of the Microbial Removal Capabilities of Riverbank Filtration, *September 10, 2003.*

[21] *Nathalie Tufenkji,* et. al., op. cit.

[22] *Federal Register, Environmental Protection Agency, 40 CFR Parts 9, 141, and 142, "National Priorities Drinking Water Regulations: Long Term 2 Enhanced Surface Water Treatment Rule; Final Rule," Thursday, January 5, 2006.*

Stormwater infiltration is required by Chapter NR 151 of the *Wisconsin Administrative Code* for many developments over one acre in size. In some cases, these requirements are being met by the use of rain gardens or bioretention basins. A concern about the use of rain gardens relates to the permanence of these facilities if constructed on individual private properties, given that property ownership and landscaping preferences can change over time. This could result in the filling and loss of some facilities over time. One means of addressing this concern would be the development of larger-scale rain gardens serving multiple property owners and located on common, or public, areas with oversight by a unit of government. Such facilities may be constructed as bioretention facilities that would have engineered subsurface soils. Larger-scale rain gardens, or bioretention facilities, can serve multiple purposes, including groundwater recharge, nonpoint source pollution control, and as an onsite aesthetic amenity. To properly serve these purposes, the site development must be specifically designed with these purposes in mind.

- Certain stormwater management measures, such as grassed drainage swale systems, including grassed roadway drainage ditches, bioretention basins, and surface sand filters are measures designed to encourage infiltration. These measures have typically been used to reduce stormwater runoff rates and volumes. As such, these facilities can be used to serve multiple purposes. In some cases, these measures can be used to meet the stormwater infiltration requirements of Chapter NR 151 of the *Wisconsin Administrative Code*.

- Recharge ranches are tracts of land, usually agricultural, managed to capture recharge to establish a right to use groundwater. Often the land will be fallowed or planted in crops with low water demand to enhance recharge. Recharge ranches are typically used in states with well-defined water rights or allocations systems that are usually tied to land ownership. In Wisconsin, no such water rights exist and the water would be part of a common pool equally available to adjacent landowners. As a result, recharge ranches in Wisconsin would have to be placed up-gradient in close proximity of the intended target of the recharged water.

- Enhanced recharge methods use man-made changes of the land to increase recharge or decrease removal of groundwater by evapotranspiration In arid and semiarid regions enhanced recharge methods often include removal of deep rooted plants called phreatophytes, such as cottonwoods and salt cedars. In more humid regions, such as southeastern Wisconsin, restoration of farmland to native prairie or woodland may increase recharge by reducing runoff. Studies indicate that the percentage of land that is in natural condition—woodlands, grasslands, and wetlands—is an important factor in the enhancement of groundwater recharge.[23] Runoff may be reduced by up to about 25 percent by converting cropland to woodland or native prairie with a net increase in groundwater recharge.[24] The amount of tree canopy in the City of Milwaukee area was estimated in a 2003 report to reduce stormwater runoff by 5 to 22 percent.[25] While the runoff reduction impacts of tree canopy development have been estimated, the groundwater infiltration relationships are not clear because of the interrelated affects of runoff, infiltration, and evapotransporation. Evaluation of the impacts of the application of specific vegetative land cover changes on infiltration requires site-specific study. The conversion of land to specific types of vegetative cover with root development considered inducive to infiltration may enhance aquifer recharge.

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[23]*Douglas S. Cherkauer and S.A. Ansari, "Estimating Groundwater Recharge from Topography, Hydrogeology, and Land Cover,"* Ground Water, *January-February 2005.*

[24]Environment 1999, An Assessment of the Quality of Vermont's Environment, *The Vermont Agency of Natural Resources, Available at: www. Anr.vt.us/Env99/waterfor.html.*

[25]*Milwaukee Metropolitan Sewerage District,* Evaluation of Stormwater Reduction Practices, *March 2003.*

- Water banking involves storing water in an aquifer with the intent of recovering the water at some unspecified future date. Water banking requires some legal framework for the owner of the water to maintain control of the water to prevent others from using it. This usually requires a well-developed water rights system. States that use right of capture or riparian based water rights systems, such as Wisconsin, do not allow the recharging party to protect the water or recognize a benefit from placing it in the aquifer, so water banking is unlikely to be a practical option.

- Wetland restoration has many positive attributes, including improved water quality and reduction in peak flood flows. In theory, it also has the potential to increase recharge. However, most wetlands are in groundwater discharge areas making them unfavorable locations for recharge. Upland wetlands, though less common, do have potential to increase recharge, because they are located farther up-gradient in the groundwater flow system. Most wetlands have a layer of low-permeability soil that reduces the infiltration rate and limits the amount of recharge that can be achieved. In practical terms, it may be easier to use artificial recharge to help restore a wetland than to use a wetland to accomplish artificial recharge.

- Detention dams, dikes, and weirs are used to detain surface water flows down streams or intermittent channels to allow the water to infiltrate. These systems require suitable channels with the potential to recharge groundwater, such as losing river reaches or dry channels above the water table. The availability of such features is likely to be limited in southeastern Wisconsin.

Subsurface Infiltration Methods

Subsurface methods are used where the shallow soils are unsuitable for surface infiltration or where insufficient surface space is available. Subsurface methods use trenches, wells, or other types of excavations to get the water past impermeable soil layers near the surface, perching layers in the unsaturated zone, or confining units above the aquifer. Subsurface methods include several infiltration methods where water is placed into the unsaturated material below the surface, but above the water table, and several direct injection methods where water is directly injected into the aquifer. Subsurface infiltration methods may be used to increase recharge of aquifers. Such facilities may be subject to the Federal underground injection control program if the method of placing the fluid is the use of the injection well. An injection well may be a bored, drilled, or driven shaft; a dug hole, deeper than wide; an improved sinkhole; or a subsurface fluid distribution system, such as a drain field or similar system.

- Infiltration trenches and galleries use excavated ditches with perforated pipe or permeable fill to infiltrate water. The trenches are usually excavated through shallow impermeable soils or perching layers to facilitate recharge. Trench systems can also be covered and used for other purposes such as parking lots, sports fields, and other uses. Infiltration galleries consist of multiple trenches.

- Dry wells are wells completed above the water table in the unsaturated zone. The wells can be completed with screens or slotted casing and are usually used to move water past a perching zone that is too deep for a trench system.

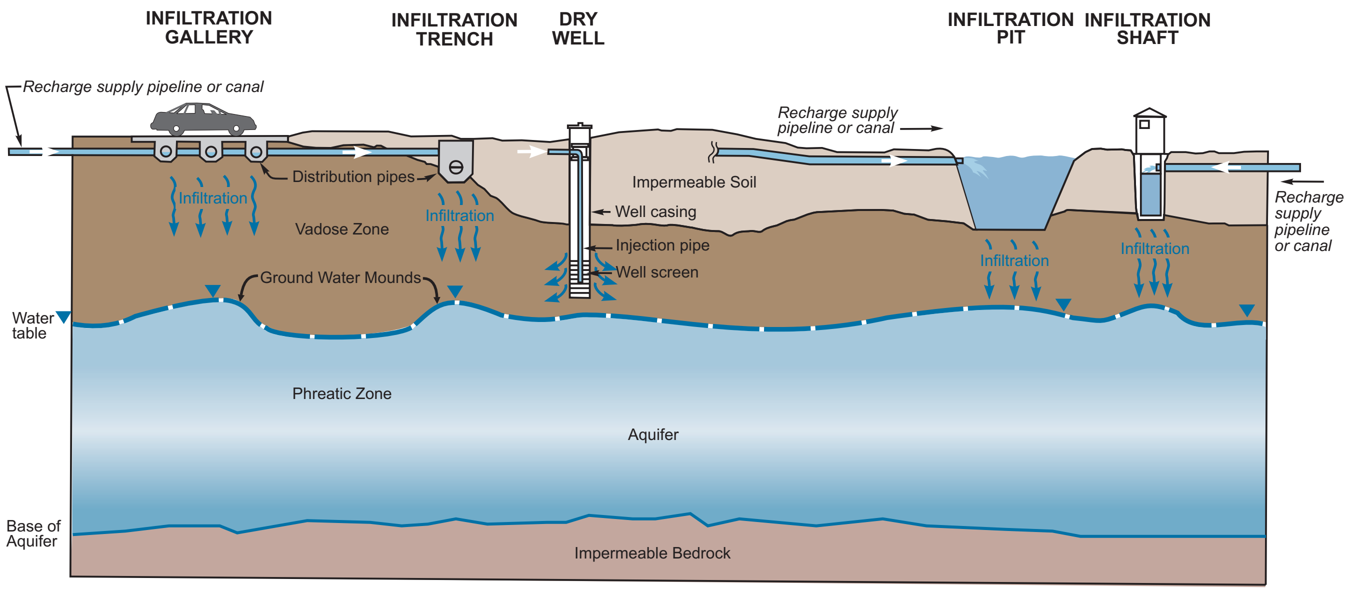
- Infiltration shafts are larger-diameter excavations drilled through a perching layer, but completed above the water table. The shafts can be completed with slotted casing or screens, or filled with permeable fill, such as gravel, and completed as an open hole.

- Infiltration pits are similar to infiltration shafts but are larger in diameter and may not be circular in shape.

Figure 11 illustrates several common subsurface infiltration methods, including trenches and galleries, dry wells, infiltration shafts, and infiltration pits. Water for recharge is applied beneath the land surface, but also above an unconfined aquifer where conditions preclude surface infiltration techniques. This type of application can be used where surface, or near-surface, materials have low permeability or where other land uses are not compatible with surface infiltration facilities.

Figure 11

EXAMPLES OF SUBSURFACE INFILTRATION TECHNOLOGIES



Source: Colorado Geological Survey Department of Natural Resources and SEWRPC.

Direct Injection Methods

Figure 12 illustrates direct injection methods including vertical, radial, and horizontal injection wells, including aquifer storage and recovery wells.

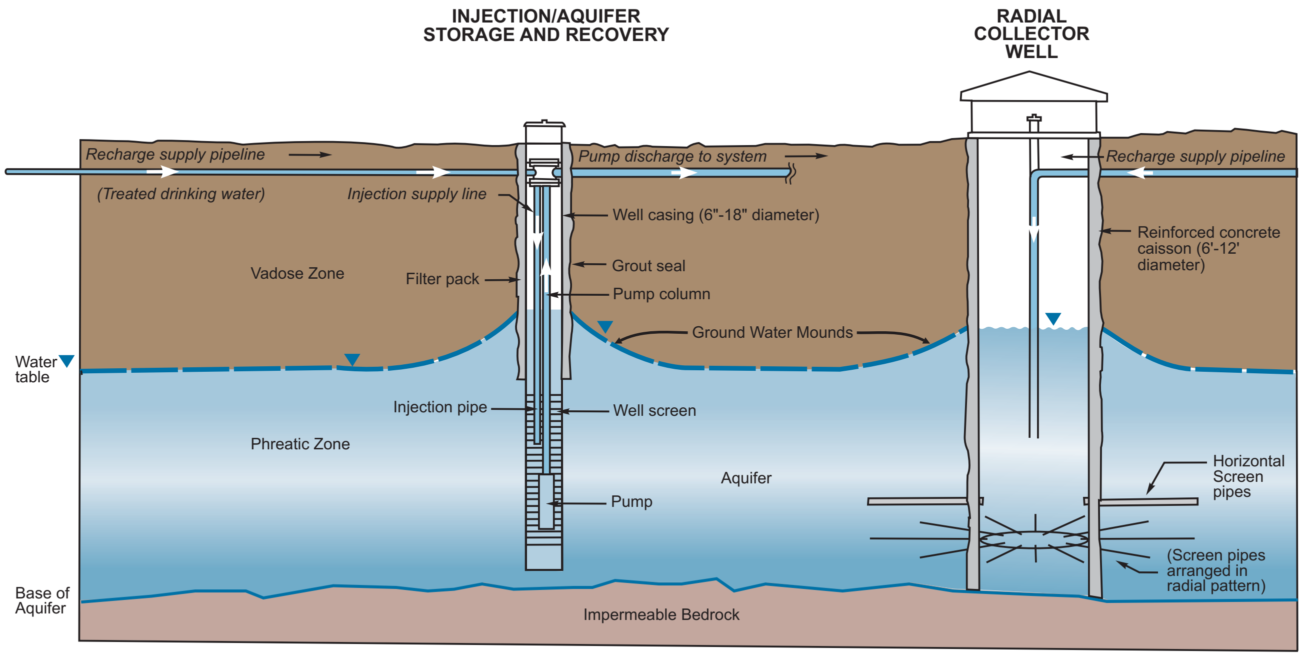
- Injection wells are completed in the saturated portion of the aquifer and allow direct injection of recharge water. Injection wells can be completed with slotted casing, well screens, or as open holes in competent formations. Injection wells minimize the vertical transit time of the water to the aquifer and can avoid unfavorable reactions between the water and soils or minerals in the unsaturated zone. Injection wells can be drilled vertically, radially using horizontal collector arms, or horizontally using directional drilling technologies.

- Horizontal wells can be used for direct injection or riverbank filtration methods of artificial recharge. Horizontal wells have been used for decades. Until recently, most horizontal water wells consisted of horizontal wells screens, called laterals, projecting radially from large-diameter caissons. These wells are commonly called horizontal collector wells. Typical collector wells have several laterals projecting up to about 200 feet from the caisson. Often the laterals are projected under surface waterbodies to induce recharge. Collector wells can also be used to maximize the screened area that can be completed in a thin aquifer. Collector wells have several limitations that have prevented their wider use. Most significant is that they are relatively expensive to drill and maintain. In addition, the laterals can be projected a limited distance from the caisson and cannot be steered while drilling to follow the aquifer.

  Within the last decade, directionally drilled wells have begun to replace collector wells due to their lower cost and the ability to steer the borehole to follow any desired path. Screen lengths of directionally drilled wells can be much longer than collector well screens, commonly exceeding 1,000 feet. Directionally drilled boreholes can deviate around obstructions or turn to follow aquifers or sources of recharge. Many of the early attempts to drill directional water wells suffered from

Figure 12

DIRECT INJECTION METHODS



Source: Colorado Geological Survey Department of Natural Resources and SEWRPC.

irreversible formation damage caused by the heavy drilling mud needed to construct the hole. The formation damage reduced the yield of the wells and could not be reversed by conventional redevelopment efforts. However, recent advances in drilling mud technology have reduced the formation damage issues. Many of the new drilling mud technologies use organic polymers that are not approved for use in water supply wells.

A new technology is under development that uses cryogenic fluids to temporarily consolidate sand and gravel aquifers and allow direction wells to be drilled with no formation damage. This technology has yet to be demonstrated, but promises to significantly improve the yield of directionally drilled water wells. Another technology is in limited use that uses modified drill rigs to advance rigid well casing at angles of approximately 30 degrees from horizontal. Well screens and production casing are installed inside these inclined wells. The casing is then removed to expose the well screen and production casing. Inclined wells avoid the problems associated with drilling mud, but the wells cannot be steered, are not truly horizontal, and offer only about twice the length of screen that would be provided by a traditional vertical well.

Aquifer Storage and Recovery

Aquifer storage and recovery systems use injection wells to store water in an aquifer. The water is generally treated drinking water although systems using treated wastewater have been developed and systems using partially treated stormwater have been proposed. The water is stored in the aquifer around the well and recovered, typically by pumping the same well, to reuse the water with minimal additional treatment. Aquifer storage and recovery systems are most often developed in confined aquifers though some systems in unconfined aquifer have been developed.[26] Such systems have been used to:[27]

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[26]*R. David G. Pyne,* op. cit.

[27]*American Water Works Association,* Survey and Analysis of Aquifer Storage and Recovery (ASR) Systems and Associated Regulatory Programs in the United States*, August 2002.*

- Store water for seasonal, daily, or emergency demands;
- Reduce disinfection byproducts;
- Improve water quality;
- Stabilize aggressive water, that is, water that may be corrosive to the distribution system;
- Restore water levels in an aquifer;
- Reduce subsidence;
- Control salt water intrusion;
- Manage distribution system pressures and flows;
- Avoid expansion of distribution system to meet peaks; and
- Control water temperature for fish hatcheries.

Aquifer storage and recovery systems have been in use in the United Sates since 1969, and approximately 69 such systems are in operation within the United States as of March 2004.[28] About 100 sites have been tested nationwide. Such systems are in operation in the United Kingdom, Australia, Israel, and Canada.

Aquifer storage and recovery systems typically have storage volumes from 0.5 to 100 MG.[29] Sandstone, carbonate and unconsolidated sand and gravel aquifers have been used for storage. Theoretically, the injected water moves as a single mass into the aquifer and displaces the native groundwater as a uniform slug of water. The injected water is later recovered by pumping the well. In theory, the stored water moves back to the well as a uniform slug with little mixing with the groundwater. In practice, it is impossible to obtain such uniform flow in an aquifer. Heterogeneities in the aquifer cause uneven flow rates and promote mixing and dispersion with the native groundwater. This is especially significant when thick aquifers, or multiple aquifers, are used as storage zones for aquifer storage and recovery systems. Mixing issues are less significant if the native groundwater in the storage zone is of acceptable quality. Density differences in saline or brackish aquifers increase the degree of mixing and reduce the recovery efficiency of the system.

Aquifer storage and recovery systems typically build up a buffer zone of mixed water in the storage zone by running several storage and recovery cycles that only recover a portion of the injected volume. In theory, the unrecovered water forms a slug of mixed quality water that moves in and out in response to injection and recovery of subsequent aquifer storage and recovery cycles. The buffer zone prevents direct mixing between the stored water and the native groundwater. After several storage and recovery cycles, most such systems can recover nearly all of the injected water for each cycle before the water quality exceeds target values. Case histories have indicated that actual mixing is more complex than the theoretical models, and mixing of water in the storage zone with native groundwater is an issue that needs to be considered further. This issue will require more research and evaluation. It is also possible to recover more than the injected volume of a storage and recovery cycle by pumping some of the buffer zone water to meet an immediate need. However, the quality of the later portion of the recovery cycle will usually trend toward the quality of the native groundwater as the buffer zone is consumed.

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[28]*ASR Forum, Available at: www.asrforum.com/where.html, last updated October 18, 2004.*

[29]*R. David G. Pyne, Philip C. Singer and Cass T. Miller,* Aquifer Storage Recovery of Treated Drinking Water, *AWWA Research Foundation, Prior to March 2006.*

ARTIFICIAL RECHARGE SYSTEM DESIGN CONSIDERATIONS

Hydrogeologic Factors

Perhaps the most important design consideration in an artificial recharge project is its location relative to the target of the project. The recharge system must be located up-gradient of the body that is intended to receive the water. If the target is a stream or wetland, the recharge system can often be located near the discharge portion of the groundwater system near the receiving body. However, if the objective is to restore an aquifer or augment a well field, the recharge structure must be in the recharge area of the aquifer or up-gradient of the well field. This may involve transmitting the recharge water some distance up-gradient from the source, which can increase the cost of the project. Raising the water level in an aquifer can have undesired negative impacts on surrounding structures and land. This is particularly true for structures or land uses that may have been developed after depletion of an aquifer and which did not account for a rebound in water levels.

The recharge system must also be designed to fit the geologic conditions of the site. Figure 13 illustrates that every recharge system has three basic elements: a surface soil layer; a deep vadose—or unsaturated—zone; and an aquifer. The surface soil layer is usually thin enough that it can be removed if it has a lower permeability than the deep vadose zone. If the vadose zone is permeable, a surface recharge system is usually the most economic option (see Figure 14). If the deep vadose zone contains a low permeability zone that is relatively shallow, trenches or infiltration pits may be needed (see Figure 15). If the deep vadose zone has a low permeability perching zone at greater depth, dry wells or deeper trenches may be appropriate (see Figure 16). Factors such as swelling clays, or the precipitation or dissolution of minerals, may make contact of the recharge water with the vadose zone undesirable. If the deep vadose zone has low permeability, or is geochemically incompatible with the recharge water, injection wells or direct recharge methods may be necessary (see Figure 17). The choice of recharge method has a significant impact on the land requirements, construction costs, and operation and maintenance.

Several other factors must be considered when designing a recharge system. The depth to the zone of saturation will affect the performance of a recharge system. If the vadose zone is relatively thin, the groundwater mounding that occurs during recharge may cause pooling in the recharge structure and reduce the recharge rate. For sites where groundwater is near the surface, the rate of recharge will be limited to the ability of the aquifer to transmit the water from the site into the local groundwater flow system. If the vadose zone is too deep, the vertical transit time to the aquifer may be too long, or large volumes of water may be needed to overcome the partial pore pressure in the unsaturated soils to allow the water to reach the aquifer. Heterogeneous vadose zone soils exacerbate these problems by encouraging perching or pooling of water in the unsaturated zone. Heterogeneous soils also increase the lateral dispersion of the recharging water, thereby increasing the time and distance the water must travel. Conversely, very uniform soils can increase the problems of air entrainment in the vadose zone that can dramatically reduce recharge rates. The temperature of the water is also a factor, as colder water is more viscous. The recharge rate of cold water may be significantly lower than that of warm water.

Source Water Considerations

The quality and quantity of recharge water is another important factor controlling the performance of a recharge system. Many sources of water have been used for recharge systems. These sources include:[30]

- Surface water from streams, canals, lakes, and reservoirs;
- Reclaimed wastewater;
- Rainfall and stormwater runoff;
- Imported water from other areas;
- Groundwater from other aquifers; and
- Treated drinking water.

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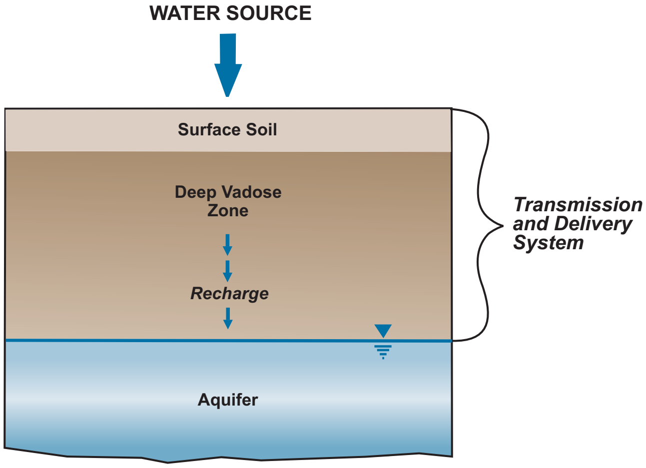
[30] *American Society of Civil Engineers,* op. cit.

Figure 13

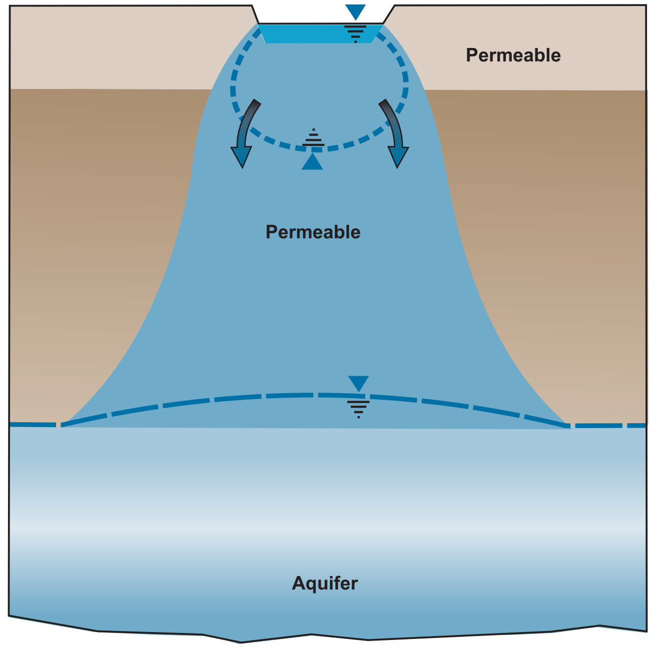
THREE BASIC ELEMENTS OF A RECHARGE SYSTEM



Source: Daniel Stevens, Presentation to the Groundwater Resource Association of California, San Jose, and SEWRPC.

Figure 14

SURFACE RECHARGE SYSTEM WITH A PERMEABLE VADOSE ZONE



Source: Daniel Stevens, Presentation to the Groundwater Resource Association of California, San Jose, and SEWRPC.

Several factors must be considered when choosing the most desirable source of water for a recharge system. The two most significant factors are availability and quality. It is important to note that, for many water sources, the quality of the water is variable. In many cases, the water quality is poorest when the water is most abundant. This is true for river sources, where turbidity is often highest during high flow events, or for surface water runoff when road salt or agricultural chemicals can be highest during spring runoff or major storm events. When estimating system performance and cost it is important to factor in the cost of treatment and the duration of down time for maintenance and cleaning that are necessary for a given water source.

Pretreatment for Artificial Recharge

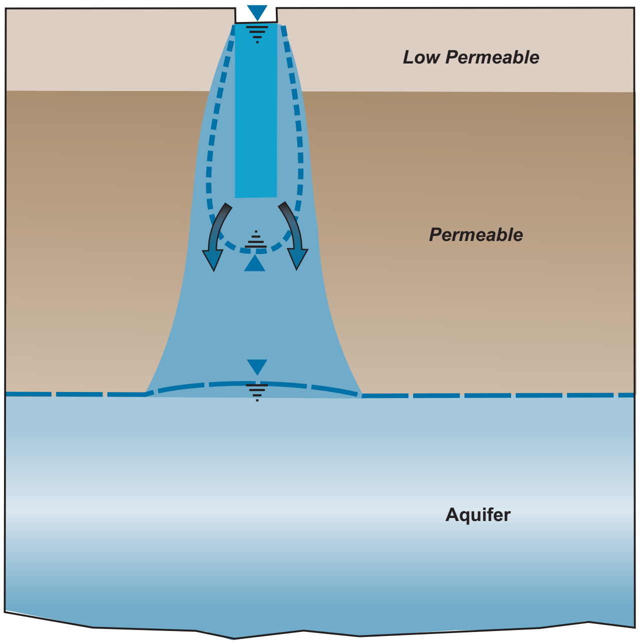
Most water sources for artificial recharge require some form of treatment prior to recharge. This may include normal drinking water treatment for aquifer storage and recovery systems, simple sedimentation for river water systems, or extensive tertiary treatment for wastewater. Many water quality problems for surface water sources can be corrected with simple sedimentation basins to remove silt and turbidity, and by avoiding recharge when high levels of pollutants, such as chlorides or agricultural chemicals, are present.

The generally consistent supply of sewage effluent makes wastewater an attractive source for recharge water. However, wastewater presents several important challenges, including poor quality, the presence of human pathogens, pharmaceuticals and personal care products, and other dissolved chemicals, and significant issues of public acceptance. Wastewater sources generally require primary and secondary treatment with disinfection for use in a surface infiltration system. In situations where groundwater quality will not be degraded, primary treatment may be sufficient for surface infiltration systems that use a process known as soil aquifer treatment to provide additional treatment during the recharge process.[31] When wastewater is used for direct injection or

[31]*American Society of Civil Engineers*, op. cit.

Figure 15

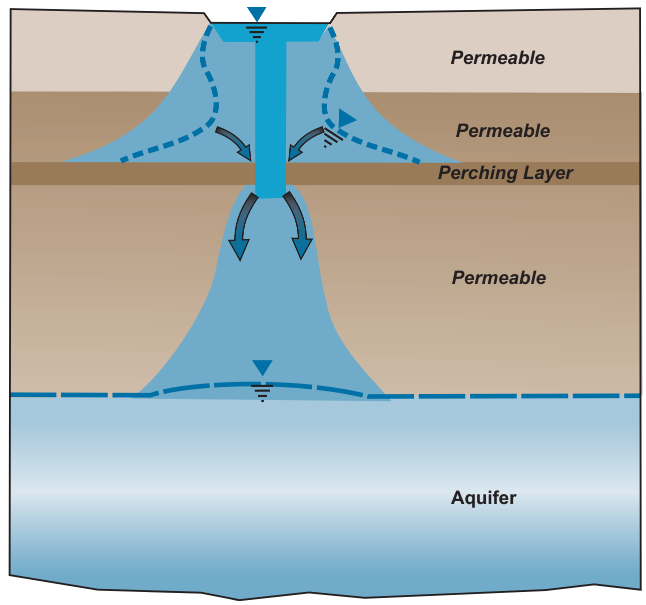
RECHARGE TRENCH WITH SHALLOW LOW-PERMEABILITY LAYER



Source: Daniel Stevens, Presentation to the Groundwater Resource Association of California, San Jose, and SEWRPC.

Figure 16

DEEPER RECHARGE TRENCH OR PIT FOR DEEPER PERCHING LAYER



Source: Daniel Stevens, Presentation to the Groundwater Resource Association of California, San Jose, and SEWRPC.

subsurface recharge, higher levels of treatment are generally needed to protect the groundwater quality and prevent clogging of the recharge structures. In some places, such as California, pretreatment can include microfiltration, reverse osmosis and carbon filtration,[32] which significantly increase costs. The quality of the recharge water may, in some situations, exceed the quality of the native groundwater or the water that will be recovered by the well field. In these cases, the aquifer is actually used as a barrier to avoid the direct reuse of wastewater. This provides both a buffer to protect against the accidental break through of contaminants and a buffer against the public objections towards the direct reuse of wastewater.

No Federal guidelines have been established for groundwater recharge with reclaimed wastewater in the United States. Consequently, standards for recharge with reclaimed wastewater are established by State agencies and local water districts. When determining pretreatment requirements, public health and safety and public acceptance are the most important concerns. Removal of pathogenic microorganisms is the primary concern, but trace metals and organic compounds can also be important issues. Pretreatment processes may be required to reduce synthetic organic compounds (SOCs), higher molecular weight organic compounds called natural organic matter (NOM), disinfection byproducts (DBPs), and emerging compounds such as nitrosdimethylamine (NDMA), endocrine disrupting compounds (EDCs), and pharmaceutically active compounds (PhACs). If an underground injection well is used, the injectate must meet primary drinking water maximum contaminant levels and health advisory levels if the fluid is directly placed into a saturated aquifer. No injection is allowed to endanger the quality of an underground source of drinking water.

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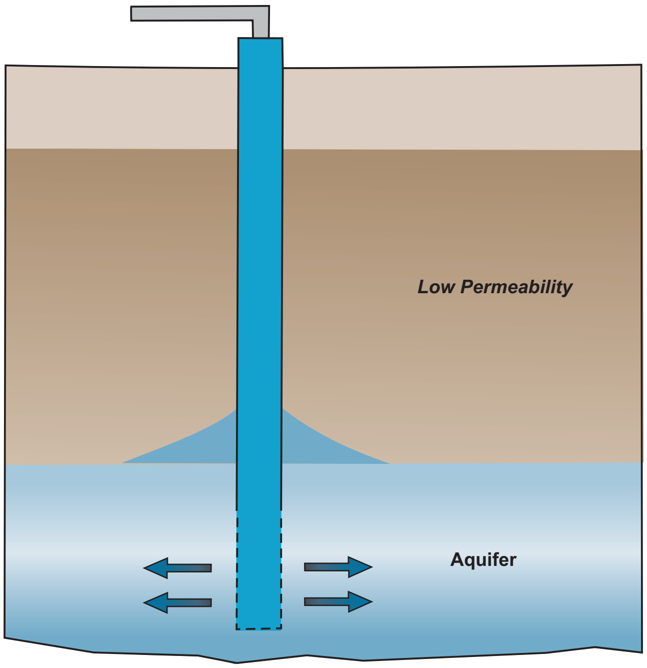
[32]*Asano and Cotruvo, Groundwater recharge with reclaimed municipal wastewater: health and regulatory considerations,* Water Research *38, 2004.*

Figure 17

INJECTION WELLS FOR LOW-PERMEABILITY VADOSE ZONE



Source: Daniel Stevens, Presentation to the Groundwater Resource Association of California, San Jose, and SEWRPC.

Soil Aquifer Treatment

A process that uses the soil layer, unsaturated zone, and the aquifer itself to improve the quality of the recharged water prior to use has been developed to reduce the cost of using recharge water of marginal quality. This process, called soil aquifer treatment, reduces synthetic organic compounds and nitrates, removes and degrades bacteria and viruses, reduces BOD and biodegradable organic compounds, volatilizes some volatile and semi-volatile organic compounds, and removes metals, phosphate and fluoride.[33] Most of the processes are sustainable, but phosphate, metals, fluoride, and some organic compounds may accumulate in the treatment zone and may cause an eventual reduction in treatment efficiency.

Wastewater recovered from aquifers after soil aquifer treatment is usually suitable for nonpotable uses such as irrigation. Potable use is also possible if sufficient blending with native groundwater has occurred to meet drinking water standards. The long-term efficacy of such systems is not well known. The American Society of Civil Engineers (ASCE) recommends that these systems use higher levels of monitoring, and that additional pretreatment be added as needed to avoid undesired effects. In addition, accumulation of some compounds in the recharge area could be an environmental concern when a soil aquifer treatment system is decommissioned and the land is to be returned to some other use.

Advanced Wastewater Treatment

When wastewater is used for subsurface or direct recharge, the ability of the unsaturated zone to reduce compounds of concern is reduced or eliminated. This is because much of the biological and geochemical degradation and adsorption of metals, organic compounds, bacteria, and viruses occurs in the shallow soil zone and unsaturated zone, and those zones are partially or completely bypassed when recharge occurs directly to the aquifer. It is often necessary to use higher levels of treatment prior to injection to protect the quality of the groundwater and avoid clogging the recharge structure. Advanced wastewater treatment generally involves tertiary water treatment and may include chemical clarification, air stripping, membrane treatment (including reverse osmosis), and carbon filtration.[34] Chlorine used for disinfection may form undesirable and persistent disinfection byproducts and make the water more reactive with the aquifer and native groundwater. In these cases, ultraviolet disinfection or advanced oxidation using hydrogen peroxide may be more desirable disinfection systems. Where reverse osmosis is included, the water will have low total dissolved solids and may be more chemically aggressive.

When advanced wastewater treatment is used, the recharge water may be of higher quality than the native groundwater. In these cases, the aquifer is used primarily as a detention system to avoid direct reuse of the wastewater and provide a buffer as an additional safety margin. California has proposed a set of guidelines for the

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[33]*American Society of Civil Engineers,* op. cit.

[34]*Asano and Cotruvo,* op. cit.

treatment stream, underground detention time, and recovery well set back distances for recharge systems using sewage effluent.[35]

Source Water Considerations for Aquifer Storage and Recovery Systems

Most aquifer storage and recovery systems use treated surface water as their source water.[36] The source water generally has a higher redox (oxidation/reduction) potential than the native groundwater, which can cause undesirable chemical reactions with the groundwater and aquifer matrix. Aquifer storage and recovery systems have mobilized several metals from the aquifer matrix, most notably arsenic, iron, and manganese. Iron and manganese have limited health concerns, but arsenic exposure has been linked to several forms of cancer and other serious diseases. Such systems have also had problems with precipitation of several minerals, deflocculation of clay minerals, and swelling clay minerals. All of these problems are generally less significant when groundwater is used as the source water due to the greater similarity between the chemical properties of the injected water and the groundwater in the storage zone. Pretreatment with caustic chemicals to increase pH has been used to stabilize metals in the formation by forming oxidized coatings to encapsulate minerals and immobilize metals. Pretreatment with calcium chloride has also been used to control clay dispersion in an injection test.[37]

Treated surface water frequently contains halogenated compounds called disinfection byproducts created by a reaction between organic carbon in the surface water and chlorine used as a disinfectant. Disinfection byproducts are a health concern due to their carcinogenic properties. Aquifer storage and recovery systems have been shown to significantly reduce or eliminate disinfection byproducts during the storage and recovery cycle.[38] The reduction achieved is greater than can be explained by simple mixing and dilution. At least some of the reduction appears to be associated with microbial degradation, usually under reducing conditions and accompanied by nitrate reduction. In some cases brominated disinfection byproducts have proven to be more resistant to degradation than chlorinated species.

OPERATION AND MAINTENANCE CONSIDERATIONS

Recharge structures are subject to clogging from a variety of sources. These sources include clogging from silt or fine particles, biological clogging, air entrainment, swelling clay, and chemical precipitation. The magnitude of the clogging problems depends on the characteristics of the recharge water, the soils, native groundwater, and the design of the recharge structure. Eventually, clogging issues will reduce the infiltration rate of the structure to the point where some form of cleaning is needed to restore the function of the system. The frequency of the cleaning processes varies from daily to periods of several years. The time out of service needed to clean the recharge structure must be factored into the performance of the recharge system when calculating the cost and recharge rates.

Clogging Issues for Surface Infiltration Systems

Most sources of recharge water carry some level of suspended particles. These particles collect at the bottom of the recharge basin and cause clogging. Biological growth, including bacteria and algae, can also cause clogging. Eventually the clogging problems reduce the permeability of the recharge face and reduce the recharge rate through the structure. When this happens, the clogging layer must be removed by scraping off the material or by raking or tilling the layer to enhance permeability. Some recharge basins have been designed to use wave action

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[35]*Herman Bouwer*, op. cit.

[36]*R. David G. Pyne*, op. cit.

[37]Ibid.

[38]*R. David G. Pyne, Philip C. Singer and Cass T. Miller*, Aquifer Storage and Recovery of Treated Drinking Water, *American Water Works Association Research Foundation, 1996.*

to wash the side-walls of the basin to reduce clogging. It is common to alternate recharge in a series of recharge basins to allow basins to dry out periodically. Drying a basin facilitates cleaning operations and reduces biological clogging. Settling basins, or wet detention basins, can be used before infiltration to remove sediments and reduce clogging. Figure 18 is a schematic representation of a recharge basin that shows the major types of clogging problems that can occur.

Chemical reactions between the recharge water and the soils or native groundwater can cause clay minerals to swell or minerals to precipitate. These problems can generally be removed if they occur at or near the bottom of the recharge basin. However, said clogging can occur at significant depth below the bottom of the recharge structure. Many of these reactions are irreversible and may eventually cause the recharge system to fail. As a result, it is critical to identify these issues during the design phase of the project so that steps can be taken to eliminate or control the problem or a new location can be chosen.

Many sources of recharge water contain dissolved gases that are unstable in the subsurface. This excess air leaves solution and collects as air bubbles in the pore space of the saturated portion of the recharge system. The air bubbles cling to the soil matrix and partially block the migration of fluids. Reductions of hydraulic permeability of an order of magnitude have been reported.[39,40] Once the recharge system has become air-locked, the air can remained trapped for years in the subsurface.[41] Soils with uniform particle size are more prone to air locking than poorly sorted soils with a wide range of particle sizes.

The potential for rain gardens and bioretention facilities to clog is dependent upon the factors, such as the type of vegetation and its associated root system, the permeability of the underlying soil, and the quality of the stormwater being retained. It has been reported that the use of prairie-type plants with deep roots can be effective in minimizing clogging and, in some cases, improved infiltration over time has been experienced. Because of the importance of various factors in clogging, the issue must be considered on a site-specific basis.

Clogging Issues for Subsurface Infiltration Methods

All of the clogging issues associated with surface infiltration systems apply to subsurface systems, but not all of the cleaning methods can be used. The fact that the recharge structures are constructed in excavations or wells prevents simple cleaning methods such as scraping or raking from being used. Cleaning subsurface recharge structures typically involves flushing with chemical solutions, physical agitation, and a variety of methods more commonly associated with rehabilitating water wells. These methods are more expensive and the degree of cleaning that can be achieved is limited in some cases. As a result, subsurface infiltration systems require more expensive maintenance and may ultimately need to be replaced if clogging problems cannot be reversed.

Clogging Issues for Aquifer Storage and Recovery Systems

Aquifer storage and recovery wells are subject to clogging from several sources. These clogging problems increase the resistance to flow and reduce the storage and recovery rates of the system. Periodic maintenance is needed to manage these issues and maintain the efficiency of such wells.

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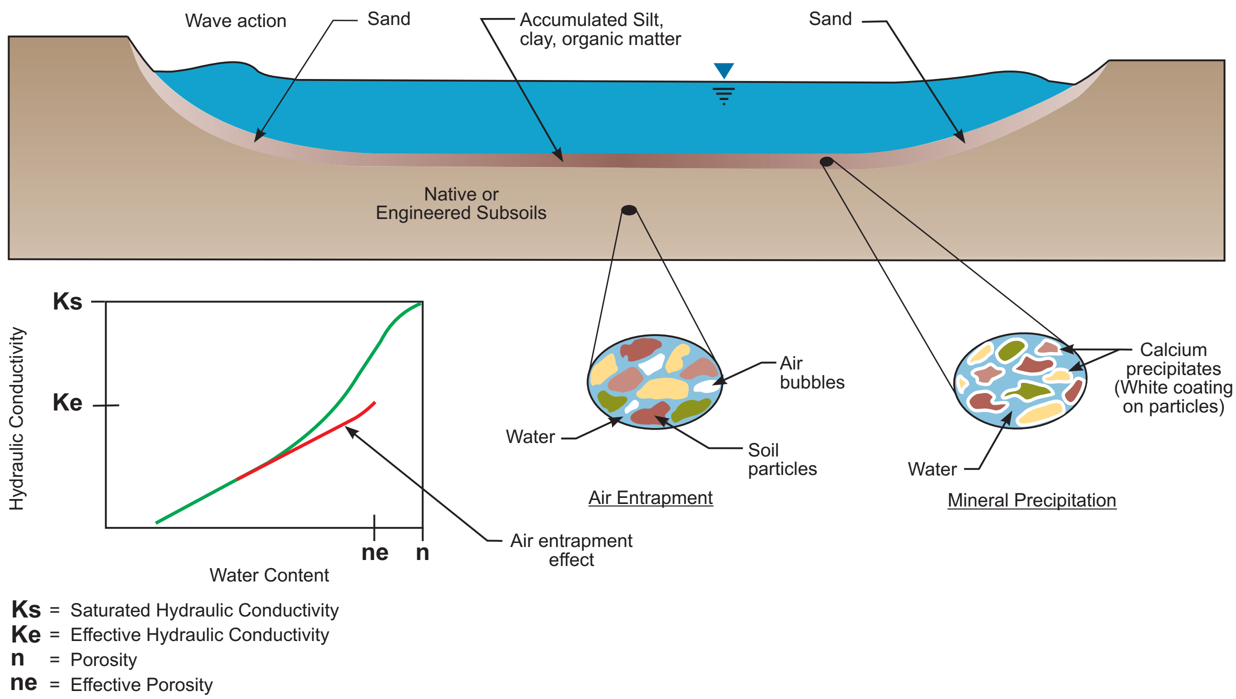
[39]*Kip D. Solomon, "Trapped Gases Beneath a Recently Completed Reservoir: Using Artificial Recharge as an Analogue to Natural Processes,"* Geological Survey of America Abstracts with Programs*, Vol. 36, No. 5, 2004, p. 470.*

[40]*Victor M. Heilweil, The Geological Society of America, 2002 Denver Annual Meeting (October 27-30, 2002), "Use of Dissolved Gas Tracer to Evaluate Permeability Reduction Caused by Trapped Gas Beneath an Artificial Recharge Pond," 2002.*

[41]*Kip D. Solomon,* op. cit.

Figure 18

ILLUSTRATION OF COMMON CLOGGING PROBLEMS OF A RECHARGE BASIN



Source: Daniel Stevens, Presentation to the Groundwater Resource Association of California, San Jose, and SEWRPC.

Particulates in the source water build up on the face of the borehole of aquifer storage and recovery wells. Some systems filter the source water prior to injection to reduce this problem. Most systems periodically reverse the flow during an injection cycle by briefly pumping the well to displace the sediment and clean the well face. Mineral precipitation and biological fouling also occur on the well face. These issues can be reduced to some extent by periodic pumping during injection, but eventually these materials need to be removed by traditional well rehabilitation methods such as chemical treatments and physical agitation of the formation.

Air entrainment is a more serious problem for aquifer storage and recovery systems.[42] If the recharge water is allowed to cascade down the well casing, it can entrain air and carry that air into the formation. Source water with high dissolved gases can also release air during injection. Once in the formation, the air forms bubbles within the pore space of the aquifer. The bubbles reduce the effective porosity of the aquifer and effectively reduce the permeability of the formation. This reduces the flow rate and storage capacity of the storage zone. Once in the formation, the air bubbles can only be removed by slowly dissolving back into the water, which can take months or years. Several techniques have been developed to prevent air entrainment problems. These include valves designed to prevent cascading water, injection through dedicated injection lines or the pump column, and sealing the wellhead during injection.

REGULATORY ISSUES

Stormwater Infiltration Systems

Stormwater infiltration structures are currently regulated by Chapters NR 110, 140, 151, 815, and 216 of the *Wisconsin Administrative Code*. Stormwater infiltration is required for any new developments that disturb over

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[42]*R. David G. Pyne*, op. cit.

one acre of land. Residential developments are required to infiltrate 90 percent of the predevelopment infiltration volume based on average annual rainfall, and 25 percent of the post development runoff volume from the two-year, 24-hour design storm. Nonresidential developments are required to infiltrate 60 percent of the predevelopment infiltration based on average annual rainfall, and 10 percent of the post development runoff volume from the two-year, 24-hour design storm. The regulations have exemptions for sites with tight soils, soils that are too coarse, contamination issues, shallow water tables, shallow bedrock, karst features, within 400 feet of a community well, or within 100 feet of a private well. Chapter NR 815 prohibits recharge of stormwater directly into groundwater through a well but allows injection of stormwater through a well into unsaturated formations of an aquifer. This injection must be permitted under Chapter NR 216 and satisfy groundwater quality standards of Chapter NR 140.

The recharge system is required, to the extent that is technically and economically feasible, to minimize the level of pollutants entering the groundwater and maintain compliance with Chapter NR 140 preventive action limits at the point of standards application. The recharge system is also required to meet Chapter NR 140 enforcement standards (ES) at the point of standards application. Pretreatment is required for parking lot runoff and for runoff from new road construction in commercial, industrial, and institutional areas that will enter an infiltration system. Pretreatment may include oil and grease separation, sedimentation, biofiltration, filtration, and filter strips or swales. The systems are intended to infiltrate the runoff water from land uses that are considered to have the least contamination in runoff to prevent groundwater contamination. This may require greater infiltration rates from low pollution sources, such as roofs, and lower infiltration rates from higher pollution sources, such as roadways or parking lots. It should be noted that rooftops and other "cleaner" surfaces may, in fact, be contaminated from sources, such as road salting and bird activity on rooftops.

The intent of these regulations is to balance the desirable effects of maintaining natural infiltration rates as land is developed, while avoiding, to the extent possible, the undesirable effects stormwater infiltration can have on water quality. Stormwater frequently contains objectionable levels of contaminants, including agricultural chemicals, organic compounds, metals, and a variety of inorganic chemicals, most notably, high levels of chloride. These regulations provide a starting point for artificial recharge in Wisconsin, but they are not designed to regulate recharge for potable water systems. Significant additional restrictions would be needed before a large-scale infiltration system could be developed to safely supplement potable water resources. These restrictions would need to consider the characteristics of the recharge source water, the buffering capacity of the soils and aquifer, and the time the water will be sequestered in the aquifer prior to reuse. As is currently the case in most states, these restrictions will probably need to be developed on a case-by-case basis to effectively protect the public and the environment.

Wastewater Infiltration Systems

Wastewater infiltration systems are regulated by *Wisconsin Administrative Code*. Chapter NR 206 prohibits underground injection of municipal or domestic wastewater through a well. Land treatment systems, including subsurface absorption soil absorption systems designed to infiltrate wastewater, must treat the water to meet Chapter NR 206 effluent standards and may require additional treatment to meet Chapter NR 140 water quality standards as approved by the Wisconsin Department of Natural Resources (WDNR). The concentration of biochemical oxygen demand (BOD), total nitrogen, total dissolved solids, and chloride in the effluent are limited. Chapter NR 110.25 requires a minimum separation distance for all land disposal systems of 250 feet to a private well. A minimum separation distance of 1,000 feet to a public water supply well is recommended. Chapter NR 206 requires a minimum of three groundwater monitoring wells for any system infiltrating over 0.015 mgd to demonstrate the system is meeting Chapter NR 140 water quality standards. A minimum schedule of quarterly sampling is required. Sampling for any or all of the following parameters may be required: groundwater elevation, BOD, field specific conductance, chemical oxygen demand (COD), organic nitrogen, ammonia nitrogen, nitrate plus nitrite as nitrogen, chlorides, sulfate, total dissolved solids, alkalinity, hardness, temperature, and pH. The WDNR may also require sampling for other parameters on a case-by-case basis.

The WDNR has determined that it is not technically and economically feasible for wastewater absorption pond systems to meet Chapter NR 140 preventive action limits for nitrate, total dissolved solids, and chloride with secondary wastewater treatment. Thus, a tertiary treatment level designed to remove these contaminants would have to be provided or variances to the regulations obtained. For a system that has exceeded an enforcement standard at a point of standards application, the Department may require a modification in the design or operation of the system or may require closure of the system. The Department may grant a variance to the groundwater quality standards if it is demonstrated that it is not technically or economically feasible for the absorption pond system to comply, and that the concentration of the substance has been minimized to the extent technically and economically feasible.

Spray irrigation systems, ridge and furrow systems, and overland flow systems are all regulated to prevent or minimize infiltration to the groundwater by restricting application rates based on soil types and requiring minimum thicknesses of unsaturated soil above the water table. Without modification, these regulations essentially eliminate the possibility of using these systems for artificial recharge because the regulations are designed to prevent application of wastewater at a rate that allows recharge to groundwater.

It should be noted that the report is focused on groundwater recharge technologies and the requirements noted herein are intended to reflect that purpose. Wastewater infiltration can also be considered as a means of wastewater disposal as opposed to aquifer recharge. In such cases, the infiltrated wastewater typically is infiltrated in the vicinity of a river or stream to which the groundwater, including the infiltrated wastewater, discharges. Wastewater could also be reused for irrigation purposes, with the intention being focused on being a source of water for vegetation, and the wastewater being applied in a manner which is consistent with vegetation needs and uptakes, rather than for aquifer recharge. The intended use and means of such wastewater infiltration or irrigation system would be a factor in determining requirements for such systems.

All of these regulations are designed to facilitate disposal of wastewater with minimal degradation of the groundwater. The Wisconsin Department of Natural Resources regulations have attempted to place barriers between drinking water sources and pollution sources. As with the stormwater infiltration regulations, these regulations are not intended to develop safe artificial recharge systems for potable use. Protection of human health must be the first priority when using water of impaired quality for artificial recharge. Experience has shown that these regulations often allow significant degradation of the groundwater quality down-gradient of the infiltration system. In their present form, these regulations would not be adequate to develop a safe artificial recharge system using a wastewater source. Significant additional restrictions would be needed before a large-scale infiltration system could be developed to safely supplement potable water resources. These restrictions would need to include higher levels of pretreatment of the wastewater, consider the buffering capacity of the soils and aquifer, and consider the time the water will be sequestered in the aquifer prior to reuse. As is currently the case in most states, these restrictions will need to be developed on a case-by-case basis to effectively protect the public and the environment.

Aquifer Storage and Recovery System Regulations

Aquifer storage and recovery system wells fall under the broad category of Class V injection wells under the U.S. Environmental Protection Agency underground injection control program.[43] Class V injection wells include a wide variety of structures, most pertaining to waste disposal. Aquifer storage and recovery systems are unlike these other Class V injection wells in that the intent is to inject and recover treated drinking water. Many states, including Wisconsin, have adopted specific regulations to manage aquifer storage and recovery systems.

In Wisconsin, aquifer storage and recovery systems are regulated by Chapter NR 811, subchapter XIV, of the *Wisconsin Administrative Code*. Chapter NR 811 mandates Wisconsin Department of Natural Resources approval before any water can be recovered through an aquifer storage and recovery system. Such systems can only be operated by municipal water systems. A pilot study and development testing are required before an aquifer storage and recovery system can be approved. At least one monitoring well is required for each pilot study. A separate study may be required for each well. The source water must comply with Chapter NR 809 drinking water

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[43]*American Water Works Association*, op. cit.

standards and the water in the storage zone must comply with Chapter NR 140 groundwater standards at the property boundary of the well site. The Chapter NR 140 groundwater standards for disinfection byproducts are much lower than the Chapter NR 809 drinking water standards, which means that stored water with disinfection byproducts over Chapter NR 140 standards cannot move past the well site property. An operation plan is required for all aquifer storage and recovery systems, which includes testing of each such cycle. The Wisconsin Department of Natural Resources may modify the operation plan to ensure compliance.

RELEVANT CASE HISTORIES

Artificial recharge of groundwater covers a wide range of technologies. Each method is designed to satisfy different site conditions, project objectives, and regulatory environments. Experience with significant recharge projects spans many decades and widely varying site conditions. A rigorous discussion of the full spectrum of artificial recharge projects would not be relevant to the objectives of this report. As a result, artificial recharge projects that are well documented or are directly relevant to the climate and geologic conditions of southeastern Wisconsin have been selected to demonstrate important physical concepts or design issues.

Surface Recharge Systems

Leaky Acres

Leaky Acres is a groundwater recharge facility operated near the City of Fresno, California. The system was built in 1970 and currently consists of 26 ponds covering 200 acres.[44,45] The surface soils are sandy, but two low-permeability aquitards are present at depth of 30 to 60 feet that are the limiting factor controlling the recharge rate. The water table is normally about 105 feet below ground surface. An average of 18 mgd of surface water from the San Joaquin and Kings River are recharged to the groundwater at the site. The system was formerly taken out of service for approximately 45 days each year to dry the beds and remove sediment and plugging material from the beds. The annual cost to remove the plugging material averaged about $60 per acre. However, the cost of the water that was lost when the recharge system was out of operation for maintenance was approximately $270,000 per year. A system of ridges and furrows has been built on the bed of the basins to trap the sediment in the furrows and maintain clean infiltration faces on the ridges. This increases the infiltration capacity of the basins and reduces the time the recharge facility is out of service.

Equus Beds Demonstration Project

The City of Wichita, Kansas obtains its water supply from the Equus Beds aquifer and a surface water reservoir. Water levels in most City wells dropped over 40 feet from 1940 to 1992 due to mining of the aquifer. The City became concerned that the aquifer would not be able to support future needs. The Equus Beds groundwater recharge project began as a demonstration project in 1995 as a cooperative effort between the City of Wichita, the U.S. Bureau of Reclamation, and the U.S. Geological Survey.[46] Water is taken from the Little Arkansas River during periods of surplus flow and recharged into the Equus Beds aquifer, a part of the High Plains aquifer system that consists of alluvial sand and gravel interbedded with silt and clay. The objective of the project is to determine the feasibility of large-scale artificial recharge to replenish the aquifer, as well as to control the migration of plumes of high-chloride groundwater from the Arkansas River and an oil field.

Since 1997, water has been pumped from a well completed adjacent to the River that receives induced recharge from the River. The water is pumped to the Halstead recharge site where it is recharged to the aquifer through a

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[44]*City of Fresno, Department of Public Utilities, Water Division,* Groundwater Recharge Program, *Last Updated 08/19/05, Available at: www.ci.fresno.ca.us/public_utilities/water/water_recharge.asp.*

[45]*Dennis E. Peyton, "Maximizing Infiltration Efficiency at Leaky Acres,"* Southwest Hydrology, *November/ December 2003.*

[46]*U.S. Geological Survey,* "Highlights of Equus Beds Ground-Water Recharge Demonstration Project,*" Last Modified: 06/15/2005, Available at: http://ks.water.usgs.gov/Kansas/studies/equus/equus_hilities.html.*

basin and trench system and a recharge well. A second recharge site, the Sedgwick recharge site, uses water drawn directly from the River after treatment with powdered activated carbon to remove turbidity and organic compounds, including pesticides. The recharge basins place the water in the aquifer over a mile from the River in positions where the recharge water can infiltrate to the deeper aquifer, rather than flowing back into the River from which it was drawn.

Recharge has been occurring since 1997. From 1997 to 2002, a total of about 1.0 billion gallons of water have been recharged at the two sites, which represents only about 3 percent of the water pumped from the aquifer by the City of Wichita for municipal use. Water levels have recovered approximately 10 feet in the aquifer since 1992, primarily due to decreased pumpage for irrigation and an increase in the use of the surface water reservoir for the Wichita municipal water supply. After six years of monitoring, no adverse changes in groundwater quality have been detected in the portion of the aquifer receiving artificial recharge, with the exception of increased arsenic levels in a single monitoring well. In 2002, recharge through prototype aquifer storage and recovery wells began.

The project has demonstrated that artificial recharge of the aquifer is feasible. However, the system must be scaled-up significantly before it can make a substantial contribution to the water supply of the City of Wichita. The feasibility of this project is entirely dependent on the availability of excess surface water from the Little Arkansas River. Artificially recharging the water reduces treatment costs over placing surface water from the River or a reservoir directly into the system. However, the system requires the water to be pumped a significant distance away from the River before recharging to prevent the water from discharging back into the River. This type of system may not be feasible if local geologic conditions do not allow for the recharge system to reach an aquifer that is not in direct connection with the surface waterbody that the water is taken from, or if it is not possible to place a well field between the recharge area and the surface waterbody receiving the groundwater discharge.

Dayton, Ohio

The City of Dayton, Ohio has used artificial recharge to replenish their aquifers and supplement their municipal water supply since the 1930s.[47] The City has two well fields that supply water to treatment plants.[48] The Mad River well field has 70 wells and the Miami well field has 37 wells. Both well fields produce water from the Miami Valley Buried Aquifer, which consists of glacial sand and gravel deposits.

Artificial recharge has been used at the Mad River well field since the 1930s. Water is diverted from the Mad River into a series of interconnected channels and lagoons on a 20-acre portion of Rohrer’s Island. The water is used to recharge the sand and gravel aquifer and maintain water levels in the Mad River well field.

In 1965, the City developed a second artificial recharge system for the Miami well field. Water is diverted from the Miami River into a 20-acre stilling basin where polymers are added to remove silt from the river water. The water is pumped from the stilling basin into a system of 31 recharge ponds and two recharge lagoons adjacent to the Miami well field. The recharge ponds and lagoons have gravel-filled trenches to penetrate a clay unit near the surface. Water utility staff report that the artificial recharge system is critical to sustaining the well field, especially in summer months.[49]

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[47] *W.M. Alley, T.E. Reilly, and O.L. Franke,* Sustainability of Ground-Water Resources, *U.S. Geological Survey Circular 1186, 1999.*

[48] *“Well Fields,” City of Dayton Website, last updated December 21, 2005, Available at: http://water.cityofdayton.org/water/wst/ground.asp.*

[49] *Personal communication with Phil Van Atta, Water Department, City of Dayton, Ohio, March 3, 2006.*

Pabst Farms
The Pabst Farms development consists of an area of approximately 1,500 acres in City of Oconomowoc and Town of Summit in Waukesha County.[50] The land is being converted from agricultural to mixed retail, commercial, and residential use. The site topography is generally flat and the soils are very permeable. As a result, the site produced little runoff while in agricultural use. Concerns were raised about the impact of the development of the site on groundwater levels and water quality in several nearby lakes. A technical advisory group convened by the developer recommended that the peak rate of discharge of stormwater after development should not exceed predevelopment conditions. To meet this goal, a system of stormwater pretreatment and infiltration ponds were designed to recharge 65 percent of the stormwater runoff from the site.

Two areas, totaling about 300 acres, have been identified as the first phase of the development. Stormwater runoff from these areas is directed into water quality ponds to remove at least 80 percent of the suspended sediment. The water quality ponds have impervious liners and also serve as aesthetic water features for the development. The water is directed from the ponds into three infiltration basin complexes designed to infiltrate the water from a 100-year recurrence interval storm event within three to four days. A stormwater district was formed to monitor the operation and maintenance of the stormwater facilities.

The soil and topography of the Pabst Farms site are uniquely suited for the ambitious infiltration system developed for the site. While conditions at other sites are likely to be less favorable to large-scale infiltration and groundwater recharge, the Pabst Farms development provides an example of what can be accomplished to reduce the impact of development on groundwater recharge and surface water quality.

The development of the Pabst Farms development illustrates the complexity of the impacts of urban development on groundwater hydrology. Prior to development, the principal use of the groundwater on the site was for spray irrigation, the water being drawn from the underlying shallow aquifer by several high-capacity wells. Much of the water would have been lost through evapotranspiration, but some would have been returned to the shallow aquifer. Upon development for urban use with public sanitary sewer and water supply services, the principal use of groundwater on the site would be for residential, commercial, and industrial supply. The water would, however, be withdrawn from the deep, not the shallow, aquifer, with the spent water being conveyed to the City sewage treatment plant and discharged to the Oconomowoc River. The Maquoketa shale formation aquitard pinches out in the vicinity of the Pabst Farm development. Therefore, there is a direct connection between the shallow and deep aquifers underlying the development area. A small amount of the shallow groundwater underlying the site may be lost through leakage into the sanitary sewerage system. The design of the stormwater management system for the development is such, however, that at least as much, or more, water is returned to the shallow aquifer than under the previous agricultural use. The preparation of comparable water budgets for the area in order to quantify the hydrologic flows from and to the shallow aquifer underlying the site under pre- and post-development conditions would be a complex and costly task.

Lake Geneva, Wisconsin
Approximately 120 public wastewater systems in Wisconsin discharge their effluent into the ground.[51] Most of these systems use infiltration basins called seepage cells. The largest of these systems is operated by the City of Lake Geneva, Wisconsin. Lake Geneva uses a system of eight seepage cells, located on an area of about 45 acres, to dispose of an average of 1.5 mgd of treated wastewater.[52] The wastewater receives primary and secondary

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[50]*F. Spelshaus, and P. McIlheran, "Successful Storm Water Infiltration at Wisconsin's Pabst Farms,"* Storm Water, *May/June 2004.*

[51]*E. Morse, "Speaking of Groundwater; The Wastewater/Chloride Dilemma,"* Wisconsin Rural Water Journal, *July 2005.*

[52]*D. Winkler and S. Tesmer, "Lake Geneva Water Commission Chloride Reduction Program," presented at the Wisconsin District Waste Water Operators Meeting, Fall, 2005.*

treatment with a three-ring oxidation ditch and two clarifiers. The water is pumped approximately one mile from the treatment plant to a holding pond. The water is discharged three times a week into one of eight seepage cells.

The seepage cells are constructed in a former gravel pit. The soils beneath the seepage cells consist of coarse sand, gravel, and cobbles. The water flows downward to the local groundwater fairly rapidly. Once at the water table, the water flows generally eastward approximately 2,000 feet to where it discharges to a large wetland drained by a tributary of the White River. The residence time of the recharged wastewater in the groundwater system is on the order of a few months assuming reasonable estimates of hydraulic conductivity and gradient. No water supply wells or other receptors are located between the seepage cells and the tributary that receives the groundwater discharge.

The City is required to monitor several water quality parameters in nine monitoring wells around the seepage cells. Groundwater down-gradient from the seepage cells shows an increase in chloride and total dissolved solids concentrations. While the increase is not striking, given that the impacted groundwater is not used for potable water supply, chloride levels exceed the enforcement standard of 250 parts per million (ppm), and total dissolved solids exceed the preventive action limit of 633 ppm. Given the elevated levels of chloride in the wastewater and the lack of any natural attenuation of chlorides in groundwater, it is not possible for the City to meet these standards in the groundwater down-gradient from their seepage cells without additional treatment that would be prohibitively expensive. Lake Geneva has undertaken an aggressive program to reduce chloride levels in their wastewater that includes a program to replace older water softeners with on-demand units that use less salt and potentially adopting a surcharge for septage that contains high levels of chloride. While the City has made serious efforts to reduce chloride levels in their wastewater, it is unlikely that it will be able to reduce concentrations enough to meet the enforcement standards for groundwater.

The Lake Geneva infiltration system is capable of infiltrating the volume of wastewater generated by the City. The cells are scraped about once a year to remove vegetation and any solids that build up on the beds of the basins. The success of the system is due to the availability of a site with extremely permeable soils with a sufficient depth to the water table to accommodate the volume of water. It is likely that the number of sites in southeastern Wisconsin that have similar infiltration capacity with suitable locations to receive wastewater are limited. In addition, the wastewater would probably require membrane treatment to reduce total dissolved solids and chloride concentrations and effective disinfection before infiltration to avoid undesirable changes in groundwater quality.

Riverbank Filtration Systems

Riverbank filtration systems have been in use in Europe for over 140 years and in the United States since the 1950s.[53] Riverbank filtration systems are common along the Ohio River and its tributaries using vertical wells adjacent to the River and horizontal collector wells with laterals projected under the riverbed to induce recharge from the River. The City of Cincinnati, Ohio operates a field of 10 vertical wells adjacent to the Great Miami River that produces 15 to 30 mgd.[54] The well field is specifically designed to induce recharge to sustain the water production, particularly in times of drought. Louisville, Kentucky has developed a 20 mgd collector well adjacent to the Ohio River and has plans to develop a riverbank filtration system capacity of 45 mgd by constructing additional wells.[55]

Des Moines, Iowa uses riverbank filtration along the Raccoon River. Kansas City, Missouri has installed a collector well adjacent to the Missouri River. Lincoln, Nebraska produces water almost entirely induced from the Platte River using a field of 38 vertical wells and two collector wells in the alluvial deposits adjacent to the Platte

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[53]*S. Hubbs and T. Caldwell,* op. cit.

[54]*William D. Gollintz,* et. al., *December 2003,* op. cit.

[55]*D. Schafer,* op. cit.

River.[56] Several other cities, including St. Louis and New York, are considering riverbank filtration systems to help meet some of their water demands.

The City of Manitowoc

In Wisconsin, riverbank filtration systems have been used on a smaller scale. The City of Manitowoc operated a system of three horizontal collector wells with laterals projected under Lake Michigan at a park adjacent to the lake. The system was installed in the 1940s.[57] Two of these wells remain in service as an emergency backup supply for the surface water intake that now serves the City.

The City of Mequon

The City of Mequon studied the feasibility of using a vertical well field in Virmond Park adjacent to Lake Michigan to induce lake water into the aquifer.[58] Subsequent test pumping in the 1990s indicated significant blending with native groundwater that increased the total dissolved solids and hardness of the water above the levels in treated lake water, available from either the water treatment plant operated by the North Shore Water Commission, or the City of Milwaukee system. The former was eventually chosen as the source of supply for a private water system serving portions of the City.

The City of Wisconsin Rapids

The City of Wisconsin Rapids operates four horizontal collector wells intended to increase the production capacity of a thin sand and gravel aquifer. Three of these wells are not located near any surface waterbody and are not intended to induce recharge from surface water. One of the collector wells, Well 4, was constructed near the headwaters of Bloody Run Creek. Reductions in the base flow of the creek have led to allegations that the well is inducing recharge from the creek and harming the aquatic habitat. The City has established a groundwater monitoring network around the well and is in the process of searching for a new well location to allow the City to reduce its pumpage from Well 4 during critical periods.

The City of Waukesha

The Waukesha Water Utility recently drilled two wells in the sand and gravel aquifer adjacent to the Fox River. Wells 11 and 12 are designed to intercept groundwater from the shallow aquifer immediately before it would normally discharge into the River. A low permeability clay layer between the aquifer and the riverbed significantly retards the movement of water from the River to the aquifer so the amount of induced recharge produced by the well is expected to be minimal, and the flow through the confining layer will be relatively slow. The well field is intended to function primarily as a means of capturing surface water discharge from the groundwater system, rather than directly inducing recharge from the surface water. The well field is positioned less than two miles downstream from the City of Waukesha sewage treatment plant that receives the return flow from the City water system. The water that is captured by the wells is returned to the River via the sewage treatment plant a short distance upstream from the point of removal, thereby mitigating any potential negative environmental impacts caused by the pumpage.

Subsurface Recharge Methods

Odana Hills Golf Course

Subsurface recharge methods have been used to a much more limited extent in Wisconsin due to the higher costs of construction. One project has recently been constructed in the Madison area. Madison Gas and Electric is

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[56]*D.L. Galloway, W.M. Alley, P.M. Barlow, T.E. Reilly, and P. Tucci,* op. cit.

[57]*Wisconsin Department of Natural Resources Drinking Water System,* Well Construction Reports, *Available at:* *http://prodmtex00.dnr.state.wi.us/pls/inter1/watr$well_constr.queryviewbykey* *Accessed on 3/17/2006.*

[58]*Douglas S. Cherkauer and Barry Zvibleman, Department of Geological Sciences University of Wisconsin-Milwaukee,* Final Report to City of Mequon, Department of Public Works On: Induced Recharge Feasibility Study*, September 5, 1978.*

currently finishing a subsurface recharge system designed to offset groundwater pumping used to support base flows in the Yahara River and offset water drawn from Lake Mendota for electric power generation plant cooling.[59] The artificial recharge project is designed to replenish the groundwater pumped to supplement the Yahara River. The system is designed to take stormwater from the Odana Pond, pump the water to a higher area, and then recharge the water through a drain field. The drain field lies beneath the rough of a municipal golf course. The system is designed to have a maximum infiltration capacity of 80 million gallons per year. The water will be treated by microfiltration to remove suspended particles prior to recharge to avoid clogging of the drain field. The capital cost of the artificial recharge project, as estimated in 2006, was reported to be $1.9 million.

Artificial Recharge of the Sandstone Aquifer in Chicago

Water levels in the sandstone aquifer in northeastern Illinois had dropped by more than 850 feet from predevelopment conditions in 1971 in response to heavy pumpage. Regional water authorities began planning to extend the area served by Lake Michigan water to reduce pumpage from the aquifer. A novel artificial recharge was proposed to stabilize water levels in the deep sandstone aquifer in the Chicago area as an alternative to abandoning the wells. The project was proposed in 1982 by a private consultant and the Executive Director of the National Water Well Association (now the National Ground Water Association).[60] The proposed project called for 20 recharge wells along a 38-mile stretch of Lake Michigan shoreline to take shallow groundwater from recharge galleries in the bed of Lake Michigan and inject the water into the sandstone aquifer using gravity flow. Approximately 30 to 60 mgd would have been recharged directly into the sandstone aquifer, causing an increase in head of about 69 feet 15 miles inland within one year, and about 323 feet after 50 years. Head in the aquifer was expected to rise five feet 35 miles inland within one year, and 140 feet after 50 years. The later stages of the proposed project would have used wells completed in the shallow dolomite and sand and gravel aquifers and open to the underlying sandstone aquifer to inject shallow groundwater into the sandstone aquifer near major pumping centers. The proposed project was never built for a variety of reasons, but it does illustrate how large-scale artificial recharge of the sandstone aquifer was considered in the past.

Aquifer Storage and Recovery Systems

The first aquifer storage and recovery well was developed in Wildwood, New Jersey in 1969. The well is still in operation and is now part of a system of four such wells.[61] Currently, about 69 aquifer storage and recovery systems are in operation in the United States. These systems range from single-well installations to systems of up to 30 wells. System capacities vary from about 0.5 mgd to over 100 mgd. Map 3 indicates that in the United States most of the active aquifer storage and recovery systems are located along the coasts or in the arid west. Such systems are in widest use in Florida, with 13 systems in the State having a total of at least 47 wells, with more wells in the planning stage. A system of over 300 wells is under consideration to store treated surface water as part of a restoration plan for the Florida Everglades.[62] California has 12 aquifer storage and recovery systems, with at least 33 wells.

The City of Oak Creek

Aquifer storage and recovery use in Wisconsin has been limited. The City of Oak Creek has the only permitted aquifer storage and recovery well in the State.[63] The well was developed in 1998 to meet peak demands on the

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[59]*Montgomery Associates, "Odana Hills Enhanced Groundwater recharge Design Report," June 2005.*

[60]*T. Bennet, T. Gass, J. Lehr, L. Aller, and D. Nielsen, "A Cost Effective Water Supply Alternative For the Chicago Suburban Area: Artificial Ground-Water Recharge," unpublished report prepared by Bennett and Gas Consulting Geologists and the National Water Well Association, August, 1982.*

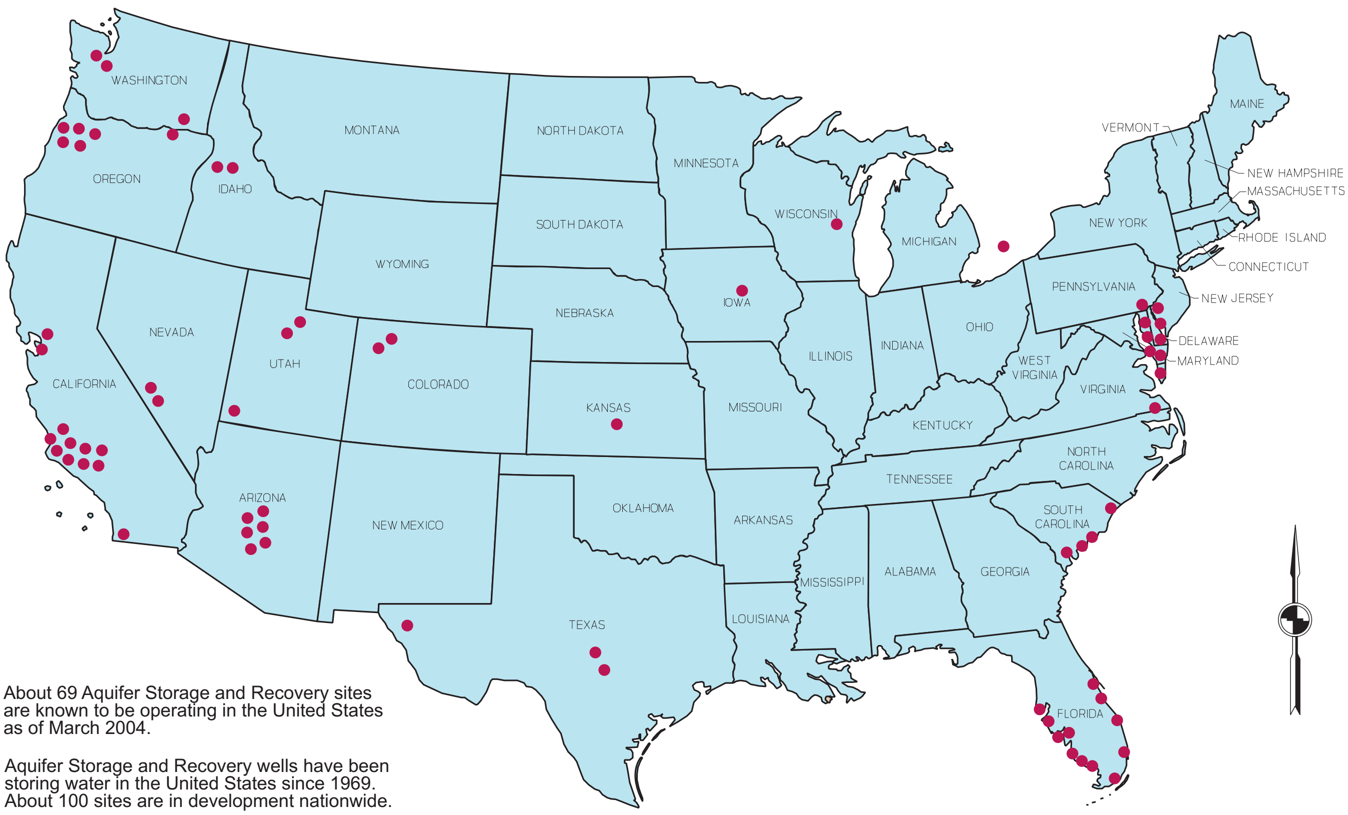
[61]*ASR Forum*, op. cit.

[62]*U.S. Army Corps of Engineers and the Southwest Florida Management District, "Aquifer Storage and Recovery (ASR) Regional Study and Pilot Projects," November, 2002.*

[63]*Personal communication with Michael Sullivan, Oak Creek Water Utility, 02/08/06.*

Map 3

AQUIFER STORAGE AND RECOVERY SYSTEMS OPERATING IN THE CONTIGUOUS UNITED STATES: 2004



Source: Aquifer Storage and Recovery Forum, 2004 and SEWRPC.

City water system and to delay, or avoid, an expansion of the surface water treatment plant. The well stores approximately 42 million gallons of treated drinking water in the Cambrian and Ordovician aquifer using an existing municipal well. The recharge water is surface water provided by the City water treatment plant located on Lake Michigan. The system was operating from 1998 through 2004, as part of an extended testing period upon the completion of which it was permitted by the Wisconsin Department of Natural Resources in 2004. The system has stored and recovered water for seven cycles, typically on an annual basis. Initial concerns over placing treated surface water that contained disinfection byproducts that were below drinking water standards, but exceed groundwater standards in Wisconsin, were overcome when it was demonstrated that the compounds degraded in the aquifer to acceptable levels.[64]

Currently, the recovered water meets all current State drinking water standards. The water contains slightly elevated levels of manganese, which is believed to be caused by mobilization of manganese from oxidation of sulfide minerals in the aquifer matrix. It is believed that manganese levels will decrease after additional storage and recovery cycles depletes the sulfide minerals and precipitates iron hydroxide minerals in the aquifer within the storage zone.

The City of Green Bay

The City of Green Bay tested an aquifer storage and recovery well, beginning in 2002. The system was intended to store treated Lake Michigan water from the City's water treatment plant in the Cambrian and Ordovician

[64] *J. Schultz, "Oak Creek Aquifer Storage and Recovery Case Study," University of Wisconsin, Green Bay, Groundwater Resources and Regulations Group Project, Fall 2002.*

aquifer using an existing municipal well. Aquifer storage and recovery would allow the Green Bay Water Utility to avoid construction of a second supply line to Lake Michigan and serve several new municipal water customers at a lower cost.[65] Water recovered from the first two injection and recovery cycles contained elevated levels of arsenic that exceeded the Federal and State maximum contaminant level**.**[66] The arsenic is believed to have been mobilized by oxidation of sulfide minerals in the aquifer matrix. The City installed casing across the suspected arsenic zone to reduce the potential for mobilizing arsenic. Water recovered by additional testing conducted in 2003 after installing the casing also exceeded the maximum contaminant level.[67] It was believed that additional injection and recovery cycles would reduce arsenic content, but the project was abandoned due to deadlines for the suburban communities to commit to an alternative water source.

SUMMARY OF SUITABLE ARTIFICIAL RECHARGE TECHNOLOGIES FOR SOUTHEASTERN WISCONSIN

All of the artificial recharge methods described in this report could potentially be used in southeastern Wisconsin. However, considerations, such as cost, environmental impacts, public acceptance, and regulatory issues, make several of the technologies less attractive or impractical. The following text presents some general comments on the potential application in southeastern Wisconsin of the technologies concerned.

- Surface infiltration methods are being used in southeastern Wisconsin to control runoff and dispose of wastewater. Both of these uses can have negative impacts on groundwater quality. If surface infiltration were to be used to augment sources of water supply, the recharge water would have to be of sufficient quality to avoid degrading the groundwater. This could be accomplished by using only treated water for recharge. The level of treatment required would depend on the source of the water. Runoff from forest or prairie lands may need no additional treatment. The volume of water available from these sources, however, is likely to be limited. Runoff from farmland or developed areas is likely to contain levels of contaminants such as nitrates, pesticides, or road salt that could, without treatment prior to recharge, cause contamination of the groundwater. Wastewater would probably require membrane treatment in addition to traditional primary and secondary treatment to reduce chloride and total dissolved solids levels. The cost of this treatment may exceed the cost of alternate water supplies, such as treating surface water for direct use as a water source. Even after extensive treatment, public reaction to recharging wastewater into potable aquifers is likely to be negative. The lack of monitoring of private wells that may receive recharged water creates an additional level of concern in terms of protecting public health.

  Some of the problems concerned could be avoided or reduced if the recharge system was not designed to supplement potable water sources. If a recharge basin were designed to supplement base flow to a stream, wetland, spring or other critical surface water feature, the act of recharging the water to the aquifer would typically improve the water quality at the receiving body over direct runoff. In addition, the recharge process could serve to reduce peak surface water flows and increase low flows by storing the water from large storm events in the groundwater system and slowly releasing the water to the surface through groundwater discharge. Placing the recharge structures near the discharge point of the groundwater flow system would allow lower quality water to be used with no degradation of the water resources. It would also limit the number of private wells that may be

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[65]*Don Behm of the* Journal Sentinel *Staff, "Aquifers May Store Water, Not Just Supply It," Last Updated March 4, 2002.*

[66]*Peter Rebhahn, Green Bay Press-Gazette, "Aquifer Storage Plan Needs Work, 2003," Available at: www.greenbaypressgazette.com.*

[67]Ibid.

impacted and reduce the need to pump treated wastewater up hill to suitable groundwater recharge areas above well fields.

With this in mind, it may be more practical to use recharge basins to offset the negative impacts from pumpage up-gradient from the recharge basin or to protect critical aquatic habitats below the basin. The use of this technology will be limited by the availability of suitable sites with permeable soils in appropriate locations relative to the target of the recharge. As such, the application may be limited but it may prove to be a useful technique in specific cases.

- Riverbank filtration has the potential to increase water supplies without degrading the environment, especially when the wastewater can be returned to the same stream. Some additional level of treatment may be required if the travel time between the wellheads and the surface waterbody is too short and the wells are considered to be under the direct influence of surface water. However, in many cases additional treatment will probably not be necessary or will be limited to additional disinfection. The use of this technology will be limited by the availability of suitable aquifers adjacent to surface waterbodies that have surplus flow. Horizontal drilling technologies could significantly increase the number of sites that could be used for riverbed filtration.

- Direct infiltration methods, such as aquifer storage and recovery or injection wells, will require recharge water that meets drinking water standards. This limits the practical application of this technology to long-term storage of large volumes of water. It is conceivable that some future water sources may have restricted availability at certain times of the year. Examples of this could be shallow wells that have the potential to impact aquatic habitats during critical times of the year, or treatment plants or wells that have surplus capacity under average conditions but cannot meet peak demands. In these cases, water storage in aquifers could provide economic and environmental advantages. Extensive testing would be required to determine if the recharge water is compatible with the aquifer and native groundwater. The cost of this testing represents a significant investment to determine if the method is feasible.

- Enhanced recharge and recharge ranches are low impact technologies that could be incorporated into green space development and certain types of residential and commercial developments. These methods could be used to protect and enhance critical recharge areas. While it is unlikely that any one of these projects will place a large volume of water into the aquifer, the cumulative effect of several of these projects could provide significant benefit.

  While no recharge ranches are known to be in operation in Wisconsin, in theory, such ranches could be used to support specific objectives. Farms or open land in favorable locations could be graded to capture runoff from rain and snow and direct the water to recharge structures. The land use could be controlled to avoid activities that would cause water quality problems such as chemically intensive agriculture or the application of road salt. These parcels could be located in areas of permeable soil up-gradient from well fields or sensitive surface waterbodies. The enhanced recharge could replace all or some of the water pumped by the well field or supplement the groundwater discharge to a stream, wetland, or spring.

  By controlling the land use in the catchment area of the recharge structure, the quality of the recharged water could be protected. The availability of suitable sites within southeastern Wisconsin will be limited. In theory, the land could be developed as a conservation subdivision, providing the application of lawn chemicals and road salt are controlled and any onsite disposal systems are designed to provide adequate treatment to prevent contamination of the groundwater. In practice, the best use for the land in the catchment area would be a green space or park.

COSTS FOR GROUNDWATER RECHARGE AND MANAGEMENT

The costs for artificial recharge vary widely from project to project. Much of the cost variation is related to the cost of land, the type of recharge system, and the cost of acquiring and treating the recharge water. The cost of water is a major cost factor for recharge projects in the western U.S. where all available water is usually fully allocated and the water must be purchased before it can be recharged. Wisconsin does not have a water allocation system, and water is free to any reasonable use. In most cases any purchases of water in Wisconsin for artificial recharge would involve treated drinking water that would predominantly be limited to aquifer storage and recovery or to other artificial recharge methods with short-term storage components.

The use of wastewater for artificial recharge for potable uses generally involves high levels of treatment, such as Advanced Wastewater Treatment technologies that include membrane treatment, carbon filtration, advanced disinfection, and other higher-level treatment methods. These treatment costs generally exceed the cost of drinking water treatment and are only economic if no other sources of water are available. Permitting requirements also vary widely from area to area. Some jurisdictions allow the use of soil aquifer treatment, particularly when the recharge project supports nonpotable uses, which reduces the cost of using wastewater for recharge. Based on current state regulation, it is unlikely that artificial recharge for potable uses would be allowed without higher levels of treatment.

Land prices are much higher in many areas where artificial recharge projects are extensively used. The high land prices increase the construction costs of surface infiltration systems or drive the use of more expensive subsurface recharge technologies that use less land. Most published cost data do not provide detailed breakdowns on the land costs, and the cost for these projects vary widely. Many of the recharge systems developed in the Midwest were constructed several decades ago, and detailed cost data are not available. For these reasons, it is difficult to compare cost data from other regions to form a reasonable estimate for a potential project in southeastern Wisconsin.

To provide more useful estimates of the cost of artificial recharge in southeastern Wisconsin, as much data as could be found was gathered on the operation and maintenance costs of typical artificial recharge projects and estimates of actual construction and permitting costs independent of land cost and water purchases. Estimated land costs and treatment costs more typical for southeastern Wisconsin were used to calculate the cost estimates. Costs from local projects were used whenever possible.

Surface Infiltration Systems

The cost of surface infiltration systems is very site-specific. Where recharge is feasible, the unit cost of recharged water is usually very low.[68] The costs are limited to the acquisition of the land, construction of the system, purchase and treatment of the water, and nominal operation and maintenance costs. Cost data on recharge systems is difficult to find and generally provides little detail. Leaky Acres in Fresno, California has annual operation and maintenance costs of $60 per acre, or about $9,000 per year.[69] However, the value of the water lost during the period when the basins were dry for cleaning amounts to $270,000 per year.

The available cost data on surface infiltration systems include a multitude of factors that may not be relevant to southeastern Wisconsin. To compensate for these differences, calculations were made for the approximate cost to construct an artificial recharge system, similar to the infiltration basins operated by the City of Lake Geneva, under three sets of assumptions. The estimates assume a system consisting of eight infiltration basins over a 20-acre site in an area with soils that are suitable for a surface infiltration system, assuming an infiltration capacity of 1.5 mgd. The cost estimates cannot be linearly extrapolated to estimate the costs of systems with different

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[68]*Personal communication with Herman Bouwer, USDA-ARS US Water Conservation Laboratory, Phoenix, AZ, 02/27/06.*

[69]*D. Peyton,* op. cit.

capacities because some of the treatment processes have significant cost differentials base on the scale of the system. It is also likely that more land will be needed for a larger system, but the actual size of the site will be controlled by soil conditions and the need for a buffer zone around the infiltration basins. For all three estimates, a land cost of $400,000 was assumed ($20,000 per acre for 20 acres), $1,770,000 for capital cost of the basins and related structures and for one mile of dedicated transmission line. These costs will vary significantly depending on local conditions and are only intended as a first-order estimate. These costs include 30 percent provision for legal services, engineering and design, and contingencies.

The first case assumes that the recharge water is taken directly from a treatment plant providing standard primary and secondary sewage treatment and that the systems incurs no extra treatment costs, similar to the Lake Geneva system. This type of recharge system would not be suitable for potable uses, but would be suitable to restore base flow to a surface waterbody, providing that there were no human receptors between the recharge system and the surface waterbody. This type of system is not expected to meet the State groundwater standards for, at least, chlorides, dissolved solids, and nitrates over the long-term. Thus, addition of tertiary treatment will be required or variance from the regulations obtained in order to develop such a system. The second case assumes that the water will be used to recharge an aquifer for potable use with a minimal level of treatment that may be acceptable. The water is assumed to be treated by membrane filtration to reduce chlorides and total dissolved solids. Advanced disinfection by ozonation is also assumed. The third case assumes a higher level of treatment by adding carbon filtration to remove pharmaceutically active compounds, endocrine disruptors, emerging contaminants, and trace organic compounds to the treatment stream used for the second estimate.

Given these assumptions, the capital cost to build a recharge system to infiltrate 1.5 mgd of wastewater effluent treated to secondary standards is approximately $2.17 million, or about $1.45 million per mgd of recharge capacity. Operation and maintenance costs are minimal and would be limited to periodically raking the beds.

Adding membrane treatment and ozonation adds $6.0 million in construction costs ($8.18 million total capital costs) and $630 per MG in operation and maintenance costs. This represents a capital cost of about $5.45 million per mgd of recharge capacity. Orange County California reported a cost range of $251 to $387 per acre-foot ($770 to $1,190 per MG) to treat wastewater to potable standards using microfiltration in 1993.[70] The difference in these estimates probably reflects the reduction in costs in the microfiltration process over the last decade.

Adding carbon filtration to the processing stream adds an additional $10.7 million in capital costs ($18.9 million total capital costs) and $1,630 per MG in operation and maintenance costs. This represents a capital cost of $12.6 million per mgd of infiltration capacity.

Direct Injection Systems

Direct injection systems typically have higher capital costs, due to the need to drill injection wells, and higher operation and maintenance costs due to the higher costs of cleaning well screens. If wastewater is used as the recharge water, higher levels of water treatment are usually required because the water is directly injected into the aquifer, which does not provide any protection for the groundwater. As an example, the Hueco Bolson recharge project in El Paso, Texas is a 10.0 mgd recharge project that uses 10 injection wells to recharge wastewater treated by advanced wastewater treatment processes to recharge an aquifer at a depth of about 350 feet. The system had a capital cost of $33 million in 1985 with operation and maintenance costs of $1.88 per thousand gallons.[71] Wisconsin law only allows treated drinking water for injection wells.

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[70] *Committee on Ground Water Recharge, National Research Council, "Ground Water Recharge Using Water of Impaired Quality," National Academy Press, 1994.*

[71] Ibid.

Aquifer Storage and Recovery Systems

The Oak Creek Water Utility has the only permitted aquifer storage and recovery system in Wisconsin. They operate a single aquifer storage and recovery well with a storage volume of 42 million gallons. An existing municipal well in the deep sandstone aquifer was converted for use as an aquifer storage and recovery well. They estimate that the cost to convert the production well to an aquifer storage and recovery well, with testing, permitting, and the lobbying efforts needed to change well codes, was approximately $1.0 million.[72] Future aquifer storage and recovery wells in Wisconsin would not incur all of these costs, as the regulatory changes and permitting process have been established. They estimate more typical costs to convert and permit the first well for a new aquifer storage and recovery system, which would be $500,000 to $750,000, and about $300,000 to $500,000 for a second well in the same geologic formation, assuming a second well would not require a dedicated monitoring well for the permitting process. Operation and maintenance costs are essentially the same as a typical municipal well.

Using the Oak Creek cost data, an initial aquifer storage and recovery well in the deep sandstone aquifer for a new aquifer storage and recovery system in southeastern Wisconsin would cost approximately $330,000 to $750,000 per mgd for recovery capacity, assuming a recovery capacity of between 1 to 1.5 mgd per well. Additional wells in the same aquifer storage and recovery system would cost $200,000 to $500,000 per mgd. These costs assume that an existing well and pump house is available for conversion to an aquifer storage and recovery system. If a well and pump house were constructed for the project, an additional cost of $750,000 to $1.0 million would be incurred, increasing the cost to $830,000 to $1.75 million per mgd for an initial well, or $700,000 to $1.5 million per mgd for subsequent wells.

These costs are similar to published estimates for the U.S. of $200,000 to $600,000 per mgd for retrofitting and permitting existing wells or drilling and permitting new ASR wells with annual operation and maintenance costs of $15,000 per mgd.[73] The cost to retrofit an existing municipal well, purchase wholesale water, permitting, and pumping costs for an aquifer storage and recovery well in the Denver Basin was estimated at $2.45 per thousand gallons, over a 20 year period.[74]

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[72] *Michael Sullivan,* op. cit.

[73] *R. David G. Pyne,* et. al., op. cit.

[74] *J. Halepaska, "Case History of Aquifer Storage and Recovery in the Denver Basin Aquifers," Presented at the Association of Engineering Geologists Annual Conference, Fall 2005.*

Chapter VII

WATER CONSERVATION

INTRODUCTION

On a global scale, potable water is a limited and increasingly precious natural resource that needs to be carefully husbanded and conserved. Under the pressure of increased population levels, water is becoming a scarce and costly commodity in some areas of the world. Within some parts of the United States, water has for some time been a limited resource of great concern to competing agricultural and urban users. Southeastern Wisconsin, however, is a water-rich area and water supply has long been regarded as a virtually limitless resource. That historic viewpoint is, however, changing under the effects of areawide urbanization, and the attendant increases in water use and changes in hydrology due to increases in impervious surfaces. The need for, and importance of, water conservation and water supply system efficiency are becoming increasingly evident to elected and appointed officials, the business community, and citizens. In addition to water supply system efficiency and demand side water conservation measures, stormwater management measures designed to maintain or improve the infiltration of stormwater into the groundwater aquifers are important to a comprehensive water supply management strategy in many parts of the Region. Such measures are described in Chapter VI of this report. This chapter is intended to focus upon water conservation measures, including water system efficiency and demand side measures.

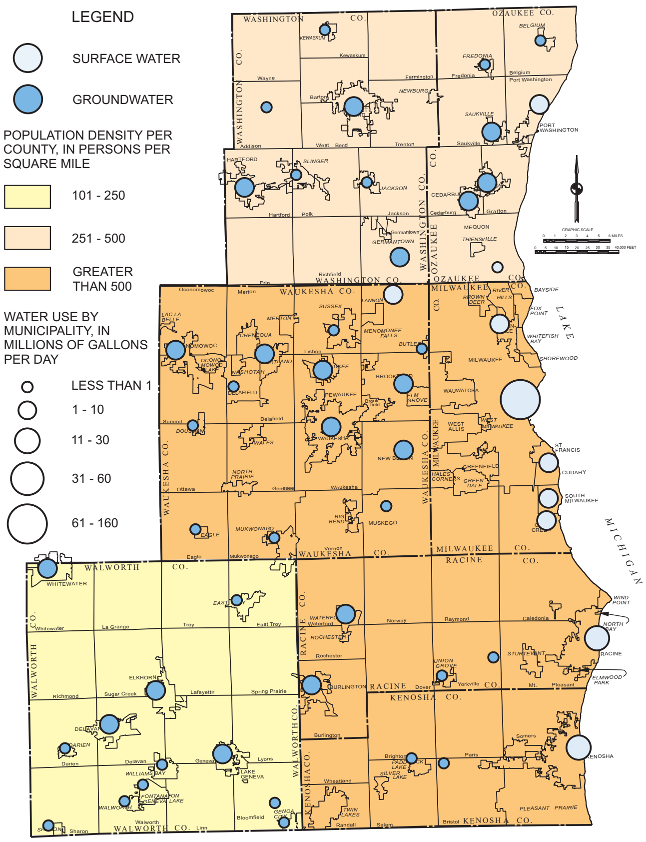
Historically, water conservation was sometimes viewed as the retention of water during periods of high stream flow in reservoirs for future use during periods of low flow. This definition involved the construction of dams and the diversion of surface waters that could result in damage to natural ecosystems. In the early 1970s, the perception of water conservation changed to the present concept of efficient and effective use. Public interest in, and concern over, water conservation varies in different areas of the United States. In the arid southwest, conservation efforts are routinely accepted. In more humid areas where water is more plentiful, such as southeastern Wisconsin, public interest in water conservation has developed only relatively recently.

Southeastern Wisconsin has an abundant supply of water, contained in over 1,150 miles of perennial streams, 176,000 acres of wetlands, 77 miles of Great Lakes shoreline, 101 major inland lakes, and two major groundwater aquifers. Groundwater levels in the deep sandstone aquifer underlying the area, however, have been steadily falling over the past century. This decline may be primarily attributed to pumping from that aquifer for use by rapidly developing urban communities in southeastern Wisconsin and northeastern Illinois. Estimates of water use by municipality and population density in the Southeastern Wisconsin Region are shown on Map 4.

Regardless of the abundance of the supply, there are a number of potential benefits attendant to the conservation of water, including: reduction in the costs of treatment, transmission, and distribution; reductions in associated energy consumption; and environmental protection. In addition, implementation of effective water conservation measures has the potential to reduce future capital costs of water supply facilities, and may contribute to

Map 4

POPULATION DENSITY BY COUNTY AND WATER USE BY MUNICIPALITY IN THE SOUTHEASTERN WISCONSIN REGION: 2000



Source: U.S. Geological Survey, 2002, and SEWRPC.

maintaining a sustainable water supply. These savings and related benefits of water conservation measures may be accompanied by a loss of revenue. This chapter presents information on water conservation practices that are considered potentially applicable within southeastern Wisconsin. Included are sections on the descriptions of water conservation measures, the cost of such measures, and the potential impact of the measures on water supply system demands.

WATER CONSERVATION AND WATER SUPPLY SYSTEM EFFICIENCY IMPLICATIONS

Water conservation and water supply efficiency are interrelated terms. Water conservation may be defined as any beneficial reduction in water loss, waste, or use, including reduction in water use accomplished by implementation of water conservation or water efficiency measures and improved water management practices. Water supply efficiency may be defined as the planned management of water to accomplish a function, task, process, or result with the minimal amount of water practicable. Water supply efficiency is a resource management practice indicative of the relationship between the amount of water required for a particular purpose and the quantity of water actually used or delivered. In these definition of terms, water supply efficiency is a water conservation measure. Given the amounts of water and other resources involved, and the ability to control implementation, water supply efficiency is likely to be the most direct and effective water conservation measure available to water utility managers. This chapter is intended to focus on water conservation measures and practices, including those associated with water utility system efficiency.

All of the utilities within the Southeastern Wisconsin Region have some form of water supply efficiency program. Such programs may include meter testing for accuracy, leak detection and repair, and repair or replacement of water mains with identified problems. These efficiency measures are well established and are system-specific. Such programs are under the control of the utilities and can, therefore, be implemented directly without customer action. However, these programs do require financial resources which need to be provided through water sale revenues. Reductions in revenues supporting these efficiency programs resulting from water conservation programs will have to be made up through increases in rates.

The need for, and implications of, water conservation within the seven-county Southeastern Wisconsin Region differs markedly between those areas utilizing Lake Michigan as a source of supply, and those areas utilizing groundwater as a source of supply. In general, but with some exceptions, the areas utilizing Lake Michigan as a source of supply are located east of the subcontinental divide. Areas utilizing groundwater as a source of supply are located both east and west of the subcontinental divide. In addition, there is a distinction to be made relative to water conservation programs between water users served by private, self-supplied water systems, and those water users supplied by municipal water supply systems. Those areas of the Region served by Lake Michigan supplied systems have access to a bountiful source of high-quality water. Those areas of the Region served by groundwater-supplied systems must be concerned with the continued ability of the groundwater aquifers to meet the increasing demands placed upon them by urbanization, and, in the absence of wise use, this ability may become a constraint on the continued social and economic development of the Region. The general need for, and implications of, conservation will, therefore, be different within the areas of the Region served by Lake Michigan-supplied systems, and those areas served by groundwater supplies. The need for, and implications of, conservation will also differ in the particulars concerned, such as the characteristics of the individual public and private water supply systems involved. The implications of conservation will be quite different for a water supply system utilizing Lake Michigan as a source of supply and operating at well below design capacity, than for a public water supply system utilizing groundwater as a source of supply and operating at design capacity. The manner in which the spent water supply is disposed of will also affect the need for conservation. In areas utilizing Lake Michigan as a source of supply, the spent water supply is largely returned to the source, along with additional sewerage system clearwater infiltration and inflow, the return flows will typically exceed in total the amount of water supplied. In the areas using groundwater as a source of supply, the spent water is typically not returned to the source of supply. Accordingly, the development of water conservation measures must recognize the differing needs for conservation within the Region.

APPROACH TO WATER CONSERVATION

For the purposes of the regional water supply planning effort, a water conservation program is defined as a combination of practices, procedures, policies, and technologies used to reduce the amount of water usage or to improve or maintain water system efficiency. Public interest in, and demand for, water conservation programs are motivated by several factors, including: perceived limitation of water supplies, high costs and difficulties in developing new supplies, and public interest in, and support for, natural resource conservation and environmental protection.[1]

Water supply planning is a task in which water supply utilities must consider meeting the needs of the communities served in a cost-effective fashion. Water supply planning also requires the consideration of the need to protect and sustain the water resources of the Region. Ideally, utilities should consider a full range of supply and conservation strategies in order to assure that both valid system performance and environmental objectives are met.[2] Conservation programs must be developed on a utility-specific basis to find the best means available for meeting the water supply needs, while maintaining the sustainability of the source, or sources, of supply.

There are several approaches available to the development of a water conservation program. The U.S. Environmental Protection Agency (USEPA) publication *Water Conservation Plan Guidelines* describes a number of such approaches dependent on the size of the population served by individual water suppliers. The guidelines encourage the suppliers to consider and evaluate all practical conservation measures.[3] Once developed, water conservation programs may be carried out by a number of measures, including incentives and regulations. Conservation measures are intended to result in more efficient water use and to meet water conservation objectives. Water conservation measures may involve the use of new technologies, or the promotion of behavioral change. Conservation regulations are measures imposed upon users through legal measures. Conservation incentives are the measures intended to motivate behavioral change on the part of the users. Public education campaigns and water rate structure revisions are examples of conservation incentives.

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[1]*American Water Works Association (AWWA),* Water Conservation Programs-A Planning Manual*, 2006 (11).*

[2]*Great Lakes Commission,* Selected Guidelines of Water Conservation Measures Applicable to the Great Lakes-St. Lawrence Region*, 2002, Available at: http://www.glc.org, viewed 08/16/06.*

[3]*U.S. Environmental Protection Agency,* USEPA Water Conservation Plan Guidelines*, August 1998.*

COSTS AND BENEFITS

The costs and benefits associated with water conservation have traditionally been difficult to quantify. Each conservation program is unique to the water system concerned. Conservation programs impose costs on both the water suppliers and the water users, with differential attendant benefits.

Water conservation programs can be designed to either reduce the amount of water customers use and/or to reduce the amount of water pumped to meet customer demands through increased water system efficiency. Utilities will incur costs for implementation of conservation programs. The direct costs of conservation programs include staff salaries, contract costs, and program support needs, such as educational materials and publicity. Utilities may incur decreased revenues as a result of implementation of water conservation programs designed to reduce customer demands. Such water conservation programs are intended to result in a reduction in the amount of water supplied to customers; therefore, a loss of revenue will typically be incurred. This reduction in revenue will be proportional to the level of water conservation achieved and will occur over an extended period of time. Such programs may require utilities to modify future budgets to reduce costs or increase rates to maintain needed revenue over time. Capital costs are typically fixed for some period of time and, if water use and attendant revenues are reduced, water rates may need to be increased to recover these fixed costs. Benefits that may accompany reductions attendant to conservation programs that are related to increased efficiencies in operation include reductions in the cost of variable inputs to production, such as chemicals and energy costs. Water saved through increased system efficiency is typically not accounted for in sales and, thus, does not affect revenue.

In most systems, the reduction in revenues attendant to conservation programs will exceed the reductions in direct production costs by a significant amount. In the Southeastern Wisconsin Region, typically 15 to 25 percent of the operation and maintenance budget, and all of the capital-related budget, represent fixed costs that are largely unaffected by conservation measures. Only 7 to 15 percent of the typical utility budget is related to costs which are variable with water demands. Thus, for each $1.00 of water revenue reduction, it is likely that $0.15 or less could be offset by an immediate savings in cost, while $0.85 or more will need to be recovered by other means, including rate increases or reduction in service. A higher proportion of the utility costs may be offset by savings resulting from reductions in water use if the utility concerned has a need for new capital facilities. The avoided cost of such facilities can be a significant factor favoring water conservation programs for utilities which anticipate such capital needs. However, within the Southeastern Wisconsin Region, such capital costs capacity expansion may not be required until well into the future, particularly for those utilities using Lake Michigan as a source of supply. For other utilities, these costs may be more imminent, and avoided capital cost savings will be realized in a relatively short time frame of five to 10 years.

Water customers also incur certain costs and savings when attempting to become more water efficient. The savings that customers will obtain often will result from reduced water bill costs; operation and maintenance of more efficient equipment, fixtures, and appliances; and in energy costs. The costs involve the purchase and installation of the equipment, fixtures, and appliances. If these costs become too high, customers are less likely to participate. Some utilities offer incentives to customers willing to install more-efficient equipment, fixtures, and appliances. In Wisconsin, as of 2006, such a practice is not allowed under the Public Service Commission of Wisconsin utility rate structure policies. Additional capital and operation and maintenance expenses may also be incurred for industrial or commercial facilities that install more-efficient equipment, fixtures, and appliances. Careful consideration of all other costs and benefits of a water conservation program must be considered to ensure the success of a water conservation program.

Costs attendant to the water conservation measures herein considered were obtained from multiple sources. These are cited throughout the remainder of this chapter. These data were updated to 2005 costs using the *Engineering News Record* (ENR) cost indices, as described in Chapter I of this report.

CURRENT LAWS RELATED TO WATER CONSERVATION

A companion SEWRPC technical report contains detailed information on water supply law.[4] This section summarizes those laws relating to water conservation.

The Federal government has enacted several regulations and instituted some policies to address the issue of water conservation. Although some of these regulations apply directly, many of the policies are intended to promote development of conservation programs on the state or local level. Since water conservation needs vary by and within each state, the creation of a single program for the entire country, or even for entire states, is virtually impractical. The Federal laws that most directly affect water conservation in the United States include:

- *The Federal Safe Drinking Water Act*—The Federal Safe Drinking Water Act regulates the level of contaminants in drinking water and the disposal of wastes in groundwater supplies. This act also encourages states to develop and implement strategies for the protection of water supplies. The Amendments of 1986 requires the enforcement of wellhead protection programs in all of the states. This program requires the protection of the area surrounding a well from which groundwater is drawn. The Amendments provided for increased contaminant protection measures, improved consumer information measures, and funding for State and local water systems. While not directly related to water conservation programming, these amendments are considered indirectly related by virtue of their overall impact on water supply system design and operation.

- *The Federal Energy Policy Act (EPAct)*—The Federal Energy Policy Act was enacted in 1992. This act established national water efficiency requirements, including maximum water-flow rates for toilets, urinals, showers, and faucets. This requirement is placed on fixtures for new and renovated residential and nonresidential facilities. The projected goal of the Act is to save between six and nine billion gallons of water per day by the year 2020.[5]

- *The Great Lakes Charter Annex 2001*[6]—The Great Lakes Charter Annex 2001 was adopted by the eight Great Lakes states and two Canadian provinces on June 18, 2001, as a supplementary agreement to the Great Lakes Charter. The stated purpose of the Annex was to develop "an enhanced water management system that is simple, durable, efficient, retains and respects authority within the Basin, and most importantly, protects, conserves, restores, and improves the Waters and Water-Dependent Natural Resources of the Great Lakes Basin." Under the Annex, the Governors and Premiers agreed to develop, within three years from the point of adoption of the Annex, binding agreements and implementing legislation to protect, conserve, restore, improve and manage use of the waters and water-dependent natural resources of the Great Lakes basin. The work done pursuant to the Great Lakes Charter Annex has resulted in the Great Lakes Annex Implementing Agreements. On December 13, 2005, the Great Lakes-St. Lawrence River Basin Water Resources Compact (Compact) was signed by the eight Great Lakes State Governors. This Compact will be binding on all the eight Great Lakes states only after it is ratified through concurring legislation by the eight states and consented to by Congress. The objective of this Compact is to establish an enforceable environmental standard for protecting the use of the "Waters and Water-Dependent Natural Resources of the Great Lakes." The agreement has two major components. First, the Compact would prohibit all "diversions" outside the Great Lakes basin, with certain limited exceptions. A "diversion" occurs whenever water

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[4]*SEWRPC Technical Report No. 44,* Water Supply Law*, April 2007.*

[5]*Amy Vickers*, Handbook of Water Use and Conservation, *2001*.

[6]*The Great Lakes Charter Annex is included under the Federal laws and regulations, since it is a multi-state compact requiring Congressional approval.*

is transferred from the Great Lakes basin into another watershed by any means other than incorporation into a product. Second, the Compact requires each signatory to manage and regulate new or increased withdrawals and consumptive uses in accordance with the provisions of the Compact.

The Compact includes provisions that the regulatory program established by the State for new or increased withdrawals and consumptive uses, and allowed diversions of surface water or groundwater from within the basin must, at a minimum, require compliance with certain criteria. One of these criteria is the implementation of environmentally sound and economically feasible water conservation measures. Environmentally sound and economically feasible water conservation measures are those measures for efficient water use, for reducing water loss, and for reducing withdrawals, that are environmentally sound, reflect best practices, are technically feasible and available, are economically feasible and cost-effective, and take the particular facilities and processes involved into consideration.

Each state has also enacted its own regulations related to water conservation. Wisconsin is a relatively water-rich state with extensive ground and surface water resources, as well as a relatively high amount of annual precipitation. However, many areas in the State have experienced significant reductions in the quality and quantity of water supplies available for use. The following State regulations and policies relate to water conservation:

- *Section NR-140 of the Wisconsin Administrative Code* regulates the quality of groundwater. This code establishes groundwater quality standards to regulate contaminants that may enter or are currently present in groundwater. *Chapter NR 141 of the Wisconsin Administrative Code* establishes standards for the design, construction, abandonment, and documentation of groundwater monitoring wells. NR 140 and 141 together are intended to ensure that existing sources of water are not compromised, which would further reduce the supply.

- *Chapter NR 142 of the Wisconsin Administrative Code* regulates water management and conservation of the waters of the State, including the management of Wisconsin water supply systems. This chapter provides for the management of the waters of the State through the development of a statewide water quantity resources plan; requires the registration of major withdrawals from the waters of the State; and requires Wisconsin Department of Natural Resources (WDNR) approval for major interbasin diversions and consumptive uses of water in order to protect public and private water rights in the State when the level, flow, use or quality of the waters of the state is threatened.

- *Chapter NR 809 of the Wisconsin Administrative Code* establishes standards and procedures for the protection of public health, safety, and welfare in the obtaining of safe drinking water.

- *Chapter NR 811 of the Wisconsin Administrative Code* regulates the management of community water systems and the regulation of wells and water as proposed in NR 140. This code also regulates aquifer storage recovery within the State, which involves the recharge of aquifers.

- *Chapter NR 812 of the Wisconsin Administrative Code* regulates the construction, or reconstruction, abandonment, and maintenance of water systems, including wells. Currently, approval of new high-capacity wells requires the Wisconsin Department of Natural Resources approval. Such approvals involve technical well construction procedures and materials designed to protect the public health.

- *Section 281.34(5) of the Wisconsin Statutes* limits the Wisconsin Department of Natural Resources review of a proposed high-capacity well to determining whether a proposed well adversely affects a public water utility supply well, is located in a groundwater protection area, has a significant environmental impact on a spring, or will result in a water loss of more than 95 percent of the amount of water withdrawn.

- *Section 281.35 of the Wisconsin Statutes* requires conservation measures relating to major water withdrawals. The Statute requires that persons seeking new or increased withdrawals resulting in a "water loss" averaging more than two million gallons per day in any 30-day period apply for and obtain a water loss permit. However, this provision has not been widely enforced in Wisconsin due to the small number of entities that reach two million gallons per day.

- *Section Comm 82.34 of the Wisconsin Administrative Code* sets forth the requirements for design and installation of plumbing wastewater devices, as well as appurtenances and systems. The provisions of this section also regulate the treatment of wastewater for reuse.

- *Section Comm 82.70 of the Wisconsin Administrative Code* establishes plumbing treatment standards for plumbing systems that supply water to outlets based on the intended use. The Wisconsin Department of Commerce requires that a plumbing system supply a quality of water at the outlet or at the termination of the plumbing system that meets or exceeds the minimum requirements as specified within the code. Comm 82.70 applies to wastewater treatment devices for reuse systems such as graywater systems.

- *The Groundwater Quantity Act (2003 Wisconsin Act 310)* is a groundwater protection law that expands the State's authority to consider environmental impacts of high capacity wells and takes the first step toward addressing regional water quantity issues in southeastern Wisconsin and the lower Fox River Valley. In addition, the law creates additional oversight of well construction activities and establishes a Groundwater Advisory Committee to recommend strategies for groundwater management and future legislation.

  In this regard, two reports are due to the standing committees of the Legislature with jurisdiction over environmental and natural resources matters on December 31, 2006, and December 31, 2007. These reports are to: 1) provide recommendations on how to best manage groundwater resources in areas of the State with existing groundwater problems; and 2) report on how the scope of the current groundwater legislation is working to protect the groundwater resources. The first charge to be completed by the end of 2006 specifically relates to the regional water supply planning effort in that it is to include recommendations for strategies for addressing groundwater management issues in areas designated as "groundwater management areas" which includes all, or portions, of each of the counties in the Southeastern Wisconsin Region. Ideally, the regional water supply plan for southeastern Wisconsin will serve as the basis for developing management recommendations in the groundwater management areas.

The WDNR also has several programs that relate to the conservation and protection of water supplies. Reports are created and made available to the public to monitor the progress of conservation efforts within the State. In August 2005, the Governor created *Conserve Wisconsin*, a combination of legislation and executive orders designed to protect the State waters, conserve the land, and ensure a sustainable energy future.[7] As part of that initiative, in September 2006, a report entitled *Water Conservation: A Menu of Demand Side Initiatives for Water Utilities* was completed by the Public Service Commission and the Wisconsin Department of Natural Resources which identifies a number of demand side measures for water management and presents information on the economic, environmental, and social aspects of these measures. The list of measures includes water conservation education, water conservation accountability, the use of water saving plumbing and other fixtures, water conservation rate structures, and water reuse and recycling. The list of water conservation initiatives has been designed to provide flexibility for Wisconsin water utilities as they work on their own individual strategies to promote water conservation. The report recognizes the uniqueness of the utilities in the State with regard to water use issues.

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[7] *Public Service Commission of Wisconsin,* Water Conservation Initiative, *2005, Available at: http://psc.wi.gov/conservationWater/index-waterConservation.htm.*

MUNICIPAL WATER CONSERVATION MEASURES

According to the U.S. Environmental Protection Agency, there are over 55,000 community water supply systems in the United States that process nearly 34 billion gallons of water per day.[8] In the Southeastern Wisconsin Region, as of 2005, there are 79 municipal water utilities and 187 other than municipal, community water supply systems. These supply systems were responsible for the efficient retrieval, treatment, and distribution of potable water. All of the municipal water utilities, and a number of the other than municipal, community water supply systems, may be expected to have some water conservation programs in place. The conservation measures considered viable for municipal systems in southeastern Wisconsin include public education; fixture and plumbing management; water reuse and recycling in industrial, commercial, and residential settings; rate structures; outdoor water use reductions and restrictions; and water system maintenance and loss management.

Public Education

Measures

Water conservation can best be achieved through a cooperative effort between water utilities and water customers. There are several different types of measures that may be used to educate the public, including: water bill inserts, feature articles and announcements in the news media, workshops, booklets, posters and bumper stickers, and the distribution of water-saving devices. To raise public awareness of the need for conservation, educational programs are often a successful measure. School-age children are typically the center of educational programs, since they are the potential future ratepayers and can also influence other family members. Many states, including Wisconsin, have developed contests for elementary children to design educational posters to promote water conservation. Wisconsin has a program called *BeSMART* that encourages high school and college students to find new and innovative ways to reduce waste and recycle water and other materials.[9]

Although school programs to educate children are important, it is also vital that adults become educated about water issues. Adult participation in water conservation programs may be expected to lower water use in the present, and provide positive examples for children. Studies have indicated that although many families may be water conservation oriented with respect to indoor use, outdoor use of water for landscaping and other activities is much higher than necessary.[10] Public educational programs to promote water conservation should address the need to reduce water use for both indoor and outdoor purposes.

The U.S. Environmental Protection Agency has created a program called WaterSense. WaterSense is a voluntary, public-private, partnership to promote and enhance the market for water-efficient services and products. The American Water Works Association (AWWA) has also created an online informational resource for water conservation called WaterWiser. This resource provides updated news on the water conservation issue, as well as links to several educational portals.[11] In addition, there are a number of hard copy and electronic water conservation data sources available. Examples include the Great Lakes Information Network website[12] and the series of fact sheets entitled "The State and Future of Our Water," produced during 2006 by the University of Wisconsin-Milwaukee Great Lakes WATER Institute. In addition, Waukesha County and the City of Waukesha

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[8]*American Water Works Association (AWWA),* Stats on Tap*, 2006, Available at: http://www.awwa.org/Advocacy/pressroom/statswp5.cfm.*

[9]*Wisconsin BeSMART Coalition,* BeSMART Annual Report*, 2005, Available at: http://www.besmart.org/index.html.*

[10]*Amy Vickers,* op. cit.

[11]*American Water Works Association (AWWA),* WaterWiser*, 2006, Available at: http://www.awwa.org/waterwiser/.*

[12]*Great Lakes International Network, http://www.glin.net.*

have formed a Water Conservation Coalition with the goal of developing and delivering water supply demand side conservation educational information.

Certain aspects of public informational and educational programming on water conservation can often be carried out most effectively at the county, regional, or State level where programming and related supporting materials have specific applicability. An example of such materials is the special Wisconsin Department of Natural Resources magazine insert entitled, “Groundwater, Wisconsin’s Buried Treasure.” This is a free-standing educational document containing several articles on groundwater and references to other related sources.

Cost Data

The direct reduction in water use among those who are targeted by public education and the costs to implement this type of conservation program are difficult to estimate. The costs of such educational efforts as brochures, water bill redesign, bill enclosures, media advertisements, billboards, and attendant postage, differ depending on the extent of the program. Many water supply related professional and trade organizations have produced a variety of public educational materials ranging from brochures to educational videos; and these can be utilized by utilities. Funding for public education may come from water rates or government grants. If little or no funding is directly available for water supply related public education, it may be possible to combine such educational programs with existing programs of other municipal departments, neighboring water systems, local environmental groups, or community organizations. Cost data associated with educational programs are presented, along with the cost of other conservation measures, later in this chapter.

Fixture and Plumbing Management

Measures

The efficiency of water fixtures and plumbing systems is an important factor in the management of a successful conservation program. Bathroom fixtures represent over 50 percent of indoor water use, and residential water use comprises approximately 26 percent of the total water use in the United States, or an average of 26,100 million gallons per day (mgd).[13] There have been steady improvements in the efficiency of plumbing fixtures and appliances over the past 25 years. These improvements have been primarily the result of state and national legislative initiatives, and improved industry standards. In 1989, Massachusetts was the first state to require 1.6 gallon per flush toilets, and many other states followed suit.[14] Recent estimates of indoor water use with and without conservation are summarized in Table 18.

As already noted, the Federal Energy Policy Act of 1992 is intended to promote national water use efficiency. The State of Wisconsin has also created standards for fixture and plumbing management. Comm 84 of the *Wisconsin Administrative Code*, administered by the Wisconsin Department of Commerce, governs the quality and installation of plumbing materials, fixtures, appliances, appurtenances, and related equipment. In southeastern Wisconsin, residential, commercial, and industrial buildings built prior to 1994 were not required to have new water-saving fixtures. Retrofitting of older buildings with water-saving plumbing fixtures can result in reduced water billing, but at a significant capital cost. The highest savings in water may be expected to be for homes which have toilets installed prior to 1950 when 7.0-gallons-per-flush toilets were used. The lowest savings would be for homes with toilets with 3.5 gallons per flush, which were typically used between 1980 and 1993. It should be noted, however, that it is likely that many of the fixtures in homes built prior to 1980 have already been replaced by homeowners as part of remodeling or repair programs.

Cost Data

A significant amount of data are available on the costs and savings associated with fixture and plumbing management. For typical water efficiency measures that involve fixture and appliance replacement, estimated costs incurred by the water supplier and water savings are presented in Table 19.

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[13]*Amy Vickers*, op. cit.

[14]Ibid.

Table 18

ESTIMATES OF INDOOR WATER USE WITH AND WITHOUT CONSERVATION MEASURES

Type of Use	Without Conservation		With Conservation		Reduction (percent)
	Amount (gpcd)[a]	Percent of Total	Amount (gpcd)[a]	Percent of Total	
Toilets	18.3	28.4	10.4	23.2	44
Clothes Washers	14.9	23.1	10.5	23.4	30
Showers	12.2	18.8	10.0	22.4	18
Faucets	10.3	16.0	10.0	22.5	2
Leaks	6.6	10.2	1.5	3.4	77
Baths	1.2	1.9	1.2	2.7	0
Dishwashers	1.1	1.6	1.1	2.4	0
Total	64.6	100.0	44.7	100.0	31

[a]*Gallons per capita per day.*

Source: American Water Works Association, WaterWiser, "Household End Use of Water Without and With Conservation," 1997 Residential Water Use Summary – Typical Single Family Home.

Table 19

FIXTURE AND PLUMBING MANAGEMENT: WATER EFFICIENCY MEASURE COSTS AND SAVINGS

Water Efficiency Measure	Costs per Measure	Estimated Water Savings
Residential		
Single-Family Toilet Retrofit	$120	7.9 gpcd(1)
Single-Family Showerheads and Aerators	10	5.5 gpcd(2)
Single-Family Clothes Washer Rebate	170	4.4 gpcd(1)
Multi-Family Toilet Retrofit	105	7.9 gpcd(1)
Multi-Family Showerheads and Aerators	10	5.5 gpcd(2)
Multi-Family Clothes Washer Rebate	150	4.4 gpcd(3)
Commercial		
Commercial Toilet Retrofit	$185	26.0 gpd(3)
Coin-Operated Clothes Washer Rebate	210	24.0 gpd(4)

NOTES: All costs are updated to 2005 costs. The following abbreviations were used: gpcd for gallons per capita per day, and gpd for gallons per day.

Source: Adapted from the following:

(1) AWWA WaterWiser, "Household End Use of Water Without and With Conservation," 1997 Residential Water Use Summary – Typical Single Family Home.

(2) BMP Costs & Savings Study, *California Urban Water Conservation Council, July 2000.*

(3) Amy Vickers, Handbook of Water Use and Conservation, *May 2001.*

(4) GDS Associates, Inc., Texas Water Development Board Study, *May 2001.*

Water Reuse
Measures
Water reuse is a practice that is gaining in acceptance, particularly for irrigation purposes. Water reuse reduces the demand on surface or groundwater supplies and may offer a new source of income for wastewater utilities. Such reuse requires the installation of a dual water supply system at substantial capital and operational costs. Capital costs entailed include the construction of a dual treatment, storage, and distribution facility. Operational costs include energy, chemicals, and staff. The economic benefits to this type of conservation vary from area to area. The economics of reuse are typically least favorable in situations where the existing primary water supply infrastructure for a service area is in place and the reuse water supply is to be retrofitted to serve all, or portions of, that service area. The economics are typically most favorable when considering an internal facility single-use system, or a dedicated supply, for irrigation of nonfood product lands, such as a golf course. However, treatment needs and public health and acceptance issues must also be considered. In addition, climate is an important factor to consider in the design and cost of dual distribution systems. In climates such as that in southeastern Wisconsin, it is necessary to install water mains and appurtenances to depths, and with techniques, that avoid freezing.

Spent water can also be reused for groundwater recharge. In the case of most communities in the Southeastern Wisconsin Region which use groundwater as a source of supply, municipally treated wastewater treatment plant effluent is discharged to the rivers and streams where it is conveyed downstream into other areas. If the wastewater treatment plant effluent were allowed to recharge shallow aquifers, the water could potentially be reclaimed by the water utility for some uses. However, as noted in Chapter VI of this report, considerable additional treatment of the wastewater and related public health issues would have to be addressed for this concept to be implemented.

Industrial and Commercial
Industrial and commercial water customers are often the largest volume users of public water supply systems. The industrial—excluding mining and thermoelectric use—and commercial use in the Southeastern Wisconsin Region, are estimated to average 51 mgd and 90 mgd, respectively in 2000. Because of this high use, implementation of water conservation measures by industrial and commercial water customers can have a significant impact on a water system.

A large number of industrial and commercial water users do not require potable water for all water uses. A major portion of water use by industrial and commercial establishments maybe for cleaning, cooling, heating, and irrigation applications. When nonpotable water is acceptable for use, the reuse of municipal wastewater, onsite treated process water, and domestic graywater—untreated, used water from domestic use—may be used as an alternative. Care must be taken, however, to exclude any water from toilets or from other uses that may come in contact with human waste. In Wisconsin, this practice is constrained by regulations set forth in Chapter Comm 82.34 of the *Wisconsin Administrative Code*, which does not permit the treatment of wastewater discharged from water closets or urinals for drinking water, but does allow treatment for nonpotable reuse if permitted by the Wisconsin Department of Natural Resources or a POWTS that includes an onsite soil dispersal system. Additional information on water reuse is presented later in this chapter.

Residential
The reuse of municipal wastewater treatment plant effluent for irrigation is currently the most viable option for water reuse. However, it is possible to reuse water for other nonpotable water needs, such as toilet flushing, or for aesthetic uses, such as fountains, providing such aesthetic uses are protected from human contact. However, for such aesthetic uses, the provision of recirculation systems using potable water is often a preferred option. Several states have standards and laws that allow the use of onsite graywater systems in some residences. In Wisconsin, this practice is regulated by Chapter Comm 82.70 of the *Wisconsin Administrative Code*, in which plumbing systems are required to supply water of a quality that meets or exceeds the plumbing treatment standards set forth in the Chapter.

The expanded use of, and increased recharge of, rainwater and snowmelt are related measures which can be used to conserve water and maintain groundwater supplies. Many of the municipalities in the Southeastern Wisconsin

Region are implementing stormwater management plans to ensure that rainwater and snowmelt can penetrate the ground to replenish groundwater and to reduce the amount of stormwater that runs off. Chapter VI of this report includes information on various type of measures which can be considered for groundwater recharge. Water may also be reused with the use of rain barrels and other rainwater harvesting systems. Some water utilities in arid climate areas have developed programs that provide an incentive or rebate for the implementation of rainwater harvesting practices for residential and commercial customers.

Cost Data

The costs of water reuse programs varies with the specific industrial, commercial, and residential applications concerned. The variables involved include cost of conservation devices, the attendant installation costs, the costs of any necessary renovation of existing plumbing, appliances, or related connections, and water use. For large-scale municipal reclaimed water facilities, the capital costs can be substantial, depending upon the level of treatment and storage needed, and the demand upon and extent of the system. For less sophisticated methods of water reuse, cost data are more readily available. The cost to install a graywater system, including pipes, valves, and tanks, at a single-family residential property can be several hundred to several thousand dollars, depending on the size of the system and the method of installation. Typical costs and savings of residential and commercial rainwater harvesting and rain barrel use are summarized in Table 20. The cost per measure includes the rebate and the cost of implementation, which includes labor and advertising.

Rate Structures

Measures

Water utility rates can be a particularly effective means of influencing customers' behavior. However, rate structures which promote reductions in water use may be expected to result in reduced revenue. This reduction in revenue may reduce the incentive for utilities to support this type of conservation measure. The rate structure that is available to a water customer may be expected to have a direct impact on the amount of water that is used. The water rate structure selected should be designed to promote utility and community objectives. There must also be an effective means of communication to the customers in order to influence the choices to be made relative to water use patterns. The different types of rate structures available include:

- *Nonpromotional water rates—Nonpromotional, or conservation-related, rates,* provide a financial incentive for customers to reduce water use. This is usually done by applying a surcharge on peak-month usage, or by charging a higher rate as water usage increases. Examples include: inclining block (tier) rates; seasonal rates; marginal cost pricing; and Individually tailored rates.[15]

- *Other rate structures*—Other rate structures do not offer incentives to customers to adopt water-saving measures. Examples include: declining block structures; flat rate structures, or fixed fee regardless of use; and uniform rate structures, or same unit charge regardless of quantity used.

- *Time of day pricing*—Time of day rate structures level relatively higher prices during peak use periods. This tends to restrict water use during peak periods of demand, and promotes water use during nonpeak periods.[16]

Currently, utilities in the Southeastern Wisconsin Region typically utilize a decreasing block rate structure in which the rates decrease as water use increases. This type of rate does little to encourage water conservation. In Wisconsin, increasing rates as water use increases, or inclining block (tiered) structures, have not been used to date, although they offer an incentive for reducing water use. Table 21 summarizes typical United States water

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[15]*American Water Works Association (AWWA),* Water Conservation-Oriented Rates: Strategies to Extend Supply, Promote Equity, & Meet Minimum Flow Levels*, 2005.*

[16]*American Water Works Association (AWWA),* op. cit.

Table 20

WATER REUSE: WATER EFFICIENCY MEASURE COSTS AND SAVINGS

Water Efficiency Measure	Cost per Measure	Water Savings (gpd)[a]
Residential		
Single-Family Rainwater Harvesting Rebate..........................	$ 310	21.6
Single-Family Rain Barrel Rebate..	65	2.3
Multi-Family Rainwater Harvesting Rebate	2,475	205.7
Commercial		
Rainwater Harvesting Rebate	$2,475	205.7

NOTE: All costs are updated to 2005 costs.

[a]*Gallons per day.*

Source: Adapted from GDS Associates, Inc., Texas Water Development Board Study, May 2001.

Table 21

TYPICAL WATER UTILITY RATE STRUCTURES IN THE UNITED STATES

Rate Structures	Rate Feature	Likely Impact on Water Conservation
Flat Rate	Charges the user a fixed price regardless of the amount of water used	Least effective in encouraging water usage reduction
Uniform Rate	Charges the same unit rate for all water usage	Can be minimally effective in encouraging water usage reduction
Declining Block Rate	Charges the user less as usage increases	Does not encourage water usage reduction for large water users
Increasing Block Rate	Charges the user more as usage increases	Rewards efficient water usage
Seasonal Block Rates Differentiated Seasonal Summer Seasonal	Charges users a higher rate for water used during the summer Surcharge directed only to users whose peak season use exceeds average use during off-peak season	Encourages water users to be efficient by reducing uses during peak season

Source: Midwest Environmental Advocates, 2005.

utility rate structures, together with attendant potential conservation impacts. It should be noted that rate structure revisions have different impacts on different customer classes. Such variations relate to water use amounts and purposes, as well as to a variety of customer-specific considerations. When implemented, rate structures may offer a valuable means to conserve water.

Cost Data

The costs attendant to modifying a community rate structure are variable. However, typically, the costs may be expected to approximate a one-time cost of $5,000 to $10,000 for staff data development and analyses, and an additional one-time cost of $5,000 to $10,000 for outside consultant services.

Outdoor Water Use Restrictions

Water Use Restrictions

Outdoor water use restrictions are typically applied as a means to manage public water supply during times of drought or other emergency. However, such restrictions may also reduce water use during some nonemergency times. It is important for a water utility to educate the public about the reasons for the water use restrictions. The highest water use peak days typically occur during the summer months when customers irrigate lawns, trees, and other landscaping plant materials. Lawn watering during the heat of the day can—due to evaporation—use up to six times the amount of water required in the morning or early evening.

Currently in Wisconsin, there are few restrictions on water usage. Table 22 illustrates the quantity of water that is used in the Region. Additional information on outdoor water use reductions are included under the heading "Private Water Supply Conservation" later in this chapter.

Water Conservation on Municipally Managed Lands

Miscellaneous municipal water use in the Southeastern Wisconsin Region totals about 11.9 million gallons per day. Such uses include, among others, fire protection, public facility building and outdoor uses, and park and open space uses. The municipal outdoor water uses can be managed for water conservation using measures similar to those described later in this chapter for individual homeowner outdoor water use, and for agricultural and irrigation uses. The applicable measures include the use of more-efficient irrigation equipment and practices and the use of water-efficient landscape planning and design.

Cost Data

The costs associated with outdoor use restrictions involve public informational and educational activities and, in some cases, the cost of monitoring and enforcement. The public informational and educational activities may be covered under the budgets for broader programs. The cost for monitoring and enforcement can involve seasonal employees or contracted services which are dependent upon the size of the community involved.

Water Supply System Efficiency Measures, Including Maintenance and Water Loss Management *Measures*

Water utilities typically have some form of water system efficiency program in place, involving maintenance and water loss minimization measures. An effective water loss management strategy may be expected to have several beneficial outcomes, including: more efficient use of supplies; reduced loss due to leakage; reduced disruption to customers; increased knowledge of supply-distribution system, and increased system efficiency.

There are two main types of losses that occur in water utilities: real and apparent. Real losses are the actual physical losses of water from the distribution system through, among other factors, leakage and storage facility overflow. Real losses can increase water utility production costs and cause stress on water supply resources. Apparent losses are losses that occur due to meter inaccuracies, billing errors, and unauthorized consumption. These losses can cost the utility revenue and noticeably alter consumption data required to evaluate conservation measures.[17]

Water utilities that implement apparent loss control have the advantage of recovering economic losses that are due to the correction of errors. These errors occur due to inaccurate supply, faulty meters, and errors in estimating, accounting, and billing structure. Management of these errors also provides the utility with the opportunity to correct tampering with meters and bypasses, as well as eliminating illegal connections. The review of billing and the comparison to inventory population data and historic water use data can help identify unauthorized water users.

Real loss control is a particularly important component of good utility management. The detection and correction of leaks within a distribution system will decrease the amount of treated water that does not reach the customer. Although a totally leak-free system may be virtually impossible to create, a water utility that maintains a capability to identify and repair leakage will have the advantage of designing or optimizing the distribution system to prevent current and future problems. Currently, unaccounted-for water utilities in the Southeastern

[17]*American Water Works Association (AWWA),* op. cit.

Table 22

ESTIMATED USE OF WATER IN THE SOUTHEASTERN WISCONSIN REGION: 2000

Type of Use	Amount (million gallons per day)
Domestic	103.1
Industrial	89.9
Commercial	51.0
Agriculture and Irrigation	12.7
Public and Municipal Uses and Losses	67.1
Total	323.8

Source: U.S. Geological Survey.

Wisconsin Region average about 12 percent of total pumpage, with a range of from 8 to 13 percent for the average unaccounted-for water within each of the seven counties in the Region. The amount of unaccounted-for water pumped by utilities operating within the Region during 2005 was about 10.7 billion gallons, or an average of 29.0 million gallons per day.

The promotion of water supply system efficiency is often termed “supply-side” conservation. The reliability of routine utility auditing and control of water losses are the two principal factors that supply-side conservation relies upon. A water audit is a compilation of the consumptive uses and losses of the water within a system. Water audits are commonplace in most water supply utilities, but generally do not follow a standardized procedure. The lack of standardization makes it difficult to determine the comparative extent of water loss that is occurring within a water distribution system and in the selection of a water control management plan. The International Water Association (IWA) and the AWWA combined efforts to develop a methodology to control water losses. In the combined Water Audit Method, performance indicators are used to evaluate utilities on specific features, such as average pressure within a distribution system and number of service connections.[18] The water balance components for this method are summarized in Table 23.

The IWA/AWWA Water Audit Method provides consistent definitions for water consumption and loss in drinking water utilities. These definitions, along with the performance indicators provided in Table 24, facilitate the assessment of water losses and performance comparisons with other utilities. The audit provides a way to determine how much loss is occurring, as well as the associated costs. All water is accounted for in this method by measurement or estimation, allowing for a more accurate assessment of the financial impact losses incurred by the water utility.

Cost Data

As previously noted, water supply efficiency measures, including system maintenance and water loss management, are likely to be the most effective and practical water conservation measures. All of the utilities in the Southeastern Wisconsin Region carry out such measures to some extent. The associated costs vary dependent upon the extent of the current and past efficiency measures, the condition of the water supply system, and the level of unaccounted-for water being experienced. For all systems, a level of water efficiency is needed just to maintain the current level of unaccounted-for water. The need for, and costs associated with, additional measures should be determined site-specifically using the IWWA-AWWA procedures previously cited.

[18] *American Water Works Association (AWWA),* Water Audit Methodology: Definitions and Performance Indicators for IWA/AWWA Method*, 2006, Available at:* *http://www.awwa.org/WaterWiser/waterloss/Docs/03IWA_AWWA_Method.cfm*.

Table 23

COMPONENTS OF WATER BALANCE FOR A DISTRIBUTION SYSTEM

System Input Volume (corrected for known errors)	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption (including water exported)	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Nonrevenue Water (NRW)
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorized Consumption	
			Customer Metering Inaccuracies	
			Data Handling Errors	
		Real Losses	Leakage on Transmission and Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to point of Customer Metering	

Source: American Water Works Association, 2000.

Table 24

PERFORMANCE INDICATORS FOR NONREVENUE WATER AND WATER LOSSES

Performance Indicator	Function	Comments
Volume of Nonrevenue Water As a Percentage of System Input Volume	Financial–Nonrevenue water by volume	Can be calculated from a simple water balance; good only as a general financial indicator
Volume of Nonrevenue Water As a Percentage of the Annual Cost of Running the Water System	Financial–Nonrevenue water by cost	Allows different unit costs for nonrevenue water components
Volume of Apparent Losses per Service Connection per Day	Operational–Apparent losses	Basic, but meaningful indicator once the volume of apparent losses has been calculated or estimated
Real Losses As a Percentage of System Input Volume	Inefficiency of use of water resources	Unsuitable for assessing efficiency of management of distribution systems
Normalized Real Losses–Gallons per Service Connection per Day When the System is Pressurized	Operational–Real losses	Good operational performance indicator for target-setting for real loss reduction
Unavoidable Annual Real Losses (UARL)	UARL (gallons/day) = (5.41Lm + 0.15Nc + 7.5Lp) x P where Lm = length of water mains, miles Nc = number of service connections Lp = total length of private pipe, miles = Nc x average distance from curbstop to customer meter P = average pressure in the system, psi	A theoretical reference value representing the technical low limit of leakage that could be achieved if all of today's best technology could be successfully applied. A key variable in the calculation of the Infrastructure Leakage Index (ILI) It is not necessary that systems set this level as a target unless water is unusually expensive, scarce or both
Infrastructure Leakage Index (ILI)	Operational–Real losses	Ratio of Current Annual Real Losses (CARL) to Unavoidable Annual Real Losses (UARL); good for operational benchmarking for real loss control

Source: American Water Works Association, 2000.

PRIVATE WATER SUPPLY CONSERVATION

Private Well Use

As of 2005, there were about 126,000 private wells that were operational in the Southeastern Wisconsin Region. Chapter NR 812 of the *Wisconsin Administrative Code* includes regulations for the design, construction, abandonment, and water quality of private wells within the State. However, there are few regulations for the use of private well water by the owner. Although private water suppliers and systems do not provide potable water in the quantities that municipal or government-owned systems supply, the shallow aquifers that these private wells tap into may be needlessly diminished if not managed properly. In more arid areas of the country, including areas that experience moderate to severe drought, it is not uncommon for private wells to "dry out" for extended periods of time. When properly carried out, private water conservation can play an important role in the sustainability of water supply resources. In this regard, most, but not all, of the residences and other land uses served by private wells are also served by onsite sewage disposal systems. This typically results in most of the spent water being returned to the groundwater system. Thus, in areas served by onsite sewage disposal systems, conservation for water quantity maintenance purposes is less an issue than in areas where the spent water is discharged and transported out of the local hydrologic system. This is not the case where a holding tank is the means of onsite sewage disposal and where the spent water discharged to such systems is trucked away from the site for treatment and disposal—usually by a public sewage treatment plant. Map 5 depicts the estimated amount of water used by residents served by private wells in the seven-county southeastern Wisconsin area.

Conservation programs for private water systems are similar to those of municipal water systems. Public education is stressed in the promotion of private water conservation. Water users who do not understand the necessity or importance of reducing water demands, or who do not know what measures to take, are less likely to practice conservation measures. The previous section of this chapter presents information on measures and programs, including public education, and fixture and plumbing management which are also applicable to private well owners. The following section outlines additional water conservation measures and practices that may be applicable to private well owners and public water supply system customers alike, including additional information on outdoor water use conservation and on individual behavioral changes.

Conservation Measures for Private and Public Water Consumers

Nationally, the combined indoor and outdoor water use in a single-family household is estimated to average 101 gallons per capita per day (gpcd). Per capita water use in multi-family households ranges between 45 and 70 gpcd.[19] In general, multi-family dwellings use minimal water outdoors and have fewer appliances and fixtures. In southeastern Wisconsin, the combined indoor and outdoor water use in single- or two-family households is estimated to average about 68 gpcd. A breakdown of this water use is shown in Table 25.

The installation of more efficient water fixtures and appliances can provide up to a 30 percent reduction in per capita water use.[20] Indoor water conservation can be implemented by fixing leaks, reducing pressure at water outlets, as well as with the installation of low-flush toilets, toilet displacement devices, low-flow showerheads, faucet aerators, and high-efficiency clothes- and dishwashers.

The use of higher-efficiency water softeners can be another water conservation measure. Water softeners use about 6 percent of the total flow through the tank for regeneration. Depending upon the percent of the water softened in a residence, this amounts to two to four gallons per capita per day. The savings which could be expected by conversion to more-efficient softeners based upon water volume and/or quality rather than based upon time could be one to two gallons per capita per day. In addition to improved efficiency, water softeners could reduce the amount of sodium chloride discharged to the sanitary sewer system or onsite sewage disposal

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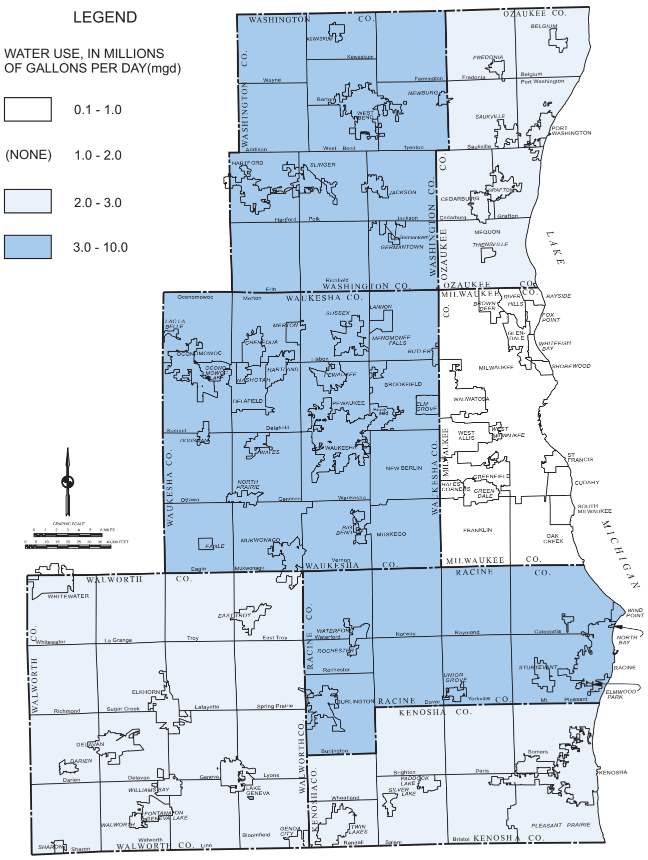
[19]*Amy Vickers,* op. cit.

[20]*American Water Works Association (AWWA),* Stats on Tap, op. cit.

Map 5

DOMESTIC SELF-SUPPLIED WATER USE BY COUNTY IN THE SOUTHEASTERN WISCONSIN REGION: 2005



Source: SEWRPC.

system. The use of Lake Michigan as a source of supply would reduce the need for water softening. Rainwater also typically would not require softening if used for nonpotable indoor uses. Such use may, however, be accompanied by the possibility of cross connection with the potable supply and attendant health risks. Outdoor uses of rainwater are described in the following section.

Outdoor Water Use Management

Outdoor water use, primarily lawn, tree, and landscaping plant material irrigation, in the United States is estimated to equal 7.8 billion gallons per day (bgd), or 30 percent of the overall water use.[21] Lawn and landscape maintenance often requires large volumes of water, especially in areas with low rainfall. Outdoor residential water use varies greatly and is highly dependent on geographic location and season. In the United States, outdoor water use in the arid west and southwest is much greater than that in the Midwest. Outdoor water uses also include washing automobiles, maintaining swimming pools and fountains, and cleaning sidewalks and driveways. Outdoor water use by nonresidential customers, such as commercial and publicly owned landscaped areas, is mainly allocated for turf irrigation, and demands approximately 2.7 bgd, on average.[22] However, in Wisconsin, it is expected that outdoor water use, on an annual average, is much lower than that typically estimated in the literature, because of the limited seasonal time period during which outdoor water use occurs. This factor has been accounted for in the development of the data provided in Table 25.

A lush, green lawn is commonly considered to be the ideal groundcover for a home and many businesses in the United States and contributes to real property values. Many homeowners are reluctant to reduce the amount of water used to maintain landscaping. To facilitate the use of water for irrigational purposes, many new approaches to landscape design, improved choices in turf and plant selection, and improvements in irrigation systems have been developed. Water-efficient landscaping techniques are popular in the arid southwest. Such techniques incorporate seven principles that promote water conservation and environment protection. While these principles were developed for more arid regions, they are all considered applicable, to some extent, in southeastern Wisconsin: proper planning and design; creation of practical turf areas; selection of low-water plants; use of soil amendments; use of mulches; efficient irrigation; and proper landscape maintenance.

An effective measure for reducing outdoor water use is to encourage the use of water conserving landscape designs. A natural landscape is typically inherently low maintenance because plants that are chosen are native to the area and have adapted to the climate and the amount of rainfall. Low amounts of supplemental water are required after the plants have become established. Natural landscaping techniques can also decrease the amount of

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[21]*Amy Vickers*, op. cit.

[22]Ibid.

Table 25

ESTIMATES OF RESIDENTIAL WATER USE WITHOUT AND WITH CONSERVATION ADJUSTED FOR CURRENT CONDITIONS IN SOUTHEASTERN WISCONSIN

Type of Use	Without Conservation (gpcd)[a]	With Conservation (gpcd)[a]	Estimated 2005 Water Uses for Southeastern Wisconsin Areas[b]
Indoor Use[c]			
Toilets	18	10	16
Clothes Washers	15	10	14
Showers	12	10	11
Faucets	10	10	10
Leaks	7	2	3
Baths	1	1	1
Dishwashers	1	1	1
Subtotal	64	44	56
Outdoor Use[d]			
Lawn and Garden Watering	25	N/A	9
Swimming Pools	0	N/A	1
Car Washing	0	N/A	1
Driveway Cleaning and Miscellaneous	0	N/A	1
Subtotal	25	N/A	12
Total	89	- -	68

NOTE: Water use associated with water softening is not specifically included, since it is variable throughout the Region. Where water softeners are used, the regeneration cycle can use about 6 percent of the tank throughput. This would equate to two to four gallons per capita per day.

[a]*Gallons per capita per day.*

[b]*Ruekert & Mielke, Inc., and SEWRPC.*

[c]*For columns without and with conservation, AWWA,* WaterWiser, *1997 Residential Water Use Summary.*

[d]*For column without conservation, AWWA,* Evaluating Urban Water Conservation Programs, A Procedures Manual*, 1993.*

Source: American Water Works Association, Ruekert & Mielke, Inc., and SEWRPC..

fertilizers and chemicals applied to landscapes and promote the infiltration of water into the ground to recharge aquifers.

Outdoor water conservation may be achieved through the utilization of more efficient landscape irrigation practices and equipment. Typical measures that can be implemented include automatic hose-shutoff nozzles, sensors that shut off sprinkling systems after rain, soil moisture sensors, soaker hoses, improved irrigation system design, weather-driven irrigation system programming, drip irrigation, improved sprinkler heads, rainwater harvesting, and leak repair of hoses and sprinkler systems.

Water conservation may also be achieved through the harvesting of rainwater and use of cisterns. Rainwater harvesting may be defined as the capture, diversion, and storage of rainwater for landscape irrigation (and potable water, in some cases). Rainwater is typically captured in cisterns, barrels, or other types of storage tanks, and can be used for maintenance of landscaped areas, such as parks, schools, commercial and industrial sites, parking lots, and apartment complexes, as well as in landscape plantings for residences. The capture of water from roofs and other impervious surfaces can reduce the amount of runoff that can potentially contribute to stormwater management problems.

More extensive rainwater harvesting systems are used on a limited basis in other areas. Such systems are sometimes designed to serve a dual function of reducing stormwater runoff and harvesting rainwater for selected nonpotable uses. Most rainwater harvesting collection systems are designed to capture rainwater from the roofs of buildings. The water is then transported through gutters and other pipes into cisterns or tanks, where it is stored until needed. The water collected can be used for various nonpotable uses. A typical rainwater collection system may consist of a collection area, usually a roof; a means for conveying the water, usually gutters, downspouts, and piping; a storage tank or cistern; and a system to distribute the water as needed. All collected rainwater will contain some suspended solids and other contaminants which can be present, due to bird droppings, air pollution fallout, and other sources. Thus, care must be taken to prevent unintended human consumption of the water. Some systems have been designed to incorporate first flow diverters, or presettling facilities, to reduce the sediment and related contaminant content of the runoff.

Water Conservation: Behavioral Change

In addition to the physical changes that may be made to reduce indoor and outdoor water usage, a change in the behavior of water consumers is important to water conservation. Behavioral practices include the changing of water use habits to reduce the volume of water consumed in a household or building. The U.S. Environmental Protection Agency recommends a series of water-conserving practices that can be applied to indoor and outdoor water usages. For indoor water conservation, these measures range from not running taps during such chores as shaving, brushing teeth, and washing dishes, to shorter showers and more efficient use of appliances, such as dishwashers and washing machines.

Cost Data

Literature research indicates that the costs attendant to private and public water conservation measures by consumers vary greatly depending on multiple factors. Conservative estimates of these costs are provided in Table 26. Due to the differences in costs found in literature review, a range of values is provided, as summarized in Table 26.

AGRICULTURAL AND OTHER IRRIGATION WATER CONSERVATION

In the United States, agricultural irrigation is the predominant use of freshwater supplies. According to the most recent U.S. Geological Survey of national water use conducted in 2000, total freshwater withdrawals for agricultural and horticultural irrigation and other uses, including golf course irrigation, are estimated at 134 bgd, which equals approximately 39 percent of the total withdrawal of freshwater. Of the 134 bgd in withdrawals for these purposes, approximately 61 percent is consumed by crops and livestock, 20 percent becomes return flow to surface water and groundwater supplies, and 19 percent is lost.[23] In the Southeastern Wisconsin Region, during 2000, agricultural and other irrigation water uses were estimated to be 12.7 million gallons per day, or about 4 percent of the total water used within the Region, excluding thermoelectric uses. A depiction of the total water use and locations of irrigation wells throughout the southeastern Wisconsin seven-county region is shown on Map 6.

Several factors affect agricultural water use, including: the price of water, water availability, climate and weather, crop requirements, soil, type of irrigation system used, control of water application, and farm characteristics. The depletion of water supplies for agricultural use is an important agricultural concern due to the dependence of some types of farming on irrigation, and the high water usages that some types of farming incur. The protection of surface and groundwater sources from runoff pollution and erosion are also issues that need to be addressed in agricultural water conservation.

Measures

Agricultural irrigation efficiency may be defined as crop yield per unit of water use. Irrigation efficiency is also called water use efficiency (WUE). The efficiency of water use on a farm, and indeed in any water supply system,

[23]*Amy Vickers,* op. cit.

Table 26

TYPICAL CONSERVATION MEASURES, COSTS, POTENTIAL SAVINGS, AND ADVANTAGES

Conservation Measure	Cost to Implement[a]	Potential Savings in End Use[b]	Advantages
Utility System Leak Detection and Repair	Leak detection: $160-$530 per mile, repair: variable costs[3]	10-20 percent[1]	Benefits include reduced operation and maintenance costs, such as chemicals, energy and labor, and reduced capital costs for production, treatment, storage, transportation, and distribution facilities
Utility System Water Audits	Audit cost: $530-$2,650 per leak[3]	12-33 percent [1]	Utility audits are a reliable and standardized way to improve the reporting accuracy for water delivery components of valid usage and losses
Plumbing Retrofits	$15-$40 per kit per household (with installation)[4] $2-$25 per kit per household (without installation)[4]	13.4 gpcd[2] or 20 percent of plumbing and fixture water use	Residential retrofit is one of the most practical and effective approaches in providing water consumers with "how-to" information on altering water use habits. At the same time, it provides them with the technology to save water with the least impact on their lifestyle. The greatest water savings can be achieved by combining the use of conservation devices with behavioral changes since these two actions tend to reinforce each other
Toilet Retrofit	$60-$245 per unit[3]	7.9 gpcd[5]	Toilet retrofit programs can promote consumers in older communities to replace water-inefficient toilets. Toilet rebates and replacements offer attractive incentives to consumers who install ultra-low flush toilets that use 1.6 gpf or less
High-Efficiency Clothes Washer Rebate	$60-$620[4]	4.4 gpcd[4]	High-efficiency clothes washers have the capability to save large quantities of water. Washer rebates promote the water customer to install newer models that save water and reduce energy and utility bills
High-Efficiency Water Softener Installation	$400-$700	1.0 to 2.0 gpcd	Effectiveness is variable throughout the Southeastern Wisconsin Region. The use of high-efficiency water softeners would reduce the sodium chloride levels in the wastewater. Areas served by Lake Michigan as a source of supply do not need water softening
Residential Surveys and Public Education	$40-$215 per survey, Variable costs for other materials[3]	5-10 percent[1] of use by targeted customers	Public information/education programs are critical tools that create community awareness about water conservation and market water efficiency strategies to customers. The direct costs to implement this type of program, as well as the direct water savings associated, differ with each area and are difficult to estimate
Residential Graywater Reuse	$1,050-$3,160 in parts and installation[3]	20-30 gpcd[1]	Graywater systems have the capability of reducing potable water use for applications such as nonfood irrigation and toilet flushing
Outdoor Residential Audit	Variable costs[3]	5-10 percent of outdoor use[2]	Over 50 percent of residential water use is due to outdoor water use. Residential audits can help the customer become aware of the high usage and to promote more efficient use of water
Rate Structure–Increasing Block Rate	Variable costs[1]	5 percent[2]	Inclining block rates promote water conservation by increasing the price of water as consumption increases
Residential Metering	$265-790 per meter[3]	20 percent[2]	Metering of residential water allows suppliers to target the areas/households that do not have efficient water use for future conservation programs
Landscape Require-ments for New Developments	Variable costs[3]	10-20 percent of outdoor water use in sector[2]	Landscape requirements for developers promotes the builders to install efficient irrigation systems. Homeowners in new developments are also required to utilize natural plants that are more water efficient
Landscape Irrigation Ordinance	Variable costs[3]	10-20 percent of outdoor water use[2]	Landscape irrigation ordinances can reduce the total water demand, as well as peak water demand

Table 26 (continued)

Conservation Measure	Cost to Implement[a]	Potential Savings in End Use[b]	Advantages
Rainwater Harvesting	$1,000-$10,000[(4)]	Variable savings due to regional rainfall differences and operational variability[(4)]	Collected rainwater may be used to save potable water, energy, and chemical costs since the rainwater is used directly instead of first being treated and distributed by a supplier
Rain Barrel	$70-$140		

NOTES: gpcd means gallons per capita per day. Water use associated with water softening is not specifically included, since it is variable throughout the Region. Where water softeners are used, the regeneration cycle can use about 6 percent of the tank throughput. This would equate to two to four gallons per capita per day.

[a]*Costs to implement are based on direct and indirect costs and are updated to 2005 costs.*

[b]*Actual water savings can vary substantially according to a number of factors.*

Sources: (1) PBS&J, Burton & Associates, Water Supply Needs & Sources Assessment: Alternative Water Supply Strategies Investigation: Assessment of the Cost Effectiveness of Specific Water Conservation Practices*, 1999.*

(2) U.S. Environmental Protection Agency, USEPA Water Conservation Plan Guidelines*, August 1998.*

(3) A & N Technical Services, Inc., BMP Costs & Savings Study: A Guide to Data and Methods for Cost-Effectiveness Analysis of Urban Water Conservation Best Management Practices*, March 2005.*

(4) Amy Vickers, Handbook of Water Use & Conservation*, 2001.*

(5) AWWA WaterWiser*, "Household End Use of Water Without and With Conservation," 1997 Residential Water Use Summary – Typical Single Family Home.*

is inevitably less than 100 percent, regardless of conservation measures. This loss is due to a portion of the applied water that is unavailable to crops because of application and weather conditions. Evapotranspiration, leaching requirements, and stored moisture in the soil are the basic needs of a plant that must be satisfied to benefit the crops concerned. The reduction of farm water use by improved irrigation technologies and efficient water management practices are the two types of agricultural water conservation. Irrigation efficiency (IE) is defined by the following equation:[24]

$$IE = \frac{\text{Volume of Irrigation Water Beneficially Used}}{\text{Volume of Irrigation Water Applied}} \times 100$$

Three basic types of agricultural irrigation are currently in use: surface—or gravity—irrigation, sprinkler irrigation, and micro-irrigation. Table 27, provides information on the typical efficiencies for each type of irrigation system.

Surface irrigation systems are the most widely used irrigation method in the United States. Fifty percent of the total irrigated farmland uses this type of irrigation.[25] However, this system typically has the lowest water-use efficiency of any irrigation system. Surface irrigation methods include flood and furrow, border, and basin irrigation. In these systems, water is generally pumped to the upper end of a ditch or pipe to create a high enough head to allow water to flow by gravity across the field surface. Capital costs are low with the use of this irrigation system. However, design and management depend largely on soil properties that are difficult to measure, which can create problems.[26] This type of irrigation is not typically used in the Southeastern Wisconsin Region.

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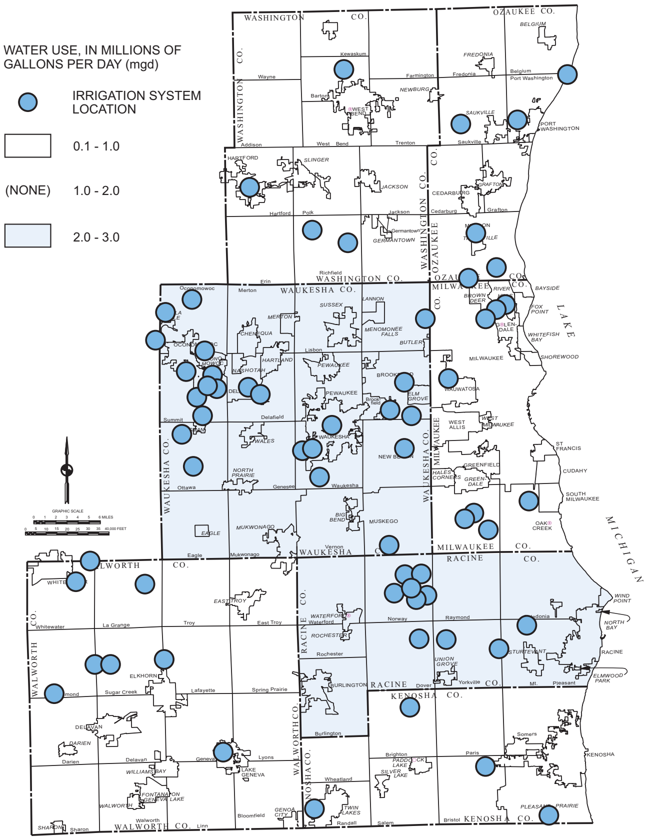
[24]Ibid.

[25]Ibid.

[26]*Blaine Hanson, and Larry Schwankl,* On-Farm Irrigation, *Water Management Handbook Series (Publication No. 94-01), 1994, Available at: http://www.energy.ca.gov/process/agriculture/ag_pubs/surface_irrigation.pdf*.

Map 6

IRRIGATION WATER USE SYSTEM LOCATIONS AND WATER USE BY COUNTY IN THE SOUTHEASTERN WISCONSIN REGION: 2000



Source: U.S. Geological Survey, 2002, and SEWRPC.

Sprinkler irrigation involves the application of water in a manner similar to natural rainfall. The water is pumped through a system of pipes, where it is sprayed into the air and onto the crops concerned through sprinkler heads. The pump supply system, sprinklers, and operating conditions are designed to provide a uniform application of water. In the United States, approximately 46 percent of irrigated farmland is watered by sprinkler systems. In general, sprinkler systems are more water efficient and require less labor than gravity systems, since farmers can more readily control the irrigation schedule and the amount of water applied. Runoff and percolation below the crop root zone is significantly reduced. Sprinkler systems require higher capital costs and more energy than gravity systems.[27] This type of irrigation is most commonly used in the Southeastern Wisconsin Region.

Micro-irrigation, commonly known as drip irrigation, is an irrigation method that slowly applies water to the roots of plants. This is done by depositing the water on the soil surface or directly into the root zone using a network of pipes, valves, tubing, and emitters. Micro-spray heads are sometimes used in place of emitters, in which water will spray in a small area. This type of irrigation is typically used on tree and vine crops, as well as nonrotated crops. Subsurface drip irrigation (SDI) uses buried dripperline or drip tape, and this type of irrigation is becoming more widely used for row crop watering in areas where freshwater supplies are limited. Bubbler irrigation releases small streams of water to form pools on the soil surface. The goal of this type of irrigation system is to minimize water waste. Micro-irrigation is the most costly system of the three basic types, and approximately 4 percent of farmland in the United States is irrigated by this system.[28] This type of system is not typically used in the Southeastern Wisconsin Region.

Agricultural programs that are sponsored by regional, State, and Federal agencies and water utilities can encourage farmers and other irrigators to use water more efficiently. In California, for example, the Colorado River Basin and a few other freshwater-limited regions have experienced the use of new approaches to pricing and allocating irrigation water. Tiered pricing strategies have been implemented in which farmers are able to purchase, sell, and trade water based on their needs. These regions also use water banking, which enables a farmer to "deposit" unused water in a bank for another farmer to rent at a price for the depositor.[29] Several options for improving agricultural on-farm irrigation efficiency and crop productivity are summarized in Table 28.

The potential water savings from improved agricultural water practices can be as high as 50 percent.[30] Improvements in agricultural water use can be achieved through the use of more efficient technology and water management practices, including water metering (measurement), and improved irrigation scheduling.

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[27]*Amy Vickers*, op. cit.

[28]Ibid.

[29]Ibid.

[30]Ibid.

Table 27

EFFICIENCIES OF TYPICAL IRRIGATION SYSTEMS

System Type	Efficiency[a] (percent)	System Type	Efficiency[a] (percent)	System Type	Efficiency[a] (percent)
Surface Systems		Sprinkler Systems		Micro-Irrigation Systems	
Level Border	60-80	Linear move	75-90	Surface/subsurface drip	85-95
Furrow	60-80	Center pivot (low pressure)	75-90	Micro spray or mist	85-90
Surge	65-80	Fixed solid set	70-85		
Graded Border	55-75	Center pivot (high pressure)	65-80		
Corrugate	40-55	Hand move or side roll laterals	60-75		
Wild Flood	25-40	Traveling gun	60-70		
		Stationary gun	50-60		

[a]*Efficiencies shown assume appropriate irrigation system selection, correct irrigation design, and proper management.*

Source: Modified from ATTRA, 2006 (http://www.attra.ncat.org).

Table 28

OPTIONS FOR IMPROVING AGRICULTURAL ON-FARM IRRIGATION EFFICIENCY AND CROP PRODUCTIVITY

Category	Options
Institutional	Conservation coordinator to provide technical assistance Conservation plan and program development assistance Policies or inventories for efficient on-farm water use and penalties for inefficient use
Educational	On-farm water audits Field and workshop training programs Training materials, workbooks, and software Newsletters and periodicals Internet information networks and listservs
Financial	Conservation-oriented pricing Water marketing Low-interest loans Grants and rebates for purchase of more efficient irrigation equipment and tools
Managerial	On-farm water measurement (metering) Soil moisture monitoring Irrigation scheduling Evapotranspiration rates and other data from weather station networks Tailwater reuse Conservation tillage Canal and conveyance system lining and management Limited irrigation/dryland farming Deficit irrigation
Technical	Laser-graded land leveling to allow more uniform application of water Furrow diking to promote soil infiltration and minimize runoff Low energy precision application (LEPA) to reduce water losses from evaporation and wind drift Surge irrigation to spread irrigation applications uniformly Drip irrigation to reduce water losses from evaporation, increase crop yields, and reduce chemical and energy use
Agronomic	Enhanced precipitation capture (rainwater harvesting) Reduced evaporation through improved use of crop residues, conservation tillage, and plant spacing Sequencing of crops to optimize yields, given soil and water salinity conditions Selection of native and drought-tolerant crops to match climate conditions and water quality Breeding of water-efficient crop varieties

Source: Amy Vickers, Handbook of Water Use and Conservation*, May 2001.*

It should be noted that in the Southeastern Wisconsin Region, the majority of the farming operations do not use irrigation. Thus, the relatively low percentage—approximately 4 percent—of the total water supply is used for this purpose. However, as land becomes more valuable and farming practices change to more-intensive uses, the need for water supply to sustain agricultural lands may increase over time. This will likely be the case on a per acre of agricultural land basis.

Cost Data

Several costs must be considered in the development of agricultural water conservation plans. Table 29 summarizes common agricultural water conservation measures and the cost of implementation for each.

INDUSTRIAL, COMMERCIAL, AND INSTITUTIONAL WATER CONSERVATION

In the Southeastern Wisconsin Region, commercial and industrial water use was estimated to average 51 mgd and 90 mgd, respectively, in 2000. This accounts for about 43 percent of the total use, not including thermoelectric water use. The water that is used by industrial and commercial water consumers is provided by a combination of public supply systems and self-supplied sources. Map 7 depicts the total self-supplied withdrawals for industrial use in the southeastern Wisconsin seven-county region.

Commercial water users generally provide a retail service or product. Retail stores, including food and drug stores, hotels, and amusement complexes are typical examples of commercial users. Institutional water users generally perform a service or function and are similar in the type of water use needs to commercial and businesses. However, water uses are generally high for facilities, such as schools and hospitals. These customers usually require water for domestic applications, cooling and heating, and landscape irrigation. Industrial customers generally engage in product manufacturing and processing operations, such as food and beverage, paper, steel, electronics, and chemicals. This type of customer uses water for four primary functions: heat transfer—heating and cooling, materials transfer—industrial processing, washing, and as an ingredient.[31] Conservation programs for industrial and commercial water users are site-specific and often are typically more difficult to create and execute than for residential users. Industrial, commercial, and institutional processes vary greatly and there may be significant differences in processes used by several companies within the same industry.

There are several State and local government agencies that promote water conservation within industrial commercial, and institutional facilities. Funding, water audits, and consultation are available to many establishments that wish to reduce the total use of water within their processes. For example, the State of Washington has a Toxic Reduction Engineering Efficiency (TREE) team that provides free technical assistance to industry. The goal of this program is to reduce the generation of toxic wastes, as well as to reduce the use of water. Incentives are often the most effective way to motivate industrial, commercial, and institutional water users to engage in water conservation measures. Some water suppliers motivate commercial entities to reduce water use by providing a cash rebate based upon the amount of water use reduction.[32] Inclining water rates and restrictions or prohibitions on inefficient usage are incentives that are often used to drive conservation. Increasing customer awareness of economic, environmental, and regulatory benefits of conservation practices is also a means of promoting efficient water use. Water conservation can create benefits to industrial, commercial, and institutional facilities by a reduction in water use and often with an attendant reduction in wastewater flows. However, the amount of water use reduction which is practically achievable will vary with a number of factors, including the current state of the facilities and processes with regard to water efficiency, the type of facility, and its current water use. In addition, there is typically a cost involved in equipment and process operational changes. Thus, the cost-effectiveness of water conservation can best be determined on a case-by-case basis by the facility owner and operator.

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[31]Ibid.

[32]*GDS Associates, Inc.,* op. cit.

Table 29

COSTS OF AGRICULTURAL IRRIGATION WATER CONSERVATION MEASURES

Conservation Measure	Cost to Implement[a]
Irrigation Measurement (metering)	$250-$2,200 per meter
Soil Moisture Monitoring	
Gypsum Blocks and Meter	$6-$20 per block, $250 for meter
Heat Dissipation Blocks and Meter	$40-$65 per block, $185-$745 per meter
Tensiometer	$60-$95
Neutron Probes	$4,300-$5,600 (automated permanent installation: $15,000)
Gravimetric Measurement	$30-$125 per sample
Infrared Thermometer	$3,100-$6,200
Pressure Bomb	$1,400-$3,100
Resistance Probe	$12-$220
Hand-Held Resistance Meter	$185-$310
Capacitance Probe	$620
Irrigation Scheduling	Dependent on needs and existing tools and practices
Laser Leveling	$50 per acre (every two to three years)
Furrow Diking	$185-$310 per row
Low Energy Precision Application (LEPA)	$49,500-$55,600 per system, ($8,000-$10,500 for conversion of existing partial-drop, center-pivot system)
Surge Valves	$15 per acre ($1,250-$1,850 per valve)
Drip Irrigation	$1,050-$1,250 per acre
Tailwater Reuse	Varies (purchase and installation of pumps, pipeline, surge valves, and operation and maintenance costs)
Conservation Tillage	$0-20 per acre
Canal and Conveyance System Lining and Management	Varies significantly

[a]*All costs are updated to 2005 costs.*

Source: Adapted from Amy Vickers, Handbook of Water Use and Conservation*, May 2001.*

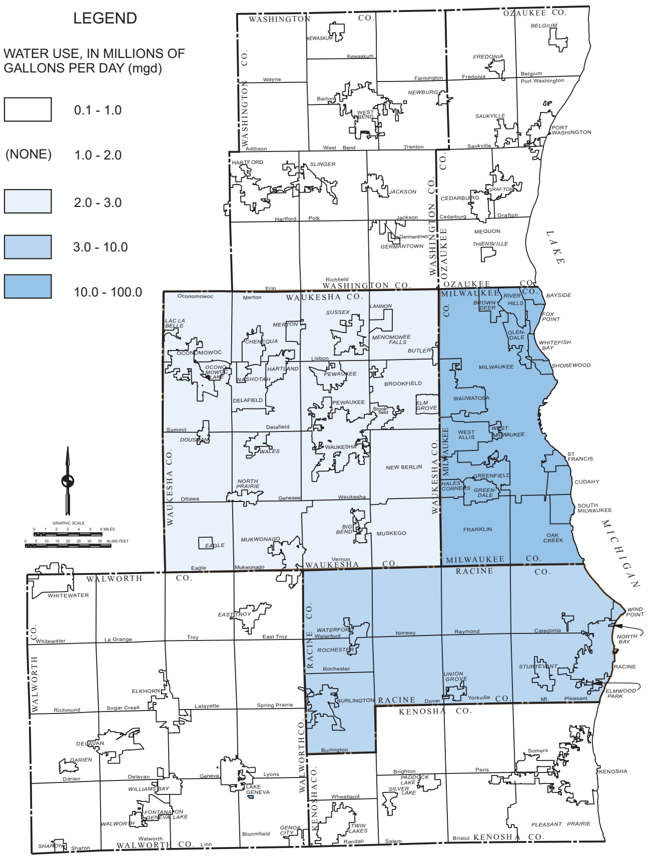
Measures

Water use practices differ greatly for industrial, commercial, and institutional entities, and several technologies and water-efficiency measures are applicable to the water-using activities, processes, and equipment commonly found in these facilities. Many of the measures applied involve operational adjustments and engineering design changes that are unique to particular processes and facilities. The water use of commercial facilities and institutions is often related to the populations they serve, such as the number of customers, students, visitors and patients, and employees. There are several methods to estimate the efficiency of water use among industrial, commercial, and institutional facilities, however, the use of an onsite water audit for each facility can produce the most accurate assessment. Conducting a water audit and the preparation of a site water conservation plan are the first steps toward increasing water-use efficiency. The basic steps in conducting a water audit and creating an effective water conservation program can be seen in Table 30.

For industrial, commercial, and institutional (ICI) facilities, the greatest water savings have traditionally been achieved through the use of domestic plumbing fixtures such as low-volume toilets, urinals, showerheads, and faucets. The adjustment of blow-down cycles in cooling equipment and recycling process water also contributed to water savings, particularly in industrial facilities. The alteration, or reduction, of irrigation schedules offers a significant savings in water use, and may be considered one of the most cost-effective measures that can be applied. The evaluation of water use at ICI facilities may also be more cost-effective if water audits are focused on water-efficiency measures for domestic uses, especially at commercial, governmental, and institutional locations. In general, meters and meter readings are beneficial to ICI facilities by providing information on how

Map 7

INDUSTRIAL SELF-SUPPLIED WATER USE BY COUNTY IN THE SOUTHEASTERN WISCONSIN REGION: 2000



Source: U.S. Geological Survey, 2002, and SEWRPC.

much and where water is being used. However, facilities with complex production processes that use water will typically require a more complex analysis to identify opportunities for water conservation. The average potential water savings from conservation measures at various types of commercial and institutional facilities has been estimated from onsite water audits and has been summarized in Figure 19.

Cost Data

The costs associated with industrial, commercial, and institutional water conservation programs are difficult to determine, varying significantly on a site-specific and process-specific basis. Case studies and water-efficiency audits of a large number of industrial, commercial, and institutional facilities have reported variable water savings from conservation measures. ranging from 10 percent to 90 percent of previous water use. The costs for the various measures and practices are variable with the type and size of the facility and the type of process and equipment in place. Furthermore, the analysis of the benefits of potential water savings must be coupled with the costs of equipment and process and operational changes to determine the potential cost-effectiveness of water conservation measures. Thus, no specific cost data is provided herein.

THERMOELECTRIC WATER CONSERVATION

Thermoelectric power generation is the production of energy from fossil fuels, nuclear energy, or geothermal energy. The United States uses more water to produce electricity than for any other application. Thermoelectric plants convert water into steam by heating it with fossil or nuclear fuels, and in turn, the steam drives turbine generators. Water is circulated throughout the power plants in large quantities to cool the turbines, clean scrubbers and boilers, and perform a number of other tasks. This type of electricity generation provides 97 percent of electric power in the State of Wisconsin.[33] Figure 20 depicts the quantity of thermoelectric water use in Wisconsin versus all other uses. The location of thermoelectric power plants in the southeastern Wisconsin seven-county region is shown in Map 8.

Thermoelectric power plants utilize a majority of the water that is withdrawn for cooling the power-producing equipment. Most of the large power plants utilize once-through cooling systems in which water is withdrawn from a source, circulated through the heat exchangers, and then returned to a surface waterbody.

Closed-loop cooling refers to cooling systems in which water is withdrawn from a source, circulated through heat exchangers, cooled, and recycled for further use. Subsequent water withdrawals for a closed-loop system are used to replace water lost to evaporation, blowdown, drift, and leakage. Closed-loop cooling systems typically withdraw less water than once-through cooling systems. However, closed-loop systems result in larger quantities of water that is consumed rather than returned to the source. Power plants that are equipped with once-through

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[33]*B.R. Ellefson, et. al.* Water Use In Wisconsin, 2000, *U.S. Geological Survey Open-File Report 02-356. 2002. Available at: http://wi.water.usgs.gov/.*

Table 30

BASIC STEPS OF A COMMERCIAL/INDUSTRIAL WATER AUDIT

Step 1:	**Obtain Support from the Facility's Owner, Managers, and Employees** Management support is essential to ensure that the resources required to implement a conservation program—personnel, time, and money—are available. Emphasizing the advantages of saving water and related benefits can boost support
Step 2:	**Conduct An Onsite Inventory of Water Use** A fundamental part of a water management plan is knowing where and how much water is used at the facility. Collect meter-reading records for all onsite meters. Complete a walk-through survey of the facility with the plant manager or engineer to collect information on each water-using process, piece of equipment, fixture, and activity. Record the measured or estimated water use and flow rates. The end product of this survey should be a water "balance sheet" that identifies and quantifies water use throughout the facility
Step 3:	**Calculate All Water-Related Costs** Results from the audit and data collected on the water balance sheet can be used to prepare a summary of the volume and cost of water used at the site. Costs associated with water use include those for water and sewer service, energy costs, chemical treatment costs, and waste pretreatment. In cases in which excessive use or leaks have caused property damage, the cost of mitigating the damage should be included. Other costs to consider are future increases in the price of water and sewer service, chemicals, and energy
Step 4:	**Identify and Evaluate Water-Efficiency Measures** Identify all potentially feasible water-efficiency measures for each water-using activity. A detailed description of water-efficiency measures that are applicable to customers, along with information about potential water savings that could be achieved with each measure, determine the capital cost and related expenses associated with the measure. Based on these data, estimate a simple payback period, or the amount of time required for projected cost savings from the measure to equal the investment cost
Step 5:	**Evaluate Payback Periods Using Life-Cycling Costing** Life-cycling costing is a more accurate method for evaluating the cost-effectiveness of efficiency measures because it amortizes costs and benefits over the measure of the life of the measure, including changes in interest rates, instead of taking into account only the initial investment. A measure that appears to be too expensive may be a cost-effective investment when its costs and benefits are amortized
Step 6:	**Prepare and Implement an Action Plan** Prepare a written version of the facility's water management plan. The plan should clearly state the program's goals, the way water is used, the water-efficiency measures to be implemented, projected water savings, benefits and costs associated with the efficiency measures, estimated payback periods, the schedule for implementing the measures, and the person responsible for the program. Once the plan is approved, it should be implemented promptly
Step 7:	**Track and Report Progress** Monitor results of the water-efficiency measures that were implemented to determine reductions in water use and related operational expenses. Keep employees informed about changes in the facility's water demand. Announce water savings in employee bulletins, corporate reports, publications of the facility's trade and professional organizations, and press releases to the media

NOTE: Water-efficiency measures for certain water uses and industries, such as medical and food-processing facilities, should be reviewed with appropriate local, State, and Federal regulatory agencies and officials before being implemented.

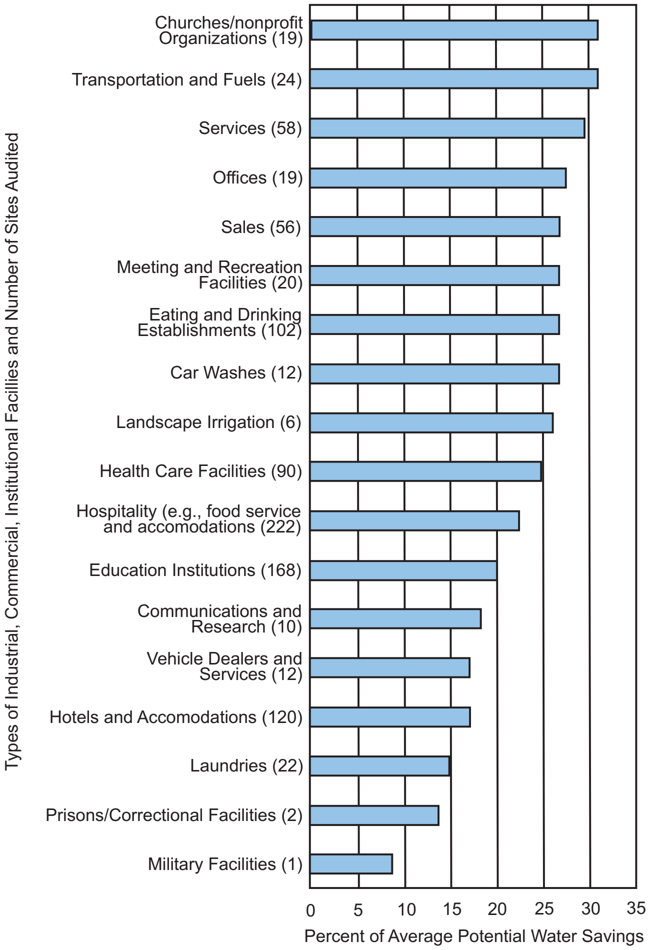
Source: Adapted from Amy Vickers, Handbook of Water Use and Conservation*, May 2001.*

cooling systems account for approximately 91 percent of water withdrawals for thermoelectric power, while plants equipped with closed-loop cooling systems withdraw the remaining 9 percent in the United States.[34] Cooling technologies that require less water also allow for the production of thermoelectric power in areas where water is scarce or strictly managed. Water-scarce States such as Arizona, Nevada, and New Mexico use closed-loop cooling systems rather than the more water-intensive once-through cooling systems.

[34]*U.S. Geological Survey*, Estimated Use of Water in the U.S. in 2000*, Mar 2004, Available at: http://pubs.usgs.gov/circ/2004/circ1268/htdocs/text-pt.html.*

Figure 19

AVERAGE POTENTIAL WATER SAVINGS FROM CONSERVATION FOR MAJOR INDUSTRIAL, COMMERCIAL, AND INSTITUTIONAL MARKETS



Source: Amy Vickers, Handbook of Water Use and Conservation, *and SEWRPC.*

In the City of Oak Creek, Wisconsin, the existing Oak Creek Power Plant is authorized to draw up to 1.8 billion gallons of Lake Michigan water per day for use in the once-through cooling system. An expansion is under construction that will have about a 20 percent increase in water withdrawal in the same type of system. This expanded plant is expected to return nearly all of the water back to the Lake. Similar cooling systems are in place at the Valley Power Plant in the City of Milwaukee, and the Port Washington Power Plant in the City of Port Washington. The Pleasant Prairie Power Plant in the Village of Pleasant Prairie, Wisconsin is located five miles away from Lake Michigan, where a closed-loop system with large cooling towers is used. The majority of the water used is make-up water for cooling the towers. We Energies reports that nearly 75 percent of the water used is make-up water for evaporation losses in the plant cooling tower system.[35] There are also two small peaking combustion turbine power plants in the Southeastern Wisconsin Region: one in the Village of Germantown in Washington County, and one in the Town of Paris in Kenosha County. These plants use limited amounts of well water for cooling and nitrogen oxides control on an intermittent use basis. The Milwaukee County power plant purchases treated surface water from the municipal water system for cooling and other process uses.

In order to conserve water in thermoelectric power production, new technologies are under development to reduce the amount of water withdrawn and consumed in cooling processes. Reductions in water withdrawals and water consumption for thermoelectric power production are also achievable through the use of dry cooling systems. In these systems, water does not come in contact with air. Dry cooling reduces the amount of water needed to replace water lost to evaporation significantly. However, dry cooling systems are less efficient than once-through water cooling systems and have higher capital costs.[36]

In addition to the use of improved technologies, reductions in water withdrawals and water consumption for the purposes of power production may be achieved through energy conservation. When less energy is in demand a lesser amount is produced by power plants, which can conserve the natural resources required in the production process. Although more costly to implement, wind, solar and other renewable energy systems are a growing trend in the United States that can reduce the need for resource consuming power plants. The major power company which serves the Southeastern Wisconsin Region, We Energies, is actively pursuing alternative forms of energy.

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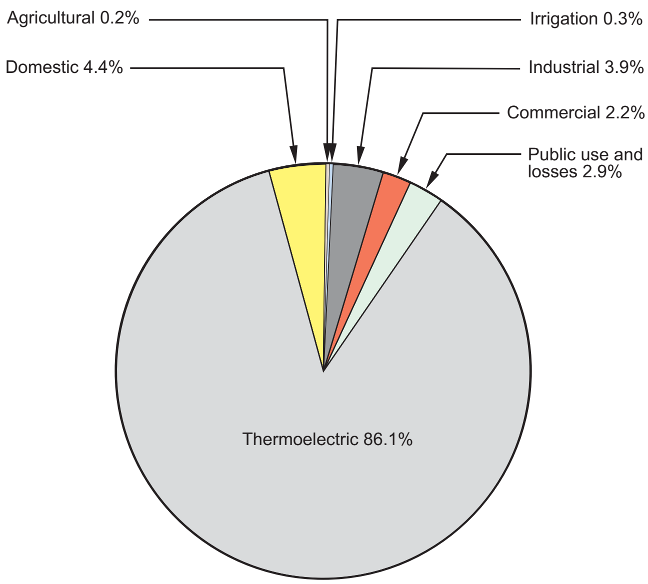
[35]*We Energies,* Oak Creek Power Plant Expansion: Protecting Lake Michigan, *2003, Available at: http://www.powerthefuture.net/publications/factsheet_oakcreek_waterusage.pdf.*

[36]*Midwest Environmental Advocates,* Protecting Wisconsin's Water: A Conservation Report & Toolkit, *2005, Available at: http://www.midwestadvocates.org/.*

Figure 20

THERMOELECTRIC AND OTHER WATER USES IN SOUTHEASTERN WISCONSIN: 2000



NOTE: WATER USE EXPRESSED IN MILLIONS OF GALLONS PER DAY.

Source: U.S. Geological Survey and SEWRPC.

Cost Data

Optimization of cooling process water use can result in considerable water savings. The costs to implement more water efficient technology in thermoelectric power plants varies significantly with the water requirements required by the size of the plant. Most of the power used in the Southeastern Wisconsin Region is generated in power facilities using once-through water cooling systems which are the most efficient in terms of water use. Given the private ownership and design and operation expertise of the facility owners, it may be concluded that the cost and benefits of water use conservation measures can only be considered by the utilities involved as facilities are expanded and upgraded.

WATER REUSE AND RECLAMATION

Some communities throughout the United States are considering the reclamation and reuse of water to reduce demands on freshwater supply systems. Water reuse is the use of water or reclaimed water from one application for another. A large number of industries have begun to consider other uses for treated wastewater effluents to regain investments made in the treatment of wastewater to meet restrictive discharge limits. Reclaimed wastewater is currently used as an alternative source of water for a variety of applications, such as landscape and agricultural irrigation, toilet and urinal flushing, industrial processing, power plant cooling, wetland habitat creation, restoration and maintenance, and groundwater recharge.[37] A few communities have fully incorporated the reuse of wastewater into water supply systems, and some states require that municipalities consider water reuse before upgrading or building a new water or wastewater treatment plant.

For public health and aesthetic reasons, reuse of treated sewage effluent is presently limited to nonpotable applications such as irrigation of nonfood crops and provision of industrial cooling water. There are no known direct reuse schemes using treated wastewater from sewerage systems for potable water uses. Indeed, the only known systems of this type are experimental in nature, although, in some cases, treated wastewater is reused indirectly, as a source of aquifer recharge. Table 31 presents guidelines for the utilization of wastewater, indicating the type of treatment required, resultant water quality specifications, and appropriate setback distances. In general, wastewater reuse is a technology that has had limited use, primarily in small-scale projects in the Region, owing to concerns about potential public health hazards. Water reuse and reclamation has been used in Wisconsin only for limited applications, such as the use of treated wastewater treatment plant effluent for various wastewater treatment plant process waters.

Irrigation

Measures

In the United States, less than 1 percent of irrigation withdrawals are from reclaimed water, as of 2001.[38] Agricultural irrigation represents 40 percent of the total water demand in the country, and over 50 percent of the

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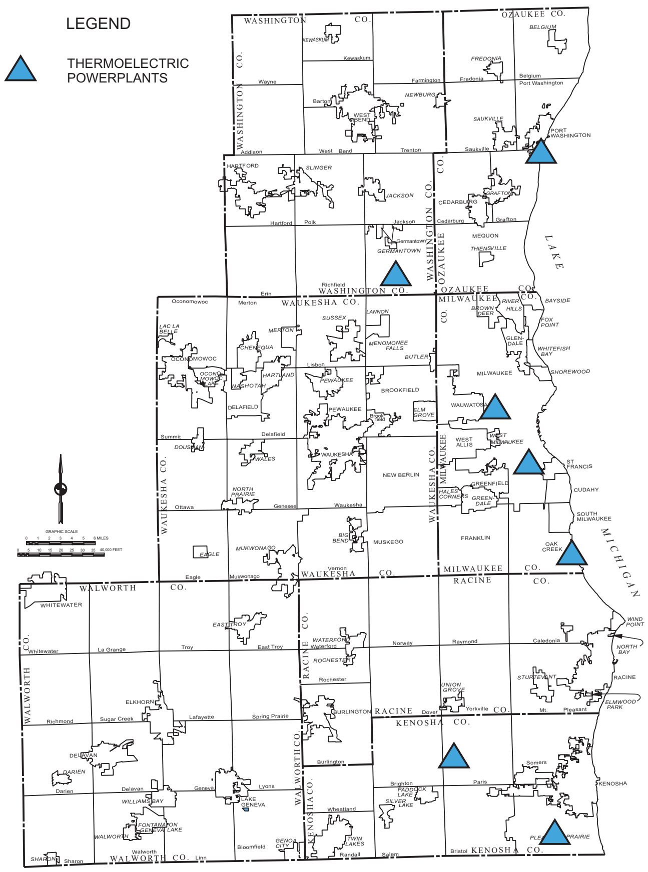
[37]*U.S. Environmental Protection Agency,* Guidelines for Water Reuse, *September 2004, Available at:* *http://www.epa.gov/ORD/NRMRL/pubs/625r04108/625r04108.pdf.*

[38]*Amy Vickers,* op. cit.

Map 8

THERMOELECTRIC POWER PLANT LOCATIONS IN THE SOUTHEASTERN WISCONSIN REGION



Source: U.S. Geological Survey, 2002, and SEWRPC.

average residential water use is for outdoor irrigation. In the Southeastern Wisconsin Region, irrigation represents less than 3 percent of the total water demand, and it is estimated that 17 percent of residential demand is for outdoor water use. The irrigation of golf courses, parks, cemeteries, and large landscaped areas in urban areas draws large quantities of freshwater. With this high demand, water conservation can create significant benefits with the use of reused or recycled water.

The application of reused water to the groundwater system is regulated under Chapters NR 206 and 140 of the *Wisconsin Administrative Code*. Land treatment systems designed to infiltrate wastewater must treat the water to meet Chapter NR 206 effluent standards and may require additional treatment to meet Chapter NR 140 water quality standards as approved by the Wisconsin Department of Natural Resources. Irrigation systems are regulated to prevent or minimize infiltration to the groundwater by restricting application rates based on soil types and requiring a minimum thickness of unsaturated soil above the water table. These regulations essentially eliminate the possibility of using these systems for groundwater recharge purposes because the regulations are designed to prevent application of wastewater at a rate that allows such recharge.

In Florida, irrigation with reclaimed water has become common, and additional municipal utilities based upon recycling and water reuse have been developed. A regional water reuse partnership has been created between Hillsborough and Pasco Counties, Tampa Bay Water, and the Southwest Florida Water Management District in which infrastructure costs are shared for the creation of a large-scale water reclamation program. The utilities are also able to expand their reclaimed water customer base to maximize water reuse year-round. [39]

The use of reclaimed water may be an economical means of supplying water for irrigation for some customers. For some water utilities, reclaimed water is estimated to cost 20 to 25 percent less than potable water. Customers that use large quantities of water, such as landscapers and construction companies, may be offered reclaimed water free of charge. However, the use of reclaimed water for irrigation may be costly when the water must be stored.

In agricultural applications, tailwater reuse is common. Tailwater reuse involves the capture of field runoff in pits dug at the end of gravity-irrigated rows in low-lying areas of a field or farm and reapplying the water. Tailwater runoff occurs when soil becomes saturated, causing water to travel down the drainage ditches. Water losses from evaporation and deep percolation may result. A typical tailwater reuse system consists of a drainage ditch, a

[39]*Ralph Metcalf, et. al.,* Reuse It All, *Water Environment & Technology Magazine, May 200.*

Table 31

GUIDELINES FOR WATER REUSE

Type of Reuse	Minimum Treatment Required	Reclaimed Water Quality	Recommended Monitoring	Setback Distances
Agricultural Food Crops Commercially Processed (not allowed in Wisconsin) Orchards and Vineyards (not allowed in Wisconsin)	Secondary, plus Disinfection	pH = 6 - 9 BOD ≤ 30 mg/l SS = 30 mg/l FC ≤ 200/100 ml Cl_2 residual = 1 mg/l min	pH weekly BOD weekly SS daily FC daily Cl_2 residual continuously	300 feet from potable water supply wells 100 feet from Areas Accessible To Public
Agricultural Food Crops Not Commercially Processed (not allowed in Wisconsin)	Secondary, plus filtration disinfection	pH = 6 - 9 BOD ≤ 30 mg/l Turbidity ≤ 1 NTU FC ≤ 0/100 ml Cl_2 residual = 1 mg/l min	pH weekly BOD weekly Turbidity daily FC daily Cl_2 residual continuously	50 feet from potable water supply wells
Pasturage	Secondary, plus disinfection	pH = 6 - 9 BOD ≤ 30 mg/l SS = 30 mg/l FC ≤ 200/100 ml Cl_2 residual = 1 mg/l min	pH weekly BOD weekly SS daily FC daily Cl_2 residual continuously	300 feet from potable water supply wells 100 feet from areas accessible to public
Forestation	Secondary, plus disinfection	pH = 6 - 9 BOD ≤ 30 mg/l SS = 30 mg/l FC ≤ 200/100 ml Cl_2 residual = 1 mg/l min	pH weekly BOD weekly SS daily FC daily Cl_2 residual continuously	300 feet from potable water supply wells 100 feet from areas accessible to public
Groundwater Recharge	Site-specific and use-dependent (see Chapter VI)	Site-specific and use-dependent	Depends on treatment and use	Site-specific

Source: U.S. Environmental Protection Agency, Process Design Manual: Guidelines for Water Reuse*, 1992. (Report No. EPA-625/R-92-004).*

tailwater reservoir, and a pump and pipeline to collect the tailwater and return it for redistribution. Tailwater reuse pits have the potential to create water savings of 10 to 30 percent.[40]

Cost Data

A reclaimed water system requires considerable resources to construct, operate, and maintain its treatment, storage, and distribution facilities. In some site-specific instances, facilities may be more cost-effective than tapping new potable water sources. However, in other site-specific situations, the significant economic and resource investments needed for reuse may not be justified, particularly for nonessential uses, such as lawn irrigation. Large-scale reuse of wastewater is still relatively new in the United States, and the true costs of such reuse systems are not yet fully understood.[41]

Graywater Systems

Measures

The installation and use of onsite graywater systems has been approved and is regulated in several states, including Wisconsin. Graywater is typically defined as untreated, used household water that does not contain human wastes. The U.S. Environmental Protection Agency has determined that this water may be reused for toilet flushing and other nonpotable applications, including gardening, lawn maintenance, landscaping, and other uses.

[40]Ibid.

[41]Ibid.

Graywater is a potential water resource, provided it is managed in an environmentally responsible manner, and public health is protected. Capturing graywater and using it in an appropriate manner as an alternative to the municipal water supply can reduce water consumption. The use of graywater in Wisconsin is regulated under Chapter NR 82 of the *Wisconsin Administrative Code*. That code sets forth standards for graywater which are relatively stringent and may require treatment of the graywater depending upon the source.

Unless carefully designed and managed, graywater systems can be a potentially unsafe source of water. Graywater can contain disease-causing microorganisms, such as bacteria, protozoa, viruses, and parasites. It may also contain fats, oils, detergents, soaps, salt, nutrients, food, and hair derived from household and personal cleaning activities. These constituents can pose both grave health and environmental risks.

Soil or plants can process many of the contaminants in graywater if the system is carefully designed and managed, including organic material, nutrients, salt, and sediment. Nutrients can be beneficial in moderate concentrations, for example, on lawns. Some graywater contaminants are not capable of being treated or degraded in the soil. Principal among these is sodium chloride—common salt—which can be contributed in significant amounts by water softening and detergents and can cause soil degradation.

A treatment system will remove the bacterial load and chemical pollutants from graywater so that it can be stored. However, satisfactory treatment tends to be costly and impractical on a residential scale. Treatment processes can include filtering, settling of solids, anaerobic or aerobic digestion, and chemical removal of pollutants and disinfection. Graywater systems have the capability of reducing potable water use. However, this type of reuse system may have limited benefits for indoor water use savings as plumbing fixtures and appliances become more water efficient and reduce indoor residential water demand. Since a limited amount of graywater is available for outdoor reuse, the installation costs, energy requirements, and maintenance required for the graywater system may not be practical for most residential applications. Residences and other types of facilities with larger outdoor water demands are more likely to benefit from an onsite graywater system. In Wisconsin, graywater systems have not been widely accepted as a method of water conservation. The Wisconsin Department of Commerce regulations govern the use of graywater systems. Chapter Comm 82.70 allows the use of treated graywater for once through cooling water, surface irrigation, except food crops, vehicle washing, toilet and urinal flushing, air conditioning, soil compaction, dust control, washing aggregate, and making concrete. Each type of reuse must conform to the plumbing treatment standards put forth by the code, including, but not limited to: minimum requirements for pH, BOD_5, TSS, fecal coliform, and chlorine residual.

Cost Data

The costs of installing a graywater system, including pipes, valves, and tanks, at a single-family residential property ranges from several hundred to several thousand dollars, depending on the size of the system.

Dual Systems

Measures

Dual distribution systems may be used to provide reclaimed water for various nonpotable purposes in urban areas. In a dual distribution system, reclaimed water is delivered to customers by a parallel network of distribution mains separate from the potable water distribution system. A reclaimed water system can become an additional utility in the community. A dual distribution system may be operated, managed, and maintained like a potable water system. The oldest municipal dual distribution system in the United States is located in the City of St. Petersburg, Florida. The facility has been in operation since 1977 and distributes reclaimed water to a combination of residential properties, commercial developments, industrial parks, a resource recovery power plant, a baseball stadium, and schools.[42]

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[42] *U.S. Environmental Protection Agency,* Guidelines for Water Reuse, *September 2004, Available at: http://www.epa.gov/nrmrl/pubs/625r04108/625r04108chap2.pdf.*

The installation of a dual distribution system in newly developed areas may be expected to be significantly lower than the cost of retrofitting existing urban areas. In 1984, the City of Altamonte Springs, Florida, required that developers install reclaimed water lines so that all properties within a development would be provided service. This stipulation reduced the line sizes and looping requirements of the potable water system. Retrofitting a developed urban area with a dual distribution system can be relatively expensive. However, in some areas the benefits of conserving potable water can rationalize the cost, such as when additional water supplies are scarce or must be obtained from considerable distances.

Water reclamation facilities must provide the required level of treatment to meet appropriate water quality standards for the intended use. In addition to secondary treatment and disinfection, tertiary treatment is generally required for reuse in an urban setting. Urban reuse may involve irrigation of properties with unrestricted public access or other types of reuse where human exposure to the reclaimed water is likely. These circumstances require that reclaimed water is of a higher quality than may be necessary for other reuse applications. In cases where a single, large customer needs higher-quality reclaimed water, the customer may have to provide additional treatment onsite. A dual distribution system can include an extensive array of storage reservoirs, pump stations, and a distribution piping system. Reclaimed water in the dual distribution system can be made available upon demand by customers. It is typically delivered through separate service connections and meter facilities.

Dual distribution water systems transport reclaimed water from treatment plants to irrigation or industrial sites. In many areas, development of a wastewater reuse system provides reclaimed water at a lower cost than potable water. Substitution of reclaimed water for potable water for certain uses can reduce demands on groundwater supplies and can reduce or eliminate the amount of wastewater treatment plant effluent discharged to environmentally stressed surface waters.

Plumbing cross-connections, or the actual or potential connections between a potable and nonpotable water supply, may constitute a serious public health hazard if not implemented properly. The contamination of drinking water and the spread of disease are typical problems that are associated with this type of system. Once a cross-connection has been installed, careful management and monitoring of faucets and storage units must be performed to control possible hazards. Nonpotable water connections must be properly identified and labeled to avoid risk to public health. The U.S. Environmental Protection Agency established the Cross-Connection Control Manual as a tool for health officials, water-works personnel, plumbers, and others who may be directly or indirectly involved in the design and construction of water supply distribution systems. A contaminated source of water may enter the potable water system when the pressure of the polluted source exceeds the pressure of the potable source, which is commonly referred to as backsiphonage or backflow. In 1933, Chicago experienced an epidemic due to old, defective, and improperly designed plumbing fixtures that permitted the contamination of drinking water. This contamination resulted in the deaths of 98 individuals, and the contraction of amebic dysentery by 1,409 persons.[43]

Cost Data

The costs associated with dual distribution systems are highly variable, depending on the size of the facilities concerned and the site-specific characteristics of the distribution area and related uses. The cost of constructing a new distribution system may be expected to be similar to that for laying regular distribution pipelines. In effect, the installation of a dual distribution system approximately doubles the cost of construction of the distribution system, although some savings may be achieved if the two systems are installed at the same time. Operation and maintenance costs of the second system may also be expected to be similar to those incurred for a normal distribution system. For a community in southeastern Wisconsin with an average water use of 2.6 mgd and an approximate service area of seven square miles, the estimated costs associated with the installation of a dual distribution system are summarized in Table 32. The costs include, but are not limited to, capital costs of upgrading the wastewater treatment facility to treat the water to a level required by the Wisconsin Department of

[43] *Environmental Protection Agency,* Cross-Connection Control Manual*, 2003. Available at: http://www.epa.gov/safewater/pdfs/crossconnection/crossconnection.pdf.*

Table 32

DUAL DISTRIBUTION SYSTEM COST DATA FOR A TYPICAL SOUTHEASTERN WISCONSIN RESIDENTIAL COMMUNITY

Dual Distribution System Type	Cost per Square Mile
Retrofit of Existing Potable System	
Construction of New Nonpotable System in Parallel with Existing Potable	$3.24 million
Construction of New Potable and Conversion of Existing System to Nonpotable	3.32 million
New System	
Construction of New Dual Distribution System	$4.07 million

NOTE: The costs listed above are based on use of ductile iron, open-cut construction; the costs do not include: engineering, and legal and administration fees, rock excavation, contingencies, casing pipes, directional drilling, and erosion controls.

Source: Ruekert & Mielke, Inc.

Natural Resources and local authorities, of storage and pumping facilities, of transmission mains, and of plumbing retrofits within individual households.

EXAMPLE WATER CONSERVATION PROGRAM—REGION OF WATERLOO, ONTARIO, CANADA

The Regional Municipality of Waterloo, Ontario, Canada, has been involved in implementing a comprehensive water conservation program since 1998. Because of the nature of the current water supply system, the climate, future options for water supply sources, and the cost of water, the Regional Municipality of Waterloo water conservation program is considered a comparable example for the situation in southeastern Wisconsin. The experience in the Waterloo area can serve as a useful example to consider in developing conclusions concerning potential water conservation program measures, costs, and effectiveness in southeastern Wisconsin.

Background

The Regional Municipality of Waterloo is located in Ontario, Canada. It consists of three cities and four townships. As shown on Map 9, the Waterloo area is relatively close to three of the Great Lakes, Lake Erie, Lake Huron, and Lake Ontario. The area concerned is about 530 square miles in size, and had a resident population in 2006 of about 500,000 persons. That population is expected to increase to about 730,000 persons by the year 2031. In 1998, the Regional Municipality completed and began to implement a long-term water conservation plan[44] and in 2000, a long-term water supply strategy was completed.[45] During 2006, an update[46] to the 1998 water conservation plan was completed.

The primary water supply system serving the Waterloo area consists of a large centralized integrated network of wells, water treatment plants, reservoirs, pumping stations, and water transmission mains. Prior to 1992, all of the Region’s water supply was derived from groundwater wells. In 1992, a treatment plant using river water was added to tap another source of supply. The Regional Municipality operates a large centralized water supply system which provides about 41 million gallons per day on an average daily basis. About 75 percent of the water

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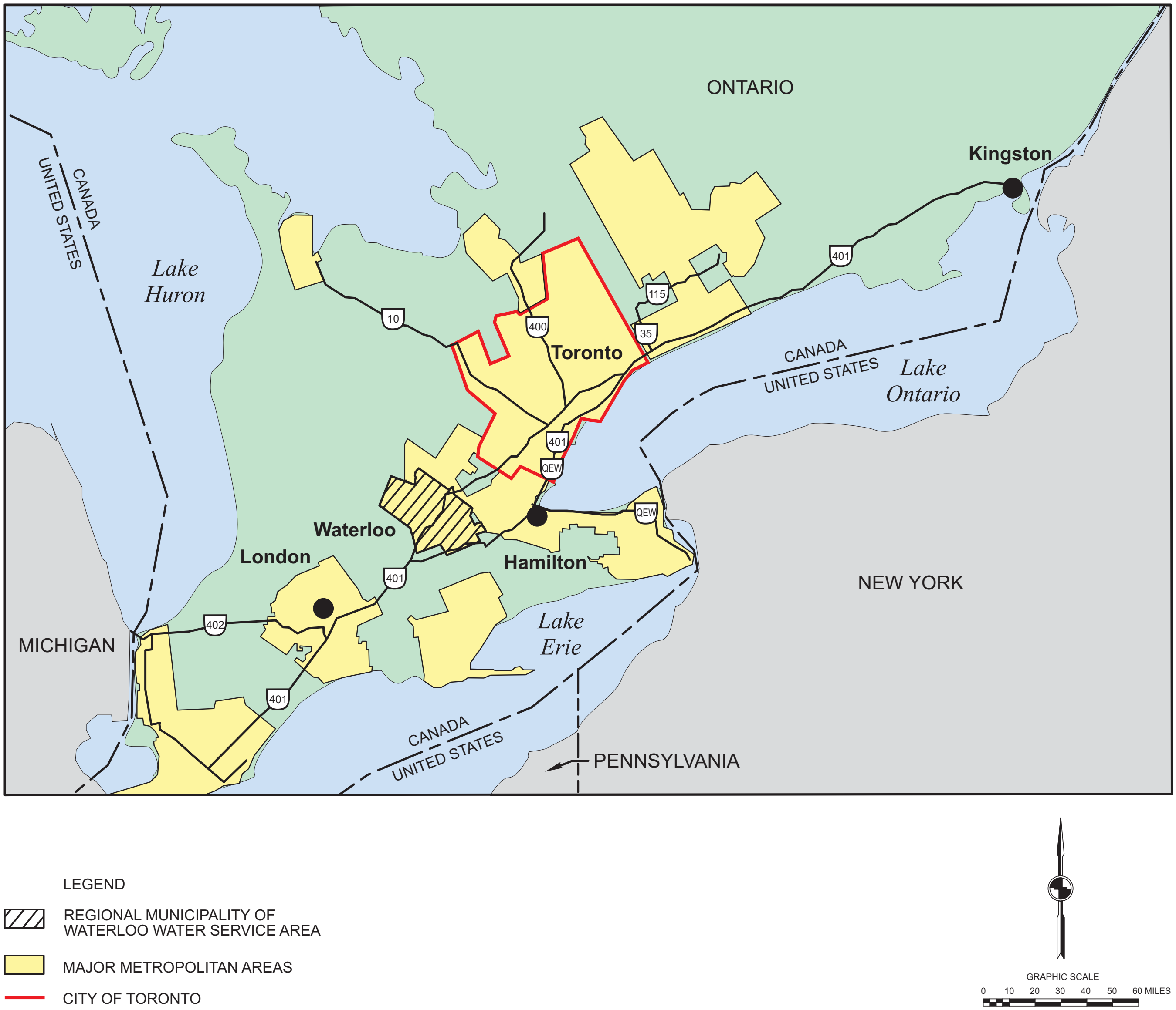
[44]*Regional Municipality of Waterloo,* Water Efficiency Master Plan, *November 1998.*

[45]*Regional Municipality of Waterloo,* Council Report: Recommendations on the Long-Term Water Strategy, 2000.

[46]*United Utilities Canada Limited, Region of Waterloo,* Water Efficiency Master Plan Update Research Report, *May 2006.*

Map 9

REGIONAL MUNICIPALITY OF WATERLOO, ONTARIO, AND VICINITY: 2005



Source: Her Majesty the Queen in Right of Canada, Natural Resources of Canada; Government of Canada, Atlas of Canada National Framework; Geography Division Statistics Canada; Ontario Ministry of Transportation; and SEWRPC.

supply of the centralized system is from groundwater, and 25 percent is from surface water. The surface water source is the Grand River, a tributary of Lake Erie. In addition to the large centralized system, there are 16 smaller water supply systems serving township areas which are operated by the Regional Municipality. These systems utilize groundwater as a sole source of supply. These 16 water supply systems provide about 2.5 million gallons per day to the users concerned.

The capacity of the large centralized water supply systems serving the Regional Municipality of Waterloo in 2000 was about 68 million gallons per day (mgd). In 2006, water supply capacity was approximately 62 mgd. This reduction in capacity has been attributed to a loss in efficiency from some well fields, water quality issues in some systems, and regulatory issues that impact how the water sources have been operated. The Regional Municipality is working on a number of projects to reestablish the full capacity of its water supply systems and to add more capacity. These projects include aquifer storage and recovery, optimizing treatment processes at the surface water and groundwater treatment facilities, and new groundwater well development. A longer-term source of supply plan providing for the construction of a pipeline to either Lake Huron or Lake Erie is also being considered. Implementation of this plan is expected by 2035, with an estimated cost of about $400 million (expressed in United States currency). That project is currently being reviewed as part of an ongoing update to the Regional Municipality's long-term plan.

The cost of water in the Region of Waterloo in 2005 was about $1.55 per 1,000 gallons on a wholesale basis and from $2.70 to $3.40 per 1,000 gallons, expressed in United States currency, plus a fixed charge which varies by community, on a retail basis.

Ongoing Region of Waterloo Water Conservation Program

The water conservation program adopted by the governing body of the Regional Municipality in 1998 established a goal of reducing water consumption by 1.8 million gallons per day by 2009. This equates to just over 4.0 percent of the average daily water use in the service area. In 2000, the governing body of the Regional Municipality adopted a long-term water strategy deigned to ensure an adequate water supply to the municipality through the year 2041. As previously noted, the strategy developed includes development of both surface and groundwater supplies, as well as a water conservation program component designed to potentially defer capital intensive capacity expansion-related projects. The following water conservation measures were included in the water conservation program developed under these two programs:

- Residential Public Awareness—These measures consisted of public informational and educational activities, including a speaker bureau; newsletters; the provision of fact sheets and other promotional materials; and a business education program.

- Residential Toilet Replacement—This measure provided rebates which varied from $35 to $65 per toilet, based upon toilet type and effectiveness. The plan provided for up to 5,000 rebates per year. (Note: The cost of installation for a toilet is reported to be only about $50 in the Waterloo area. Thus, if a toilet costs $100, the rebates cover from about 25 to 40 percent of the installed cost.)

- Rain Barrel Distribution—This measure was intended to distribute 25,000 rain barrels, at a nominal charge of $20, for use in the service area. That goal was achieved by 2005.

- Outdoor Water Use Restrictions—Areawide regulations were put in place that were intended to achieve a reduction in peak demand of 10 to 20 percent and to reduce the potential for water shortages during the summer high water use periods. These regulations included various stages of restrictions on outdoor water use based on the severity of the water supply situation. Mild restrictions would involve odd-even outdoor water rules, a moderate stage would restrict watering to once-per-week, while the most restrictive stage would prohibit outdoor watering altogether.

- Municipal Building Water Conservation—An evaluation of water use in public buildings was made with the objective of implementing water conservation measures, such as plumbing fixture replacement, when demonstrated as being cost-effective.

- Industrial, Commercial, Institutional Water Conservation—A program was instituted to encourage water conservation in industrial, commercial, and industrial buildings and facilities. Initial facility water audits and measures, such as changes in processes and in fixtures, were encouraged.

- School Curriculum Development—A school curriculum was developed, including an educational video for use in grades two through eight, and provided to schools.

- Promotion of Water-Efficient Washing Machines—A program promoting the use of water-efficient washing machines was initiated.

- Restaurant Pre-Rinse Spray Valve Efficiency Demonstration—A pilot program was initiated to demonstrate the value of more water-efficient pre-rinse spray valves in restaurants.

Water Conservation Plan Goals and Effectiveness

The Regional Municipality's planning efforts included the preparation of estimates of future water demand under the assumption of the institution of no new water conservation initiatives, and compared that demand to the estimated demand assuming implementation of the recommended water conservation program. The calculations of future water demand were based upon population and land use projections and unit water consumption and peaking factors. Figure 21 presents the alternative demand projections. The projections indicated a potential reduction in average daily and maximum weekly demands of 6.6 percent and 10.3 percent, respectively, over a 50-year period from 1991 though 2041.

The 2006 water supply plan update report[47] identified the estimated water conservation program savings associated with implementation of individual water conservation measures. Those data were compared to the water-saving targets established over the period 1998 through 2005. The comparisons are summarized in Table 33. The actual water savings over the period 1998 through 2005 was estimated at 1.46 mgd on an average daily demand basis, which exceeded the target savings of 1.35 mgd. The savings of 1.46 mgd equates to about 3.5 percent of the total water demand on an average daily demand basis.

Cost of Water Conservation Program

The cost of the capital and operation and maintenance costs for the Regional Municipality's water efficiency program was reported to be about $900,000 per year expressed in United States currency.

Future Water Conservation Program

In 2006, the Regional Municipality completed a water efficiency master plan update. The updated plan includes planning level estimates for three levels of water conservation as options for implementation in 2007 through 2015. The recommended aggressive program had an estimated program cost of $15,500,000 over nine years. The reduction in water use by the end of nine years was estimated at 8.6 mgd, or about 17 percent of the average daily water demand. The moderate-level program had an estimated cost of one-half of the cost of the more aggressive program, an estimated savings of 4.3 mgd, or about 9 percent, of the average water daily demand, by the end of the nine years. The enhanced status quo program was estimated to have program costs of $3,750,000, and the associated savings were estimated at 2.2 mgd, or about 5 percent of the average daily water demand, by the end of nine years. Table 34 highlights the estimated costs and water savings for each program. The estimated program costs include materials and external services, and were categorized as "capital costs." Regional Municipality staff costs and some educational costs were categorized as "operating costs."

The water conservation program finally recommended to the Regional Council, in July of 2006, had a nine-year total cost of about $8,500,000, including all capital and operating costs and a target reduction in water use of about 2.2 mgd, or about 5 percent of total average daily water demand. Conservation measures included in the recommended program include: public education; outdoor water use restrictions; toilet replacement program; promotion of industrial, commercial, and institutional water conservation; and water system leak detection and reduction.

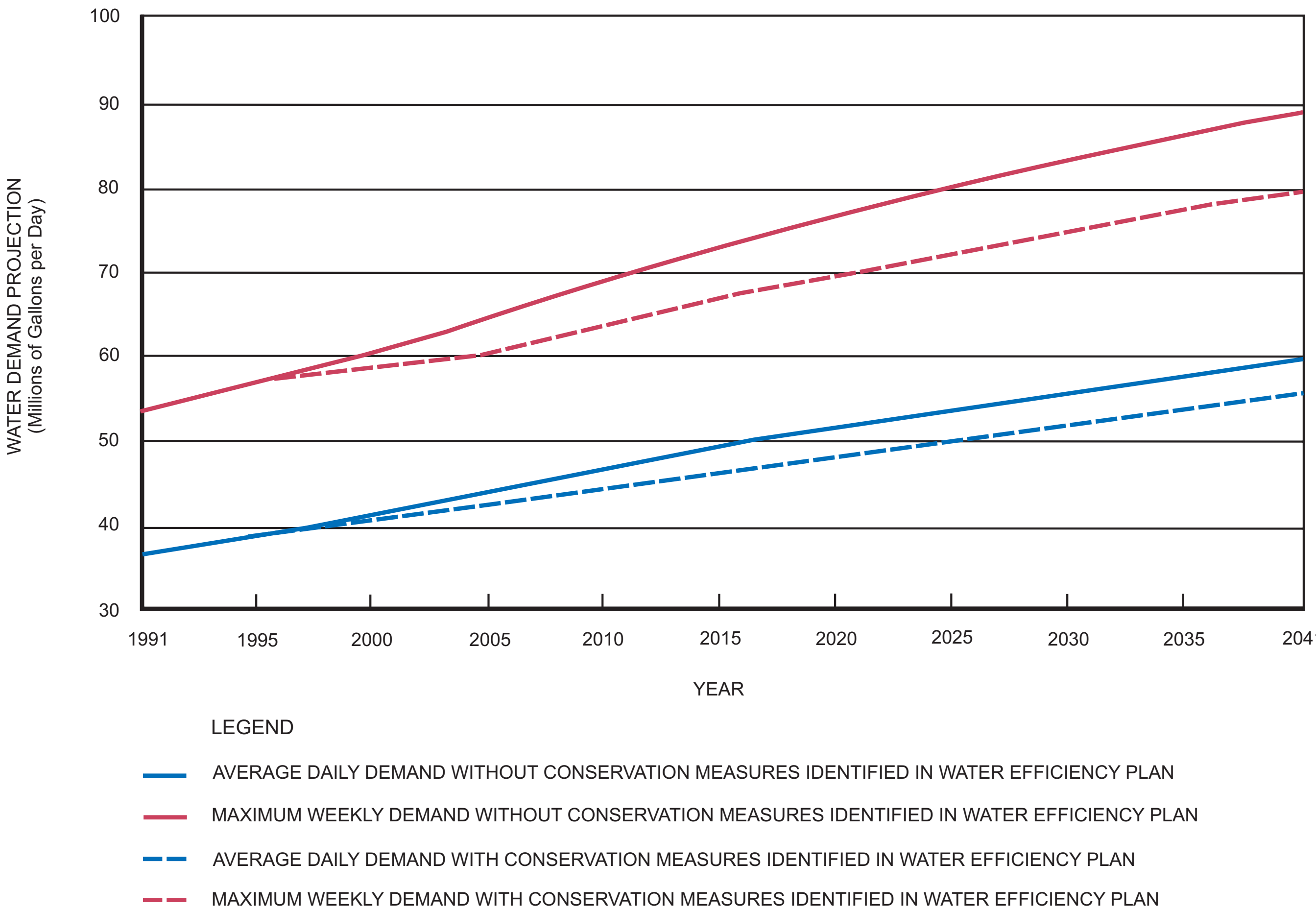
WATER CONSERVATION PROGRAM IMPACTS

Implementation of water conservation measures which reduce water demand may be expected to reduce some of the costs associated with water production, such as power and chemical costs. However, most of the water

[47]Ibid.

Figure 21

REGION OF WATERLOO WATER DEMAND FORECASTS: 1991-2041



Source: *Great Lakes Commission,* Regional Case Studies, Best Practices for Water Conservation in the Great Lakes-St. Lawrence Region, *June 2004, and SEWRPC.*

Table 33

REGION OF WATERLOO COMPARISON OF WATER CONSERVATION PROGRAM PROPOSED VERSUS ESTIMATED ACTUAL AVERAGE DAILY DEMAND WATER SAVINGS: 1998-2005

Year	Proposed Toilet Replacement Program (gpd)	Actual Toilet Replacement Program (gpd)	Proposed Residential Public Education (gpd)	Actual Residential Public Education (gpd)	Proposed Commercial, Institutional, and Industrial Public Education (gpd)	Actual Commercial, Institutional, and Industrial Public Education (gpd)	Actual Rain Barrel Program (gpd)	Proposed Reduction (mgd)	Actual Reduction	
									(mgd)	Percent
1998	70,806	72,391	0	0	0	0	0	0.07	0.07	0.2
1999	159,313	211,888	29,062	29,062	0	0	0	0.19	0.24	0.6
2000	265,521	297,489	86,922	86,922	43,329	45,178	0	0.40	0.43	1.1
2001	371,994	415,851	144,782	144,782	86,658	112,813	5,284	0.60	0.68	1.7
2002	478,466	547,422	202,641	202,641	130,251	112,813	10,568	0.81	0.87	2.1
2003	584,146	661,028	260,501	260,501	173,579	119,683	14,795	1.02	1.06	2.6
2004	690,619	816,114	290,092	318,625	217,172	143,461	19,022	1.20	1.30	3.2
2005	796,827	944,779	290,092	318,625	260,501	168,560	23,514	1.35	1.46	3.5

Source: *United Utilities Canada Limited,* Region of Waterloo, Water Efficiency Master Plan Update Research Report, *May 2006.*

Table 34

REGION OF WATERLOO ESTIMATES OF COSTS AND WATER SAVINGS AT VARIOUS PROGRAM LEVELS

Program Level	2007 to 2015 Water Savings (mgd)	Estimated 2007 through 2015 Costs					
		Capital[a]			Operating[b]		
		Total	Cost per Year	Cost per Year per Person Served	Total	Cost per Year	Cost per Year per Person Served
Aggressive	8.6, or about 17 percent of average water use	$15,500,000	$1,720,000	$3.40	$1,800,000	$200,000	$0.40
Moderate	4.3, or about 9 percent of average water use	$ 7,500,000	$ 830,000	$1.70	$ 900,000	$100,000	$0.20
Status Quo-Enhanced	2.2, or about 5 percent of average water use	$ 3,750,000	$ 416,000	$0.80	$ 450,000	$ 50,000	$0.10

[a]*Capital costs include materials and other external costs.*

[b]*Operating costs include municipal staff and some educational costs.*

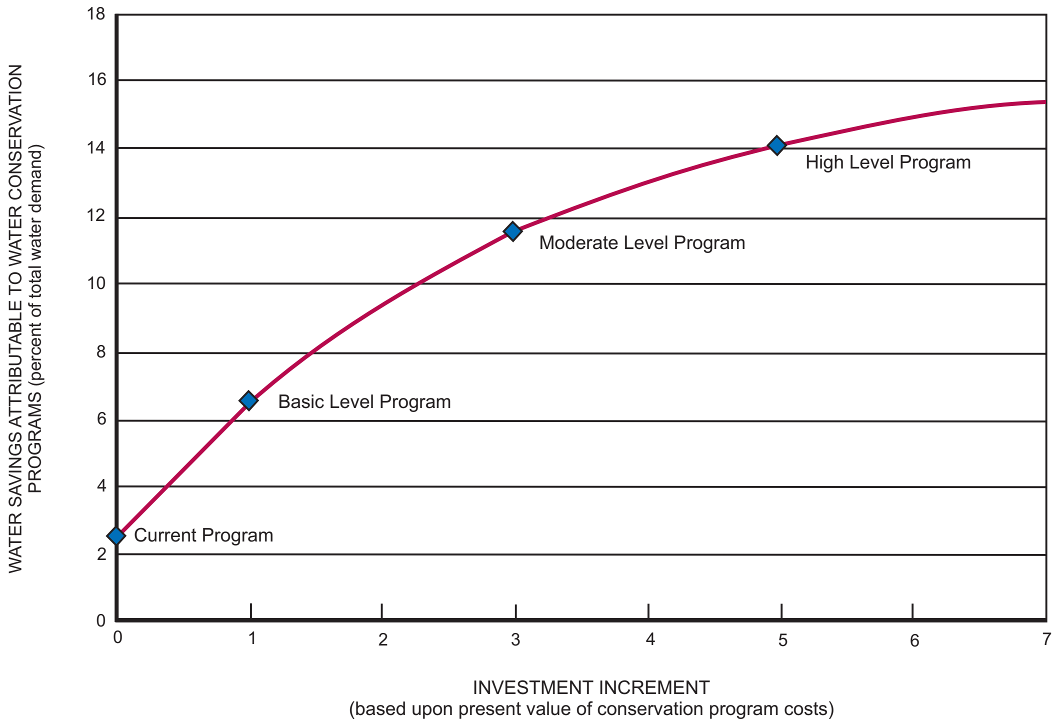
Source: United Utilities Canada Limited, Region of Waterloo, Water Efficiency Master Plan Update Research Report*, May 2006.*

production costs are relatively fixed and may not be expected to be significantly affected by water conservation measures. Water conservation programs may also be viewed as a means of preserving infrastructure capacity, reducing operation costs, and achieving sustainability in the source, or sources, of supply through reductions in demand. The institution of water conservation programs involves a level of commitment and resources which will vary depending upon several factors, including the level of conservation needed or desired, existing infrastructure, sources of supply, and the types of conservation measures to be applied. The measures to be considered may include those which impact both water supply system efficiency and reductions in water demand. Investments in water conservation programs are intended to translate into immediate savings in utility water production, operation, and maintenance costs. Such programs may also result in savings in, or deferment of, future capital costs for system expansion or improvement, and in reductions in wastewater system conveyance and treatment costs. The net costs of achieving such savings from water conservation programs will vary depending on the extent and success of the programs and on the potential reductions in operation and capital costs. When conservation programs are implemented properly, the municipal water utility benefits through a reduction in the amounts of water pumped to homes and businesses and energy and treatment chemical costs will be reduced. It should be noted, that these cost savings in energy and chemical cost savings amount to only a fraction of the water production costs, with the remaining costs being relatively fixed and not affected by water conservation. The conceptual conservation investment curve provided in Figure 22 portrays the relationship that may be expected between the costs of water conservation programs and attendant savings in water use. The actual conservation program levels and costs, as well as the attendant savings in water production costs and reductions in water use, will be utility-specific. In addition to the operational and infrastructure considerations related to water conservation, the sustainability of water supply is an important and possibly overriding consideration in designing a water conservation program. In addition to direct savings in water production costs, there is some opinion which holds that water conservation measures may also result in savings in the costs of wastewater conveyance and treatment. However, water carriage sanitary sewerage systems require flows adequate to remove the solids, as well as liquid wastes concerned, and may not perform efficiently with less carriage water. The amounts of waste to be carried—particularly in form of suspended solids—will not be changed by water conservation measures. Thus, the impact of water conservation measures on wastewater system costs is uncertain. Those impacts may be positive or negative, and may vary with the extent and configuration of the system concerned.

In order to better understand the potential impacts of the use of conservation programs in communities throughout southeastern Wisconsin, three example water conservation plan options were formulated using basic utility data for three selected communities within the Region representing a range of community sizes. Data on water use and utility operation and maintenance costs for the three selected communities were collated from the year 2005 annual reports published by the Wisconsin Public Service Commission (PSC). The plans developed provide

Figure 22

CONCEPTUAL RELATIVITY OF WATER CONSERVATION PROGRAM COSTS AND SAVINGS



Source: SEWRPC.

estimates of conservation program costs, potential water savings, and avoided costs attendant to the implementation of each of three optional levels of water conservation programs developed for the three communities. The data collated and cost calculations developed for the three water conservation options are provided in Appendix B. The estimated cost data, water savings, and related avoided costs for these conservation programs are presented in Tables 35 and 36. These tables provide the information for base-level, intermediate-level, and advanced-level conservation programs. For each conservation program level, a range of estimated annual water savings, program costs, and avoided costs are provided, as shown in Table 35, and as summarized in Table 36.

Three levels of water conservation were assumed in the development of the example programs. Under the base-level program, it was assumed that: the ongoing water system efficiency measures would be continued; a public informational and educational program would be initiated; water bills would be redesigned to highlight water consumption and water conservation concepts; and a water conserving rate structure would be initiated for residential customers. Under the intermediate-level water conservation program, it was assumed that all of the base-level measures would be included, supplemented by a program to distribute plumbing fixture retrofitting kits and an outdoor watering ordinance would be implemented. Under the advanced-level water conservation, it was assumed that all of the intermediate-level measures would be included, supplemented by increased water system efficiency measures and toilet replacement rebate programs.

The data presented are related to water demands on an average annual daily basis. That measure was selected since it is most directly related to source sustainability and is the most common measure reported upon in the references used to develop data for this chapter. It is recognized that water conservation program impacts will also affect water demands during maximum use periods such as the maximum weekly or daily demand basis. Typically, the reduction levels due to water conservation programs that can be achieved during the maximum use

Table 35

ESTIMATED CONSERVATION PROGRAM COST DATA AND ATTENDANT WATER SAVINGS OF EXAMPLE CONSERVATION PLAN OPTIONS IN SOUTHEASTERN WISCONSIN

Community Population	Conservation Plan Level	Annual Water Savings				Annual Cost of Program		Cost of Program per 1,000 Gallons Saved		Net Annual Savings[a]			
		Low		High						Low		High	
		Millions of Gallons per Year	Percent of Total Water Use	Millions of Gallons per Year	Percent of Total Water Use	Low	High	Low	High	Savings	Percent of Total Budget	Savings	Percent of Total Budget
3,000	Low	1	2.0	2	4.8	$ 1,106	$ 1,106	$1.11	$0.46	$ -786	-0.2	$ -338	-0.1
	Intermediate	2	4.8	6	12.0	2,500	2,572	1.04	0.42	-1,732	-0.4	-620	-0.2
	Advanced	3	8.0	9	20.0	37,310	38,332	9.66	4.48	-36,262	-8.8	-35,596	-8.6
70,000	Low	105	3.8	258	9.4	$ 26,265	$ 26,265	$0.25	$0.10	$ 2,371	0.0	$ 43,962	0.7
	Intermediate	140	5.1	378	13.7	33,685	35,665	0.24	0.09	4,497	0.1	67,290	1.0
	Advanced	170	7.0	453	18.0	168,685	175,415	0.92	0.36	-118,503	-1.8	-43,210	-0.7
600,000	Low	1,125	2.8	2,780	7.0	$ 225,300	$ 225,300	$0.20	$0.08	$ -21,394	0.0	$278,575	0.5
	Intermediate	1,591	4.0	4,473	12.0	609,500	769,400	0.35	0.16	-291,769	-0.5	125,341	0.0
	Advanced	2,018	5.0	5,527	15.0	1,279,500	1,439,400	0.59	0.24	-884,375	-1.5	-353,622	-0.6

NOTES: Assumptions: Energy and chemical expenses for example community of 3,000 = $16,000 per year.
Energy and chemical expenses for example community of 70,000 = $750,000 per year.
Energy and chemical expenses for example community of 600,000 = $7,250,000 per year.

Water conservation measures included are focused on the residential water customers, excepting for rate structure modification, which applies to all customers. Savings due to avoided capital costs are not included because of the variability of such costs from community to community. For each community, factors such as the need for increased infrastructure, the location of new water sources, the number and size of wells that must be constructed, the cost of water that must be pumped from source waters outside community boundaries, etc., will vary greatly.

[a]*Annual savings are based on avoided chemical and energy cost savings associated with pumping and treating water, less the cost of the conservation program.*

Source: Ruekert & Mielke, Inc.

Table 36

AVERAGE COST DATA AND WATER SAVINGS OF EXAMPLE CONSERVATION PLAN OPTIONS IN SOUTHEASTERN WISCONSIN

Community Population	Conservation Plan Level	Average Annual Water Savings (millions of gallons per day)	Range of Percentage of Water Savings	Average Annual Cost of Program	Average Cost of Program per 1,000 Gallons Saved	Average Net Annual Savings[a]	
						Savings	Percent of Total Budget
3,000	Low	2	2-5	$ 1,106	$0.78	$ -562	-0.1
	Intermediate	4	5-12	2,536	0.73	-1,176	-0.3
	Advanced	6	8-20	37,821	7.07	-35,835	-8.7
70,000	Low	181	4-9	$ 26,265	$0.18	$ 23,167	0.4
	Intermediate	259	5-14	34,675	0.17	35,893	0.6
	Advanced	334	7-18	172,050	0.64	-87,857	-1.3
600,000	Low	1,953	3-7	$ 224,725	$0.14	$ 128,591	0.2
	Intermediate	3,345	4-12	689,450	0.25	-83,214	-0.1
	Advanced	4,085	5-15	1,359,450	0.41	-618,998	-1.1

NOTES: Assumptions: Energy and chemical expenses for example community of 3,000 = $16,000 per year.
Energy and chemical expenses for example community of 70,000 = $750,000 per year.
Energy and chemical expenses for example community of 600,000 = $7,250,000 per year.

Water conservation measures included are focused on the residential water customers, excepting for rate structure modification, which applies to all customers. Savings due to avoided capital costs are not included because of the variability of such costs community to community. For each community, factors such as the need for increased infrastructure, the location of new water sources, the number and size of wells that must be constructed, the cost of water that must be pumped from source waters outside community boundaries, etc., will vary greatly.

[a]*Annual savings are based on avoided chemical and energy costs associated with pumping and treating water less the cost of the conservation plan.*

Source: Ruekert-Mielke, Inc.

periods will be somewhat higher than the reduction levels determined on an average annual daily basis to the extent that outdoor water uses contribute to the maximum use periods and water conservation measures are designed to reduce outdoor water use. Such maximum use period water conservation impacts may be important in considering future infrastructure needs. Maximum water demands on a peak hourly or shorter time frame basis may not be impacted by water conservation measures as such demands are typically governed by factors such as fire fighting needs.

Review of Tables 35 and 36 indicates that the savings in water use attendant to water conservation program options may range from less than 5 percent to over 10 percent of the average daily water use, depending upon the level of conservation program developed and the community water use profile. If water conservation is effectively achieved by the industrial, commercial, and institutional water users concerned, a reduction in average daily total water use of from 10 to 20 percent may be achievable with a high-level program. In this regard, it should be noted that all of the utilities operating within the Southeastern Wisconsin Region already engage in some water conservation practices. Those practices often include billing based upon metered water use, leak detection and correction programs, some outdoor water use restrictions, and water main maintenance and replacement. Thus, the benefits of water conservation programs in terms of percent reduction in water use achieved may be expected to be less than could be expected if no such actions were currently being taken. It should be noted that the maximum use period water demand levels may be expected to be reduced by somewhat greater percentages than noted above if outdoor water use restrictions are incorporated into the water conservation program. Based upon the findings of the example water conservation plan options, the cost of implementing a base-level water conservation program, which may be expected to achieve about a 3 to 6 percent reduction in average daily water demand, may be expected to be offset by the direct savings in operation and maintenance costs associated with a reduced level of water production. The cost of implementing an advanced-level water conservation program, which may be expected to achieve a 10 percent reduction in average daily water demand, may be expected to exceed the direct savings in operation and maintenance costs. The cost of implementing an intermediate-level water conservation program, which may be expected to achieve from 5 to 10 percent reduction in average daily water demand, may or may not be offset by savings in operation and maintenance costs.

Even though the costs of water conservation programs may exceed the attendant savings in operational costs, there may be sound reasons to develop higher-level water conservation programs in cases where avoided capital costs and water supply sustainability are important factors. Water conservation programs may extend the useful life of municipal water supply and treatment facilities, and defer needed capital investment in increased capacity. Figure 23 conceptually illustrates how water conservation can affect the timing of capital facilities and assist in delaying infrastructure investments. In the example shown, a 20 percent reduction in the design maximum demand period would permit needed capacity expansion to be delayed by approximately seven years. The resultant cost savings to the utility are represented by the difference in the present value of the costs associated with providing the needed capacity expansion in 2027 instead of 2020. The capital required for expansion of an existing water utility can be significant. For example, if a community were required to obtain a new source of groundwater supply, the associated cost of drilling the well, installing a transmission pipeline, and constructing a new pump station facility may be expected to approximate $1 million. In situations where groundwater supplies are being depleted, however, the development of high-level water conservation programs may be warranted to promote sustainability of the source of supply.

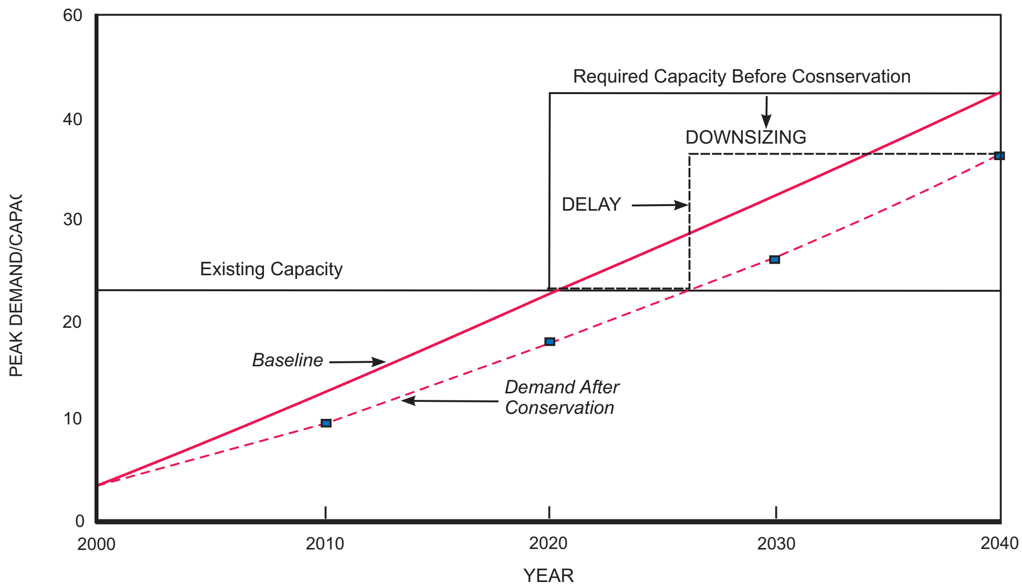
While the cost of water conservation programs can result in offsetting benefits, there are related potential impacts which also must be considered. As previously noted, the cost of the programs designed to achieve a relatively high level of water conservation may exceed the savings in costs associated with reduced water production. In addition, conservation program implementation goals may not be fully realized. If water conservation programs are successful, water rates may need to be increased, as in some cases, utility system savings may be expected to be less than revenue losses. In situations where water supply service areas are relatively fixed due to political or regulatory considerations, and where future infrastructure needs are minimal, an increase in water costs may be expected to be incurred by many users—particularly for those users who do not achieve a reduction in water use through conservation measures. Such users may include, among others, less affluent citizens who do not have the resources to retrofit older housing fixtures. The impact of high water bills on these customers may be significant. Conversely, the impacts of a higher water bill on more-affluent households maybe negligible. Such households may continue to use water as accustomed without regard to cost. Other concerns to be considered relate to the need for more water main flushing in certain segments of the transmission and distribution system to minimize retention times and maintain water quality. In addition, there may be impacts on the sanitary sewer system resulting from spent water flows inadequate to properly move solid materials through the system. These concerns must be addressed as each utility considers the development of a water conservation program.

Another issue related to the impacts of implementing water conservation programs relates to the potential impact on large water use customers. Should municipal utility water conservation measures which place financial burdens on such users as a result of required process changes or increased rates, such users may seek alternative sources of water supply. Such sources could include new private self-supplied groundwater wells at existing or alternative facility locations. Such opt out actions could reduce the municipal utility water demand and potentially further increase water rates accordingly. The potential impacts of new groundwater well development associated with such decisions may, in turn, include environmental as well as additional financial costs.

Based upon the foregoing, it may be concluded that through implementation of a water conservation program, it may be possible to achieve a reduction from 3 to 5 percent in average daily water demand, with no significant increase in cost over and above the resultant savings in operational costs. Water conservation programs designed to achieve water use reductions over and above those levels will likely result in increased annual operational costs. Thus, consideration of such programs should be based upon evaluation of the potential avoided capital costs and the sustainability of the water supply source. Such considerations must be made on a water utility-specific basis. For purposes of the regional water supply planning program, assumptions on the level of water conservation are planned to be initially generalized for purposes of projecting probable future demand and

Figure 23

EXAMPLE OF DELAYING AND/OR DOWNSIZING A CAPITAL FACILITY



Source: William Maddaus, et. al., "Integrating Conservation into Water Supply Planning," Journal American Water Works Association, *Volume 88, No. 11, 1996, pp. 57-67, and SEWRPC.*

formulating alternative system plans. The generalization is to be based upon existing and future infrastructure needs and water supply source sustainability considerations.

SUMMARY AND CONCLUSIONS

Water conservation has become an issue of increasing concern within the United States, especially in areas of increasing water scarcity. Increased efficiency in water use and reductions in demand have the potential to protect the natural resource base, reduce the cost to individual water users and water suppliers, and positively affect the reliability and sustainability of water supplies. This chapter provides information on water conservation programs and measures potentially applicable within the Southeastern Wisconsin Region. It is important to note that there are two views that can be taken of water conservation. One view focuses on achieving efficiency in utility operations by minimizing the amount of water that must be produced and conveyed to meet user demand, primarily through the reduction of unaccounted-for water. The attendant practices include metering and system performance monitoring, leak detection and repair, and system operational refinements. Water supply efficiency programs and measures are well established but are system-specific in application. Water efficiency programs are a very effective and direct water conservation measure. The other view of water conservation is focused on reducing the demand for water. The attendant practices, include water rate modifications to discourage use, use of water-saving plumbing features, water recycling, and educational activities.

These two views, or concepts, of water conservation will have quite different applicability within the Southeastern Wisconsin Region. In areas of the Region which utilize Lake Michigan as a source of supply, the concept of water conservation is focused primarily on increasing the efficiency of the water supply system and reducing the cost of water production, and may often be expected to constitute the more rational of the two approaches. For Lake Michigan supplied utilities, the water supply is abundant and the spent water is largely returned to the source. The focus, then, of the water conservation programs is on reducing unaccounted-for water as a part of the total system pumpage. This focus on system efficiency is further supported by the fact that some of the major water supply systems concerned are operating well below existing capacity, and the need to attract economic development to the core urbanized areas concerned by offering, among other inducements, an adequate water supply and attractive water rates. This approach provides water supply customers with the most favorable cost structure, an important consideration in the current era in which public officials are trying to minimize all municipal costs. However, in situations in which a Lake Michigan utility may be experiencing increasing demand that is approaching the existing infrastructure capacity, the second concept of reducing water use on the demand side will likely also have merit. In areas of the Region which utilize groundwater as a source of supply, considerations related to the sustainability of that source and infrastructure needs, may become the driving forces for the institution of water conservation programs designed to reduce use along with water system efficiency measures. A summary of measures which can be considered by utilities for inclusion in a water conservation plan is presented in Table 37.

The level of water conservation program to be developed and implemented will be utility- or community-specific based upon a number of factors, including the composition of the community water users, the operational characteristics of the utility, the level of efficiency already being achieved, the water supply infrastructure in place, that needed to meet future demands, and the sustainability of the water supply. Another factor which must be considered is the need to develop water conservation programs which are consistent with current and anticipated future rules, regulations, and policies. For example, consideration should be given to consistency with the proposed Great Lakes Charter Annex and the Wisconsin Groundwater Quantity Act and the related activities of the Groundwater Advisory Committee. Any water conservation program developed should be flexible and adaptable to the requirements of such rules, regulations, and policies. In addition, the design and implementation of conservation plans will vary significantly due to the large combinations of measures and programs that each utility or community may utilize. Similar considerations apply to self-supplied water users.

The state-of-the-art of water conservation conducted under the regional water supply planning program as presented in this Chapter indicates that, for the purposes of the regional water supply system planning program, the level of reduction in water demand that may be anticipated in the preparation of demand forecasts can best be varied categorically by utility situation. Design year water demands typically are forecast by consideration of the existing water demand levels, projection of additional incremental demand based upon application of unit demand levels to population and land use projections, and consideration of potential reductions in demand through water conservation programs. In the later consideration, the reduction values set forth in Table 38 can provide initial assumptions in the development of demand forecasts.

The potential reduction values set forth in Table 38 were developed based upon the information presented in this chapter, including, particularly, the results of the model conservation plans, the composition of the typical residential water use components as related to potential water conservation measures, and the documented example water conservation program results. The levels vary from 4 to 10 percent on an average daily demand basis, and 6 to 18 percent on a maximum daily basis, depending upon the type of utility water supply and existing infrastructure situation. It should be noted that the reduction in water use expected are anticipated as the result of implementing additional water conservation measures over and above those currently in place. The water utilities in the Region currently carry out some form of water conservation, primarily in the form of water supply efficiency programs. Such programs may include meter testing for accuracy, leak detection and repair, and replacement or repair of water mains with identified problems. As noted in Table 38, these ongoing programs have been assumed to have reduced current water use by 4 percent.

The initial water conservation levels selected are intended to be related to comprehensive water conservation programs, including both a supply side water supply system efficiency element and demand side water conservation measures. The selected levels are also intended to represent an increase in water conservation effectiveness over and above the current level which, as previously noted, is the result of a number of water efficiency and water conservation measures already in place at most municipal utilities in the Region. Thus, the selected levels may not appear as effective as would be the case in an area where no water conservation measures are in place. These initial water conservation assumption levels may be revised following the development and evaluation of the alternative plans if cost, environmental impact, or other factors relating to the achievement of plan objectives would so dictate. Such revisions in water conservation levels would then be incorporated into the recommended regional water supply plan.

Table 37

WATER CONSERVATION PROGRAM POTENTIAL COMPONENTS SUMMARY

Program Component	Potential Water Savings in Average Daily Total System Water Demand[a] (percent)	Estimated Annual Cost per Customer[b] Over a 10-Year Period	Comments
Water System Efficiency Actions	- -[c]	- -[c]	Actions can include meter testing for accuracy, leak detection and repair, water main maintenance and replacement, water system survey and audits, and water production system refinements. Some of these measures are in place in all communities in the Southeastern Wisconsin Region
Moderate-Level Public Informational and Educational Program	1-3	$1.50-$2.50	Includes redesign of water bill, collation and distribution of educational materials, utility staff training, and presentations to schools and civic groups
Higher-Level Public Informational and Educational Program	2-4[d]	$2.50-$3.50	Includes moderate-level program elements, plus development of school curriculum, and broader informational programming involving newspapers, website, and flyers
Outdoor Watering Restrictions	1-2[e]	$0.50->$2.00	Cost varies, depending upon level of enforcement envisioned
Plumbing Retrofits At No Cost to Customer	1-2[f]	$0.50-$1.00[f]	Includes low-volume shower heads and toilet displacement devices
Toilet Replacement Rebate Program	1-3[g]	$2.00-$3.00[g]	Toilet flush volumes: pre-1950 = 7.0 gallons; 1950-1979 = 5.0 gallons; 1980-1993 = 3.6 gallons; 1994 to present = 1.6 gallons Not allowed under 2006 PSC policies. Effectiveness may be limited at $100 rebate due to estimated cost of new toilet of about $100 and the cost of installation of about $150
Water Softener Replacement Rebate Program	<1-1[h]	$2.50-$3.50[h]	Not allowed under 2006 PSC policies. May be carried out for wastewater utility purposes. Effectiveness may be limited, due to modest rebate of $150 related to the cost of new softener of about $400 and the cost of installation of about $150. Has the added advantage of reducing chloride in wastewater
Clothes Washing Machine Replacement Rebate Program	1-3[i]	$3.00-$5.00[i]	Clothes washer water use per load: pre-1980 = 56 gallons; 1980-1990 = 51 gallons; 1990-present = 40 gallons for conventional; 27 gallons for high-efficiency Not allowed under 2006, PSC policies. Effectiveness may be limited, due to modest rebate of $200 related to the cost of new clothes washers of $700 or more
Water Conservation Rate Structure	2-4	$0.10-$0.20[j]	- -

Table 37 Footnotes

[a]*Potential water savings are estimated assuming a largely residential water use base. Water use savings for systems with large commercial, institutional, and industrial components will be variable.*

[b]*Cost estimated on a household residential equivalent unit basis.*

[c]*These component measures are utility-specific. Costs and effectiveness will vary with the extent of the current and past practices, condition and type of water supply system, and the current level of unaccounted-for water.*

[d]*Costs and effectiveness are total for program, including the elements in the moderate public informational and educational program.*

[e]*Effectiveness is presented in terms of annual average daily water demand. The effectiveness would be substantially higher on a maximum day or week basis.*

[f]*Cost data and effectiveness assumes 25 percent participation spread over a 10-year period.*

[g]*Cost data and effectiveness assumes 25 percent participation spread over a 10-year period. Rebate amount assumed to be $100.*

[h]*Cost data and effectiveness assumes 20 percent participation spread over a 10-year period. Rebate amount assumed to be $150.*

[i]*Cost data and effectiveness assumes 20 percent participation spread over a 10-year period. Rebate amount assumed to be $200.*

[j]*Cost data assumes a one-time contract cost spread over 10-years.*

Source: SEWRPC.

Table 38

PLANNED INITIAL ASSUMPTIONS CONCERNING EFFECTIVENESS OF WATER CONSERVATION PROGRAM LEVELS FOR USE IN ALTERNATIVE PLAN DEVELOPMENT FOR THE REGIONAL WATER SUPPLY SYSTEM PLANNING PROGRAM FOR SOUTHEASTERN WISCONSIN

Water Utility Category	Future Water Conservation Assumption Over and Above the Current Level[a]		Comments
	Average Daily Demand Reduction (percent)	Maximum Daily Demand Reduction (percent)	
• Lake Michigan Supply with Return of Spent Water • Adequate Water Supply Infrastructure in Place for 10 or More Years	4	6	• Assuming a current level of water conservation effectiveness of 4 percent,[b] these values would equate to total reduction level of 8 and 12 percent • Cost of water conservation program may be offset by savings in operational cost
• Lake Michigan Supply with Return of Spent Water • Some Water Supply Infrastructure Needs Expected During the Next 10 Years	4	10	• Assuming a current level of 4 percent,[b] these values would equate to total reduction levels of 8 and 14 percent • Cost of water conservation program may exceed savings in operating costs
• Groundwater Supply • Adequate Water Supply Infrastructure for 10 or More Years • No Major Aquifer Quality or Quantity Issues	6	12	• Assuming a current level of 4 percent,[b] these values would equate to total reduction levels of 10 to 16 percent • Cost of water conservation program is expected to exceed savings in operating costs
• Groundwater Supply • Major Infrastructure Needs Expected During the Next 10 Years • No Major Aquifer Quantity or Quality Problems	8	16	• Assuming a current level of water conservation effectiveness of 4 percent,[b] these values would equate to total reduction levels of 12 to 20 percent • Cost of the water conservation program will likely exceed the associated reduction in operational costs
• Groundwater Supply • Major Infrastructure Needs Expected During the Next 10 Years • Aquifer Quantity or Quality Problems	10	18	• Assuming a current level of water conservation effectiveness of 4 percent,[b] these values would equate to total reduction levels of 14 to 22 percent • Cost of the water conservation program will likely exceed the associated reduction in operational costs

[a] *Initial assumptions which may be revised following development and evaluation of water supply alternative plans if demonstrated as needed by cost, environmental impacts, or other factors related to the plan objectives.*

[b] *This level of water conservation is assumed to currently be carried out by the water utilities' water supply efficiency programs. Such programs may include meter testing for accuracy, leak detection and repair, and repair or replacement of water mains with identified problems.*

Source: SEWRPC.

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Chapter VIII

WATER TRANSMISSION AND STORAGE FACILITIES

INTRODUCTION

Once water is pumped from surface or groundwater sources, it needs to be delivered to the end user or consumers. The piping systems that deliver water to the consumer consist of two types of mains: distribution and transmission mains. Water transmission mains are those dedicated to carrying relatively large volumes of water at relatively high rates between sources of supply, storage facilities, and distribution mains. Water transmission mains are not intended as a means of delivering water to customers. Transmission mains may have individual service connections where there is no other economical or convenient system design to provide service to individual customers. Distribution mains are intended to be the primary method of providing water from transmission mains to the individual customers.

Water storage facilities are typically necessary for water system pressure maintenance, satisfying peak demands, normalizing pumping cycles, providing fire fighting storage, and meeting emergency situations, such as equipment and power failures. Storage can be provided by elevated, ground level, or below ground level facilities. The facilities concerned can be constructed of various materials, including steel, concrete, and other man-made materials.

COST ESTIMATION PROCEDURES

The costs of water transmission and distribution facilities are highly variable and dependent on market factors. In particular, the cost of polyvinyl chloride (PVC) pipe is very sensitive to variations in the price of petroleum, while the cost of ductile iron and steel pipe is sensitive to fluctuations in the steel market. The cost data presented in this chapter for pipelines are based upon past reports updated using an integrated Engineering News Record (ENR) cost index for the Chicago and Milwaukee areas, which stood at 9,563 in 2005, recent bid data from projects undertaken in southeastern Wisconsin, and consultations with suppliers and contractors. The costs of concrete water storage reservoirs was developed utilizing the 1990 U.S. Department of the Interior, Bureau of Reclamation data previously described in Chapter III. Those data were updated using the ENR index cited. Welded steel storage tanks, towers, and standpipe costs were developed utilizing recent bid data and information supplied by major steel suppliers and facility construction contractors.

WATER TRANSMISSION AND DISTRIBUTION

The facilities that bring water from supply sources to storage facilities and to end water users comprise the water transmission and distribution systems. These systems consist of valves, fittings, thrust restraints, pipes, hydrants, and miscellaneous appurtenances. The transmission system is that part of the water system which carries water from the source to distribution mains. The distribution piping system distributes water to the various individual users.

Planning and Policy
Sizing of all water system components, in particular water transmission mains, begins with the establishment of system-level planning and management policies. The service area policy of a water utility defines the geographic boundaries to which water service will be supplied. The projected boundaries of service, which are coupled with a desired level of service, dictate the location and size of transmission and distribution facilities. The future service area of a utility should be set forth in an adopted system plan, the preparation of which should include the hydraulic analyses of the supply, storage, transmission, and distribution system utilizing performance simulation modeling. Such modeling should be used to identify any deficiencies in the ability of the existing system to serve current needs at the desired level of service, to identify system improvements needed to serve forecast demands at a desired level of service, to consider alternative improvements, and to set forth a system plan for adoption. Chapter IX includes a description of the simulation models available for such needed system analyses. The system modeling and analyses are typically focused on needed improvements to the existing facilities. If a utility is at, or near, its maximum size due to a political policy of nonexpansion, source limitations, or other considerations, the efforts are likely to be focused on system maintenance, maximizing the use of existing facilities, and improving efficiencies of operation.

The level of service provided by a utility refers to the reliability and adequacy of the water service provided to customers. It is the general goal of all utilities to provide a safe, reliable supply of water at a reasonable cost. A reasonable level of service includes provisions for adequate pressure, fire protection, and reliability of supply. Standards by which water systems are designed are described in Chapter IX.

Design Criteria
In addition to the recommendations provided in Chapter IX, certain industry standard design criteria should be used in the planning and design of transmission and distribution mains. These criteria relate to the delineation of pressure zones, pipe sizing, and valve sizing. The detailed design of the facilities concerned is highly site-specific. The information presented herein is intended to provide a framework for developing improvement costs at the systems planning level associated with the installation of piping and storage systems. In this respect, it should be recognized that there is great variation in design practices between utilities and between engineers. The information herein presented is intended to facilitate the preparation and comparative analysis of alternative system-level plans.

Pressure Zones
Water system pressure is an important consideration in water system design, operation, and maintenance. Maximum pressure limitations are desirable to minimize leakage and power costs and to protect private plumbing systems. Minimum pressures are needed for properly operating appliances and water fixtures. Minimizing pressure fluctuations in a distribution system is desirable for customer reliability and the protection of public health.

Engineering standards for minimum and maximum pressures are presented in Chapter IX, with the range being 35 pounds per square inch (psi) to 100 psi. The system pressures concerned are expressed in terms of a hydraulic grade line, that is defined as the height above a reference datum that water would rise in piezometers connected to the piping system under static conditions for the service area that a water storage facility, pumping station, or pressure regulating valve serves. This hydraulic grade line is then expressed as feet above a particular datum. The datum used within the southeastern Wisconsin Region should be National Geodetic Vertical Datum of 1929 (NGVD 29), in order for the analysis to be related to the available large-scale topographic maps needed for system planning and design. The hydraulic grade lines associated with service pressures of 35 psi and 100 psi are equivalent to about 81 and 231 feet, respectively. Therefore, the highest elevation a pressure zone can serve is 81 feet below the lowest hydraulic grade line normally experienced in that zone. Conversely, the lowest elevation a pressure zone can serve is 231 feet below the highest hydraulic grade line normally experienced in a pressure zone. The maximum change in elevation across a pressure zone is determined by the difference between the two values.

In some cases natural or political boundaries may set pressure zone limits. Pipe crossings of highways, railways, rivers, wetlands, or other natural features are costly and may determine pressure zone delineations. City, village, town, or other political boundaries may limit system development, particularly, if alternative water supply systems are available. Some metropolitan areas have major water suppliers that can provide either retail or wholesale service to other water utilities. In these cases, pressure zones may extend beyond political boundaries.

In areas with hilly topography, it is common to have small areas on hilltops that must be served by an individual pressure zone, if pressures in other parts of the system are not to exceed 100 psi. In these areas, booster pumping stations may be required to serve a small number of customers. These small areas must be identified on a site-specific basis during detailed design, and are not considered in the system-level of planning herein considered.

Pipeline Sizing

Pipelines must be sized to meet peak flow conditions. Peak flow conditions usually occur during maximum hour demands, or when storage facilities are being refilled from remote sources of supply. Pipelines need to be sized to carry water without excessive pressure losses. Therefore, pipe sizing should be based upon engineering standards for acceptable velocity head loss related to standard pipe sizes. The use of standard pipe sizes allows a utility to limit the inventory of pipes, valves, fittings and appurtenances that need to be in stock.

In many cases the distinction that is made in the definition of transmission mains versus distribution mains is a function of the size of the water system itself. In a small system, a pipeline 12 inches in diameter may be considered to be a transmission main if it is the largest main in the system. In a larger system, a 12-inch-diameter pipeline may be considered a distribution main. Thus, this distinction will vary from system-to-system, and the actual function of the mains in the system is more important than the size in determining what category a main falls under. Transmission mains are larger pipelines that are intended to transport water longer distances, generally between major sources of supply and storage. Typical design criteria for maximum head loss in transmission mains is one to two feet of hydraulic head per 1,000 feet of pipe, using a Hazen-Williams Roughness Factor (C-Factor) of 130. Table 39 sets forth design capacities for transmission pipelines based upon this maximum head loss and C-Factor. Actual head loss calculation should, for design purposes, be based upon careful consideration of the roughness factor assigned based upon the pipe material and age of pipes, as described in Chapter IX.

Distribution mains are generally located in street rights-of-ways, and are directly connected to fire hydrants and customer service lines. Design criteria for distribution main sizing are based upon multiple factors, including standard pipe sizes, standard grid spacing of mains, fire flow requirements and head loss or velocity. In systems served by fire hydrants, standard pipe sizes for distribution mains include six-, eight-, 12-, 16- and 20-inch-diameters. In some cases utilities have used 10-, 14- and 18-inch-diameters, but most utilities no longer use these uncommon pipe sizes. Hydrants should have a six-inch barrel and valve main connection, with two, two-and-one-half-inch nozzles and one four-and-one-half-inch nozzle.

A standard grid of main spacing is often assumed at the system planning level to establish pipe sizes, particularly in areas where rectangular street patterns are common, such as in older urban areas. Figure 24 illustrates a standard grid spacing that provides adequate fire flows under varying demands and network configurations.

The primary factor influencing distribution pipe sizing is the fire flow requirement. Lower fire flow requirements in areas of single-family housing allow the use of smaller pipe diameters than do fire flow requirements in multi-family, commercial, or industrial areas. For example, a 700-foot-long, six-inch main with a static pressure of 42 psi will provide 1,000 gallons per minute (gpm) of fire flow at 20-psi residual pressure. The higher fire flows required in commercial and industrial areas will need eight-, 12- and 16-inch mains.

Table 39

PIPE DESIGN CAPACITY

Diameter (inches)	Capacity	
	Million Gallons per day (mgd)	Gallons per Minute (gpm)
12	1.3	903[a]
16	2.7	1,875[a]
20	4.2	2,917[b]
24	5.4	3,750
30	9.7	6,736
36	15.7	10,903
42	23.5	16,319
48	33.5	23,364
54	45.5	31,597
60	60.0	41,667
72	96.9	67,304
84	145.4	100,950
90	174.3	121,035
96	206.5	143,426
102	242.2	168,218
108	281.5	195,505

NOTE: Except as noted, values based upon C-value of 130, and head loss of one foot per 1,000 feet.

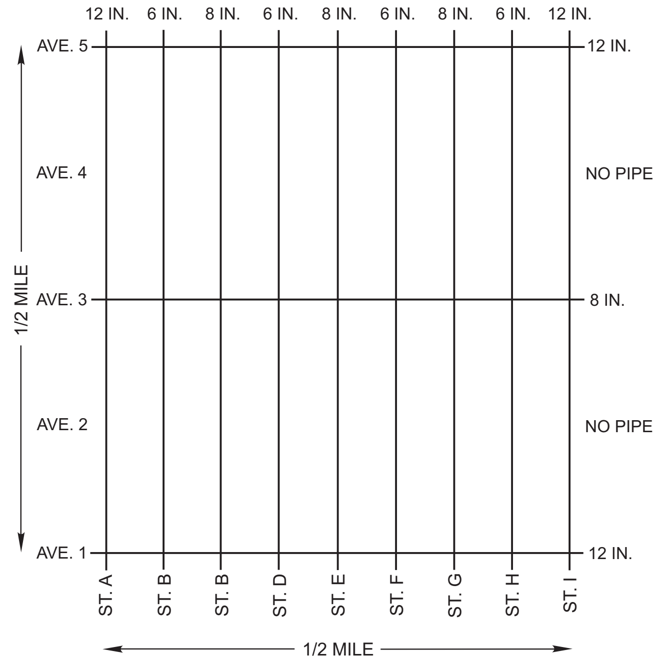
[a]*Head loss is two feet per 1,000 feet.*

[b]*Head loss is 1.5 foot per 1,000 feet and C-value is 120.*

Source: Williams and Hazen (1920).

Figure 24

SCHEMATIC OF SAMPLE STANDARD WATER MAIN GRID



NOTE: Based on Denver Water Department, 1991

Source: Lee Cesario, Modeling, Analysis, and Design of Water Distribution Systems, American Water Works Association, 1995.

Head loss and flow velocity are also sizing criteria. Some stringent design standards call for head losses of no more than two feet per 1,000 feet under peak hour flow conditions. A more widely accepted industry value of five feet per 1,000 feet under peak hour flow conditions is recommended for use in designing piping systems. Typically, distribution pipe sizes are based upon fire flow requirements rather than customer demands.

Valves

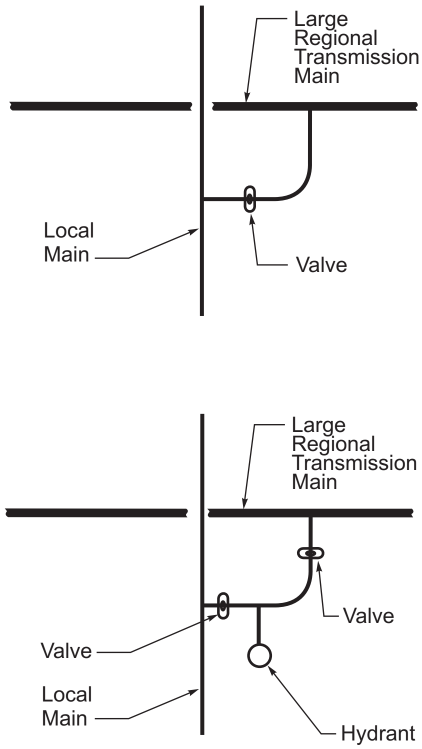
Three types of valves are used in most water systems: line valves, control valves, and pressure regulating valves. Common valve types and purposes are provided in Table 40.

Line valves are the most common and are used to isolate and shut down sections of the system during repairs or emergencies. Proper sizing and spacing of these valves is important, allows for ease of system operation, and minimizes the number of customers inconvenienced during repairs or emergencies. Line valves should be provided at every street intersection, with three or four valves at a pipe cross and two or three valves at a pipe tee, depending upon local practice and preference. There should also be a valve in the main between hydrant connections to minimize the number of hydrants out of service during a shut down, if other valves do not accomplish this goal. Valves in the distribution system should be the same nominal size as the main.

Valve spacing on transmission mains should not exceed one half mile. An example of proper hydrant and valve location at connections between transmission mains and distribution system mains is shown in Figure 25. Gate valves should be used on six-inch through 12-inch mains. Butterfly, or gate, valves should be used above 12 inches. Valves should be accessed through valve boxes up to 12-inch sizes, and through accessible vaults for 16-inch sizes and above. Valves larger than 16-inch diameter should be equipped with gears and a bypass valve. Procedures for entry into confined spaces, such as valve access vaults, should be governed by the appropriate Federal Occupational Safety and Health Administration (OSHA) and Wisconsin Department of Commerce codes. For larger valves, gearing should be used to facilitate valve operation.

Figure 25

CONNECTION OF LOCAL WATER DISTRIBUTION SYSTEMS TO LARGE REGIONAL TRANSMISSION MAINS



Source: SEWRPC.

Table 40

VALVE TYPES AND PURPOSES

Type	Purpose
Line Valve	Isolate flow
Control Valve	Control flow
Pressure-Reducing Valve	Control pressure (downstream)
Pressure-Sustaining Valve	Maintain pressure (upstream)
Pressure Relief Valve	Release pressure
Blow-Off Valve	Release flow

Source: American Water Works Association, 1995.

Control valves are used to control the flow of water in a system. Such valves may also affect pressure and this must be considered in their use. Control valves are generally used in larger systems to control flow to storage facilities or to large subareas of the system. Control valves are sized based upon the desired flow rates. The maximum allowable velocity through a control valve should be 15 feet per second (ft/s). Common control valve styles are butterfly, cone, and ball.

Pressure regulating valves are either pressure reducing or pressure sustaining. In areas of the system that are lower in elevation than other parts of the system, and that would, therefore, have a hydraulic grade line higher than desired, pressure-reducing valves are used to reduce pressure to acceptable levels. Pressure sustaining valves are used to maintain a hydraulic grade line on the upstream side of the valve. Design considerations for pressure regulating valves include the desired maximum and minimum flows, the pressure drop across the valve, and the water velocity through the valve. The use of pressure regulating valves should be minimized due to the maintenance requirements associated with such valves. Table 41 provides guidance on flow rates versus valve size for pressure regulating valves.

Hydrants

As already noted, fire hydrants should have a six-inch-diameter barrel and a six-inch valved main connector, two, two-and-one-half-inch nozzles, and one four-and-one-half-inch nozzle. Individual utilities may have different requirements based upon fire department policies. Hydrants should be located at every street intersection and at intermediate points between intersections so that the spacing does not exceed a maximum of 600 feet, and generally is between 300 and 400 feet. Hydrants should be dry barrel style and be equipped with drains. Auxiliary valves should be installed on all hydrants. Hydrants should meet American Water Works Association (AWWA) standards.

Summary

A summary of transmission and distribution system design criteria is provided in Table 42.

Other Design Considerations

Other concerns when sizing water system piping include water quality, looping, location in right-of-way, depth of cover, and pipe material. Water quality is emerging as a major concern for many utilities. Water retention times in the water distribution system can affect water quality. Based upon a survey of 800 utilities, an AWWA

Table 41

VALVE SIZES AND FLOW RATES FOR PARTICULAR SIZES OF PRESSURE REGULATING VALVES

Valve Size (inches)	Minimum Flow (gpm)	Maximum Flow (gpm)
1.5	0	60
2.0	0	160
2.5	0	240
3.0	0	350
4.0	20	600
6.0	40	1,200
8.0	50	2,300
10.0	100	3,600
12.0	200	5,100
14.0	250	7,500
16.0	300	9,500
18.0	400	12,000
20.0	500	14,000
24.0	600	22,000
30.0	1,000	33,000

NOTE: Values in this table are intended to provide a flow velocity of 15 feet per second.

Source: Ross Valve Manufacturing Company.

publication[1] reported an average distribution system retention time of 1.3 days, with a maximum retention time of 3.0 days. Examples of much longer retention times in portions of water supply systems have been reported. Water retention time is a function of primarily water demand, system operation, and system design. Water conservation, particularly the use of reclaimed water onsite, or through separate distribution systems, will tend toward longer retention times when all other factors are held constant. Water quality can change as it moves between sources of supply and treatment to the consumer. Bacteriological changes in the system can cause taste-and-odor, discoloration, slime growths, and economic problems due to corrosion and bio-deterioration. Significant decreases in the disinfectant content, and increases in disinfectant by-product formation, can also occur. Corrosion control effectiveness can also be decreased. Water quality models can be used to trace the movement of any potential contaminant in the system. The models also can predict the age of water at a given location in the system under dynamic conditions. If water quality issues are expected or experienced a water quality model should be employed to assist in determining necessary remedial actions.

Water quality can also deteriorate on dead-end water mains serving cul-de-sac streets, at the end of systems, or at pressure zone boundaries. Looping of mains provides supply to a single point in the system through two or more pipes. Looping can be employed to increase system water quality, flow, firefighting capabilities, and reliability. Illustrations of a looped and unlooped system are provided in Figure 26.

Water demand planning requirements for fire protection flows often govern water main sizing. The resultant sizing is often larger than needed to meet customer demands. This sizing consideration can contribute to water quality problems due to longer-than-desirable residence times in vulnerable portions of the water supply system. As noted above, water main looping is one method of mitigating such water quality problems. Other options include periodic flushing and the use of dual water mains in selected situations, whereby a smaller diameter main for typical customer demands is placed in parallel with a larger main designed for firefighting. The flushing option has the disadvantage of increasing water use.

When designing mains, consideration must be given to the amount of space needed for installation and future maintenance. Space is not generally an issue if the main is installed in the street right-of-way. In locations outside of street rights-of-way, easements must be obtained. The American Society of Civil Engineers Manual of Engineering Practice No. 14, "Location of Underground Utilities" sets forth recommended horizontal and vertical locations of water mains in street cross sections. A typical cross section for a land access street is shown in Figure 27. Mains should be constructed to plans and profiles, the later being properly related to established street grades. Good practice requires a minimum depth of cover for mains that place the tops of the mains below the expected frost depth. Good practice also requires a minimum vertical separation of six inches when water mains are located over sanitary sewers; and of 18 inches when water mains are located below sanitary sewers, the separation distances being based upon outside pipe diameter. The minimum horizontal separation between water

[1] *American Water Works Association and American Water Works Association Research Foundation,* Water Industry Data Base: Utility Profiles*, 1992.*

Table 42

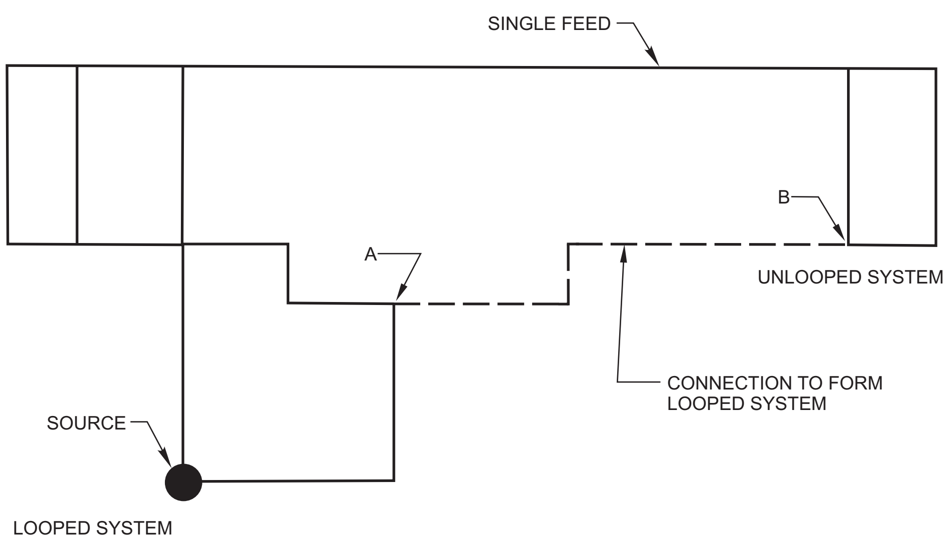
WATER TRANSMISSION AND DISTRIBUTION SYSTEM DESIGN CRITERIA SUMMARY

Transmission Pipelines	Line Valves in Transmission Pipelines	Distribution Pipelines	Hydrants	Line Valves in Distribution Pipe	Pressure-Regulating Valves
• Must be sized to handle maximum-hour flow • Common sizes: 20-, 24-, 30-, 36-, 42-, 48-, 54-, 60-, 66-, 72-, 78-inch-diameter and higher • Allowable head loss: one to two feet per 1,000 feet	Sizing • Up to two times smaller than pipe Spacing • Generally 2,640 feet apart	• Must be sized to handle the largest of maximum-hour flow, maximum-day flow plus fire flow, or replenishment flow rate • Common sizes: four-, six-, eight-, 12-, 16-, 18-, 20-inch-diameter • Allowable head loss: two to five feet per 1,000 feet • Allowable velocity: about five feet per second	• Two, two-and-one-half-inch nozzles • One, four-and-one-half-inch nozzle • Six-inch dry barrel • Drain • Auxiliary valve	Sizing • Generally same size as pipe Spacing • Between each hydrant • Three or four at a cross intersection • Two or three at a tee intersection	• Must allow maximum-hour flow • Allowable velocity: 15 to 20 feet per second • Probable minimum flow feasible: about 10 percent of maximum flow

Source: Adapted from Lee Cesario, Modeling, Analysis, and Design of Water Distribution Systems, *American Water Works Association, 1995.*

Figure 26

SCHEMATIC OF SAMPLE LOOPED AND UNLOOPED SYSTEMS



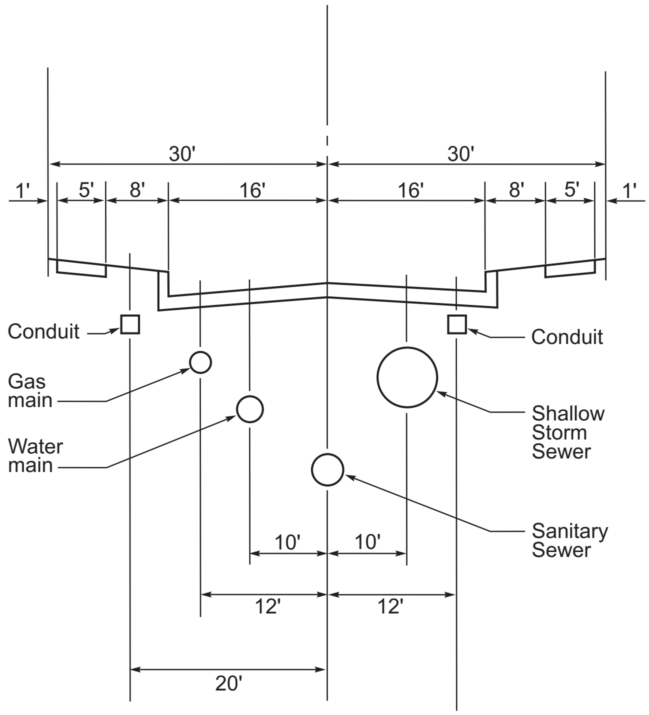
NOTE: Adding a main from Point A to Point B will "loop" the unlooped system.

Source: Lee Cesario, Modeling, Analysis, and Design of Water Distribution Systems*, American Water Works Association, 1995.*

mains and sanitary and storm sewers should be eight feet center to center. The provision of dual water mains may be cost-effective in certain situations, such as in arterial streets and in boulevards having wide rights-of-way and dual pavements. Consistency in the location of water mains and other underground utilities within the public street rights-of-way should be maintained throughout a utility service area. Careful attention should be paid to the design of connections between large regional water transmission mains and local distribution systems. Some examples of such connections are provided in Figure 25.

Figure 27

RECOMMENDED UNDERGROUND UTILITY LOCATIONS–LAND ACCESS STREET



Source: SEWRPC.

Chapter NR 811, Subchapter XI, "Distribution Systems," of the *Wisconsin Administrative Code* regulates the design of water distribution systems located in street rights-of-way or easements. Specific requirements related to materials of construction, separation requirements, depth of cover, surface water and other crossings, construction in contaminated soils or water, and water loading stations in NR 811 are provided in Table 43.

In highly urbanized areas, the use of utility tunnels can be a viable option in higher-density development areas, especially in campus-type settings for land uses, such as hospitals and school systems. Such tunnels typically can be used to carry utilities, such as steam, chilled water, communication duct banks, as well as domestic water. Such tunnels exist in the City of Milwaukee and in some other areas of the United States and in other countries. The advantages of such tunnels are primarily accessibility, maintenance, and monitoring and potential reduced deterioration. The primary disadvantage is the initial cost.

Pipe materials commonly used in southeastern Wisconsin include ductile iron and polyvinyl chloride (PVC). Concrete pressure pipe may be used in some larger systems. Ductile iron pipe should be cement lined to avoid excessive tuberculation or scaling, with attendant loss of flow capacity. For areas requiring directional drilling, high-density polyethylene (HDPE) pipe is common. Each utility will have its own preferences for type of materials. Some advantages to use of PVC pipe include its light weight in smaller diameters, and its smoothness and high C-Value. Disadvantages include lack of electric conductivity for locating, and lack of sound transmission for leak locating. Ductile iron pipe is stronger than PVC pipe, but it is also more prone to corrosion. Each pipe application should be reviewed for proper material specification and application.

Costs

Table 44 provides cost data for open cut installation of ductile iron and PVC pipe up to 36 inches in diameter. The table also includes common appurtenance costs. For sizes, construction methods, and materials not listed, individual project cost estimates will be required.

STORAGE RESERVOIRS

Supply sources, such as wells or treatment plants, operate best at steady design rates over relatively lengthy periods of time. However, demand in the system will constantly fluctuate. Most water systems experience short-term events, during which the rate of demand exceeds the available rate of supply. During such periods, water stored to meet the deficiency must be drawn upon. Examples include heavy demands due to water main breaks, water demand for firefighting, and residential lawn watering during periods of hot, dry weather. During events when the rate of demand for water temporarily exceeds the available rate of supply, reducing storage makes up the shortfall. Since storage volume is finite, such reduction cannot continue indefinitely.

Storage structures can be elevated, ground level, or underground structures that serve as suction sources for pumps. Elevated tanks, though more expensive, are desirable because of their reliability in meeting short-duration, high-demand rates through gravity flow. While a pump has a definite maximum flow rate, only the

Table 43

WATER MAIN DESIGN CONSIDERATIONS AND REQUIREMENTS

Item	Code Requirements	Standard Reference	Other Recommendations
Materials of Water Mains	Cast iron, ductile iron, steel, reinforced concrete, PVC, copper or other approved by Department	AWWA Minimum 150 psi pressure class	Polyethylene for directionally drilled pipe
Joints	Load free gaskets, elastommic for PVC	AWWA	- -
Valves	Spacing maximum 500-foot intervals commercial, 800-foot other	AWWA	- -
Hydrants	Spacing 350 feet to 600 feet and at each intersection auxiliary valves required for transmission and commercial areas	AWWA	- -
Water/Sewer Separation	Horizontal – Eight feet, except in rock were exceptions are allowed	NR 811	- -
	Vertical – Water main minimum six inches above the top of sewer or minimum 18 inches below bottom of sewer	NR 811	- -
Exception in Rock	Water main minimum 18 inches above top of sewer, with minimum three-foot horizontal separation and rock profile shown on plans	NR 811	- -
Other Exceptions	Construct gravity sewer with water main standard construction where eight-foot horizontal separation impossible	NR 811, AWWA	- -
Other Separations	Eight feet to septic tank, drain field, lift station, grave 20 feet to buried fuel tank 50 feet to sanitary landfill Case-by-case for contaminated soils	NR 811	- - Special gaskets may be needed
Surface Water Crossings	Two feet cover underwater For crossings 15 feet or longer – Flexible, water tight joints – Valves at both ends in vaults with testing taps on both sides of valve	NR 811	- -
Common Casing Crossings	For sewer/water in common casing under highway, railroad Sewers with water main standard construction – Water main six inches above sewer – Normal separation distances at each end – Force mains inside additional casing	 AWWA NR 811	- -
Water Loading Stations	No backflow to water system	NR 811	- -
Water Main Location	In rights-of-way or easements	NR 811	Consistent location in gridded streets, usually north and east side[a] Out of paved areas where possible[a] Use dual water mains on Boulevards or large streets where it is cost effective
Water Main Depth	Five to seven feet of cover	NR 811	Below frost line. In some cases, water mains with shallow cover may be insulated, as needed, to meet site-specific conditions
Water Main Construction in Contaminated Soil or Groundwater	Approval only given on a case-by-case basis	NR 811	Special pipe, joint, and other requirements may apply

[a]*American Water Works Association, Water Distribution Operator Training Handbook, 2005.*

Source: Ruekert & Mielke, Inc.

Table 44

OPEN CUT WATER MAIN AND APPURTENANCES CONSTRUCTION COSTS

Water Mains				
	Ductile Iron[a] Cost (LF)		Plastic[a] Cost (LF)	
Item	Gravel Backfill	Spoil Backfill	Gravel Backfill	Spoil Backfill
6-inch	$ 49	$ 43	$ 46	$ 40
8-inch	58	53	55	50
10-inch	79	72	75	68
12-inch	97	89	92	84
16-inch	120	106	110	98
20-inch	130	113	118	104
24-inch	140	123	135	110
30-inch	185	165	185	165
36-inch	220	195	220	195

Water Main Valves		
Item	Valve Box (each)	Vault (each + valve)
6-inch	$ 650	- -
8-inch	850	- -
10-inch	1,000	- -
12-inch	1,400	$1,200
16-inch	2,000	1,500
20-inch	3,150	1,500
24-inch	4,800	1,500
30-inch	6,200	2,000
36-inch	8,000	2,300

Special Water Main Appurtenances	
Item	Cost
16-Inch Valve in Testing Manhole At Surface Water Crossing	$9,000
20-Inch Valve in Testing Manhole At Surface Water Crossing	9,500
Fire Hydrant–Two 2.5-Inch Nozzles	2,600
Fire Hydrant–Two 2.5-Inch Nozzles; One 4.5-Inch Nozzle	2,900
Fire Hydrant–One Pumper Nozzle	2,500
Air Relief Valve in Valve Boxes–Two Inches	1,000
Air Relief Valve in Valve Box–One Inch	450
Air Relief Valve in Vault	2,400

NOTES: Hydrant cost includes valve and 12 feet of six-inch main.

Cost data in this table are intended to be used to estimate construction costs. For system-level planning, it is recommended that an allowance of 35 percent be added to the estimated construction cost in order to estimate projects costs. As noted in Chapter IX, this allowance is intended to cover engineering, contingencies, legal, and administrative costs.

[a]*Costs do not include:*

- *Pavement. Add $24 per lineal foot for pavement*
- *Engineering*
- *Legal and Administration*
- *Rock Excavation*
- *Contingencies*
- *Casing Pipes (Add $200 per lineal foot)*
- *Directional Drilling (Trenchless)*
- *Erosion Controls*
- *Slurry. Add $150 per lineal foot*

Source: Ruekert/Mielke.

strength and capacity of the distribution system limits the rate at which an elevated tank can deliver water. Flow rates of 20,000 gpm and more are available at hydrants near elevated tanks. Elevated tanks are more reliable storage structures than reservoirs, which serve as a suction source for pumps because of the possibility of pump breakdown.

Elevated tanks also are desirable because they allow simple control of pumps in filling the tank. For most control systems, a device at the elevated tank measures the water level in the tank and transmits the level signal to a central control unit. The central control unit is programmed to turn on one or more pumps when the tank level drops to a set point level and to turn the pump, or pumps, off when the level rises to a higher set point level. Pumps may run for hours to raise the tank level to the shutoff set point. Running pumps continuously for long time periods is preferable to having pumps start and stop frequently to minimize power and maintenance costs.

The topography of a water service area is an important consideration in system design and type of storage facilities to be incorporated into a water supply system. In some cases, ground level or underground storage systems can be sited at higher elevations, allowing for gravity service to all or portions of a service area or pressure zone. Elevated storage tanks can also be located to take advantage of topographic features to reduce height requirements and provide wider pressure zone coverage.

Most community water systems should have at least one elevated tank. Two tanks are desirable to improve reliability and pump control during times when one tank is out of service for inspection, painting, or other maintenance. The height of an elevated tank determines the maximum water pressure available in the part of the distribution system connected to the tank. Evaluations considering larger-scale subregional water supply systems will often indicate the need for less overall storage than if evaluations are conducted on an individual, smaller community basis. Such evaluations on a subregional basis could also provide additional options for system interconnection.

It is important to note that all elevated storage volume is not necessarily usable in supplying normal system demands. The elevated storage volume available to supply demands other than fire flow is that which is contained in the top 30 feet, or the volume which can be used without lowering system pressures below the allowable minimum of 35 psi, whichever is less.

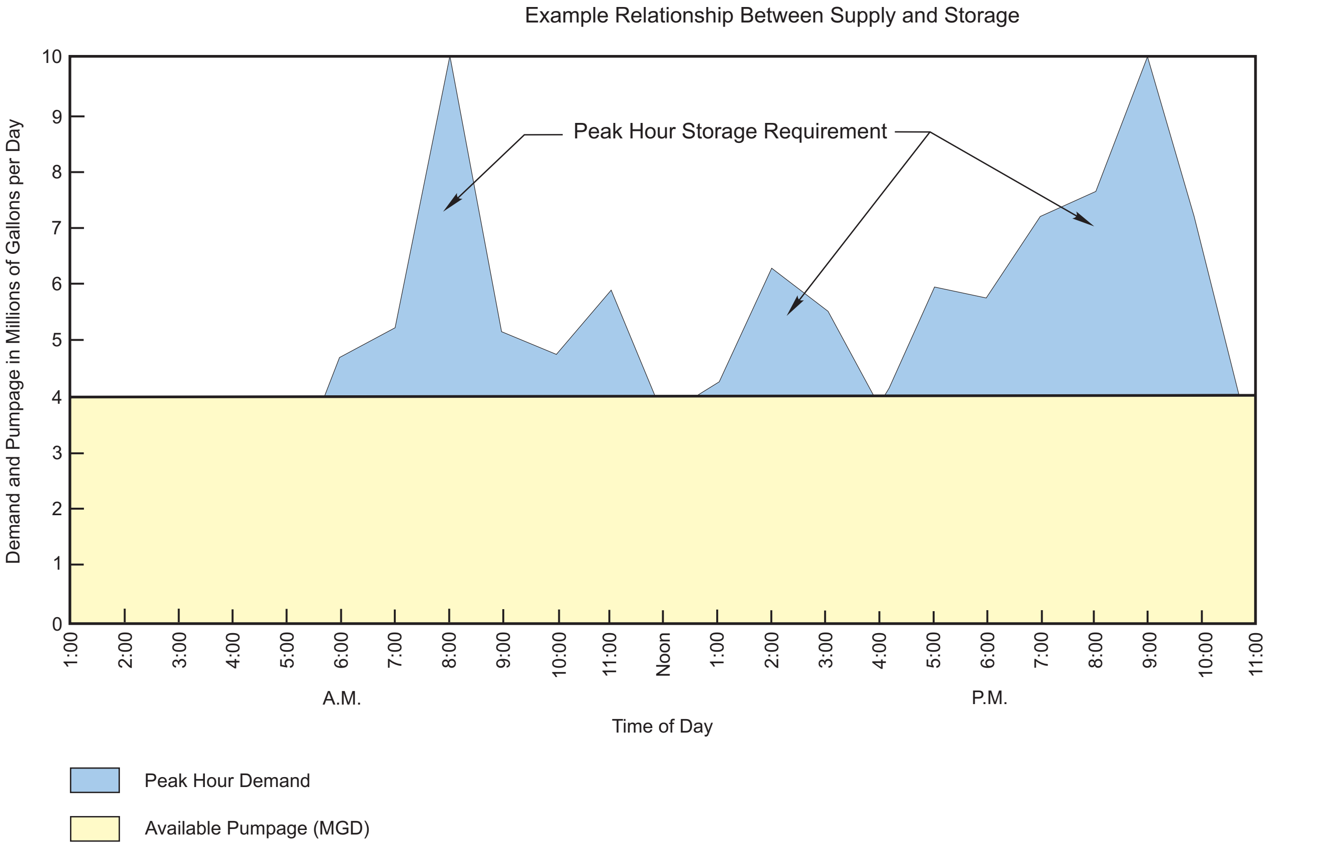
While the community water system could have all of its storage in elevated tanks, such practice may be excessively costly. Storage tanks that serve as suction sources for pumps can be used to provide a portion of the overall needed storage volume. These storage tanks normally are built at the site of a supply source. It is common to design a well pump station where the well pump discharges to an onsite reservoir. Treatment plants also commonly have large reservoirs to hold treated water. Service pumps draw water from the reservoir and discharge into the transmission and distribution system. The reservoir can be completely buried, partially buried, or completely above grade. It is desirable to have an onsite reservoir at each well to help solve potential water quality problems. Water discharged from wells often contains dissolved gases and silt or grit. If this water first goes to a reservoir, the gases will dissipate and the grit will settle to the reservoir bottom. Neither will reach the customer. Sites set aside for wells should be large enough to allow the construction of a reservoir in the future, should it become necessary.

The total amount of storage volume needed is dependent on the recommended fire flow volume, or by the amount by which the peak hour demand exceeds the available supply rate, whichever is greater. For smaller water service areas, the recommended fire flow rate and duration often is the more critical determinant of needed storage volume. The Commercial Risk Services Division of the Insurance Services Office (ISO) establishes recommended fire flow rates for a community. The ISO may evaluate even relatively small water systems based on the system’s ability to provide up to 3,500 gpm for three hours.

For larger water systems, the peak hour demand rate often determines the total recommended storage volume. Customer demand is not constant throughout the day. Figure 28 graphically illustrates how customer demand

Figure 28

EXAMPLE RELATIONSHIP BETWEEN SUPPLY AND STORAGE



NOTE: The indicated available pumpage supply capacity is the minimum reliable pumping capacity, which should be at least equal to the peak day pumpage.

Source: Ruekert/Mielke, Inc.

typically varies during the day. If it is assumed that Figure 28 indicates customer demand on a peak day, the volume represented by the demand above the maximum available supply rate must be made up by depleting storage. Historic data on peak hour demands may not always be available, as noted in Chapter X. Lacking historic data, the peak hour demand rate normally is estimated to be between one and one-half and two times the peak day demand rate.

Storage Costs

Table 45 contains costs for different size reservoirs and elevated storage facilities. Included are concrete, steel and composite structures. For volumes in excess of one million gallons for reservoirs, multiple cells of similar design should be used when estimating cost.

PUMPING SYSTEMS

Design and sizing of pumping stations involves determining the required pumping capacity and the required total dynamic head. Depending upon its relationship to other pumping and storage elements of the system, a pumping station is either sized to meet peak hour or peak day demands. In systems or pressure zones where storage is provided to satisfy peak hour demands, the pumping system need only provide the peak day demand rate. If little or no storage is provided, the pumping system must provide the peak hour demand rate. Additional pumps must be provided for fire flow when no storage or insufficient storage for fire demands is provided.

Table 45

WATER STORAGE FACILITY CONSTRUCTION COSTS

	Construction Material/Method					
	Concrete		Welded Steel			Composite
Volume (gallons)	Poured In-Place	Wire Wound[a] Prestressed	Reservoir[a]	Standpipe[b]	Elevated[c]	Elevated[c]
100,000	$ 120,000	- -	$ 70,000	$ 110,000	$ 220,000	$ 350,000
250,000	260,000	- -	17,000	$220,000	480,000	570,000
500,000	500,000	$ 620,000	270,000	$320,000	650,000	650,000
750,000	700,000	700,000	350,000	$450,000	1,200,000	1,100,000
1,000,000	900,000	800,000	550,000	$650,000	1,500,000	1,650,000
2,000,000	1,800,000	1,600,000	1,100,000	1,300,000	2,300,000	2,100,000
3,000,000	2,700,000	2,200,000	1,800,000	2,000,000	- -	- -

NOTES: Costs include construction of structure and standard appurtenances only.

Cost data in this table are intended to be used to estimate construction costs. For system-level planning, it is recommended that an allowance of 35 percent be added to the estimated construction cost in order to estimate projects costs. As noted in Chapter IX, this allowance is intended to cover engineering, contingencies, legal, and administrative costs.

[a]*Assumes 30-foot height.*

[b]*Assumes 80-foot height.*

[c]*Assumes 150-foot height.*

Source: Ruekert & Mielke, Inc.

Pump total dynamic head refers to the feet of head the pump must add to the system for it to reach a desired hydraulic grade line under operating conditions. The dynamic suction head is the vertical distance between the high water level on the suction side of the pump and the pump centerline, minus any friction loss. The dynamic discharge head is the vertical distance between the pump centerline and the high water level on the pump discharge side, plus friction losses. The difference between the two is the total dynamic head. Therefore, pumps are described by capacity and head.

Pump stations that pump to a single pressure zone have multiple pumps that pump at various rates, but have the same head. It is common practice to vary the speed of a pump using variable speed or frequency drive units. This allows a single pump to pump to the same head over a wider range of rates.

Booster pumps are used to increase pressure from one pipeline (suction) to another pipeline (discharge). These types of pumps generally have lower head requirements and use less energy than pumps that take suction from reservoirs.

Pumping Station Costs
Chapters III and IV include costs for surface water treatment finished water pumping facilities and well pumping facilities. Table 46 provides costs for use in evaluating booster or other pumping station costs.

SUMMARY

Water mains, storage facilities and pumping systems represent a high percentage of the cost of a water system. This chapter provides design criteria for use at the system planning level related to the sizing of transmission and distribution facilities, storage reservoirs, and water pumping stations. Costs to be used in the evaluation of alternative system plans are also provided. In some cases, facilities of significantly larger sizes may be required under the alternative plans. In those cases, case-specific estimates of probable cost will need to be developed.

Table 46

WATER PUMPING STATION CONSTRUCTION COSTS

Peak Pumping Capacity (MGD)	Type		
	Buried Can (steel)	Above Ground Prefabricated	Built in Place
0.1	$ 75,000	$200,000	$250,000
0.5	85,000	280,000	350,000
1.0	100,000	320,000	375,000
2.5	140,000	375,000	400,000
5.0	220,000	400,000	500,000
7.5	250,000	450,000	600,000
10.0	300,000	500,000	680,000

NOTES: Costs Include: Station, pumps and piping, controls, and emergency power.

Cost data in this table are intended to be used to estimate construction costs. For system-level planning, it is recommended that an allowance of 35 percent be added to the estimated construction cost in order to estimate projects capital costs. As noted in Chapter IX, this allowance is intended to cover engineering, contingencies, legal, and administrative costs.

Source: Ruekert & Mielke, Inc.

Chapter IX

DESIGN STANDARDS

INTRODUCTION

The overall objective of the state-of-the-art report is to provide the pertinent technical information required to prepare a sound water supply system plan for southeastern Wisconsin. Accordingly, this chapter sets forth pertinent planning and design standards for use in the development and evaluation of water supply system and facility plans. The information provided is intended to be useful in local, as well as regional, water supply system planning and design.

In the development of the standards set forth in this chapter, applicable State and Federal laws were reviewed and are referenced where appropriate. Other industry standards, including particularly those of the American Water Works Association (AWWA), were also reviewed and incorporated as appropriate. The standards herein presented are minimum standards which, when followed, should facilitate the planning and design of technically sound water supply systems in southeastern Wisconsin.

WATER SUPPLY SUSTAINABILITY ANALYSIS

Water supply sources have limits on their ability to sustain the demand placed upon them over time without potential unacceptable changes in the aquifer and its encompassing hydrologic environment. For surface water systems in the Southeastern Wisconsin Region, a source of supply sustainability evaluation has not been a major consideration, given the size of the resource compared to the uses, and given the return of most spent water to the source of supply. For groundwater supplied systems, a water supply source sustainability evaluation is an important part of the water supply planning process. As the demand for water from an aquifer increases, there is a possibility that it may exceed the ability of the aquifer to meet this demand without unacceptable changes, such as the decline in water tables. For this reason, sound water supply planning requires that the sustainable capacity of an aquifer be evaluated considering the projected water uses and demands and the management measures to be incorporated into the water supply system. Any use of groundwater theoretically reduces the amount of groundwater or its contribution to surface waters. Thus, the definition of the term "sustainability"[1] is a key consideration in any analyses directed toward achievement of "sustainability." Ideally, such an analysis should include an evaluation of groundwater-surface water impacts, as well as groundwater recharge and level maintenance.

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[1]*For purposes of the regional water supply planning program, sustainability has been defined in Chapter V of SEWRPC Planning Report No. 52,* A Regional Water Supply Plan for Southeastern Wisconsin, *as the beneficial use of water supply resources in such a way that those resources support the current and probable future needed uses, while simultaneously ensuring that the resources are not unacceptably damaged by such a beneficial use.*

The water supply source sustainability evaluation for groundwater supplied water supply systems can take many forms, all of which typically require information on existing and future water supply demands and the management measures expected to be used. In some local system planning, the sustainability evaluation may involve estimating the capacity of a proposed well with specified limitations for groundwater drawdown. In more complex system analyses, well pumping optimization analysis, system component linkages, and groundwater-surface water modeling analyses must be considered. For purposes of the regional water supply planning effort, the procedures followed included, first, the estimation of the current and future water supply demands generated by each of the planned urban service areas using design standards set forth in this chapter. Second, a number of alternative plans are designed to meet the identified water supply demands; again, using the design standards and related information included in this report. These alternative plans are to include management measures, including water conservation and groundwater recharge, as well as groundwater withdrawal provisions. In addition, the systems are to be designed and evaluated using a groundwater-surface water modeling analyses, including a well pumping optimization routine designed to minimize groundwater and surface water impacts. Each alternative plan will then be evaluated with regard to an agreed-upon set of plan objectives, principles, and standards under which, among other considerations, the impact on the groundwater system in terms of sustainability and the impacts on surface water impacts is evaluated. That alternative plan development and evaluation is described in Chapter VIII of SEWRPC Planning Report No. 52, *A Regional Water Supply Plan for Southeastern Wisconsin*. A recommended plan is then to be selected based upon a combination of the best features of the alternative plans, and which alternative best meets the plan objectives, principles, and standards. Should the analyses determine that there are subareas of the Region wherein impacts on groundwater sustainability or the surface water system, such as stream flows and lake levels, are unacceptable, recommendations directed toward land use development plans may be made.

This chapter is intended to provide guidance for developing forecasts of future water demands as the first step in the plan design process. The water supply demands associated with given land uses are, in fact, independent of the adequacy of the water supply. Only when such demands have been calculated from a land use plan, can consideration be given to alternative means of meeting those demands—or of modifying the land use plan. The findings of the supply adequacy and sustainability analyses attendant to the land use and alternative water supply plans are documented in Chapters VIII and IX of the aforenoted regional water supply plan report.

ENGINEERING DESIGN AND PLANNING STANDARDS FOR PUBLIC WATER SUPPLY FACILITIES

Water Demand

The development of water supply systems requires the long term investment of large amounts of capital. The facilities concerned have relatively long physical, as well as economic, lives. Therefore, water supply systems and facilities must be planned and designed to meet future, as well as existing, needs. Accordingly, forecasts of the probable future demand for water must be prepared as a basis for sizing future water supply, storage, transmission and distribution facilities. The preparation of water demand forecasts requires consideration of historic trends in water use, projection of water demands associated with planned future land use patterns, and assumptions regarding the impacts on demand of probable future regulations, programs, policies, and other influencing factors, including water conservation programs.

Forecasting future water demand can be accomplished in a number of ways, including development and application of per capita unit water demand factors, extrapolation of historic trends, and water demand modeling. The use of unit water demand factors for the various user categories is an effective method in areas like southeastern Wisconsin where good data bases on existing and historic water uses, on existing and historic land use patterns, and sound comprehensive land use planning are in place. That technique was selected for use in the regional water supply planning program for southeastern Wisconsin. The process to be followed involves the preparation of alternative projections of future socioeconomic and land use conditions and the selection of a forecast from among the alternative projections of those conditions, followed by conversion of these projections to water demand by application of unit demand factors. The water demand forecasts involve consideration of potential future resident population and household and employment levels, as well as future land use development patterns in the planning area. These socioeconomic projections and forecasts have been developed under the regional planning program to the plan design year of 2035.[2] As already noted, these socioeconomic and land use forecasts are then converted to water demands utilizing the unit water demand coefficients set forth in this chapter.

In order to assess the variations in demands between municipal water systems due to system age, land use development patterns, and demographics, a review of water use for the years 2000, 2004, and 2005 by community was performed. Water use data are reported on an annual basis to the Wisconsin Public Service Commission (PSC) by each regulated utility. Other public utilities, such as unregulated water trusts, report water pumpage in accordance with State requirements and may or may not meter actual usage. Water use data were reviewed for the years 2000, 2004, and 2005, with the year 2000 being the base year for the regional water supply planning program. Detailed population and household level and land use data are available for that base year. In addition, the water use data were reviewed for the last two years for which the data were available, as of mid-2006. Those years being 2004 and 2005. These two years presented a range of precipitation conditions, with 2004 having higher than average precipitation, and 2005 having lower than average precipitation, especially during the growing seasons, thus, placing the year 2000 data within a range.

Existing demands for regulated utilities are determined using recorded data for the base year—2000—and checked against data for more recent years to identify possibly anomalous situations. Once existing demand and pumpage patterns are established for systems, or groups of systems, unit demand factors can be calculated and applied to future development scenarios to obtain forecast future demand. Assumptions concerning potential reductions in demand due to conservation can be made and applied as alternate analyses dictate. The units of measure used in the analyses are listed in Table 47.

Existing annual usage is determined for each category listed in Table 47. The category of other urban demand is comprised of uses not tracked under the four specific user classifications. Unaccounted-for water is determined by subtracting metered—or other accounting system—from the total water pumped into the system. Water used in water production is estimated by subtracting water pumped into the distribution system from total water pumped.

It should be noted that there are a number of complex, interacting factors which can have significant impacts on water demand associated with each category of use, including population, household and employment levels, household sizes, household incomes, land use, climate, conservation programs, and costs of services. Thus, it must be recognized that long-range forecasting of water uses are inherently subject to variation. Sound water supply planning must take this into account and recommendations developed should be flexible and adaptable to potential changes in the factors affecting future demand.

Residential

Existing residential demand is first calculated on an annual basis. This annual demand is then divided by 365 to obtain average residential usage per day. Estimates are then made of the population of those households included in the residential reporting component. The total residential usage per day is then divided by the population to develop unit use coefficients expressed as gallons per person per day. The average daily residential usage can also be divided by the number of acres of residential use served to obtain gallons per acre per day use coefficients. In this regard, it should be noted that the residential water use reported to the PSC by the water utilities excludes water use by multiple-unit dwelling units which have a single meter serving three or more units. Those uses are included in commercial uses. To compute a residential demand factor, only the population associated with the reported water usage was used. This required the segregation of the population housed in one- and two-family housing units from the total population to estimate unit use factors. As previously noted, residential water use

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[2]*SEWRPC Planning Report No. 48,* A Regional Land Use Plan for Southeastern Wisconsin: 2035*, June 2006; SEWRPC Technical Report No. 10, 4th Edition,* The Economy of Southeastern Wisconsin*, July 2004; and SEWRPC Technical Report No. 11, 4th Edition,* The Population of Southeastern Wisconsin*, July 2004.*

Table 47

WATER DEMAND CATEGORIES AND TYPICAL UNITS OF MEASURE

Demand Category	Demand Expressed As
Residential	Gallons per person per day
Commercial	Gallons per acre per day
Industrial	Gallons per acre per day
Institutional	Gallons per acre per day
Other Urban	Gallons per acre per day
Unaccounted-For	Percent of Pumpage
Water Used in Water Supply Production	Percent of, or gallons per, 1,000 gallons produced

Source: Ruekert & Mielke, Inc.

over time is influenced by a number of factors, including the type of new residential development, household size and make up, household incomes, climate, level of water conservation achieved, and cost of service.

Commercial

Commercial usage does not have a population component associated with it. Therefore, commercial usage is expressed in terms of a per acre per day unit use factor. The use of a unit coefficient based upon water use per employee is an option, but employment may significantly fluctuate and good data by small geographic areas are difficult to obtain. As previously noted, the reporting practices used by the PSC and the water utilities include some multi-family residential water uses in the commercial water use category. In addition, institutional water uses are included in the commercial category. Thus, in order to estimate an applicable water demand factor on a per acre basis, land uses associated with multi-family residential and institutional land uses were combined with commercial land uses. The resulting area was then divided into the reported water use amounts. As previously noted, commercial water use over time is influenced by a number of factors, including the type of new development and redevelopment, economic conditions, technology, level of conservation, and cost of service.

Industrial

Industrial usage, as for commercial usage, does not have a direct relationship to population component associated with it. Therefore, industrial usage is expressed in terms of a per acre per day unit use coefficient basis. The use of a unit coefficient based on water use per employee is also an option. But, as for commercial usage, the employee levels may fluctuate widely by small geographic area and the necessary data are difficult to obtain. As previously noted, industrial water use over time is influenced by a number of factors, including the type of new development, changes in industrial users, economic conditions, technology, level of conservation, and cost of service. Changes in large water use industries can have a significant impact on water demands. Those industries which typically have relatively large water uses include breweries, bottling plants, paper mills, printing, foundries and metal fabricators, tanneries, industrial laundries, petroleum refining, and selected food processing.

Institutional

Although generally a small percentage of total usage, usage by schools, government buildings, and other institutions can be an important usage component for some systems. Large institutions or schools are one of the higher rate and volume users in some systems. Institutional usage is, like commercial and industrial usage, expressed on a per acre per day use factor basis. As previously noted, the institutional land water use factor was calculated as part of a water factor combining water uses from commercial, institutional, and some multi-family land uses. Also, as previously noted, water uses from institutional uses over time is influenced by a number of factors, including the type of new development and redevelopment, technology, level of conservation, and cost of service. Changes in large water use institutions can have a significant impact on water demands. Institutional uses which typically have relatively large water uses include hospitals, colleges, and universities.

Miscellaneous Municipal

The PSC records provide for an accounting of other urban usage, including unmetered water use. This unmetered use represents water used for firefighting, main flushing, main breaks, wastewater treatment, and other similar uses. When these other urban uses are added to the other use classifications, a total water accounting is obtained. This can then be compared to the total volume pumped into the system from wells or surface water sources, with the difference representing unaccounted-for water. Other urban uses are determined on a per acre of urban land per day unit factor basis.

Water Used in Water Supply Production

Water used in production and for miscellaneous uses prior to water being pumped into the distribution system is generally accounted for at water treatment facilities, and can be expressed in terms of total gallons used, or as a percentage of, or gallons per, 1,000 gallons of water produced. Historic rates are typically used to project future rates. This water use component is estimated as the difference between the total water pumped and the water pumped into the distribution system. In projecting future demands, however, potential changes in treatment methods and post-treatment recovery must be considered.

Unaccounted-for Water

Water that is metered, together with that which is not metered, but estimated, comprises the total customer "demand" for water. Unaccounted-for water may be defined as that water which is supplied by pumping facilities to the distribution system, but is not accounted for by metered or estimated delivery to users. This may include water which is delivered, but not metered due to meter inaccuracies, system leakage, unrecorded water main flushing, unaccounted-for losses associated with water main breaks or storage tank overflows, water theft, and unrecorded water use for firefighting. The amount of unaccounted-for water is an important consideration for water utilities since, to the extent that it can be minimized, it represents an opportunity for an effective reduction in water supply requirements.

Estimates of unaccounted-for water should be reviewed annually to determine the percentage of lost pumpage. The PSC regulations require that the estimated unaccounted-for water not exceed 25 percent of station pumpage for smaller utilities, and not more than 15 percent for larger utilities.[3] If unaccounted-for water is in excess of these percentages, a water audit should be performed by the utility. Water audits generally consist of leak detection activities for smaller utilities, and a combination of mathematical analyses, systemwide use monitoring, and leak detection activities for larger utilities. All utilities should routinely check water meters for accuracy in accordance with PSC regulations. Systems with ongoing leakage problems should have an annual leak detection program combined with an aggressive water main maintenance and replacement program. Ideally water utilities should strive for minimization of unaccounted-for water. Water systems with 10 to 15 percent unaccounted for water are generally considered to be performing well,[4] and distribution system losses of 10 to 20 percent are generally considered reasonable.[5]

Goals of 10 percent or less for unaccounted-for water are used in some areas of the United States. However, the most recent AWWA recommendations as of 2006, do not contain a specific standard for the percentage of water loss. The organization, instead, recommends that water utilities focus on providing efficient systems that minimize unaccounted-for water through leak detection and water main replacement programs in conjunction with cost control auditing.

Total Demand and Pumpage

The projected average daily demand is recommended to be calculated as the sum of the following:

- Residential average daily demand
- Commercial average daily demand
- Industrial average daily demand
- Institutional average daily demand
- Miscellaneous municipal uses

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[3]Wisconsin Administrative Code, *PSC 185.85 (4).*

[4]*L.M. Bennevelli,* Accounting for Unaccounted-for Water, *Four, NEWWA, 93:2:258-266, September 1978.*

[5]*C.W. Keller,* Analysis of Unaccounted-for Water, *Four, AWWA, 68:3:159-162, March 1976.*

- Unaccounted-for water
- Water used in water supply production

As part of the regional water supply planning program, data reported to the PSC by all of the utilities operating within the Region were collated and analyzed for the years 2000, 2004, and 2005. The data is summarized in Tables 48, 49, and 50, and Figures 29, 30, and 31. Based upon consideration of these data, and of industry standards, the unit water supply demand factors listed below were developed for use in the regional water supply planning program. The factors were applied to planned design year socioeconomic and land use conditions to project an incremental increase in average day demand. This incremental increase was then added to the known existing base year use to project total future demand. The Commission planning data base provided data on existing and planned design year 2035 land uses and attendant resident population, households, and employment by U.S. Public Land Survey section, and could be readily aggregated by quarter-section and section to provide projected and forecast data for planned urban service areas. The incremental water uses developed using the unit demand factors were then adjusted under future conditions for each of the alternative future plan conditions considered to reflect expected water conservation practices.

As can be seen by review of Tables 48, 49, and 50, there is generally a relatively consistent pattern of residential water uses between counties. Figures 29, 30, and 31 also indicate that residential water use is typically the largest singular category of water use in each county. There is variability between counties in the commercial, institutional, and multi-family, and the industrial use factors expressed on a per acre basis. This variability may be expected under existing land use conditions, given the various specific types of commercial, industrial, and institutional facilities occupying these land uses and the historic development and redevelopment patterns which exist. This variability may be expected to be reduced to some extent with respect to the new development expected to occur between 2000 and 2035. Such development is expected to comprise about 13 percent of the total year 2035 urban land uses within the Region; 87 percent being comprised of uses which existed in 2000. Given this, it is considered appropriated for regional planning purposes to consider a single set of water usage factors for estimating water usage for new development, computing such demand as an increment to be added to the metered demand exerted by the existing development. The forecasting of water use related to land use redevelopment is problematic, since such redevelopment is highly site-specific and occurs over time in response to market forces as modified by local planning. The design year 2035 regional land use plan, however, reflects redevelopment proposals known at the time of plan preparation, including the major redevelopment proposals for the central areas of the Cities of Kenosha and Racine; the central area redevelopment proposals for the City of Milwaukee—including the redevelopment of the abandoned Park Freeway East lands and the conversion of industrial uses in the peripheral areas to condominiums and apartment uses; the STH 45 corridor redevelopment in the Cities of Milwaukee and Wauwatosa; and the Menomonee Valley redevelopment in the City of Milwaukee. The following usage factors are recommended for regional planning purposes within the Southeastern Wisconsin Region:

- Residential land use, average daily demand—70 gallons per capita per day.
- 800 gallons per gross[6] acre per day.

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[6]*Gross acre area is defined as the actual site area—consisting of the ground floor site area occupied by buildings, plus the required onsite yards and parking and loading areas, together with supporting land uses, such as streets, neighborhood parks and playgrounds, elementary schools and neighborhood institutional and commercial uses. Gross area is intended to be used in considering the density and intensity of development over relatively large areas, such as neighborhood units and U.S. Public Land Survey system sections. Gross densities are in contrast to net densities, the later being based upon the areas within the actual site boundaries of the various land uses concerned.*

Table 48

WATER USE FACTORS WITHIN THE SOUTHEASTERN WISCONSIN REGION (AVERAGE YEAR 2000)

County	Residential Water Use[a]		Commercial, Institutional, and Multi-Family Residential[a]	Industrial Water Use	Miscellaneous Municipal Water Uses[b]	Total Municipal Water Use		Percent Unaccounted-for Water[e]
	Per Person[c] (gallons per capita per day)	Per Acre[c] (gallons per acre per day)	Per Acre (gallons per acre per day)	Per Acre (gallons per acre per day)	Per Acre (gallons per acre per day)	Per Person[d] (gallons per capita per day)	Per Acre (gallons per acre per day)	
Kenosha	61	836	836	2,416	62	99	642	12
Milwaukee	72	1,280	1,515	5,324	168	136	1,128	8
Ozaukee	66	581	425	4,163	57	123	543	12
Racine	63	832	829	7,483	152	156	1,010	12
Walworth..............	64	471	562	1,954	189	117	496	15
Washington..........	66	725	474	1,857	59	95	519	13
Waukesha............	64	507	653	1,248	50	106	464	11
Region Average	68	910	1,054	4,010	129	128	849	10

NOTE: Population and land use data utilized to develop this table are based on year 2000 U.S. Census Bureau and SEWRPC inventory data.

[a]*Residential category includes population associated with single-family and two-family housing units, plus some larger multi-family housing where individual water meters are used for each unit. Other multi-family units are included in the commercial water use category.*

[b]*Includes uses for fire protection services, sales to public authorities, sales to irrigation customers and interdepartmental sales.*

[c]*Reported residential water use excludes that associated with multiple-unit dwellings where a single meter serves three or more housing units. That water use is classified as commercial under the Public Service Commission of Wisconsin reporting system. The unit water uses presented on a per capita and per acre basis were calculated by adjusting the population and residential land area to be consistent with this reporting procedure.*

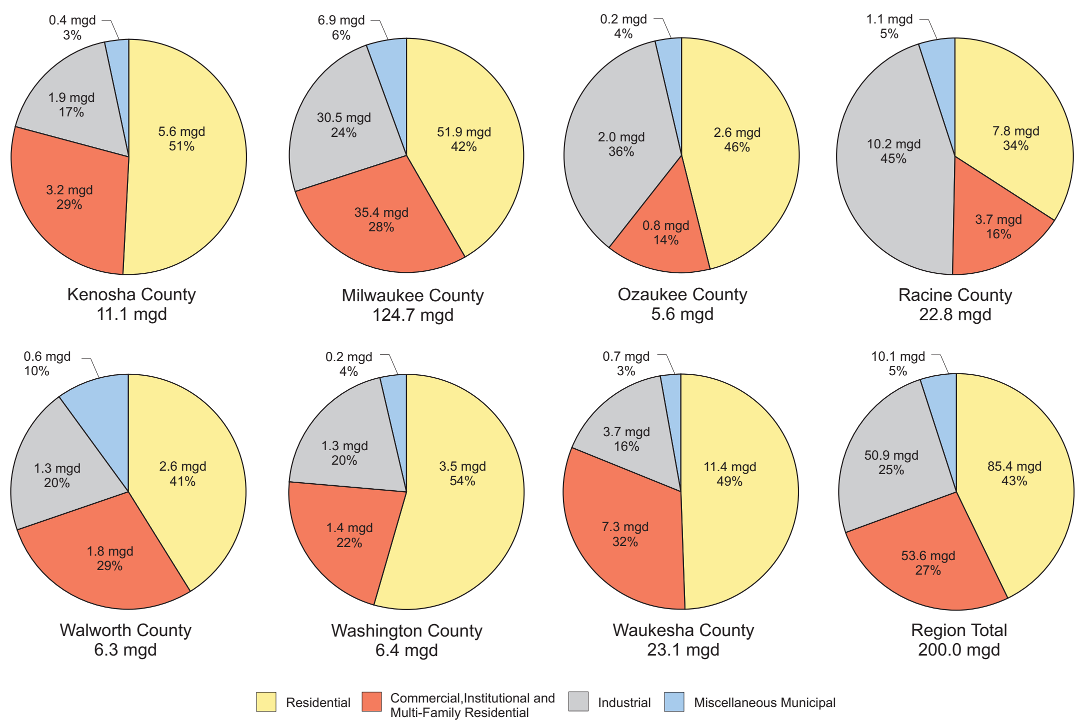
[d]*Estimated based upon total residential population served.*

[e]*Water not specifically accounted for as a percent of total pumpage.*

Source: Public Service Commission, water utilities, and SEWRPC.

Figure 29

TOTAL MUNICIPAL WATER USE BY COUNTY: 2000



NOTE: Water uses in this figure do not include estimates of unaccounted-for water.

Source: Public Service Commission, water utilities, and SEWRPC.

Table 49

WATER USE FACTORS WITHIN THE SOUTHEASTERN WISCONSIN REGION (AVERAGE YEAR 2004)

County	Residential Water Use[a]		Commercial, Institutional, Multi-Family Residential[a]	Industrial Water Use	Miscellaneous Municipal Water Uses[b]	Total Municipal Water Use		Percent Unaccounted-for Water
	Per Person[c] (gallons per capita per day)	Per Acre[c] (gallons per acre per day)	Per Acre (gallons per acre per day)	Per Acre (gallons per acre per day)	Per Acre (gallons per acre per day)	Per Person[d] (gallons per capita per day)	Per Acre (gallons per acre per day)	
Kenosha	61	826	860	2,007	68	95	630	12
Milwaukee	69	1,222	1,312	3,901	187	121	998	12
Ozaukee	67	553	523	3,660	46	117	537	12
Racine	62	818	818	6,331	148	146	931	14
Walworth	63	459	511	1,481	144	104	440	13
Washington	65	710	504	1,711	62	94	514	11
Waukesha	66	516	658	862	57	102	447	10
Region Average	67	873	959	3,049	136	117	767	12

NOTE: Population data utilized to develop this table are based upon year 2004 Wisconsin Department of Administration estimates. Land use data were approximated at the county level based upon the year 2000 SEWRPC data adjusted by the county change in population between 2000 and 2004.

[a] *Residential category includes population associated with single-family and two-family housing units, plus some larger multi-family housing where individual water meters are used for each unit. Other multi-family units are included in the commercial water use category.*

[b] *Includes uses for fire protection services, sales to public authorities, sales to irrigation customers and interdepartmental sales.*

[c] *Reported residential water use excludes that associated with multiple-unit dwellings where a single meter serves three or more housing units. That water use is classified as commercial under the Public Service Commission of Wisconsin reporting system. The unit water uses presented on a per capita and per acre basis were calculated by adjusting the population and residential land area to be consistent with this reporting procedure.*

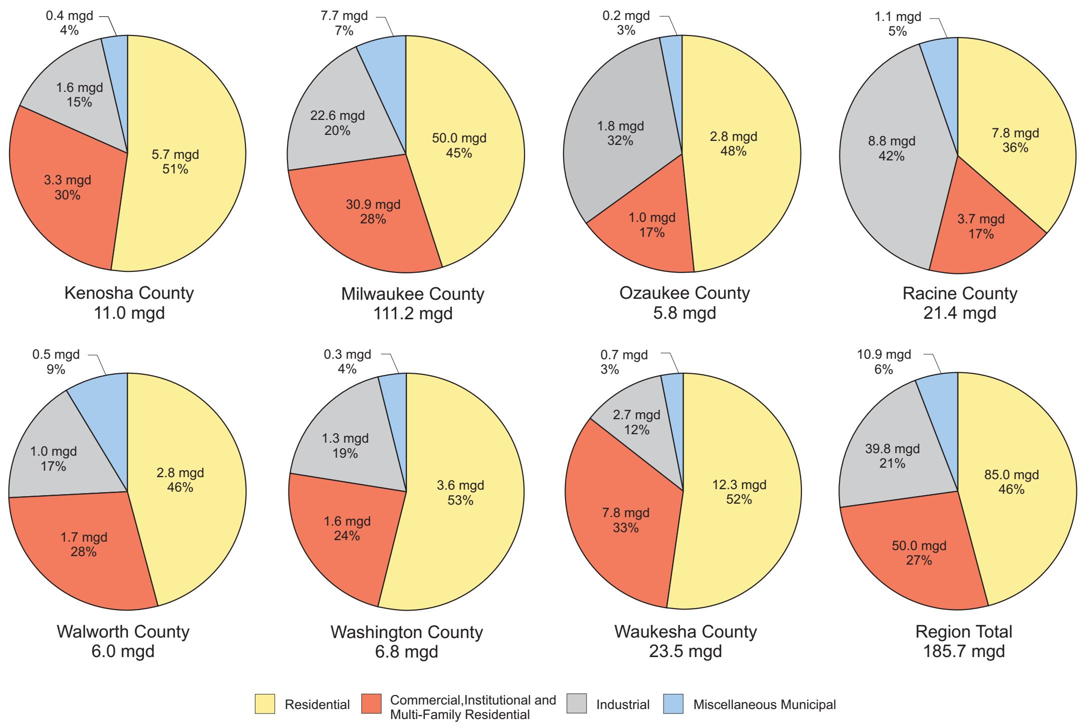
[d] *Estimated based upon total residential population served.*

[e] *Water not specifically accounted for as a percent of total pumpage.*

Source: Public Service Commission, water utilities, and SEWRPC.

Figure 30

TOTAL MUNICIPAL WATER USE BY COUNTY: 2004



NOTE: Water uses in this figure do not include estimates of unaccounted-for water.

Source: Public Service Commission, water utilities, and SEWRPC.

Table 50

WATER USE FACTORS WITHIN THE SOUTHEASTERN WISCONSIN REGION (AVERAGE YEAR 2005)

County	Residential Water Use[a]		Commercial, Institutional, Multi-Family Residential[a]	Industrial Water Use	Other Municipal Water Uses[b]	Total Municipal Water Use		Percent Unaccounted-for Water
	Per Person[c] (gallons per capita per day)	Per Acre[c] (gallons per acre per day)	Per Acre (gallons per acre per day)	Per Acre (gallons per acre per day)	Per Acre (gallons per acre per day)	Per Person[d] (gallons per capita per day)	Per Acre (gallons per acre per day)	
Kenosha	67	894	843	1,926	121	104	666	9
Milwaukee	71	1,260	1,321	3,948	197	124	1,019	12
Ozaukee	68	572	469	3,219	52	116	488	12
Racine	67	879	851	5,925	158	148	943	13
Walworth	66	508	494	1,935	169	112	489	12
Washington	67	738	508	1,292	65	92	503	13
Waukesha	72	565	689	904	50	134	478	8
Region Average	70	916	964	3,003	147	120	785	11

NOTE: Population data utilized to develop this table are based upon year 2005 Wisconsin Department of Administration estimate. Land use data were approximated at the county level based upon the year 2000 SEWRPC inventory data adjusted by the county change in population between 2000 and 2005.

[a]Residential category y includes population associated with single-family and two-family housing units, plus some larger multi-family housing where individual water meters are used for each unit. Other multi-family units are included in the commercial water use category.

[b]Includes uses for fire protection services, sales to public authorities, sales to irrigation customers and interdepartmental sales.

[c]Reported residential water use excludes that associated with multiple-unit dwellings where a single meter serves three or more housing units. That water use is classified as commercial under the Public Service Commission of Wisconsin reporting system. The unit water uses presented on a per capita and per acre basis were calculated by adjusting the population and residential land area to be consistent with this reporting procedure.

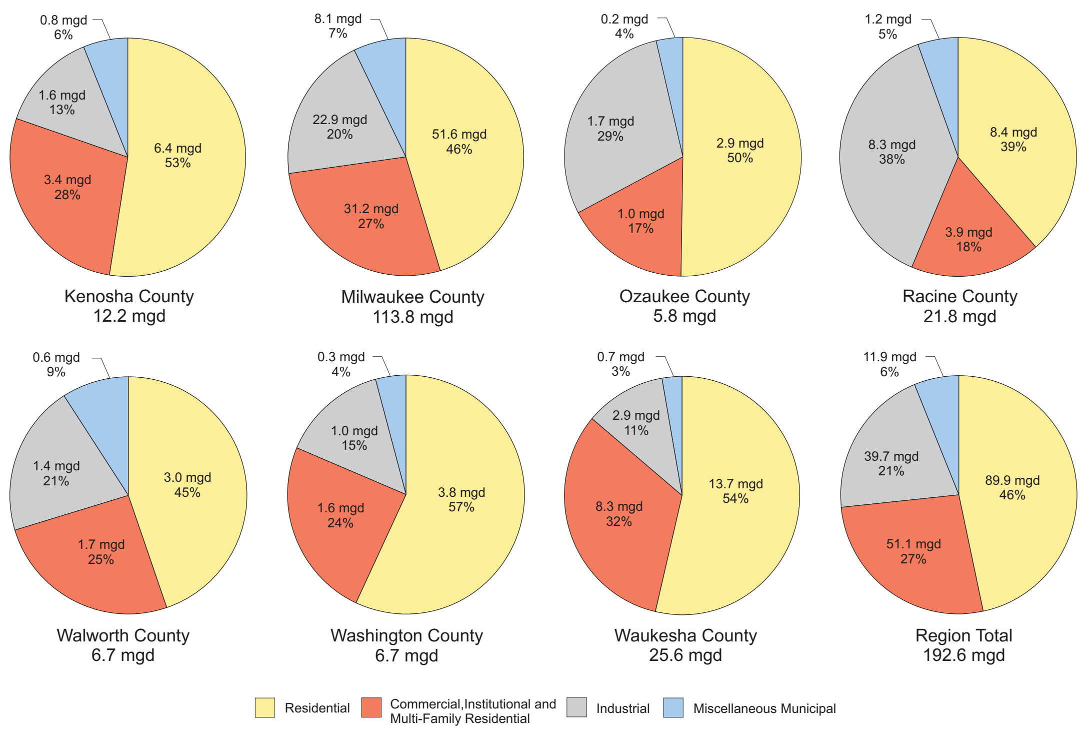
[d]Estimated based upon total residential population served.

[e]Water not specifically accounted for as a percent of total pumpage.

Source: Public Service Commission, water utilities, and SEWRPC.

Figure 31

TOTAL MUNICIPAL WATER USE BY COUNTY: 2005



NOTE: Water uses in this figure do not include estimates of unaccounted-for water.

Source: Public Service Commission, water utilities, and SEWRPC.

- Industrial land use, average daily demand—1,500 gallons per gross acre[7] per day.

- Miscellaneous municipal use, average daily demand—100 gallons per gross acre[8] of urban service area per day.

- Water used in water supply production—20 percent or 200 gallons per 1,000 gallons of water produced for surface water systems, and 5 percent or 50 gallons per 1,000 gallons of water produced for groundwater systems.

- Unaccounted-for water—10 percent of the water estimated for the abovenoted uses, except for water used in production.

Average daily demand includes only those components which can be accounted for by metered billings and treatment plant records. Average day pumpage is the total amount of water which is pumped to the distribution system. Projected average day pumpage is calculated by adding firefighting uses and other unaccountable water usage and losses to the average daily demand.

Water System Design Requirements

Design Objective–Quantity

A potable water system should be designed to provide a continuous reliable supply of high-quality water to all customers. In order to achieve this objective, the water delivered to customers must meet specified standards of quantity. The system must be able to supply the quantity of water demanded by customers, individually and in aggregate, and must be able to provide acceptable water pressure at the customer's tap. Finally, the system must have sufficient redundancy and reserve capacity to provide a reliable continuous supply of water during the most probable emergencies such as fires and anticipated equipment and power outages.

Design Standards

Recommended design standards are set forth below for the major components of a water supply system. Specific detailed standards are enumerated in Chapters NR 811 and PSC 185, of the *Wisconsin Administrative Code*, some of which are referenced below.

Peak Day to Average Day Ratio

Water use exhibits seasonal and diurnal peaks. In system design, these are accounted for by using a peak to average day use ratio. Peak day to average day ratios are typically developed from historic records and utility experience. A number of years of data are required to determine usage patterns, climatological impacts, and variations due to changes in various customer class sizes and water rates. Peak day demand is computed by multiplying the average day pumpage by the peak to average day ratio.

Peak Hour Usage

Peak hour pumpage is defined as the maximum amount of water pumped in a one-hour period. Peak hour pumpage is usually derived from historic utility records, if available, or from field measurements performed on or near the peak pumpage day. If no data exist regarding peak hour usage, it is recommended that a ratio of peak day to peak hour usage of 1.75 be used for larger (Class AB) utilities, and of 2.0 for smaller (Class C and D) utilities.

Minimum and Maximum Pressures

Pressure requirements for water utilities are established by Chapters NR 811 and PSC 185 of the *Wisconsin Administrative Code*. Section NR 811.08 (2) requires a minimum pressure of 35 pounds per square inch (psi) at

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[7]Ibid.

[8]Ibid.

all times in water mains, except under fire flow conditions, when the minimum allowable pressure is 20 psi (NR 811.08 (3)). Normal pressure variations in water mains should not exceed 6.0 psi, and no point in a distribution system should have normal pressures greater than 125 psi at the customer water meter for established systems, and no greater than 100 psi for new systems (PSC 185.82 (2)). The Wisconsin Department of Commerce regulations require individual service pressure-reducing valves to provide for a maximum pressure of 80 psi at the inlet to structures.

Fire Flow Requirements
Section NR 811.63 (3) of the *Wisconsin Administrative Code* requires a minimum fire flow of 500 GPM at 20 psi residual pressure at all hydrants in the distribution system. In many cases, much larger fire flows are needed based upon building size, occupancy, construction and other guidelines issued by the Insurance Services Office (ISO)[9] and are used to determine the fire flow requirements for various areas within a utility as well as the fire suppression rating for a community as a whole. ISO recommendations should be used to determine all fire flow requirements above 500 GPM at 20 psi residual pressure. Table 51 sets forth the categories of the five protection requirements used by the ISO. The applicable categories are established by a community survey conducted locally or by the ISO.

Supply and Storage Requirements
Water supply systems must be designed to meet average and maximum daily and peak hour demands. In order to avoid the need to design the supply facilities to meet the extreme daily and hour demand, storage facilities are usually incorporated into the systems. The conditions to be met are set forth below.

Source Capacity
For a water system supplied by a single source, such as a surface water treatment facility, the nominal capacity of the facility should exceed the anticipated peak day pumpage. In addition the reliability of the facility must be designed to assure facility capacity under adverse conditions. Adverse conditions may include a frozen intake, equipment breakdown, power outage, or a sharp decline in raw water quality. In addition, system down time for maintenance requirements must be taken into account.

For a water system supplied by multiple wells, the aggregate yield of the wells, less the largest capacity well, should exceed the peak day pumpage.

Peak Hour Storage
A water system should have enough usable elevated and ground storage volume to maintain required pressures in the system and to supply the maximum hour demand rate less the maximum day demand rate for a minimum duration of four hours with the largest pumping unit inoperable. Peak hour demand rate is assumed to be 1.75 times the maximum day demand rate.

Fire Flow
A water system should be able to supply the required fire flow for specified durations concurrent with a maximum day pumpage event. The volume required must be available from storage facilities and pump stations with the largest pumping unit inoperable. The storage volume required to meet the peak hour storage requirement noted above is not considered available to meet this requirement. Storage facilities should be considered 5 to 10 percent below full.

Emergency Supply
To be adequate, a water system should be able to supply an average day demand using only elevated storage and auxiliary power pumping. To the extent practicable, municipal water supply systems should be interconnected to provide the system redundancy required to meet emergency or unusual maintenance requirement situations.

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[9] *Insurance Services Office, Chicago, Illinois,* Fire Suppression Rating Schedule, *1980.*

Table 51

WATER SYSTEMS INSURANCE SERVICES OFFICE WATER DEMAND CATEGORIES FOR FIRE PROTECTION PURPOSES: 2003

Rate of Flow (GPM)	Duration (hours)	Total Gallons
500	2	60,000
750	2	90,000
1,000	2	120,000
1,250	2	150,000
1,500	2	180,000
1,750	2	210,000
2,000	2	240,000
2,250	2	270,000
2,500	2	300,000
2,750	2	330,000
3,000	3	540,000
3,250	3	585,000
3,500	3	630,000

Source: Insurance Services Office.

Main Looping and Sizing

Transmissions mains are generally defined as those mains 12 inches in diameter and larger which convey water between the supply, storage and distribution facilities. In a typical grid system, transmission mains should be placed at a maximum spacing of one mile. Standards for sizing and looping of mains are as follows:

- Transmissions mains should have a minimum diameter of 12 inches. Consideration of existing system inadequacies and future system expansion may require larger mains in some areas.

- To the extent practicable, all mains should be looped. Exceptions to this may include cul-de-sac streets that are less than 300 feet in length.

- Mains serving residential areas should have a minimum diameter of six inches. In some cases, eight-inch-diameter mains may be required. The previous chapter sets forth guidelines for system sizing.

- New water mains constructed in industrial, commercial, and high-density residential areas should have a minimum diameter of 12 inches. Water mains in other areas where the need for large fire flows may be anticipated should also have a minimum diameter of 12 inches. As noted above, water mains in such areas should be looped.

- All main extensions should have the needed capacities, including fire flows verified by a mathematical modeling analysis or manual hydraulic simulation.

Water main looping and sizing requirements are typically governed by firefighting requirements. In some situations, there may be opportunities for cooperative efforts between industrial and commercial developments to provide privately owned water storage in underground cisterns or elevated storage tanks to supplement the fire flows available through the public system. Indeed, such arrangements were historically common and marked by elevated storage tanks mounted on the roofs of commercial and industrial buildings. As part of the public system, underground cisterns were used in Bayside and Fox Point. The private building supplementary facilities would be provided over and above the typical requirements for building fire safety, such as alarms and sprinkling systems. Such arrangements would have to be carefully designed, developed, monitored, and maintained by the building owners, tenants, and the local fire suppression departments. One concern with such arrangements is the potential for changing ownership and tenants which could affect commitments to the maintenance of such fire suppression facilities. If such changes arise after water main construction to the area is completed, changes to the public system could be difficult and costly. These types of arrangements which would reduce municipal water main requirements are not typical municipal practice, but may have applicability in isolated instances. In addition, some buildings, particularly high-rise buildings, may install supplementary systems, such as a secondary water supply system for firefighting purposes, or dual connection to the public water main system. Any such system should be coordinated with local fire suppression and water utility departments.

Cross-Connection Control

In order to meet the primary water supply objective of providing pure water, water supply systems should be specifically designed to avoid cross-connection with nonpotable water which could be a source of contamination through back siphonage or back pressure. The Wisconsin Department of Natural Resources (WDNR) governs the operation and maintenance of public community water supply systems. The WDNR requires the supplier of such systems to develop a comprehensive cross-connection control program. These requirements are set forth in Section NR 811.09 of the *Wisconsin Administrative Code*. Furthermore, the Wisconsin Department of Commerce (WDOC) regulations include requirements for the protection of plumbing system potable water from the contamination due to cross-connection or backflow conditions. The WDOC regulations are set forth in Section Comm 82.41 of the *Wisconsin Administrative Code*.

Special Facility Design Requirements

Certain facilities, such as health care facility buildings and high-rise buildings, require special water supply considerations which are to be considered in the design of such buildings, but which should also be coordinated with local water utilities and fire suppression departments. In the case of healthcare facilities, the Wisconsin Department of Commerce regulation includes very detailed regulations which apply to such facilities. These regulations are set forth in Section Comm 82.50 of the *Wisconsin Administrative Code*.

For high-rise buildings, special internal building water supply facilities are required to provide adequate supply for domestic and firefighting uses. The design of such systems is site-specific, involving pumping and piping systems coupled with pressure regulating control systems, and pressure zoning which, in effect, create a vertical distribution system. These designs should be coordinated with local fire suppression and water utility departments.

Design and Planning Standards for Public Surface Water Supply, Groundwater Supply and Recharge Systems

The planning and design for water systems in Wisconsin is governed by the *Wisconsin Administrative Code*, primarily Chapter NR 811, “Requirements for the Operation & Design of Community Water Systems.” These requirements are based in part on U.S. Environmental Protection Agency (USEPA) requirements and, in part, on standards such as those of the AWWA, American National Standards Institute (ANSI) and American Society for Testing Materials (ASTM).

Similar standards are promulgated by the Great Lakes-Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers. These are commonly known as the “Ten States Standards.”[10] These detailed standards apply to most of the treatment technologies previously described in this report, either as part of the standards or as policy statements issued regarding a particular process. Standards are also provided for design of groundwater supply systems, pumping facilities, disposal of waste residuals and, as already noted, finished water storage and distribution system piping and appurtenances. Except where otherwise noted in this report, these standards should be used as the basis for the planning and design of water supply systems within the planning region, recognizing that Chapter NR 811 must be used as a primary basis for design. Detailed design calculations and analyses will be required for individual planning and design efforts. A listing of the table of contents of the Ten States Standards is provided in Appendix C.

Requirements related to groundwater protection, surface water discharges, and water quality are set forth in the *Wisconsin Administrative Code*. Particular chapters of interest are provided in Table 52.

Chapter NR 142 of the *Wisconsin Administrative Code* contains regulations governing the withdrawal of water from any waters of the State. It also addresses issues related to water loss to the Mississippi River and Great Lakes basins, as well as interbasin diversions. These legal issues are covered in a companion technical report[11] prepared under the regional water supply planning program.

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[10]Recommended Standards for Water Works, 2003 Edition, *“Policies for the Review and Approval of Plans and Specifications for Public Water Supplies, A Report of the Water Supply Committee of the Great Lakes Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers.”*

[11]*SEWRPC Technical Report No. 44,* Water Supply Law, *April 2007.*

Table 52

WISCONSIN CODES RELATING TO WATER DISCHARGE AND REMOVAL

Chapter	Title
NR 100	Environmental Protection General
NR 102	Water Quality Standards for Wisconsin Surface Waters
NR 108	Requirements for Plans and Specifications Submittal for Reviewable Projects and Operations of Community Water Systems, Sewerage Systems and Industrial Wastewater Facilities
NR 120	Priority Watershed and Priority Lake Program
NR 140	Groundwater Quality
NR 141	Groundwater Monitoring Well Requirements
NR 142	Wisconsin Water Management and Conservation
NR 150	Environmental Analysis and Review Procedures for Department Actions
NR 151	Runoff Management
NR 200	Environmental Protection - Wisconsin Pollutant Discharge Elimination System
NR 206	Land Disposal of Municipal and Domestic Wastewaters
NR 216	Storm Water Discharge Permits
NR 204	Domestic Sewage Sludge Management
Draft NR 820	Groundwater Quality Protection

Source: Wisconsin Administrative Code.

Surface Water Treatment Facilities

Important aspects of surface water treatment design are particular to the type of treatment and equipment used. Treatment rates for various types of filtration and other processes can vary depending upon the size and type of equipment. Raw water quality also significantly affects treatment design. For processes other than those traditionally used, it is important that smaller scale pilot plants be constructed to verify contaminant removal rates. Filtration rates, media sizes and general design considerations should follow minimum standards. More detailed engineering analyses are required when deviation from minimum standards are identified.

Groundwater Supply

Detailed design guidelines are provided in Chapter NR 811 of the *Wisconsin Administrative Code* and in the Ten States Standards for the development of water wells completed in the sand and gravel, dolomite and sandstone aquifers of the area. AWWA Standard A-100[12] also provides design and construction standards for water wells in Wisconsin.

2003 Wisconsin Act 310 sets new standards and conditions for approval of certain high-capacity wells by the WDNR and other requirements for the management of the use of groundwater. The Act defines a high-capacity well as "a well that, together with all other wells on the same property, has a capacity of more than 100,000 gallons per day." The Act requires the WDNR to undertake an environmental review under Chapter NR 150 of the *Wisconsin Administrative Code* for the following proposed high-capacity wells:

- A high-capacity well proposed in a "groundwater protection area," an area within 1,200 feet of an outstanding or exceptional resource water or any Class I, II, or III trout stream as designated by the

[12] *American Water Works Association, A-100-97 Standard for Water Wells, 1997.*

WDNR, but excluding trout streams that consists of a farm drainage ditch with no prior stream history.

- A high-capacity well that may have a significant environmental impact on a spring, an area of groundwater discharge at the land's surface that results in a flow of at least one cubic foot per second for at least 80 percent of the time.

- A high-capacity well where more than 95 percent of the amount of water withdrawn will be diverted from the basin or consumed.

The Act requires the WDNR to impose conditions on the approval for any of these wells if the WDNR determines pursuant to its environmental review that an environmental impact statement must be prepared by the applicant for the proposed well. These conditions must assure that these wells do not cause significant environmental impact. If a proposed high-capacity well will be a public utility water supply, the well will be in a groundwater protection area or may have a significant environmental impact on a spring, and the WDNR determines that there is no other reasonable alternative location for the well, then the WDNR must impose conditions on the approval that balance the well's environmental impact and its public health and safety benefits.

The Act also directs the WDNR to administer a mitigation program for wells of all sizes in groundwater protection areas. Under the program, the WDNR may require abandonment or replacement of a well, and other management strategies, in order to mitigate the effects of wells constructed in those areas before the Act's effective date. The WDNR may only require mitigation if it can provide funding for the full cost of mitigation, unless abandonment is necessary to protect public health.

Recharge Systems

Chapter VI provided detailed information on design considerations and regulatory frameworks by which to evaluate artificial groundwater recharge systems.

Drinking Water Quality Standards

Drinking water standards are established by the *Wisconsin Administrative Code*[13] in Chapter NR 809 of the *Wisconsin Administrative Code*, "Safe Drinking Water," and are administered by the Wisconsin Department of Natural Resources (WDNR). The standards are divided into two categories; primary, which are related to health; and secondary, which are related to aesthetics. The standards are further divided into the following categories; Microbiological, Inorganic, Organic, Radiological and Physical. With some exceptions, the standards generally apply to samples collected at entry points to the distribution system which are representative of water delivered to the customer's tap. Also included in Chapter NR 809 are the required sampling frequencies for the different parameters.

The Safe Drinking Water Act (SDWA) includes requirements that USEPA establish standards that public drinking water systems must adhere to. States, like Wisconsin, are given primary enforcement responsibility (primacy) for public water systems if they meet certain requirements.[14] These requirements include:

- The State must have regulations for contaminants regulated by the national primary drinking water regulations (NPDWR's) that are no less stringent than the regulations promulgated by the USEPA. States have up to two years to develop regulations after new regulations are released by the USEPA.

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[13]*Wisconsin Administrative Code,* Administrative Rules of State Agencies Published Pursuant to Chapter 227 Wisconsin Statues*, Volumes 1-19.*

[14]*http://www.epa.gov/safewater/pws/primacy.htm. Accessed on September 12, 2006.*

- The State must have adopted and be implementing procedures for the enforcement of State regulations.
- The State must maintain an inventory of public water systems in the State.
- The State must have a program to conduct sanitary surveys of the systems in the State.
- The State must have a program to certify laboratories that will analyze water samples required by the regulations.
- The State must have a laboratory that will serve as the State's "principal" laboratory, that is certified by the EPA.
- The State must have a program to ensure that new, or modified, systems will be capable of complying the State primary drinking water regulations.
- The State must have adequate enforcement authority to compel water systems to comply with NPDWRs, including:
  - The authority to sue in court;
  - Right to enter and inspect water systems facilities;
  - Authority to require systems to keep records and release them to the State;
  - Authority to require systems to notify the public of any system violation of the State requirements; and
  - Authority to assess civil or criminal penalties for violations as stringent as EPA's, if the State chooses to allow variances or exemptions.
  - The State must have an adequate plan to provide for safe drinking water in emergencies like a natural disaster.
  - The State must have adopted authority to assess administrative penalties for violations of their approved primacy program.

The rules were subsequently amended in 1986 and 1996 to include requirements that:

- As a condition of primacy, the State has administrative penalty authority for all violations of their approved primacy program, unless prohibited by State constitution.
- Increases the time to adopt new regulations from 18 months to two years and gives enforcement authority to States while applications to modify their programs are reviewed.
- Adds examples of circumstances that require an emergency plan for the provision of safe drinking water.

The State of Wisconsin meets these requirements for primacy.

WATER SYSTEM ANALYSES

In order to evaluate the adequacy of a water supply distribution system, the performance of the system should be simulated using a mathematical model of the system. In the case of water main extensions, mathematical modeling or manual calculations should be carried out to verify that the extension and related system has adequate capacity to meet existing and forecast demands. There are a number of different simulation modeling software packages available commercially, each with its own advantages and disadvantages. All of the models are based upon accepted hydrologic and hydraulic relationships, such as the Hazen-Williams formula for the calculation of pressurized pipe flow. All, therefore, require similar data inputs, including:

1. Water main length, diameter, connecting nodes, and roughness;

2. Node location and elevation;

3. Pump location and head-discharge characteristics;

4. Storage tank location and free surface elevation;

5. Control valve locations and set points; and

6. Water inflows and outflows.

In the mathematical models, a node is defined as any location where pipes meet or end. Of the mathematical model inputs listed above, the one most difficult to accurately establish is pipe roughness. New pipes have a smooth interior, which allows water to pass through them easily with a minimum of friction loss. As water mains age, the interior surface usually becomes rougher. This increase in roughness is especially significant for older cast iron pipes. For a given flow rate, the pressure loss will be greater in a rougher pipe. Field tests can be performed to measure the roughness of selected pipe segments. The field measured roughness values can then be assigned to all pipes of a similar material and similar age to the tested pipe. Typical roughness values are listed in Table 53.

After all the data are input, the accuracy of the model is calibrated and validated by comparing the model output data to field test data. The model output should match the field test data closely in many, but not all, locations. It is then common practice to adjust the pipe roughness values until all test location data match within acceptable tolerances. Typically, if the modeled data and the field measurements are within 5 to 10 percent of each other, the model is considered to be properly simulating the system performance.

After the mathematical model is calibrated, it can be used to simulate the flow rates and pressures available at any node in the system under varying demands. Where flows and pressures are too low, remedial measures can be considered and evaluated. Pipes can be added to simulate future service areas in order to determine the location, configuration and size of the mains that will be needed. Storage tanks and pumps can be proposed and their effects determined. For each configuration of existing and proposed pipes and other facilities, the model can be applied to solve for the pressures available at each node under an assumed set of inflows and outflows.

One objective of the water supply system mathematical modeling analysis is to determine how much water may be available for firefighting throughout the distribution system. The fire flow rate computed assumes that the residual system pressure is allowed to drop to 20 psi. The modeling analysis can determine the flow rate available at each node assuming a residual pressure of 20 psi at the hydrant locations concerned. The calculated flow rates are then adjusted downward so that 20 psi is the lowest pressure anywhere in the distribution system. Depending on water main diameters and the elevation range throughout the distribution system, this downward flow rate adjustment can be negligible or significant.

For firefighting conditions modeling, it is typically assumed that water is supplied by elevated tanks only. This assumption is made because it is impossible to predict which system pumps will be running at the start of a major fire. The fire flow available at a hydrant may vary significantly depending on whether the nearby pumps are operating. It cannot be assumed that the pumps will operate during a fire. The pumps may be out of service, or there may be a power outage. Water in an elevated tank, however, may be relied upon to be available through

Table 53

VALUES OF ROUGHNESS FACTORS (C) FOR USE IN HAZEN-WILLIAMS EQUATION

Type of Pipe	Condition		C
Cast Iron	New	All Sizes	130
	Five years old	12 inches and over 8 inches 4 inches 24 inches and over	120 119 118 113
	10 years old	12 inches 4 inches 24 inches and over	111 107 100
	20 years old	12 inches 4 inches 30 inches and over	96 89 90
	30 years old	16 inches 4 inches 30 inches and over	87 75 83
	40 years old	16 inches 4 inches 40 inches and over	80 64 77
	50 years old	24 inches 4 inches	74 55
Welded Steel	Values of C the same as for cast-iron pipes, five years older		
Riveted Steel	Values of C the same as for cast-iron pipes, 10 years older		
Wood Stave	Average Value, regardless of age		120
Concrete or Concrete Lined	Large size, good workmanship, steel forms		140
Ductile Iron	Large sizes, good workmanship, wooden forms		120
	Centrifugally spun		135
Vitrified	In good condition		110
Plastic or Drawn Tubing	Average value		140

$$f = 0.2083\left(\frac{100}{C}\right)^{1.85}\frac{Q^{1.85}}{d_i^{4.87}}\left(\text{Hazen - Williams Equation English Units}\right)$$

Where : f = friction loss, ft of H_2O / 100 ft

Q = flow rate, gpm

d_i = pipe internal diameter, in

C = flow coefficient

Source: Handbook of PVC Pipe Design and Construction *and Ruekert & Mielke, Inc.*

gravity flow during a fire. The only limit to the flow rate available at a specific hydrant is the capacity of the distribution system between the elevated tanks and the hydrants concerned.

The water supply system mathematical model can also be used to check pressure at nodes under peak hour demand conditions. For smaller water utilities, distribution system pressure losses normally are greatest under fire flow conditions. This is because fire flow rates are large compared to peak customer demands for smaller utilities.

For larger utilities, however, overall distribution system losses may be greatest under peak customer demands. Simulation modeling can help to identify if additional or replacement mains are needed to prevent system pressures from dropping below the recommended standard of 20-35 psi under fire flow or other peak demand conditions. Such modeling can also help to identify the size of the transmission mains that may be needed to supply future service areas.

Mathematical simulation models are typically categorized according to intended use. The four categories most commonly used are planning, operations, training, and water quality. Each type of model has a different purpose, level of detail, and required degree of accuracy. A brief description of each type of model is as follows:

- Planning—Used to plan and design water systems, determine facility requirements, schedule installation, develop operation strategies, and perform related applications. A planning model is usually developed and used by personnel in planning and engineering of water supply systems.

- Operations—Used by engineering and operations staff to study specific problems of a current or potential concern.

- Training—Used to train water system operators and other people interested in learning how to operate a particular water system. Operators can test and compare different operation scenarios to determine which one is best for their system.

- Water Quality—Used by planning, engineering, and operations staff to study the flow and distribution of various components of water. Source tracking, determination of travel times, age of water, and concentration levels of chemicals are the primary applications.

It is recommended that mathematical simulation models be applied to evaluate the potential performance of any major distribution expansions within the Southeastern Wisconsin Region.

DRAWINGS AND SPECIFICATIONS

In order to facilitate the sound management of water system systems, high-quality facility records must be completed, maintained, and filed systematically for future access and use. The completion and maintenance of such records depends, in part, on the standards used to govern the preparation of design drawings, as well as of record—so called “as-built”—drawings. The following section describes recommended practices for water system distribution plans. Similar practices are also needed for surface water treatment plants and outfalls, storage facilities, and other more-complex water supply system components. However, these facilities require plans and specifications, as well as recorded drawings, for complex structural mechanical, electrical, and other elements which must be developed on a case-by-case basis.

Water System Distribution Construction Plans and Specifications
Sections NR 108.03 and 108.04 of the *Wisconsin Administrative Code* set forth requirements and regulations for the submission of plans and specifications to the WDNR for community water systems. The WDNR typically has 90 days following complete submittal to complete the review. Project construction cannot be initiated without the final plans being reviewed and approved by the WDNR. Provisions are included in the rules for voluntary preliminary plan or conceptual design report submittal in order to obtain comments and advice prior to final plan and specification preparation and submittal.

In addition to the requirements of Sections NR 108.03 and NR 108.04 of the *Wisconsin Administrative Code* previously noted, NR 811 Subchapter II - Submission of Plans, sets forth general and specific requirements for detailed construction plans and specifications for:

- Well Design

- Well Site Investigation Reports

- Water Loss and Interbasin Diversion Approvals as defined in NR 142
- Surface Water Intakes
- Treatment Plants
- Chemical Feed Equipment
- Pumping Facilities
- Water Mains
- Storage Facilities

In addition, all reviewable projects require that an engineering report be submitted with basic requirements that the report include specific data such as:

- Project Description
- Project Location
- Topography
- Population
- Design Period
- Investigations
- Flooding
- Wetlands
- Recommendations
- Specific Information On:
  - Groundwater Sources
  - Surface Water Sources

Additional information on water treatment or chemical addition processes, pumping equipment and water storage facilities is also required by NR 811.

Owner approval of the plans is required if the engineer is not retained by the owner. The final plans and specifications must be submitted under the signature and seal of a professional engineer registered in Wisconsin. A resident project representative is also required during construction to assure that the improvements are constructed in accordance with the approved plans, specifications and conditions of approval.

In addition to the requirements of Section NR 108.04 and Chapter NR 811 of the *Wisconsin Administrative Code*, the design plans for water distribution facilities should meet applicable local code requirements. After approval, the plans should be submitted in a digital format which is compatible with local public works management systems. The concepts and a water supply system attribute list for such a system are set forth in Appendix D of this report.

The following standards should govern the preparation of design plans:

Sheet Size: Not larger than 24 inches by 36 inches.

Scale: Not smaller than one inch equals 40 feet for detailed plans; not smaller than one inch equals 100 feet for system maps (general plans).

NR 108.04(2)(f) requires that all sheets be numbered and contain:

- North point;
- Scale;
- Name of the designer;
- Name of the owner; and
- Existing facilities to be connected to or modified.

In addition, standard engineering practice indicates that plans should also include:

- Plan view
  - All other utilities existing and proposed;
  - Existing and proposed improvements;
  - Street and lot lines;
  - Dimension of lot frontages;
  - Street names;
  - Land subdivision name and block and lot numbers, certified survey map number and parcel number;
  - Street addresses of existing buildings;
  - Tax key numbers of lots;
  - Easements, with annotations for purposes and widths;
  - Dimensions of all pipes, existing and proposed;
  - Centerline stationing, typically indexed to centerline of cross street;
  - Dimensions for all separations from other utilities and lot lines, easement lines or right-of-way lines; and
  - Existing and proposed features, such as valves, hydrants, and air release vents.

- Profile View
  - All utilities, including sanitary, storm sewers, culverts, gas mains, and electric power and telecommunication cables;
  - Existing and proposed surface grades;
  - Invert, or crown, elevations and stationing for all fittings, bends, valves, and grade breaks; and
  - Grades and lengths of all pipes.

Record Drawings
Record drawings—often called "as-built" drawings—should be prepared after construction, and should accurately represent the actual line and grade and location of the constructed facilities, including appurtenances. Record drawings should be updated periodically to assure their continued accuracy for use in system operation and maintenance, as well as for use during planning and design and construction of new or rehabilitated facilities. Water system record drawings should be provided in both hard copy and digital format, and should consist of a plan and attendant profile. Digital data should be in a format compatible with the local parcel-based land information system and public works management system.

The record drawings should include:

- Property lines, subdivision name, block and lot numbers, certified survey map number and parcel number, lot frontage dimensions, and street names;
- All other utilities using a line code;
- All fittings, sleeves, valves, hydrants, and release vents; water services;
- Types of piping material used;
- Pipe lengths between fittings and services;
- Special back fill areas, such as slurry or concrete;
- Insulation—tied to fittings;
- Curb stops tied to above-ground features;
- North point;
- Scale;
- Detector wire box locations, if needed;
- Location of water main in relation to right-of-way centerline;
- An accurate profile with elevations, all high and low points and at changes in vertical alignment; and
- Title block, including: location "in," and "from and to"; Township, range, section, and quarter-section location; date of completion; scale; contractors name (firm); designers name (firm); preparers (firm); and professional engineers seal, date and signature.

When the facility is located in an easement, the easement should be described as a distance off a street. Such as:

IN: Easement located 600 feet west of Main Street
FROM: Grove Avenue
TO: Cherry Street

Much of the above information should be incorporated in the local automated public works management system. In southeastern Wisconsin, this requires that the location of mains and appurtenances, such as valves and hydrants as constructed should be given in State Plane Coordinates-North American Datum of 1927; and that the elevation of pipe crown as constructed be given in elevations—orthometric heights—referred to the National Geodetic Vertical Datum of 1929. This will insure the as-built data are accurately scale independent and will permit integration of the data into automated public works management and parcel-based land information system throughout the urbanizing Region. Global positioning system (GPS) technology provides an effective means of obtaining accurate horizontal and vertical positions of constructed facilities. GPS instruments can readily provide State Plane Coordinate positions with sufficient accuracy to meet public works management system needs. Although such instruments provide ellipsoid heights rather than orthometric heights, the vertical control network put in place within the Region by the Commission, permits ready determination of geodal heights and the conversion of ellipsoid heights to orthometric heights. A typical water supply system attribute summary for such a system is included in Appendix D.

ECONOMIC EVALUATION

The alternative plans developed under the regional water supply planning program include estimates of the associated capital and annual operation and maintenance costs estimates. Capital costs include construction costs plus engineering, inspection, legal, and contract administration costs. Operation and maintenance costs include labor, power, chemicals, utilities, materials and supplies, disposal of residuals, and related costs.

Cost-effectiveness analyses conducted under the regional water supply planning program compares the 50-year costs of the alternative plans considered. Attendant analyses include total present worth and equivalent annual cost calculations of capital expenditures—initial and probable future—operation and maintenance and salvage values based on straight-line depreciation of structures and equipment. Water mains, wells, concrete structures and storage tanks are assumed to have an economic service life of 50 years. Steel structures and electrical components are assumed to have a service life of 30 years, and pumps and equipment an economic service life of 20 years. It is recognized that certain facilities will have economic service lives which are more or less than those noted herein to be used for the purposes of cost-effective analyses. However, the service lives noted are those typically utilized for regional systems-level planning programs and are intended to represent average lives for the groups of facilities noted. It should be noted that for a cost-effectiveness analysis based upon a 50-year analysis period and a 6 percent interest rate, future salvage values of facilities at the end on the analysis period are valued at about 5.4 percent of the estimated salvage value on a present worth basis. Thus, utilizing service lives for facilities of greater than 50 years leads to little change in present worth and equivalent annual values for alternative plans. Costs are expressed as December 2005 costs adjusted to an *Engineering News Record* (ENR) value of 9,563, which represent an average of the Chicago and Minneapolis indices. All construction is assumed to be completed within 12 months. Therefore, no interest costs are assumed during construction. Project costs include a 35 percent allowance to reflect contingencies, engineering design, engineering during construction and associated legal and administrative costs. The interest rate used for the present worth analysis is 6 percent.

SUMMARY

This chapter has addressed the planning and design standards recommended for regional water supply planning program. The standards presented are intended to serve as one basis for developing and evaluating system-level alternative water supply plans and the selection of a recommended plan. The standards are also intended to provide useful information for local water supply system planning. In addition to the standards presented herein, there are a number of other considerations which need to be taken into account in evaluating regional and local water supply plans. Under the regional water supply planning program, this evaluation is being taken into account by considering the ability of the alternative plans being considered to meet a set of agreed-upon objectives, principles, and standards.

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Chapter X

APPLICATION OF STANDARDS AND COST DATA

INTRODUCTION

The preceding chapters of this report present information on water supply technologies, practices, and costs, relating to water treatment, transmission and storage and groundwater recharge, together with water demand and water conservation strategies. The information provided can be utilized to determine the anticipated cost and appropriate uses associated with various water supply management measures. In southeastern Wisconsin, water is withdrawn for treatment and use from both groundwater and surface water sources. The information presented throughout this report can be used as a guide for the selection of appropriate water supply technologies applicable to both these source waters.

CONSIDERATIONS IN SYSTEM DESIGN

The proper application of the standards and cost data presented in this report depends upon knowledge of several design factors including system demand and system hydraulics, quantity and quality of supply, conservation impacts, and current capacity considerations.

System Demand and Hydraulics

An understanding of the system demand and hydraulics associated with existing and potential water supply management measures is an important consideration in the planning and design of water supply facilities. General guidelines for the hydraulic sizing of system components is provided in Table 54. Several important factors must be considered when evaluating and selecting unit operations and processes based on the hydraulics involved. Facility capacities should be matched to the expected range of flows. Most unit operations and processes involved in water supply systems must be able to operate over a wide range of flow rates, while most such operations and processes perform most efficiently at a relatively constant rate. General guidelines for use in estimating water demand and hydraulic loadings for use in system planning and design are presented in Chapter IX.

The sizing of most treatment units in a water supply system is based on forecast peak-day demand at the end of the economic and physical life of the units concerned, with the hydraulic capacity typically being set higher than the peak day to account for recycled and treated waste streams. Typically the demands of residential, industrial, commercial, and institutional land uses are separately estimated and then appropriately aggregated to determine peak demands. Forecasts for other uses, such as fire protection and for the treatment and production of potable water, are also categories of demand that must be incorporated into the peak design flow estimate. The peak design flow on a short duration basis is generally used to determine the hydraulic sizing of treatment and storage units and of transmission mains, as described in Chapter IX.

Table 54

GUIDELINES FOR HYDRAULIC SIZING OF TREATMENT FACILITIES AND UNIT OPERATIONS AND PROCESSES

Design Flow	Facility and Unit Operations and Processes	Value to Be Used
Maximum Day[a]	All treatment processes, including intake facilities[b]	$Q_{max\ d}$
	Plant hydraulic capacity (e.g., piping)	1.25-1.50 X $Q_{max\ d}$
	Maximum capacity of chemical feeders	$Dose_{max}$ X $Q_{max\ d}$
	Sludge collection, pumping, and treatment facilities	$Q_{max\ d}$
	Clearwell capacity	1.15-1.50 X $Q_{max\ d}$
	Low- and high-life internal plant process pumps with largest pump out of service	$Q_{max\ d}$
	High-service pump station with largest pump out of service	$Q_{max\ d}$
	Maximum capacity of flowmeters[b]	$Q_{max\ d}$
Maximum Hour	High-service pump station, depending on local conditions	$Q_{max\ h}$
	Water distribution reservoir in distribution system	$Q_{max\ h}$
Average Day	Storage volume for sludge lagoon	365 X $Q_{ave\ d}$
	Unit processes with one unit out of service	$Q_{ave\ d}$ for $Q_{max\ month}$ / 30 d
	Bulk chemical storage	$Dose_{ave}$ X 30 d X $Q_{ave\ d}$ for $Q_{max\ yr}$
	Day tank for chemical feed	$Dose_{ave}$ X 12 h X $Q_{ave\ d}$ for $Q_{max\ yr}$
	Average capacity of chemical feeders	$Dose_{ave}$ X $Q_{ave\ d}$ for $Q_{max\ yr}$
Minimum Day	Minimum capacity of chemical feeders	$Dose_{min}$ X $Q_{min\ d}$
	Lower capacity of flowmeters	$Q_{min\ d}$
	Minimum flow for recycle pumps	$Q_{min\ d}$

[a]*The maximum day demand, $Q_{max\ d}$, is the forecast design year value.*

[b]*The ancillary equipment, such as flowmeters, should be designed to match the rating for the unit processes.*

Source: Montgomery Watson (MWH), Water Treatment Principles and Design*, 2005.*

Quantity of Supply

The amount of water available as a source will directly affect the selection of the water supply measures associated with withdrawal and treatment and will influence the level of water conservation deemed appropriate. The determination of the appropriate amount of raw water required is a critical step in providing for an adequate water supply. In areas where limited quantities of source water exist, it is particularly important to evaluate a full range of water supply and conservation options in order to minimize the potential for water shortages and the costs associated with the acquisition of new and/or supplemental sources of supply. In such cases, source water sustainability analyses should be conducted in conjunction with the design of the supply facilities, as described in Chapter IX.

The applicable water supply management measures and associated costs will vary throughout the Southeastern Wisconsin Region depending upon the source of supply. Generally, for utilities located in areas of the Region which utilize Lake Michigan water as a source of supply, the set of water supply measures and associated costs described in Chapter III for such utilities should be applied. Generally, for utilities which utilize groundwater as a source of supply, the water supply measures and associated costs described in Chapters IV and VI for such utilities should be applied. Water supply management measures related to transmission, storage, and water conservation as described in Chapters VII and VIII are applicable to systems located throughout the Region and supplied by both surface and groundwater.

Water Quality

Water quality standards are the foundation of the water quality-based water supply control program promulgated by the Federal Safe Drinking Water Act. These standards define the desirable characteristics of a water source by designating acceptable uses, setting criteria for protection of public health, and establishing policies to maintain and protect existing uses and high quality waters from contamination. Consideration of the standards set forth by the U.S. Environmental Protection Agency and the Wisconsin Department of Natural Resources, as outlined in Chapter IX, are important considerations in the planning and design of water supply systems.

The production and delivery of water that is safe to drink and aesthetically pleasing is the primary function of public water supply system processes and facilities. Treatment processes must be selected that, when grouped together, can be used to remove specific constituents. The most critical determinants in the selection of water treatment processes are the nature of the water source and the intended use of the treated water. Depending on the source of supply, the levels of human activity in the surrounding area of the source, and other factors, a wide range of water qualities can be encountered. The type of water quality issues that a community is experiencing may require several combinations of treatment, each with varying costs, as described in Chapters III, IV, and V. The planning process for water treatment should evaluate the constituents that are present in the raw source water and the effectiveness of the treatment processes under consideration. Table 55 summarizes the cost data provided in Chapters III and IV of this report that are associated with treatment methods considered to be viable options for resolving groundwater and surface water quality issues present in southeastern Wisconsin.

As noted above, the quality of the source water is an important determinant in the selection of water treatment processes. The Wisconsin Department of Natural Resources has conducted source water assessments for all of the municipal water supply systems within the Region. Such assessments include information on source water quality and recommend needed protection measures.

Conservation Impacts

The level of water conservation carried out will have a direct impact on the design and management measures to be considered in water supply system planning. Water conservation can be accomplished by achieving efficiency in utility operations to minimize the amount of water that must be produced and conveyed to meet user demand, primarily through the reduction of unaccounted-for water. The attendant practices include metering and system performance monitoring, leak detection and repair, and system operational refinements. Water supply efficiency programs and measures are well established, but are highly system-specific in application. Water efficiency programs are a very effective and direct water conservation measure. Water conservation can also be accomplished by reducing the demand for water. The attendant practices, include water rate modifications to discourage use, use of water-saving plumbing features, water recycling, and educational activities.

As described in Chapter VII, utilities and other water suppliers will incur costs for implementation of conservation programs. The direct costs of conservation programs include staff salaries, contract costs, and program support needs, such as educational materials, incentives, and publicity. Water conservation also has the potential to reduce certain costs associated with the water supply treatment, transmission, and distribution. In addition, implementation of effective water conservation measures has the potential to reduce future capital costs of water supply facilities, and may contribute to maintaining a sustainable water supply. A carefully planned water conservation program requires consideration of the service area composition, current and future water needs, sources of supply, level of efficiency currently being achieved, and the water supply infrastructure in place and needed in the future. Particularly important in this respect is the importance of maintaining the sustainability of the supply source.

Current Capacity Considerations

The sizing of the water supply facilities can be determined by proper application of the design criteria described in Chapter IX. Treatment processes are typically designed to hydraulically accommodate a peak demand, but are sized to effectively remove constituents from the source water at maximum daily average demands. The treatment

Table 55

TREATMENT STANDARDS AND COST DATA FOR WATER QUALITY ISSUES IN SOUTHEASTERN WISCONSIN

Groundwater			
Water Quality Issue	Treatment Standard and Technology	Capital Costs	Operation and Maintenance Costs
Arsenic	Reduction to acceptable levels		
	Adsorption	$1.36 per gpd capacity	$1,000 per MG treated
	Ion exchange	$0.20 per gpd capacity	$1,700 per MG treated
	Coagulation and filtration	$0.60 per gpd capacity	$80 per MG treated
	Electrodialysis reversal	$3.09 per gpd capacity	$840 per MG treated
	pH adjustment, or lime softening	$0.85 per gpd capacity	$250 per MG treated
	Activated alumina	$0.60 per gpd capacity	$80 per MG treated
	Reverse osmosis	$2.60 per gpd capacity	$600 per MG treated
Radionuclides	Reduction to acceptable levels		
	Hydrous manganese oxide (HMO) filtration *(radium)*	$1.10 per gpd capacity	$150 per MG treated
	Ion exchange *(radium, uranium, beta/p boton)*	$0.20 per gpd capacity	$1,700 per MG treated
	Reverse osmosis *(radium, uranium, gross alpha, beta/p boton)*	$2.60 per gpd capacity	$600 per MG treated
	pH adjustment, or lime softening *(radium, uranium)*	$0.85 per gpd capacity	$250 per MG treated
	Co-precipitation with barium sulfate *(radium)*	$0.13 per gpd capacity	Variable cost
	Electrodialysis reversal *(radium)*	$3.09 per gpd capacity	$840 per MG treated
	Activated alumina *(uranium)*	$0.60 per gpd capacity	$80 per MG treated
	Coagulation and filtration *(uranium)*	$0.60 per gpd capacity	$80 per MG treated
Synthetic Organic Compounds (SOCs)	Reduction to acceptable levels		
	Granular activated carbon (GAC)	$5.50 per gpd capacity	$1,000 per MG treated
	Packed tower aeration	$0.31 per gpd capacity	$690 per MG treated
	Oxidation	$0.13 per gpd capacity	Variable costs
	Membrane processes	$2.60 per gpd capacity	$300 per MG treated
Inorganic Nitrogen Compounds	Reduction to acceptable levels		
	Ion exchange	$0.20 per gpd capacity	$1,700 per MG treated
	Reverse osmosis	$2.60 per gpd capacity	$600 per MG treated
	Electrodialysis reversal *(nitrate only)*	$3.09 per gpd capacity	$840 per MG treated

Table 55 (continued)

Surface Water			
Water Quality Issue	Treatment Standard and Technology	Capital Cost	Operation and Maintenance Costs
Large Solids and/or Animals At Intake	Mechanical screening at intake	$0.05 per gpd capacity	Intermittent and variable cost
Zebra and Quagga Mussels	Chemical treatment and velocity control	$0.05 per gpd capacity	Intermittent and variable cost
Solids/Turbidity	Coagulation, flocculation, and sedimentation facilities	$0.70 per gpd capacity	$150 per MG treated
Groundwater and Surface Water			
Water Quality Issue	Treatment Standard and Technology	Capital Costs	Operation and Maintenance Costs
Organic Material	Filtration to prevent formation of disinfection byproducts		
	Gravity filtration[a]	$0.60 per gpd capacity	$80 per MG treated
	Pressure filtration	$1.50 per gpd capacity	$300 per MG treated
	Membrane filtration	$2.60 per gpd capacity	$300 per MG treated
Pathogenic Organisms	Disinfection to kill or inactivate organisms		
	Chlorination with chlorine dioxide	$0.04 per gpd capacity	$30 per MG treated
	Chloramination	$0.09 per gpd capacity	$100 per MG treated
	Ozonation	$0.60 per gpd capacity	$30 per MG treated
	Ultraviolet (UV) light	$0.40 per gpd capacity	$200 per MG treated
Corrosive Source Water	Chemical addition to prevent lead and/or copper leaching into water	$0.13 per gpd capacity	Variable costs

NOTE: Some water quality issues, such as inorganic nitrogen compounds, may be found in both groundwater and surface water but have been listed under the category in which they are most commonly encountered.

[a]*Does not include facilities using granular activated carbon (GAC).*

Source: Ruekert & Mielke, Inc.

costs associated with these design criteria are presented on cost curves included in Appendix A. An analysis of available records should be performed to refine the design requirements and unit process efficiencies that currently exist for each facility in order to determine current facility capacity.

COST CONSIDERATIONS FOR INFRASTRUCTURE RELATED ITEMS

Cost curves for individual water supply facilities are presented in Appendix A. The curves represent various processes which can be combined to estimate the costs of alternative water supply system configurations. The cost curves are based upon December 2005 costs. The cost data provided by the curves can generally be updated by judicious application of *Engineering News Record* cost indices.

The cost curves for the water supply facilities have been presented in terms of estimated construction cost versus flow for the flow range of 0.1 to 100 mgd. The economy of scale is usually reached at 100 mgd so that the cost of facilities greater than 100 mgd can be estimated by direct proportion to the 100 mgd cost, i.e., a 1,000 mgd plant will cost 10 times that of a 100 mgd plant with only slightly lower unit operating costs. The cost data associated with small, field-fabricated facilities that handle less than 0.1 mgd is dependent upon several factors and is not generally subject to cost curve analysis.

It is important to note that the cost data provided by the cost curves are intended to be used for system planning, including specifically for the configuration of alternative system plans. The curves present estimated construction cost data. For system-level planning, project costs should be determined by multiplying the total construction cost by 1.35 to include other expenses, including engineering, legal, contingencies, and interest during construction. The total project cost may then be annualized using an interest rate and amortization period. The service life of constructed and existing facilities should also be defined, as summarized in Chapter IX of this report.

In order to identify preferred alternatives, a sound basis of comparison is needed. Use of present worth analyses will provide such a basis and will provide for proper consideration of the design life of facilities, the time value of money, and the increase in operation and maintenance costs resulting from future higher demands. A description of this methodology is provided in Chapter IX.

OTHER CONSIDERATIONS FOR INFRASTRUCTURE RELATED ITEMS

There are several other factors that are relevant to the comparison of alternative plans and the identification of preferred alternatives. Table 56 presents these factors.

The availability of land to accommodate the current facilities, as well as possible future expansion, is a major concern. Consideration of the amount of space needed for each process and attendant buffer zones to provide landscaping and minimize visual and other impacts is necessary in the system planning process.

The ability of a treatment facility and/or process to withstand adverse climatic conditions, such as freezing, is necessary to maintain the uninterrupted treatment of water. Another important consideration is the ability of a treatment system to handle the anticipated inlet flow and influent water quality variations. The treatment process selected should be matched to the expected range of demand. For example, slower sand filters are generally not suitable for accommodating high flow rates.

The presence of some industrial pollutants can potentially inhibit the effectiveness of certain treatment processes, especially those that require the addition of chemicals. Those constituents present in the raw water that may be inhibitory to the treatment process should be monitored and the appropriate technology selected to avoid finished water quality issues.

The long-term reliability of the unit operation or process should be considered. Processes that are easily upset, or which cannot handle periodic changes in the quality of the raw water treated, may not be a viable option if these conditions exist. The complexity of a process to operate both under routine and emergency conditions must be understood to ensure that the operators have sufficient levels of training to operate and maintain the process.

Potential occupational hazards, such as chemicals, and possible air pollution, must be considered for the design of a water treatment system to avoid accidents and health risks. Waste products that are formed during treatment will require further processing. The processing of these wastes may be infeasible or expensive, and the selection of the residuals-processing system should be made with the selection of the water treatment system.

In addition to the factors listed in Table 56, there are several other factors that should considered when evaluating alternative unit operations and processes. Environmental factors, such as animal habitat and proximity to residential areas, may restrict or negatively affect the use of certain processes and types of intakes. In addition,

Table 56

OTHER FACTORS RELEVANT TO SELECTION OF WATER SUPPLY TECHNOLOGIES

Process	Land Requirements	Adverse Climatic Conditions	Ability to Handle Inlet Flow Variations	Ability to Handle Influent Quality Variations	Industrial Pollutants Affecting Process	Reliability of the Process	Ease of Operation and Maintenance	Potential Occupational Hazards	Air Pollution	Waste Products
Intake Protection and Preliminary Treatment	Minimum	- -	Good	Good	Minimum	Very Good	Fair	Structures Mechanical	- -	Screenings
Pumping	Minimum	Freezing	Good	Good	Minimum	Very Good	Fair	Structures Mechanical	- -	- -
Coagulation, Flocculation and Sedimentation	Minimum to moderate	- -	Fair to good	Good to very good	Moderate to maximum	Good to very good	Good to very good	Structures Chemicals	Odors	Sludges
Oxidation	Minimum to moderate	- -	Fair to good	Good to very good	Maximum	Good to very good	Good to very good	Structures Mechanical Chemicals	Odors (chemicals)	- -
Conventional Filtration	Moderate to maximum	Freezing	Good	Good	Minimum to moderate	Good to very good	Good to very good	Structures Mechanical	Odors	Backwash waste
Membrane Filtration	Moderate	Freezing	Good	Good	Moderate to maximum	Good to very good	Good to very good	Structures Mechanical	Odors	Backwash waste
Activated Carbon	Moderate	- -	Good	Fair	Maximum	Good	Good	Fires Explosion	Regenerant gas	Spent carbon
Ion Exchange	Minimum	- -	Fair	Good	Maximum	Good	Good	Chemicals	Odor NH_3	Waste regenerant
Disinfection	Minimum	- -	Good	Good	Maximum	Very good	Good	Structures Mechanical Chemicals	Odor (chemicals)	- -
Fluoridation	Minimum	- -	Good	Good	Maximum	Very good	Good	Structures Chemicals	Odor (chemicals)	- -
Corrosion Inhibition	Minimum	- -	Good	Good	Maximum	Very good	Good	Structures Chemicals	Odor (chemicals)	- -

Source: Ruekert & Mielke, Inc.

specific steps for the protection of the environment should be taken into consideration during design. Chemical spills or discharges may be environmental threats, and the necessary ancillary processes should be available to address these events.

Operation and maintenance requirements should be considered for each treatment process. The availability and cost of spare parts should be factored into the process selection with the objective of minimizing the time that a unit process is offline. The number of staff and the appropriate levels of skills needed to operate the unit operations or process should also be considered.

The adaptability of the system for modification to handle future treatment requirements should be understood during design to minimize potential future costs associated with expansion. The security of water treatment facilities is also an important consideration. Thus the steps and or facilities that are required to protect the overall plant from intentional mishaps should be incorporated into water supply system design.

A portion of operation and maintenance costs are influenced by several factors, including energy, chemical, and manpower use. The utilization of energy and chemicals inherently results in secondary environmental effects due to energy or chemical production. Consideration of long-term resource obligations should be taken into account in the selection of a treatment process. The cost curves presented in Appendix A that depict operations and maintenance costs for various treatment processes include energy requirements. Table 57 depicts the approximate energy requirements or various treatment processes used in surface water treatment plants with sizes ranging from one mgd to 100 mgd in size. For all categories, regardless of size, the total energy requirement is approximately 1.4 to 1.5 kilowatt-hours per 1,000 gallons of water produced. Table 58 provides approximate energy requirements for various treatment processes used in groundwater treatment facilities that differ from surface water treatment, ranging in size from one mgd to 20 mgd in size. The data presented in Tables 57 and 58 reflect energy requirement estimates for typical surface water and groundwater treatment facilities.

Most of the energy consumed in water treatment and supply systems is associated with the pumping of water. Pumping is used to convey raw water to the treatment facility, to deliver treated water to customers, and to perform general operations during treatment such as filter backwash. The energy required to pump a given quantity of water is affected by the vertical distance from the water source to the discharge point in the field, pumping lift, pressure on the discharge side of the pump to ensure proper conveyance through the distribution system, operating pressure, and pumping plant efficiency. Energy requirements decrease as pumping lift and operating pressure decrease and pumping plant efficiency increases. In order to maximize plant efficiency, the components should be matched to the site-specific conditions of total dynamic head, operating pressure, and flow rate.

USE IN ALTERNATIVE EVALUATIONS

The cost curves presented in Appendix A are intended to be used to estimate costs that may be encountered when a treatment process or combination of treatment processes are proposed to be used to reach required levels of treatment most effectively. The information provided for each treatment alternative can be used as a guide to the function for improving water quality, as well as the costs associated with its use. The source water quality should be taken into consideration prior to selection of a treatment method to ensure that the final water product will be suitable for its intended use. The treatment processes and facilities described in this report are considered viable options to be considered in planning for water supply systems in the Southeastern Wisconsin Region.

Table 57

ELECTRICITY REQUIREMENTS FOR SURFACE WATER TREATMENT FACILITIES

Treatment Process	Energy Requirement (kWh per day)					
	1 MGD	5 MGD	10 MGD	20 MGD	50 MGD	100 MGD
Raw Water Pumping	121	602	1,205	2,410	6,027	12,055
Rapid Mixing	41	176	308	616	1,540	3,080
Flocculation	10	51	90	181	452	904
Sedimentation	14	44	88	175	438	876
Alum Feed System	9	10	10	20	40	80
Polymer Feed System	47	47	47	47	47	47
Lime Feed System	9	11	12	13	15	16
Filter Surface Wash Pumps	8	40	77	153	383	767
Backwash Water Pumps	13	62	123	246	657	1,288
Treated Water Pumping	1,205	6,027	12,055	24,110	60,273	120,548
Chlorination	2	2	2	2	4	8
Ozonation	269	1,345	2,690	5,380	13,450	26,900
UV Disinfection						
Low Power Output	50	250	500	1,000	2,500	5,000
Medium Power Output	150	750	1,500	3,000	7,500	15,000
Microfiltration	252	1,260	2,520	5,040	12,600	25,200
Ultrafiltration	950	4,750	9,500	19,000	47,500	95,000
Residuals Pumping	4	20	40	80	200	400
Thickened Solids Pumping	N/A	N/A	N/A	123	308	616

Source: Electric Power Research Institute, CR-106941, Water and Wastewater Industries: Characteristics and Energy Management Opportunities, *1996; T. Elliot, B. Zeier, I. Xagoraraki, and G.W. Harrington,* Energy Use at Wisconsin's Drinking Water Utilities*, University of Wisconsin Department of Civil and Environmental Engineering, Energy Center of Wisconsin, Wisconsin Focus on Energy, July 2002; E.D. Mackey, R.S. Cushing, and G.F. Crozes,* Practical Aspects of UV Disinfection for the Inactivation of Cryptosporidium*, American Water Works Association Research Foundation, Electric Power Research Institute, Energy Center of Wisconsin, North Shore Water Commission (Glendale, WI), 2002.*

Table 58

ELECTRICITY REQUIREMENTS FOR GROUNDWATER TREATMENT FACILITIES

Treatment Process	Energy Requirement (kWh per day)			
	1 MGD	5 MGD	10 MGD	20 MGD
Well Pumping	605	3,025	6,050	12,100
Chlorination	9	45	93	186
Booster Pumping	1,210	6,050	12,100	24,200

Source: Electric Power Research Institute, 1996.

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APPENDICES

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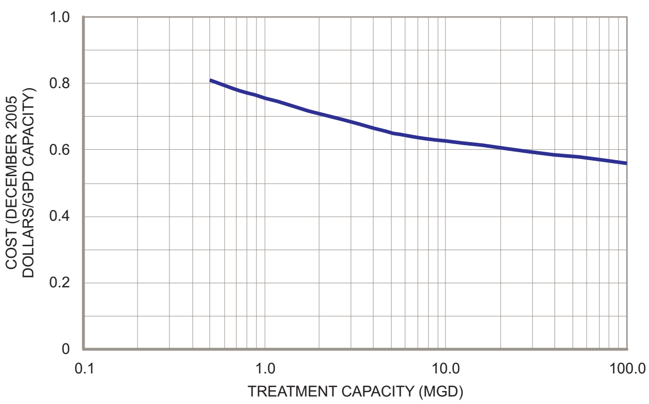
Appendix A

COST CURVES FOR WATER SUPPLY PROCESSES

Figure A-1

ESTIMATED CAPITAL COST FOR WATER PUMPING



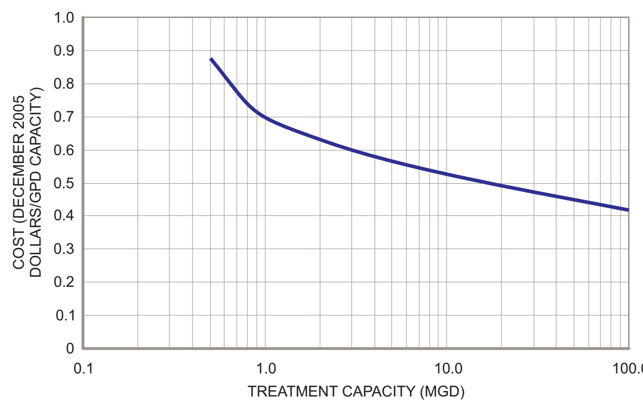
NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT.

Source: Ruekert & Mielke Inc. and SEWRPC.

OPERATION AND MAINTENANCE COST FOR PUMPING ARE ESTIMATED FOR PLANNING PURPOSES AT $600 PER MG PUMPED FOR OVER THE RANGE OF FACILITY SIZES.

Figure A-2

ESTIMATED CAPITAL COST FOR COAGULATION, FLOCCULATION, AND SEDIMENTATION

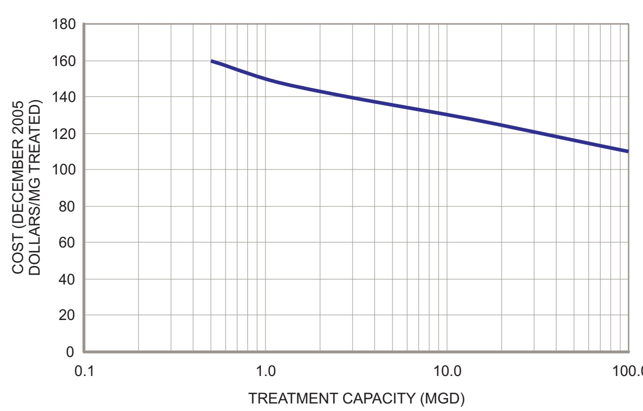


NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT.

Source: Ruekert & Mielke Inc. and SEWRPC.

Figure A-3

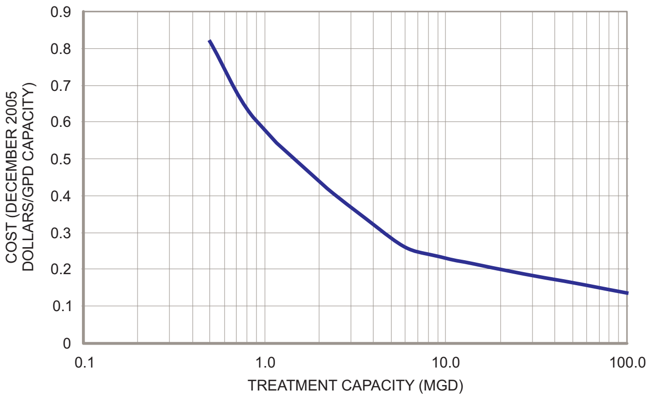
ESTIMATED OPERATIONS AND MAINTENANCE COST FOR COAGULATION, FLOCCULATION AND SEDIMENTATION



Source: Ruekert & Mielke Inc. and SEWRPC.

Figure A-4

ESTIMATED CAPITAL COST FOR RAPID SAND FILTRATION

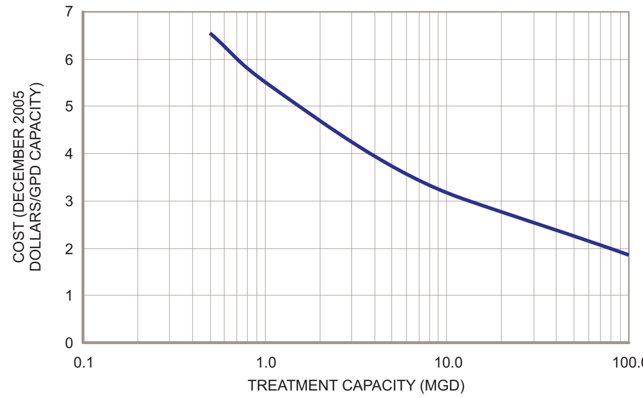


NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT.

Source: Ruekert & Mielke Inc. and SEWRPC.

Figure A-6

ESTIMATED CAPITAL COST FOR ACTIVATED CARBON FILTRATION

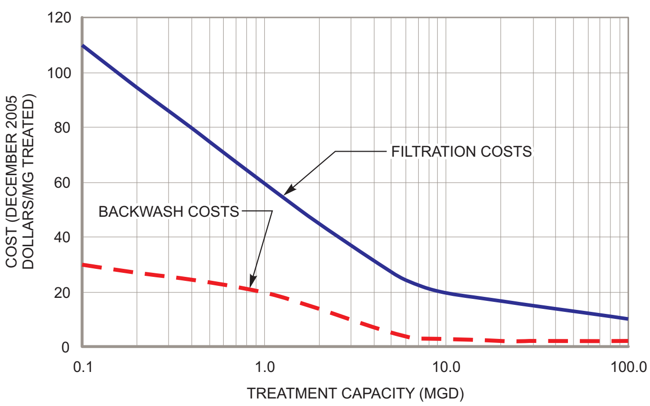


NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT.

Source: Ruekert & Mielke Inc. and SEWRPC.

Figure A-5

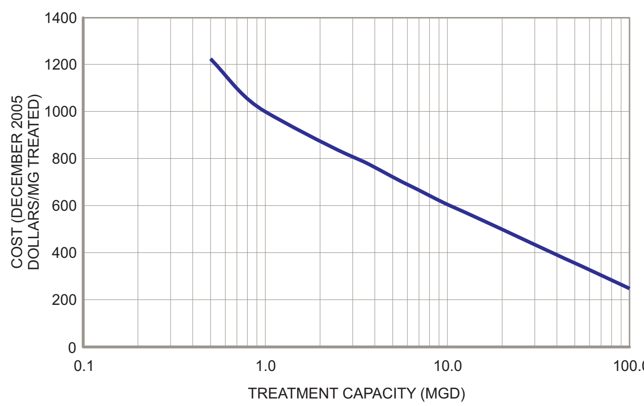
ESTIMATED OPERATIONS AND MAINTENANCE COST FOR RAPID SAND FILTRATION



Source: Ruekert & Mielke Inc. and SEWRPC.

Figure A-7

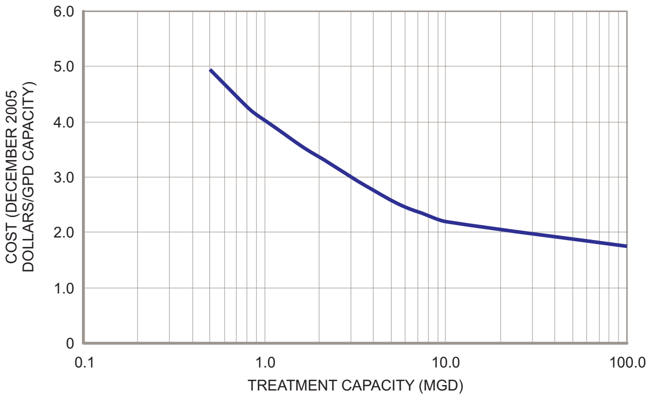
ESTIMATED OPERATIONS AND MAINTENANCE COST FOR ACTIVATED CARBON FILTRATION



Source: Ruekert & Mielke Inc. and SEWRPC.

Figure A-8

ESTIMATED CAPITAL COST FOR MEMBRANE FILTRATION

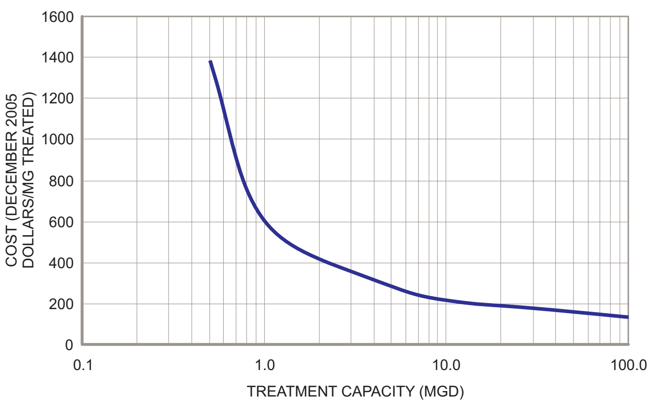


NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT.

Source: Ruekert & Mielke Inc.,AWWA, Membrane Practices for Water Treatment, 2001, and SEWRPC.

Figure A-9

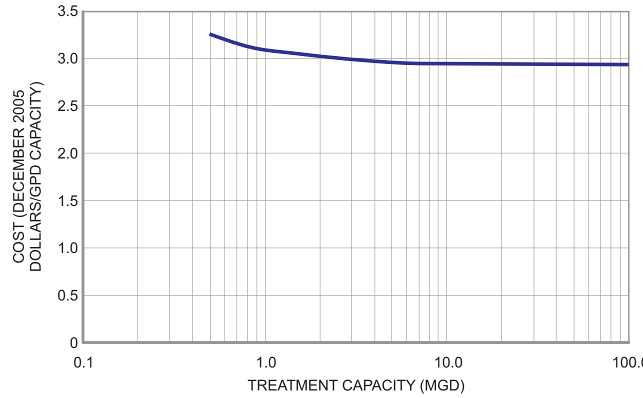
ESTIMATED OPERATIONS AND MAINTENANCE COST FOR MEMBRANE FILTRATION



Source: Ruekert & Mielke Inc.,AWWA, Membrane Practices for Water Treatment, 2001, and SEWRPC.

Figure A-10

ESTIMATED CAPITAL COST FOR ELECTRODIALYSIS REVERSAL

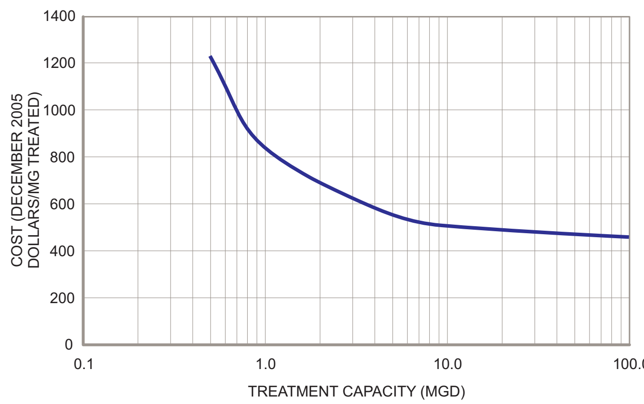


NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT.

Source: Ruekert & Mielke Inc. and SEWRPC.

Figure A-11

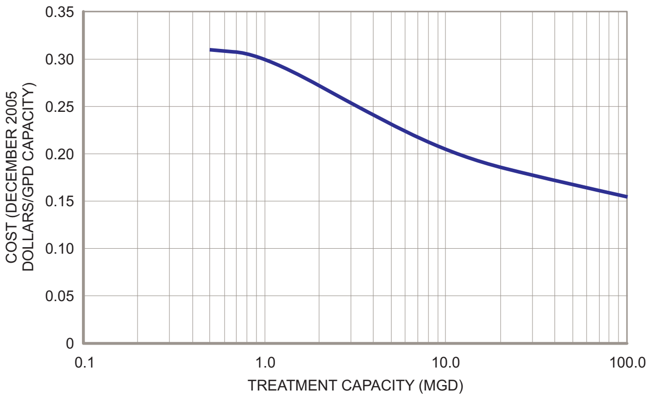
ESTIMATED OPERATIONS AND MAINTENANCE COST FOR ELECTRODIALYSIS REVERSAL



Source: Ruekert & Mielke Inc. and SEWRPC.

Figure A-12

ESTIMATED CAPITAL COST FOR PACKED TOWER AERATION

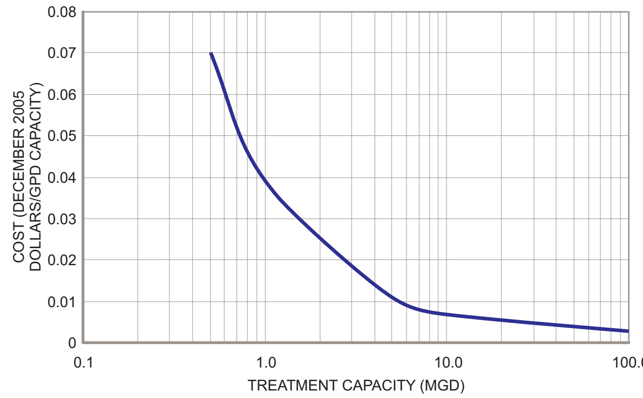


NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT.

Source: Ruekert & Mielke Inc., Duranceau, 2004, and SEWRPC.

Figure A-14

ESTIMATED CAPITAL COST FOR CHLORINATION

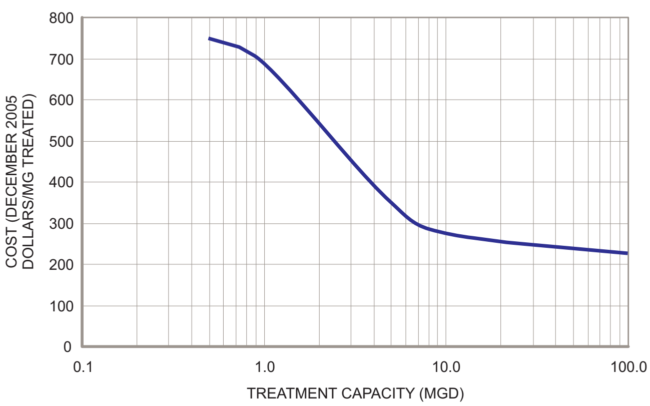


NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT.

Source: Ruekert & Mielke Inc. and SEWRPC.

Figure A-13

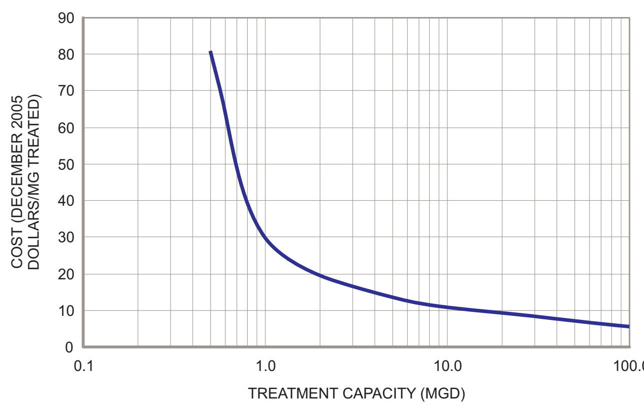
ESTIMATED OPERATIONS AND MAINTENANCE COST FOR PACKED TOWER AERATION



Source: Ruekert & Mielke Inc., Duranceau, 2004, and SEWRPC.

Figure A-15

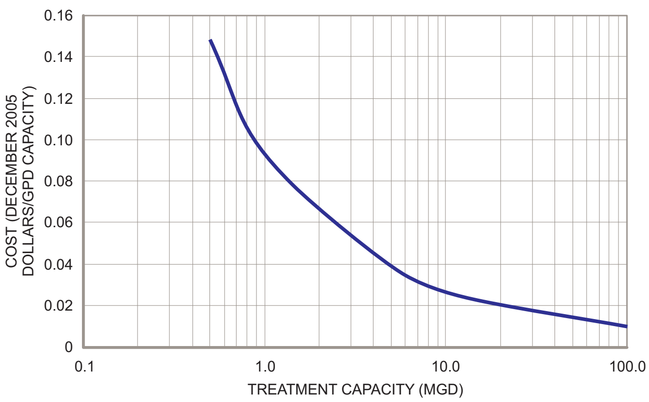
ESTIMATED OPERATIONS AND MAINTENANCE COST FOR CHLORINATION



Source: Ruekert & Mielke Inc. and SEWRPC.

Figure A-16

ESTIMATED CAPITAL COST FOR CHLORAMINATION

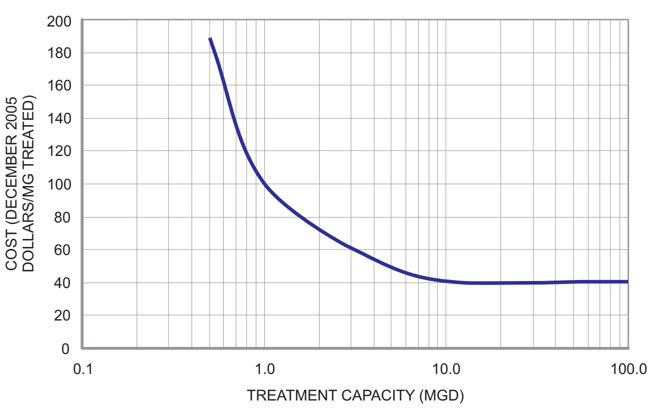


NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT.

Source: Ruekert & Mielke Inc.,AWWA, Membrane Practices for Water Treatment, 2001, and SEWRPC.

Figure A-17

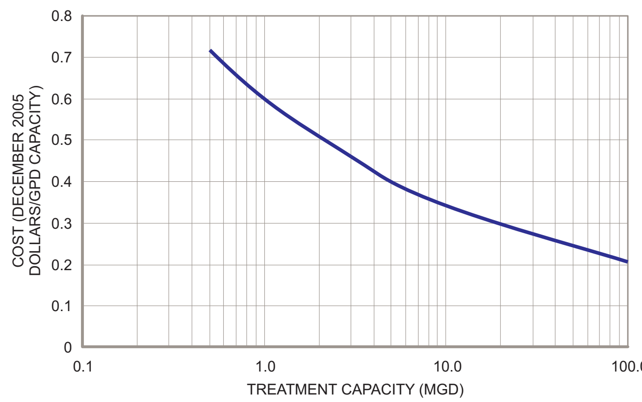
ESTIMATED OPERATIONS AND MAINTENANCE COST FOR CHLORAMINATION



Source: Ruekert & Mielke Inc.,AWWA, Membrane Practices for Water Treatment, 2001, and SEWRPC.

Figure A-18

ESTIMATED CAPITAL COST FOR OZONATION

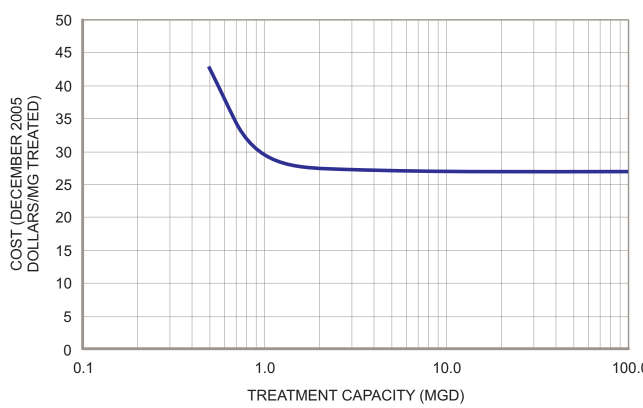


NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT.

Source: Ruekert & Mielke Inc. and SEWRPC.

Figure A-19

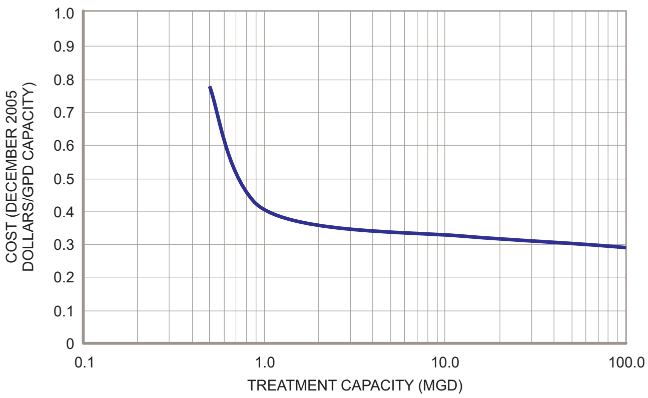
ESTIMATED OPERATIONS AND MAINTENANCE COST FOR OZONATION



Source: Ruekert & Mielke Inc. and SEWRPC.

Figure A-20

ESTIMATED CAPITAL COST FOR ULTRAVIOLET DISINFECTION

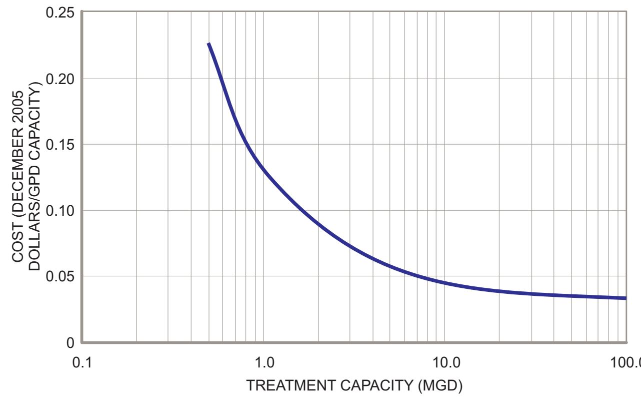


NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT.

Source: Ruekert & Mielke Inc., Duranceau, 2004, and SEWRPC.

Figure A-21

ESTIMATED CAPITAL COST FOR CHEMICAL ADDITION



NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT

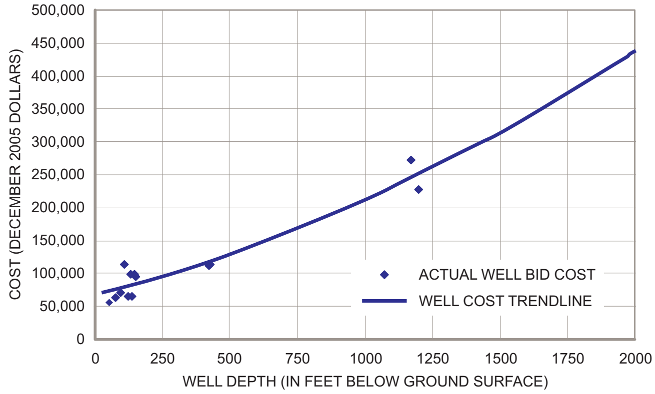
Source: Ruekert & Mielke Inc. and SEWRPC.

OPERATION AND MAINTENANCE COST ESTIMATES FOR ULTRAVIOLET DISINFECTION VARY BETWEEN $38 AND $200 PER MGD TREATMENT CAPACITY.

OPERATION AND MAINTENANCE COST ESTIMATES FOR CHEMICAL ADDITION VARY GREATLY DEPENDING ON THE TYPE AND QUANTITY OF CHEMICAL USED FOR EACH TREATMENT APPLICATION.

Figure A-22

WELL CONSTRUCTION COST vs. DEPTH - BASED UPON RECENT BID DATA FROM SOUTHEASTERN WISCONSIN

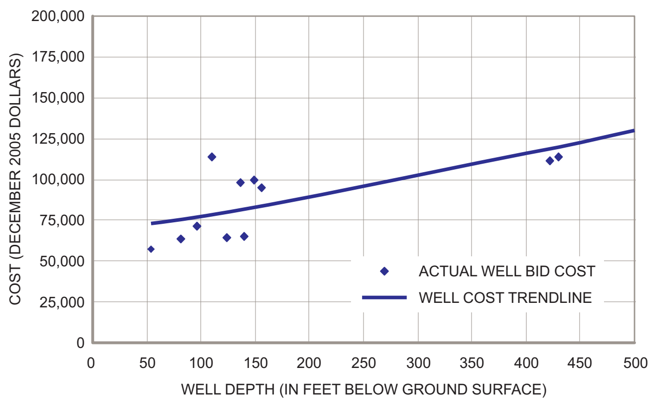


NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT.

Source: Ruekert & Mielke Inc. and SEWRPC.

Figure A-23

WELL CONSTRUCTION COST vs. DEPTH - BASED UPON RECENT BID DATA FROM SOUTHEASTERN WISCONSIN (WELLS LESS THAN 500 FEET)

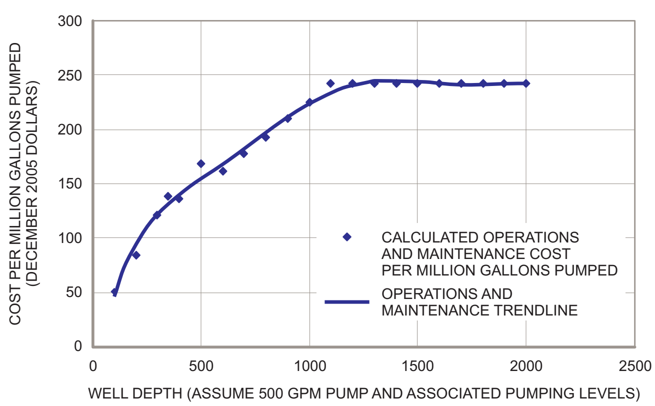


NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT.

Source: Ruekert & Mielke Inc. and SEWRPC.

Figure A-24

WELL OPERATIONS AND MAINTENANCE COST vs. DEPTH - BASED UPON ELECTRIC RATES AND WAGES FROM SOUTHEASTERN WISCONSIN



NOTE: ALL CAPITAL COSTS INCLUDE ENGINEERING, ADMINISTRATION, LEGAL, AND CONTINGENCIES AT 35 PERCENT.

Source: Ruekert & Mielke Inc. and SEWRPC.

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Appendix B

COST ANALYSIS FOR WATER CONSERVATION MODELS

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Southeastern WI Community with Population 3,000

Calculations (Page 1)

Redesign of Water Bill & Limited Public Education Program:

High: Assume 5% reduction in residential water use (Burton & Associates, 1999).
Adjusted to 3% reduction in SE WI with 60% of residences effectively impacted.
40 MG/yr x 0.03 = **1.2 MG/yr savings**

Low: Assume 1% reduction in residential water use where bills have been redesigned.
40 MG/yr x 0.01 = **0.4 MG/yr savings**

Cost: $0.10 per bill + $1,000 initial consultant cost + $100/yr for educational materials.
($0.10 x 600) + $1,000 + $1,000 = $2,060/10 years = **$206/yr**

Distribution of Information:

High: Assume 5% reduction in residential water use (Burton & Associates, 1999).
Adjusted to 3% reduction in SE WI with 60% of residences effectively impacted.
40 MG/yr x 0.03 = **1.2 MG/yr savings**

Low: Assume 1.5% reduction in residential water use where current practice is to provide some information.
40 MG/yr x 0.015 = **0.6 MG/yr savings**

Cost: Estimate $1.50 per brochure for paper and printing.
$1.50 x 600 = **$900/yr**

Water Accounting:

Assume no direct water savings or cost as this is a current practice in most communities.

Plumbing Retrofits (at no cost to customers):

High: 50% participation rate due to lack of cost and distribution by mail (GDS Associates, 2001/Vickers, 2001).
Adjusted to 30% due to existing newer toilets in many homes where toilet displacement devices are not practical.
Assume that 100% of households who receive kits will install kit components and will not remove them later.
Assume 50% of residential use is from plumbing & fixture water use (Vickers, 2001).
Assume 20% reduction in residential plumbing & fixture water use (USEPA, 1998).
40 MG/yr x 0.50 x 0.30 x 0.20 x 1 = **1.2 MG/yr savings**

Cost: $12 per kit (Vickers, 2001) + fixed cost of $1,000 over 10 years (or $100/yr).
($12 x 600 x 0.30) + $1,000 = $3,160/10 years = **$316/yr**

Low: Assume 20% participation rate due to high level of prior retrofits.
Assume that 50% of households who receive kits will install kit components and will not remove them later.
Assume 50% of residential use is from plumbing & fixture water use.
Assume 20% reduction in residential plumbing & fixture water use.
40 MG/yr x 0.20 x 0.50 x 0.20 x 0.50 = **0.4 MG/yr savings**

Cost: $12 per kit (Vickers, 2001) + fixed cost of $1,000 over 10 years (or $100/yr).
($12 x 600 x 0.20) + $1,000 = $2,440/10 years = **$244/yr**

Water Conserving Rate Structure:

High: Assume 5% reduction in total water use (USEPA, 1998).
50 MG/yr x 0.05 = **2.5 MG/yr savings**

Low: Assume 2% reduction in total water use with less effective revised structure.
50 MG/yr x 0.02 = **1 MG/yr savings**

Cost: Assume 100 hours of labor + $5,000 for consulting services.
($65/hr x 100 hrs) + $5,000 = $11,500/10 years = **$1,150/yr**

Southeastern WI Community with Population 3,000

Calculations (page 2)

Utility System Water Audit/Leak Detection & Repair:

High: Assume 5% reduction in total water use based on average of 12% unaccounted for water (Burton & Associates, 1999)
Adjusted to 2.5% due to ongoing programs in most communities.
50 MG/yr x 0.025 = **1.3 MG/yr savings**

Low: Assume 1% additional reduction in total water use based on ave of 12% unaccounted for water and ongoing programs.
50 MG/yr x 0.01 = **0.5 MG/yr savings**

Cost: Equipment and labor for audit, repair, and detection = $300/mile (A&N Technical Services, 2005).
$300/mile x 15 miles = **$4,500/yr**

Landscape Watering Ordinance:

High: Assume 30% of total residential water use is from outdoor use (Vickers, 2001).
Adjusted to 15% for Wisconsin climate.
Assume 100% participation due to fines for noncompliance.
Assume 20% reduction in residential outdoor water use (USEPA, 1998).
40 MG/yr x 0.15 x 0.20 x 1 = **1.2 MG/yr savings**

Low: Assume 15% of total residential water use is from outdoor use.
Assume 50% participation due to fines for noncompliance and increased use on allowed days.
Assume 10% reduction in residential outdoor water use.
40 MG/yr x 0.15 x 0.10 x 0.50 = **0.3 MG/yr savings**

Cost: Field Technician Wages for summer month enforcement ($12/hr).
$12/hr x 1 employee x 4 hrs/day x 5 days/week x 14 weeks/yr = **$3,360/yr**

Toilet Replacement Rebate:

High: Assume that first 20 customers will be eligible for rebate, and at least 20 will participate.
Assume that 100% of households who install toilets will not remove them later.
Assume 85% of total residential water use is indoor use (SEWRPC, 2006).
Assume 27% of total indoor residential water use is from toilets (Vickers, 2001).
Assume water savings doubles second year, triples third year, etc. due to addition of new participants.
40 MG/yr x (20/600) x 0.85 x 0.27 = 0.3 MG (first year) savings = **1.65 MG/yr average savings**

Cost: $95 per rebate (Vickers, 2001).
$95 x 20 = **$1,900/yr**

Low: Assume that first 20 customers will be eligible for rebate, and at least 10 will participate.
Assume that 50% of households who install toilets will not remove them later.
Assume 85% of total residential water use is indoor use (SEWRPC, 2006).
Assume 27% of total indoor residential water use is from toilets (Vickers, 2001).
Assume water savings doubles second year, triples third year, etc. due to addition of new participants.
40 MG/yr x (10/600) x 0.85 x 0.27 x 0.50 = 0.1 MG (first year) savings = **0.66 MG/yr average savings**

Cost: $95 per rebate (Vickers, 2001).
$95 x 10 = **$950/yr**

Conservation Related Staff

Assume no direct water savings.

Cost: Assume 400 hours of labor.
$65/hr x 400 hours x 1 employee = **$26,000/yr**

Southeastern WI Community with Population 3,000

Example Conservation Plans by Level

Conservation Level	Conservation Measure	Water Savings* (MG/yr)		Estimated Cost per Year to Utility*		Description
		Low	High	Low	High	
Low	Redesign of Water Bill & Limited Public Education Program	0.4	1.2	$206	$206	Restructure water bill to be more understandable to the consumer and to include water usage in detail.
	Distribution of Information	0.6	1.2	$900	$900	Make pamphlets available to public and include bill inserts on importance of conservation.
	Water Accounting	N/A	N/A	N/A	N/A	Implement a basic system of water accounting to provide basis for loss control over time.
	Low Level Totals:	**2%**	**5%**	**$1,106**	**$1,106**	
Intermediate	Low Level Measures	1.0	2.4	$1,106	$1,106	Includes all low level measures.
	Plumbing Retrofits	0.4	1.2	$244	$316	Advertise plumbing retrofit kits to customers at a no cost.
	Water Conserving Rate Structure	1	2.5	$1,150	$1,150	Implement water conserving rate structure to promote efficient use of water.
	Intermediate Level Totals:	**5%**	**12%**	**$2,500**	**$2,572**	
Advanced	Intermediate Level Measures	2.4	6.1	$2,500	$2,572	Includes all intermediate level measures.
	Utility System Water Audit/Leak Detection & Repair	0.5	1.3	$4,500	$4,500	Audit to assist tracking of nonaccount water use and detect and repair obvious leaks.
	Landscape Watering Ordinance	0.3	1.2	$3,360	$3,360	Implement ordinance limiting days and/or times for customers to water outdoors.
	Toilet Replacement Rebate	0.7	1.7	$950	$1,900	Offer rebates to first 20 customers to install low-flow toilets.
	Conservation Related Staff	N/A	N/A	$26,000	$26,000	Staff to assist in updating and maintaining the conservation plan selected.
	Advanced Level Totals:	**8%**	**20%**	**$37,310**	**$38,332**	

Assumptions:
Total Water Consumption = 50 MG/yr
Total Residential Water Consumption = 40 MG/yr
Number of Residential Customers = 600
Energy & Chemical Operation & Maintenance Expenses = $16,000/yr
Miles of watermains in system = 15 miles
Life of conservation plan = 10 years

*Estimates of water savings and costs to utilities are variable and are only used for an estimate. High level water savings were estimated using values cited in literature research. Low level savings are conservative values based on the assumption that values located in literature are the maximum potential savings.

It is important to note that some communities may have conservation plans in effect to some degree, and costs may reflect this. Not all communities will select the same combination of conservation programs.

Southeastern WI Community with Population 70,000

Calculations (Page 1)

Redesign of Water Bill & Limited Public Education Program:

High: Assume 5% reduction in residential water use (Burton & Associates, 1999).
Adjusted to 3% reduction in SE WI with 60% of residences effectively impacted.
2,000 MG/yr x 0.03 = **60 MG/yr savings**

Low: Assume 1% reduction in residential water use where bills have been redesigned.
2,000 MG/yr x 0.01 = **20 MG/yr savings**

Cost: $0.10 per bill + $1,000 initial consultant cost + $100/yr for educational materials.
($0.10 x 16,500) + $1,000 + $1,000 = $3,650/10 years = **$365/yr**

Distribution of Information:

High: Assume 5% reduction in residential water use (Burton & Associates, 1999).
Adjusted to 3% reduction in SE WI with 60% of residences effectively impacted.
2,000 MG/yr x 0.03 = **60 MG/yr savings**

Low: Assume 1.5% reduction in residential water use where current practice is to provide some information.
2,000 MG/yr x 0.015 = **30 MG/yr savings**

Cost: Estimate $1.50 per brochure for paper and printing.
$1.50 x 16,500 = **$24,750/yr**

Water Conserving Rate Structure:

High: Assume 5% reduction in total water use (USEPA, 1998).
2,750 MG/yr x 0.05 = **138 MG/yr savings**

Low: Assume 2% reduction in total water use with less effective revised structure.
2,750 MG/yr x 0.02 = **55 MG/yr savings**

Cost: Assume 100 hours of labor + $5,000 for consulting services.
($65/hr x 100 hrs) + $5,000 = $11,500/10 yrs = **$1,150/yr**

Water Accounting:

Assume no direct water savings or cost as this is a current practice in most communities.

Plumbing Retrofits (at no cost to customers):

High: 50% participation rate due to lack of cost and distribution by mail (GDS Associates, 2001/Vickers, 2001).
Adjusted to 30% due to existing newer toilets in many homes where toilet displacement devices are not practical.
Assume that 100% of households who receive kits will install kit components and will not remove them later.
Assume 50% of residential use is from plumbing & fixture water use (Vickers, 2001).
Assume 20% reduction in residential plumbing & fixture water use (USEPA, 1998).
2,000 MG/yr x 0.20 x 1 x 0.50 x 0.30 = **60 MG/yr savings**

Cost: $12 per kit (Vickers, 2001) + fixed cost of $1,000 over 10 years (or $100/yr).
($12 x 16,500 x 0.30) + $1,000 = $60,400/10 years = **$6,040/yr**

Low: Assume 20% participation due to high level of prior retrofits.
Assume that 50% of households who receive kits will install kit components and will not remove them later.
Assume 20% reduction in residential plumbing & fixture water use.
Assume 50% of residential use is from plumbing & fixture water use.
2,000 MG/yr x 0.20 x 0.20 x 0.50 x 0.50 = **20 MG/yr savings**

Cost: $12 per kit (Vickers, 2001) + fixed cost of $1,000 over 10 years (or $100/yr).
($12 x 16,500 x 0.20) + $1,000 = $40,600/10 years = **$4,060/yr**

Southeastern WI Community with Population 70,000

Calculations (Page 2)

Landscape Watering Ordinance:

High: Assume 30% of total residential water use is from outdoor use (Vickers, 2001).
Adjusted to 15% for Wisconsin climate.
Assume 100% participation due to fines for noncompliance.
Assume 20% reduction in residential outdoor water use (USEPA, 1998).
2,000 MG/yr x 0.15 x 0.20 = **60 MG/yr savings**

Low: Assume 15% of total residential water use is from outdoor use.
Assume 50% participation due to noncompliance and increased use on allowed days.
Assume 10% reduction in residential outdoor water use.
2,000 MG/yr x 0.15 x 0.50 x 0.10 = **15 MG/yr savings**

Cost: Field Technician Wages for summer month enforcement ($12/hr)
$12/hr x 1 employees x 4 hrs/day x 5 days/week x 14 weeks/yr = **$3,360/yr**

Utility System Water Audit/Leak Detection & Repair:

High: Assume 5% reduction in total water use based on average of 12% unaccounted for water (Burton & Associates, 1999)
Adjusted to 2.5% due to ongoing programs in most communities.
2,750 MG/yr x 0.025 = **69 MG/yr savings**

Low: Assume 1% reduction in total water use based on average of 12% unaccounted for water and ongoing programs.
2,750 MG/yr x 0.01 = **28 MG/yr savings**

Cost: Equipment and labor for audit, repair, and detection = $300/mile (A&N Technical Services, 2005).
$300/mile x 300 miles = **$90,000/yr**

Toilet Replacement Rebate:

High: Assume that first 250 customers will be eligible for rebate, and at least 250 will participate.
Assume that 100% of households who install toilets will not remove them later.
Assume 85% of total residential water use is indoor use (SEWRPC, 2006).
Assume 27% of total indoor residential water use is from toilets (Vickers, 2001).
Assume water savings doubles second year, triples third year, etc. due to addition of new participants.
2,000 MG/yr x (250/16,500) x 1 x 0.85 x 0.27 = 7 MG (first year) savings = **38.5 MG/year average savings**

Cost: $95 per rebate (Vickers, 2001).
$95 x 250 = **$23,750/yr**

Low: Assume that first 250 customers will be eligible for rebate, and at least 200 will participate.
Assume that 50% of households who install toilets will not remove them later.
Assume 85% of total residential water use is indoor use.
Assume 27% of total indoor residential water use is from toilets.
Assume water savings doubles second year, triples third year, etc. due to addition of new participants.
2,000 MG/yr x (200/16,500) x 0.85 x 0.27 x 0.50 = 3 MG (first year) savings = **16.5 MG/yr average savings**

Cost: $95 per rebate (Vickers, 2001).
$95 x 200 = **$19,000/yr**

Conservation Related Staff:

Assume no direct water savings.

Cost: Assume 400 hours of labor.
$65/hr x 400 hrs x 1 employee = **$26,000/yr**

Southeastern WI Community with Population 70,000

Example Conservation Plans by Level

Conservation Level	Conservation Measure	Water Savings* (MG/yr)		Estimated Cost per Year to Utility*		Description
		Low	High	Low	High	
Low	Redesign of Water Bill & Limited Public Education Program	20	60	$365	$365	Restructure water bill to be more understandable to the consumer and to include water usage in detail.
	Distribution of Information/Campaigns for Water Conservation	30	60	$24,750	$24,750	Make pamphlets available to public and include bill inserts on importance of conservation. Include media (TV, radio, advertisements).
	Water Conserving Rate Structure	55	138	$1,150	$1,150	Implement a water conserving rate structure to promote efficient use of water.
	Water Accounting	N/A	N/A	N/A	N/A	Implement a basic system of water accounting to provide basis for loss control over time.
	Low Level Totals:	**4%**	**9%**	**$26,265**	**$26,265**	
Intermediate	Low Level Measures	105	258	$26,265	$26,265	Includes all low level measures.
	Plumbing Retrofits	20	60	$4,060	$6,040	Advertise plumbing retrofit kits to customers at no cost.
	Landscape Watering Ordinance	15	60	$3,360	$3,360	Implement ordinance limiting days and/or times for customers to water outdoors.
	Intermediate Level Totals:	**5%**	**14%**	**$33,685**	**$35,665**	
Advanced	Intermediate Level Measures	140	378	$33,685	$35,665	Includes all intermediate level measures.
	Utility System Water Audit/Leak Detection & Repair	28	69	$90,000	$90,000	Audit to assist tracking of nonaccount water use and repair obvious leaks.
	Toilet Replacement Rebate	17	39	$19,000	$23,750	Offer rebates to first 250 customers to install low-flow toilets.
	Conservation Related Staff	N/A	N/A	$26,000	$26,000	Staff to assist in updating and maintaining the conservation plan selected.
	Advanced Level Totals:	**7%**	**18%**	**$168,685**	**$175,415**	

Assumptions:
- Total Water Consumption = 2,750 MG/yr
- Total Residential Water Consumption = 2,000 MG/yr
- Number of Residential Customers = 16,500
- Energy & Chemical Operation & Maintenance Expenses = $675,000/yr
- Miles of watermains in system = 300 miles
- Life of conservation plan = 10 years

*Estimates of water savings and costs to utilities are variable and are only used for an estimate. High level water savings were estimated using values cited in literature research. Low level savings are conservative values based on the assumption that values located in literature are the maximum potential savings.

It is important to note that some communities may have conservation plans in effect to some degree, and costs may reflect this. Not all communities will select the same combination of conservation programs.

Southeastern WI Community with Population 600,000

Calculations (Page 1)

Redesign of Water Bill & Limited Public Education Program:

High: Assume 5% reduction in residential water use (Burton & Associates, 1999).
Adjusted to 3% reduction in SE WI with 60% of residences effectively impacted.
13,000 MG/yr x 0.03 = **390 MG/yr savings**

Low: Assume 1% reduction in residential water use where bills have been redesigned.
13,000 MG/yr x 0.01 = **130 MG/yr savings**

Cost: $0.10 per bill + $1,000 initial consultant cost + $100/yr for educational materials.
($0.10 x 145,000) + $1,000 + $1,000 = $16,500/10 years = **$1,650/yr**

Distribution of Information:

High: Assume 5% reduction in residential water use (Burton & Associates, 1999).
Adjusted to 3% reduction in SE WI with 60% of residences effectively impacted.
13,000 MG/yr x 0.03 = **390 MG/yr savings**

Low: Assume 1.5% reduction in residential water use where current practice is to provide some information.
13,000 MG/yr x 0.015 = **195 MG/yr savings**

Cost: Estimate $1.50 per brochure for paper and printing and $50,000 budget for media over 10 years.
($1.50 x 145,000) + $50,000/10 years = **$222,500/yr**

Water Conserving Rate Structure:

High: Assume 5% reduction in total water use (USEPA, 1998).
40,000 MG/yr x 0.05 = **2,000 MG/yr savings**

Low: Assume 2% reduction in total water use with less effective revised structure.
40,000 MG/yr x 0.02 = **800 MG/yr savings**

Cost: Assume 100 hours of labor + $5,000 for consulting services.
($65/hr x 100 hrs) + $5,000 = $11,500/10 yrs = **$1,150/yr**

Water Accounting:

Assume no direct water savings or cost as this is a current practice in most communities.

Plumbing Retrofits:

High: Assume 50% participation due to price and lack of distribution (Vickers, 2001).
Adjusted to 30% due to existing newer toilets in many homes where toilet displacement devices are not practical.
Assume that 100% of households who receive kits will install kit components and will not remove them later.
Assume 20% reduction in residential plumbing & fixture water use (USEPA, 1998).
Assume 50% of residential use is from plumbing & fixture water use (Vickers, 2001).
13,000 MG/yr x 1 x 0.20 x 0.30 x 0.50 = **390 MG/yr savings**

Cost: $12 per kit (Vickers, 2001) + fixed cost of $1,000 over 10 years (or $100/yr).
($12 x 145,000 x 0.30) + $1,000 = $523,000/10 years = **$52,300/yr**

Low: Assume 20% participation due to high level of prior retrofits.
Assume that 50% of households who receive kits will install kit components and will not remove them later.
Assume 20% reduction in residential plumbing & fixture water use.
Assume 50% of residential use is from plumbing & fixture water use.
13,000 MG/yr x 0.20 x 0.20 x 0.50 x 0.50 = **130 MG/yr savings**

Cost: $12 per kit (Vickers, 2001) + fixed cost of $1,000 over 10 years (or $100/yr).
($12 x 145,000 x 0.20) + $1,000 = $349,000/10 years = **$34,900/yr**

Southeastern WI Community with Population 600,000

Calculations (Page 2)

Landscape Watering Ordinance:

High: Assume 30% of total residential water use is from outdoor use (Vickers, 2001).
Adjusted to 15% for Wisconsin climate.
Assume 100% participation due to fines for noncompliance.
Assume 20% reduction in outdoor water use (USEPA, 1998).
40,000 MG/yr x 0.15 x 1 x 0.20 = **1,200 MG/yr savings**

Low: Assume 15% of total water use is from outdoor use.
Assume 50% participation due to noncompliance.
Assume 10% reduction in outdoor water use.
40,000 MG/yr x 0.15 x 0.10 x 0.5 = **300 MG/yr savings**

Cost: Field Technician Wages for summer month enforcement ($12/hr).
$12/hr x 5 employees x 4 hrs/day x 5 days/week x 14 weeks/yr = **$16,800/yr**

Toilet Replacement Rebate:

High: Assume that first 5,000 customers will be eligible for rebate, and at least 5,000 will participate.
Assume that 100% of households who install toilets will not remove them later.
Assume 85% of total residential water use is indoor use (SEWRPC, 2006).
Assume 27% of total indoor residential water use is from toilets (Vickers, 2001).
Assume water savings doubles second year, triples third year, etc. due to addition of new participants.
13,000 MG/yr x (5,000/145,000) x 0.85 x 0.27 x 1 = 103 MG/yr savings = **566.5 MG/yr average savings**
Cost: $95 per rebate (Vickers, 2001).
$95 x 5,000 = **$475,000/yr**

Low: Assume that first 5,000 customers will be eligible for rebate, and at least 3,500 will participate.
Assume that 50% of households install toilets will not remove them later.
Assume 85% of total residential water use is indoor use.
Assume 27% of total indoor residential water use is from toilets.
Assume water savings doubles second year, triples third year, etc. due to addition of new participants.
13,000 MG/yr x (3,500/145,000) x 0.85 x 0.27 x 0.50 = 36 MG (first year) savings = **198 MG/yr average savings**

Cost: $95 per rebate (Vickers, 2001).
$95 x 3,500 = **$332,500/yr**

Utility System Water Audit/Leak Detection & Repair:

High: Assume 5% reduction in total water use based on average of 12% unaccounted for water (Burton & Associates, 1999).
Adjusted to 2.5% due to ongoing programs in most communities.
40,000 MG/yr x 0.025 = **1,000 MG/yr savings**

Low: Assume 1% reduction in total water use based on average of 12% unaccounted for water and ongoing programs.
40,000 MG/yr x 0.01 = **400 MG/yr savings**

Cost: Equipment and labor for audit, repair, and detection = $300/mile (A&N Technical Services, 2005).
$300/mile x 2,000 miles = **$600,000/yr**

Commercial/Industrial & Public Use Metering:

High: Assume 1% of commercial/industrial & public use water usage is not metered.
Assume 20% reduction in unmetered commercial & industrial water use (USEPA, 1998).
27,000 MG/yr x 0.01 x 0.20 = **54 MG/yr savings**

Low: Assume 1% of commercial/industrial & public use water usage is not metered.
Assume 10% reduction in unmetered commercial & industrial water use.
27,000 MG/yr x 0.01 x 0.10 = **27 MG/yr savings**

Cost: $1,000 per meter (Vickers, 2001)
$1,000 x 250 unmetered customers = $250,000/10 years = **$25,000/yr**

Conservation Related Staff:

Assume no direct water savings.

Cost: Salaries of staff.
1 Staff Member x $45,000 per year = **$45,000/yr**

Southeastern WI Community with Population 600,000

Example Conservation Plans by Level

Conservation Level	Conservation Measure	Water Savings* (MG/yr)		Estimated Cost per Year to Utility*		Description
		Low	High	Low	High	
Low	Redesign of Water Bill & Limited Public Education Program	130	390	$1,650	$1,650	Restructure water bill to be more understandable to the consumer and to include water usage in detail.
	Distribution of Information/Campaings for Water Use Reduction	195	390	$222,500	$222,500	Make pamphlets available to public and include bill inserts on importance of conservation. Devote funds to media (TV, radio, etc.) education.
	Water Conserving Rate Structure	800	2,000	$1,150	$1,150	Implement a water conserving rate structure to promote efficient use of water.
	Water Accounting	N/A	N/A	N/A	N/A	Implement a basic system of water accounting to provide basis for loss control over time.
	Low Level Totals:	**3%**	**7%**	**$225,300**	**$225,300**	
Intermediate	Low Level Measures	1,125	2,780	$225,300	$225,300	
	Plumbing Retrofits	130	390	$34,900	$52,300	Advertise plumbing retrofit kits to customers at no cost.
	Landscape Watering Ordinance	300	1,200	$16,800	$16,800	Implement ordinance limiting days and/or times for customers to water outdoors.
	Toilet Replacement Rebate	198	567	$332,500	$475,000	Offer rebates to first 5,000 customers to install low-flow toilets.
	Intermediate Level Totals:	**4%**	**12%**	**$609,500**	**$769,400**	
Advanced	Intermediate Level Measures	1,753	4,937	$609,500	$769,400	
	Utility System Water Audit/Leak Detection & Repair	400	1,000	$600,000	$600,000	Audit to assist tracking of nonaccount water use and detect & repair leaks.
	Commercial/Industrial & Public Use Metering	27	54	$25,000	$25,000	Installation of meters on unmetered commercial & industrial customers to inform of water usage and to bill customers based on total use.
	Conservation Related Staff	N/A	N/A	$45,000	$45,000	Staff to assist in updating and maintaining the conservation plan selected.
	Advanced Level Totals:	**5%**	**15%**	**$1,279,500**	**$1,439,400**	

Assumptions:
- Total Water Consumption = 40,000 MG/yr
- Total Residential Water Consumption = 13,000 MG/yr
- Number of Residential Customers = 145,000
- Total Industrial & Commercial Water Consumption = 27,000 MG/yr
- Total Unmetered Commercial/Industrial Customers = 250
- Energy & Chemical Operation & Maintenance Expenses = $6,000,000/yr
- Miles of watermains in system = 2,000 miles
- Life of conservation plan = 10 years

*Estimates of water savings and costs to utilities are variable and are only used for an estimate. High level water savings were estimated using values cited in literature research. Low level savings are conservative values based on the assumption that values located in literature are the maximum potential savings.

It is important to note that some communities may have conservation plans in effect to some degree, and costs may reflect this. Not all communities will select the same combination of conservation programs.

Cost Data and Water Savings of Model Conservation Plans

Community Population	Conservation Plan Level	Water Savings per Year (MG)		Cost of Program per Year		Cost of Program per 1000 gal Saved		Net Annual Savings*		Cost to Pump Water per 1000 gal
		Low	High	Low	High	Low	High	Low	High	
3,000	Low	1	2	$1,106	$1,106	$1.106	$0.461	-$786	-$338	$0.320
	Intermediate	2	6	$2,500	$2,572	$1.042	$0.422	-$1,732	-$620	
	Advanced	4	9	$37,310	$38,332	$9.666	$4.483	-$36,075	-$35,596	
70,000	Low	105	258	$26,265	$26,265	$0.250	$0.102	$2,371	$43,962	$0.273
	Intermediate	140	378	$33,685	$35,665	$0.241	$0.094	$4,497	$67,290	
	Advanced	184	485	$168,685	$175,415	$0.917	$0.362	-$118,503	-$43,210	
600,000	Low	1,125	2,780	$225,300	$225,300	$0.200	$0.081	-$21,394	$278,575	$0.181
	Intermediate	1,753	4,937	$609,500	$769,400	$0.348	$0.156	-$291,769	$125,341	
	Advanced	2,180	5,991	$1,279,500	$1,439,400	$0.587	$0.240	-$884,375	-$353,622	

*Annual savings are based on avoided chemical and energy costs associated with pumping and treating water less the cost of the conservation program.

Assumptions: Energy & chemical costs for community of 3,000 = $16,000/yr
Energy & chemical costs for community of 70,000 = $750,000/yr
Energy & chemical costs for community of 600,000 = $7,250,000/yr

Average Cost Data and Water Savings of Model Conservation Plans

Community Population	Conservation Plan Level	Average Water Savings per Year (MG)	Average Percentage of Water Savings	Average Cost of Program per Year	Average Cost of Program per 1000 gal Saved	Average Net Annual Savings*	Cost to Pump Water per 1000 gal
3,000	Low	2	3%	$1,106	$0.783	-$562	$0.320
	Intermediate	4	9%	$2,536	$0.732	-$1,176	
	Advanced	6	14%	$37,821	$7.075	-$35,835	
70,000	Low	181	7%	$26,265	$0.176	$23,167	$0.273
	Intermediate	259	9%	$34,675	$0.168	$35,893	
	Advanced	334	12%	$172,050	$0.639	-$80,857	
600,000	Low	1,953	5%	$225,300	$0.141	$128,591	$0.181
	Intermediate	3,345	8%	$689,450	$0.252	-$83,214	
	Advanced	4,085	10%	$1,359,450	$0.414	-$618,998	

*Annual savings are based on avoided chemical and energy costs associated with pumping and treating water less the cost of the conservation program.

Assumptions: Energy & chemical costs for community of 3,000 = $16,000/yr
Energy & chemical costs for community of 70,000 = $750,000/yr
Energy & chemical costs for community of 600,000 = $7,250,000/yr

Note: Avoided capital costs are difficult to estimate since water systems differ from community to community. For each community, factors such as the need for increased infrastructure, the location of new water sources, the number and size of wells that must be constructed, the cost of water that must be pumped from source waters outside community boundaries, etc., will vary greatly.

Appendix C

CONTENTS OF TEN STATE STANDARDS

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Recommended
Standards
For Water Works

2003 Edition

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Appendix D

WATER SUPPLY FACILITIES AND LOCAL PUBLIC WORKS MANAGEMENT INFORMATION SYSTEMS

INTRODUCTION

A public works management information system may be defined as an organized body of data about public works facilities which readily provides managers with the information needed to make good decisions about the design, construction, operation and maintenance of public works. The data should be in computer-usable and manipulatable form for efficient access and use. The system should emulate the manner in which such data have been traditionally used by public works officials in support of public works management functions. Such management functions include planning, organizing, directing, controlling, and coordinating the activities required to provide public works facilities and services in a cost-effective manner. Importantly, a public works management information system must provide for the organization, retrieval, and display of the data by geographic location.

Base Map for Public Works Management Information System

The key element of a public works management information system is an automated base map which provides the spatial link for the attribute data of the information system. Such a map can be readily prepared by digitally combining selected elements of digital topographic and cadastral base maps. The information system base map should display the real property boundaries and parcel identification numbers from the cadastral base map, together with certain text from that map, such as street names; together with the existing building outlines, pavement edges, railway tracks, and stream and lake shorelines from the topographic base map. The information base map, which should be at a scale of no smaller than one inch equals 200 feet, provides the basis for the mapping of the various public works facilities and for the assignment of facility component identification numbers that link the spatial location of each facility component to the attribute files.

It is important that the information system base map be compiled on the same survey control datums as are used for the control of land and engineering surveys in the geographic area concerned. Within southeastern Wisconsin, this means that the horizontal coordinates of the map should be based upon the State Plane Coordinate System, North American Datum of 1927, and the elevations upon the National Geodetic Vertical Datum of 1929, formerly known as Mean Sea Level Datum.

Public Works Facilities Attribute Datum

While the accurate mapping of public works facilities is valuable in and of itself, the creation of a public works facilities management information system requires the systematic development of a set of facility attribute data that can be linked by computer to the geographic location data provided by the automated base mapping. The attribute files provide the data and information on the structure, condition, and performance of the public works facilities necessary for the proper management of the facilities, and for the development over time of more efficient and effective systems of public works. A listing of typical attributes for the water supply system component of the management information system is provided in Table D-1.

SCOPE AND CONTENT OF A PUBLIC WORKS FACILITIES MANAGEMENT INFORMATION SYSTEM

The scope and content of a public works facilities management information system will vary by municipality, depending upon the size of the municipality and the type of public works facilities and services provided. Typically, however, such a system will consist of seven elements: a survey control element, a topographic map element, a cadastral map element, a public works facility information system base map element, a parcel-based land information element, a utilities element, and a public ways element. Each of the utility elements and the public ways element consist of a facilities map, compiled on the common information system base map, and a linked attribute file. The parcel-based land information element consists of the information system base map and a linked attribute file. The content of each of the attribute files must be carefully defined to provide the information needed for the proper management of each system of public works concerned.

Table D-1

WATER SUPPLY SYSTEM ATTRIBUTE DATA

General

1. System name
2. System number
3. Primary contact

Mains - data by segment between valves and reducers

1. Identification number
2. Date of construction
3. Material
4. Pipe size - inches
5. Pipe length - feet
6. Operating pressure range - pounds per square inch
7. Capacity at operating pressure - gallons per day
8. Condition
    a. Number, type and date of breaks
    b. Location of repairs
9. Plan proposals

Fittings - data by fitting

1. Identification number
2. Type
    a. Crosses
    b. Tees
    c. Reducers
    d. Pressure relief valves
3. Date of installation
4. Size - inches
5. Crown elevation - feet - NGVD-29
6. Depth of cover - feet
7. Condition
8. For control valves, pressure relief valves and hydrants - date last operated

Control Valves

1. Identification number
2. Manufacturer
3. Type, model and serial number
4. Date installed
5. Size - inches
6. Direction to close
7. Number of turns to close
8. Depth to operating nut - feet
9. Setting

Hydrants

1. Identification number
2. Date of construction
3. Type, model and serial number
4. Date installed
5. Size - inches
    a. Hydrant
    b. Connection
6. Direction to open
7. Auxiliary valve
    a. Distance from hydrant
    b. Direction to close
    c. Number of turns to close
8. Drain
9. Fire flow - gallons per minute
10. Connections
    a. Steamer connection
    b. Number of hose connections

Service Meters - data by meter

1. Identification number
2. Manufacturer
3. Type, model and serial number
4. Material
5. Date installed
6. Size - inches
7. Dates of maintenance and test
8. Service street address
9. Remote reading
    a. Type
    b. Location on premises

Storage facilities - data by facility

1. Identification number
2. Date of construction
3. Type
4. Material
5. Capacity - gallons
6. Operating level - feet - NGVD-29
7. Overflow - elevation - feet - NGVD-29
8. Condition
9. Plan proposals

Pumping stations - data by station

1. Identification number
2. Date of Construction
3. Floor
    a. Elevation - NGVD-29
    b. Drain connection
4. Type

5. Operating pressure - pounds per square inch
6. Relief pressure - pounds per square inch
7. Capacity - gallons per day
8. Reservoir - capacity - gallons
9. Pressure or surge tank
    a. Capacity - gallons
    b. Material
10. Power
    a. Primary
    b. Auxiliary
        (1) Generator
            (a) Manufacturer
            (b) Model and serial number
            (c) Horsepower
        (2) Engine
            (a) Manufacturer
            (b) Model and serial number
            (c) Horsepower
            (d) Fuel
            (e) Cooling
11. Service area - acres
12. Chemical addition
13. Plan proposals

Supply and Treatment

1. Wells - data by well
    a. Identification number
    b. Date drilled
    c. Driller
    d. Size - inches
    e. Elevations
        (1) Surface - feet - NGVD-29
        (2) Bottom - feet - NGVD-29
        (3) Depth of well - feet
        (4) Depth of casings - feet
        (5) Depth of grout - feet
        (6) Static water level when drilled
        (7) Screen
            (a) Material
            (b) Height - feet
            (c) Diameter - inches
            (d) Slot size - inches
            (c) Gravel pack material
            (d) Gravel pack size
    f. Well pump
        (1) Manufacturer
        (2) Model and serial number
        (3) Date installed
        (4) Setting depth - feet - NGVD-29
        (5) Impeller type
        (6) Impeller material
        (7) Bowl material
        (8) Stages

(9) Tail pipe length - feet
(10) Suction strainer type
(11) Revolutions per minute
(12) Motor
    (a) Manufacturer
    (b) Model and serial number
    (c) Date installed
    (d) Efficiency - percent
    (e) Starter type
    (f) Horsepower
    (g) Voltage
    (h) Shroud
        [1] Diameter - inches
        [2] Material
(13) Bearing material
(14) Oil tube size - inches
(15) Shaft
    (a) Size - inches
    (b) Material
(16) Column
    (a) Size - inches
    (b) Material
    (c) Length - inches
    (d) Coating

g. Source aquifer
h. Capacity - gallons per day
i. Draw down at capacity
j. Quality
k. Treatment
l. Service area - acres
    (1) Resident population
    (2) Commercial area
    (3) Industrial area
m. Condition
n. Plan proposals

2. Surface water - data by intake
    a. Identification number
    b. Date of construction
    c. Source
    d. Intake size - inches
    e. Intake length - feet
    f. Intake invert elevation - feet - NGVD-29
    g. Intake capacity - gallons per day
    h. Treatment
        (1) Type
        (2) Capacity - gallons per day
    i. Condition
    j. Plan proposals