SUBTASK 1.24 – OPTIMIZATION OF COOLING WATER RESOURCES FOR POWER GENERATION

Final Report

(for the period of May 16, 2007, through March 31, 2009)

Prepared for:

AAD Document Control

U.S. Department of Energy
National Energy Technology Laboratory
626 Cochrans Mill Road
PO Box 10940, MS 921-107
Pittsburgh, PA 15236-0940

Cooperative Agreement No. DE-FC26-98FT40320
Project Manager: Andrea McNemar

Prepared by:

Daniel J. Stepan
Richard E. Shockey
Bethany A. Kurz
Wesley D. Peck

Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

2009-EERC-03-07

March 2009

SUBTASK 1.24 – OPTIMIZATION OF COOLING WATER RESOURCES FOR POWER GENERATION

ABSTRACT

The Energy & Environmental Research Center (EERC) has developed an interactive, Web-based decision support system (DSS, © 2007 EERC Foundation) to provide power generation utilities with an assessment tool to address water supply issues when planning new or modifying existing generation facilities. The Web-based DSS integrates water and wastewater treatment technology and water law information with a geographic information system-based interactive map that links to state and federal water quality and quantity databases for North Dakota, South Dakota, Minnesota, Wyoming, Montana, Nebraska, Wisconsin, and Iowa.

TABLE OF CONTENTS

LIST OF FIGURES

SUBTASK 1.24 – OPTIMIZATION OF COOLING WATER RESOURCES FOR POWER GENERATION

EXECUTIVE SUMMARY

Adequate supplies of quality water are critical to the existing and future power generation needs of the nation. While producing nearly 60% of the nation's annual energy needs, fossil energy production places a great demand on suitable and available water resources. Power production is comparable to irrigation in terms of annual water withdrawals in the United States, accounting for nearly 40% of those withdrawals. New economic development and population increases will create an even greater demand for fossil energy and further stress available water supplies.

The Energy & Environmental Research Center (EERC) has developed an interactive, Web-based decision support system (DSS, © 2007 EERC Foundation) to provide power generation utilities with an assessment tool to address water supply issues when planning new or modifying existing generation facilities. The Web-based DSS integrates water and wastewater treatment technology and water law information with a geographic information system-based interactive map that links to state and federal water quality and quantity databases. The DSS includes sections that provide information on water law, water and wastewater treatment technologies, and conventional and nonconventional water resources, all of which are linked to other Web sites that provide in-depth information. This allows users to leverage and integrate knowledge of water and wastewater treatment technologies with the physical and spatial relationships of available water sources, competing uses, and current water demands.

The DSS described in this report was developed for a three-state region that includes North Dakota, South Dakota, and Minnesota; however, this effort has been expanded with funding from the U.S. Department of Energy to include Wyoming, Montana, Nebraska, Wisconsin, and Iowa. The expanded DSS will provide a useful tool to an even larger audience, which is not just limited to those involved in power generation. It also benefits users from other industries, agriculture, and municipalities who are seeking new water resources or potential options for treatment and reuse of existing water supplies.

SUBTASK 1.24 – OPTIMIZATION OF COOLING WATER RESOURCES FOR POWER GENERATION

INTRODUCTION

Adequate supplies of quality water are critical to the existing and future power generation needs of the nation. While producing nearly 60% of the nation's annual energy needs, fossil energy production places a great demand on suitable and available water resources. Power production is comparable to irrigation in terms of annual water withdrawals in the United States, accounting for nearly 40% of those withdrawals. New economic development and population increases will create an even greater demand for fossil energy and further stress available water supplies.

Recent U.S. Department of Energy (DOE) projections suggest that freshwater withdrawals could decrease, but that freshwater consumption would likely increase as much as 21% to 48% on a national scale (1). The same report projected regional differences in freshwater withdrawals with significant variation, ranging from 25% increases to 30% reductions. However, freshwater consumption was projected to increase in all regions and, in some cases, by more than 350%.

Thermoelectric power generation faces significant and numerous societal, political, technical, and legal challenges in addressing water needs. To help overcome these challenges, the Energy & Environmental Research Center (EERC) developed a Web-based decision support system (DSS, © 2007 EERC Foundation) that allows users to rapidly assess critical water issues for power generation, including the availability of adequate supplies of suitable water for new generation facilities or the assessment of supplemental water supplies at existing power plants.

Initially, the DSS was developed for a three-state region that includes North Dakota, South Dakota, and Minnesota. This region was selected to encompass three of the key power-generating states in the Midwest. This report summarizes the development of the DSS and the information that it contains; however, it should be noted that this effort is ongoing as a second phase of work has been awarded that incorporates an additional five states into the DSS (Montana, Wyoming, Nebraska, Iowa, and Wisconsin).

EXPERIMENTAL

The objective of this activity was to initiate the development of a regional DSS tailored to provide power generation utilities with an interactive assessment tool to address water supply issues when planning new, or modifying existing, generation facilities. A DSS recently developed by the EERC for the DOE-sponsored Plains CO_2 Reduction (PCOR) Partnership (www.undeerc.org/pcor) served as a prototype for this project (2).

The goal of the Web-based DSS was to integrate water and wastewater treatment technology and water law information with a geographic information system (GIS)-based interactive map that houses or links to water quality and quantity databases. This allows users to leverage and integrate knowledge of water and wastewater treatment technologies with the physical and spatial relationships of available water sources, competing uses, and current water demands. The interactive nature of the DSS enables users to define, evaluate, and compare a wide range of water utilization scenarios. To ensure maximum utility of the DSS, the EERC sought input from power generation company representatives. The iterative nature of this input process was key to shaping the DSS and resulted in pertinent water and wastewater technologies as well as an effective and up-to-date database and modeling system.

GIS-Based Interactive Map

As previously mentioned, the interactive map was developed using a GIS interface that allows operators and developers to browse, query, and analyze water data in a spatial context as well as in a traditional tabular format. During construction of the interactive map, whenever practical, effort was made to network directly to state and federal water and geographic databases to minimize data redundancy, acquisition, and updates.

GIS data contained within the interactive map includes water resource availability figures from surface water, groundwater, industrial process effluent, municipal wastewater treatment plant effluent, mining waters, and produced waters from oil and gas operations. These data were collected from federal and state sources (U.S. Environmental Protection Agency [EPA], U.S. Geological Survey [USGS], and state geological surveys and water commissions), county-level governments (water boards), and natural resource agencies.

Because quality is an important consideration when the viability of a water resource is evaluated for use in power generation, available water chemistry data for each resource were also included in the data set. Data are readily available from online water-quality databases, such as the EPA STORET® (short for STOrage and RETrieval) database, as well as various state- and county-level agencies. STORET is a repository for water quality, biological, and physical data submitted by state and federal agencies, Indian tribes, watershed groups, and universities. STORET is Web-enabled, which means information can be downloaded or submitted by the user; this encourages data sharing on a national level. This information is stored in the STORET Data Warehouse and is free and available to all users (3).

Surface Water Resources

Discharge data for surface water such as streams and rivers were obtained through accessing the USGS gauging stations via the Internet at http://waterdata.usgs.gov/nwis/rt. This site allows selection of a gauging station’s real time, daily, monthly and annual hydrological data, peak stream flow measurements, field measurements, historical water quality data, and annual data reports. The gauging stations are dispersed throughout the United States at significant streams and rivers for water quality and streamflow quantity monitoring. All of the USGS gauging stations in North Dakota, South Dakota, and Minnesota were placed in the interactive map with an active link to the USGS Web site. Selecting a gauging station from the interactive map takes the user directly to the gauging station page, where data acquisition for that station may be made (4).

Groundwater Resources

Water resource data for subsurface water supplies were available for Minnesota and North Dakota. Information for North Dakota was obtained from the North Dakota State Water Commission and the North Dakota Department of Health. In Minnesota, the data were compiled from the Minnesota Department of Natural Resources and the Minnesota Geological Survey. In each case, the data describe a yield (or yield range) for hydrogeologic, or water-bearing, units for the Quaternary (surficial, unconsolidated) deposits. There is a large degree of uncertainty in the values presented in the published datasets. This uncertainty is due partly to the age of the data (1979 for Minnesota) and partly to the fact that neither state officially tracks more reliable yield data for the aquifers. In South Dakota, no yield data were identified for aquifers. Maps are available showing a wide distribution of water-bearing materials, but no yield data accompany these maps.

Nontraditional Resources

Nontraditional resources contained within the interactive map include treated municipal and industrial wastewater, produced water from coalbed methane, oil and natural gas wells, mine drainage, and other innovative/emerging water sources. Most of the effluent from these sources is discharged to a receiving water body, which necessitates the acquisition of a National Pollutant Discharge Elimination System (NPDES) permit from the state in which the discharge takes place. The NPDES permit is on file at the state department of environmental quality, health department, pollution control agency, or similar entity. Among the data on file at these state agencies is historical discharge data. Some states, such as Minnesota, have these data available in an online database, which makes access to this information very easy. Other states do not have these data online, so the respective agency personnel must manually access and scan in pertinent data from the permit and e-mail it to the user, which is a time-consuming endeavor (5).

Additional DSS Components

Emerging water conservation technologies and novel application of existing technologies will play an important part in the development of future power generation facilities. The DSS includes nongeographical-based information on applicable water treatment technologies and scenarios for water conservation, reuse, and minimization opportunities. This information may assist in successful integration of water availability and the need to site power generation facilities where they are needed most. This information was compiled using existing literature as well as the knowledge and expertise of EERC scientists and engineers. Where appropriate, Web links were included for more in-depth information on water resources and treatment technologies.

Water law also plays a critical role in assessing the unencumbered availability of a given water supply. Existing appropriations, the right to withdraw water, water right conversions, and effluent discharge issues are all issues that will need to be addressed at some level before the availability of the water resources at a given location is determined. The Midwest region provides a good example of legal complexities as it includes areas subject to both eastern and western water laws as well as Indian Reserved Water Rights. For this reason, information on federal, state, and tribal water law was included in the DSS for the tristate region.

RESULTS AND DISCUSSION

DSS Development

One of the goals of the DSS is to provide ease of access to information on quantity and quality of all surface, groundwater, reuse, and alternate water sources in the tristate region. An interactive, GIS-based map was developed to meet this goal. Figures 1 through 13 outline the interactive map pages with key features such as surface water maps of the tri-state region, data distribution such as aquifer yield data, wastewater treatment plant (WWTP) permits, USGS gauging station current data, and historical streamflow data. Shown in the figures are screen captures that display some of the interactive map features.

Supplemental Data

Water Treatment Technologies

Thermoelectric generation and fossil fuel extraction and processing can dramatically impact water resources because of the vast amounts of water they require. It is critically important to protect U.S. water supplies while providing the energy needed to power the nation into the 21st century. Conventional water supplies may be either fully appropriated or very limited in the arid/semiarid western United States. Nonconventional water supplies such as treated wastewater, produced water, and mine drainage may fully provide or supplement water requirements. Often, conventional as well as nonconventional water supplies may require additional treatment to make them suitable for use as process or cooling water. Wastewater treatment (to remove organic contaminants), filtration (to remove suspended solids), softening (to remove calcium and magnesium), and disinfection (to destroy microbes) are among the technologies that are used to improve water quality. Each potential alternate water supply should be thoroughly characterized both chemically and physically. It is possible that a treatment scheme may need to be individually tailored for each water source to treat it to the desired quality (6–9). Following are descriptions of potential water sources and treatment technologies that can be employed.

EERC RS34081.CDR

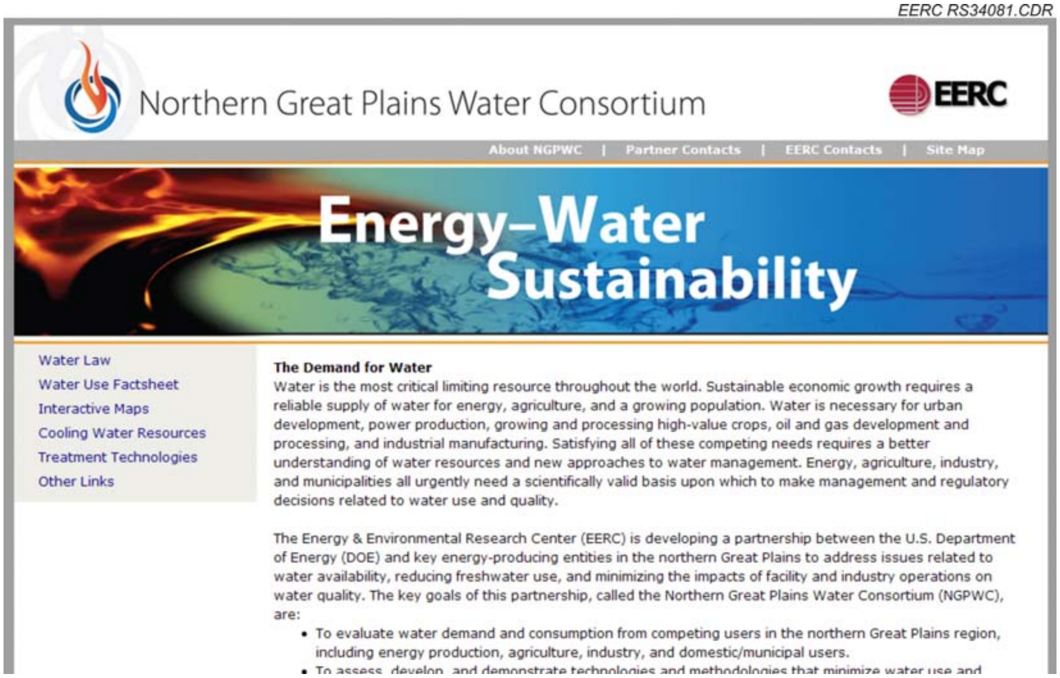

Figure 1. The Northern Great Plains Water Consortium DSS homepage.

EERC RS34091.CDR

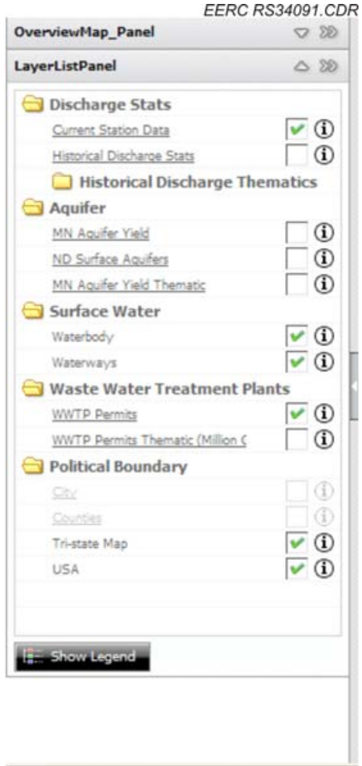

Figure 2. Layer list panel window for the interactive map.

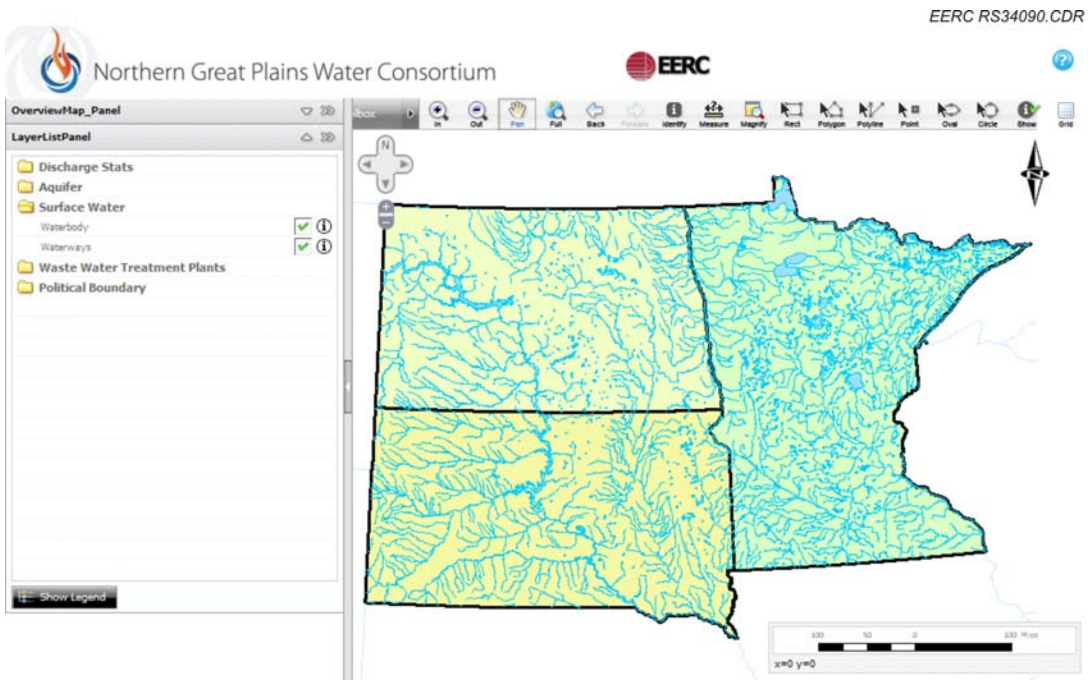

Figure 3. Tristate area showing surface water maps.

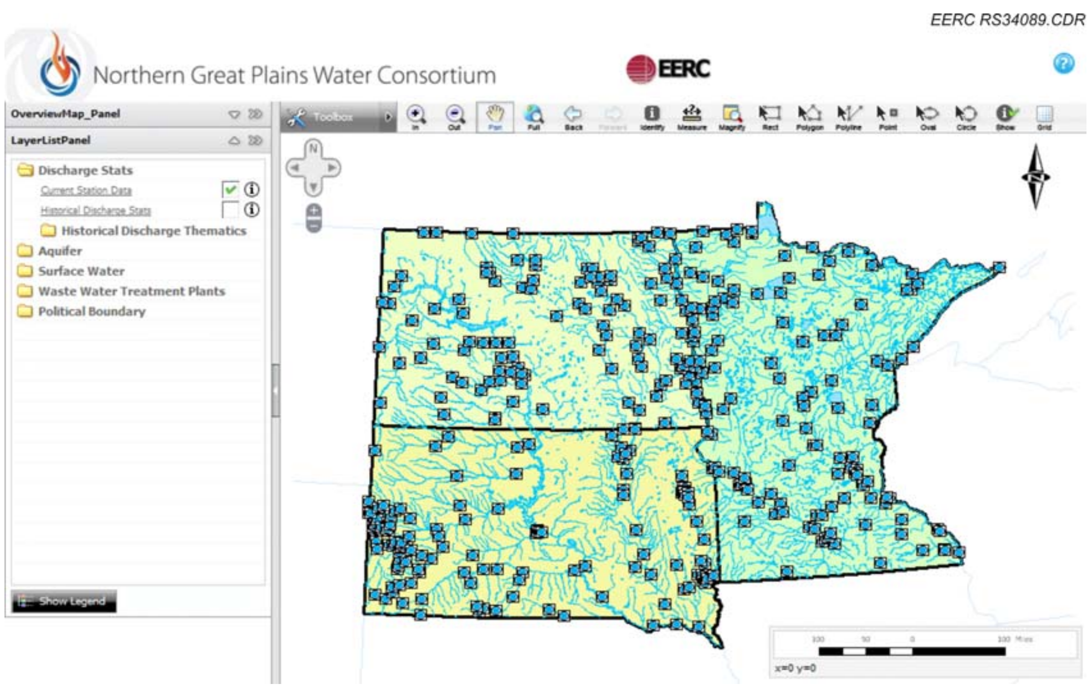

Figure 4. Current station discharge data gauging stations map.

EERC RS34088.CDR

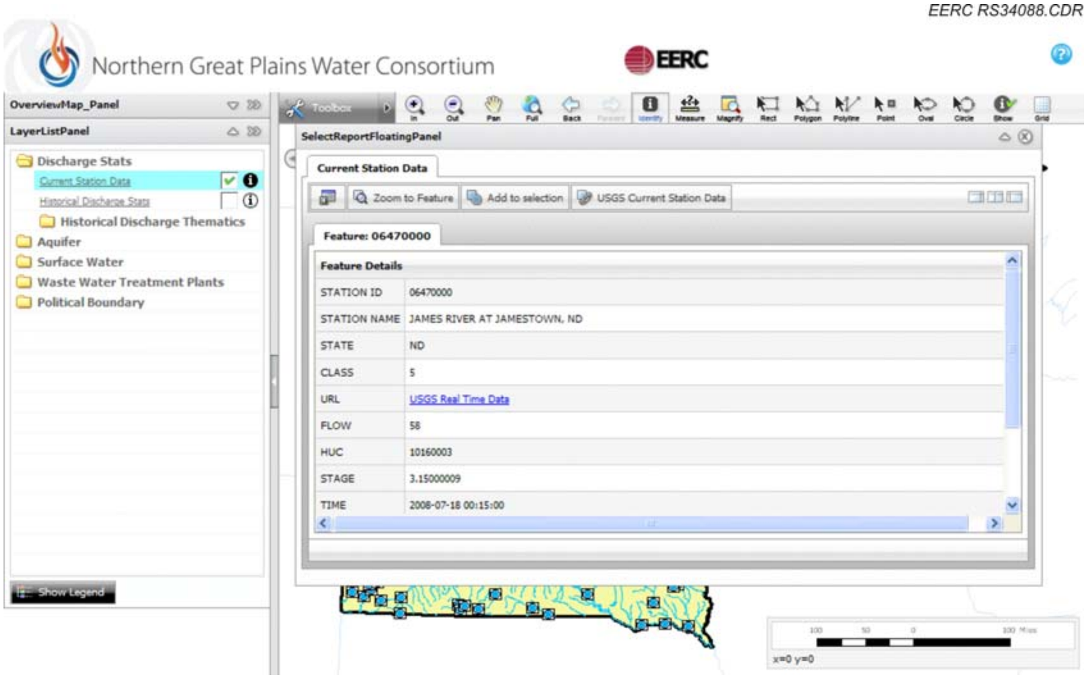

Figure 5. Real-time flow data with a live link to the USGS gauging station.

EERC RS34087.CDR

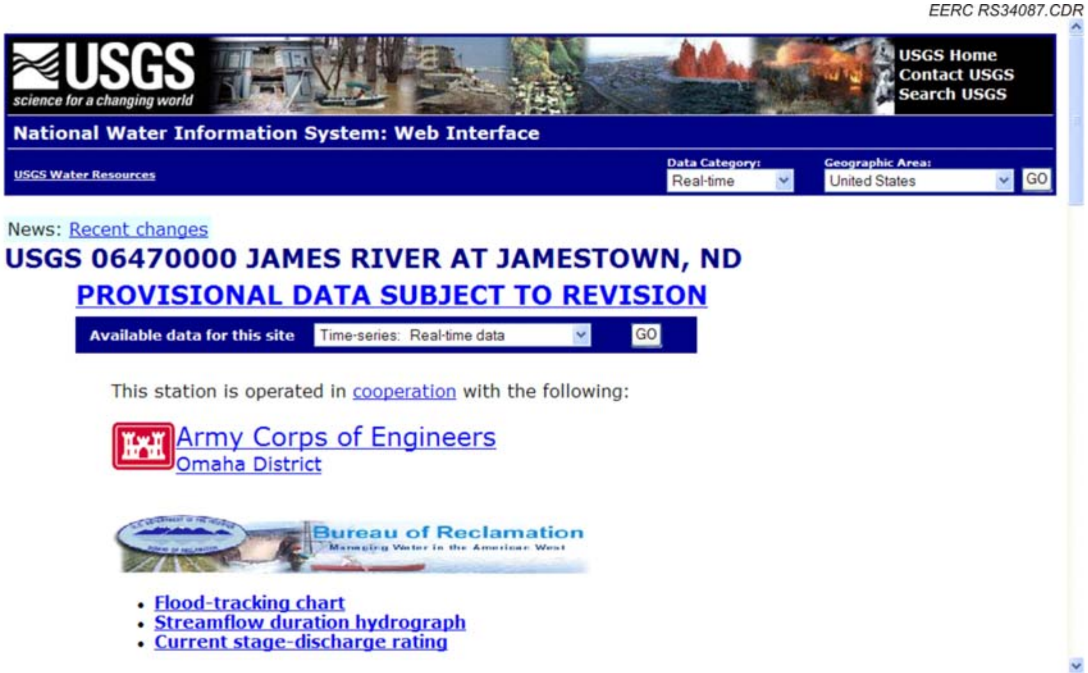

Figure 6. James River USGS gauging station data Web page.

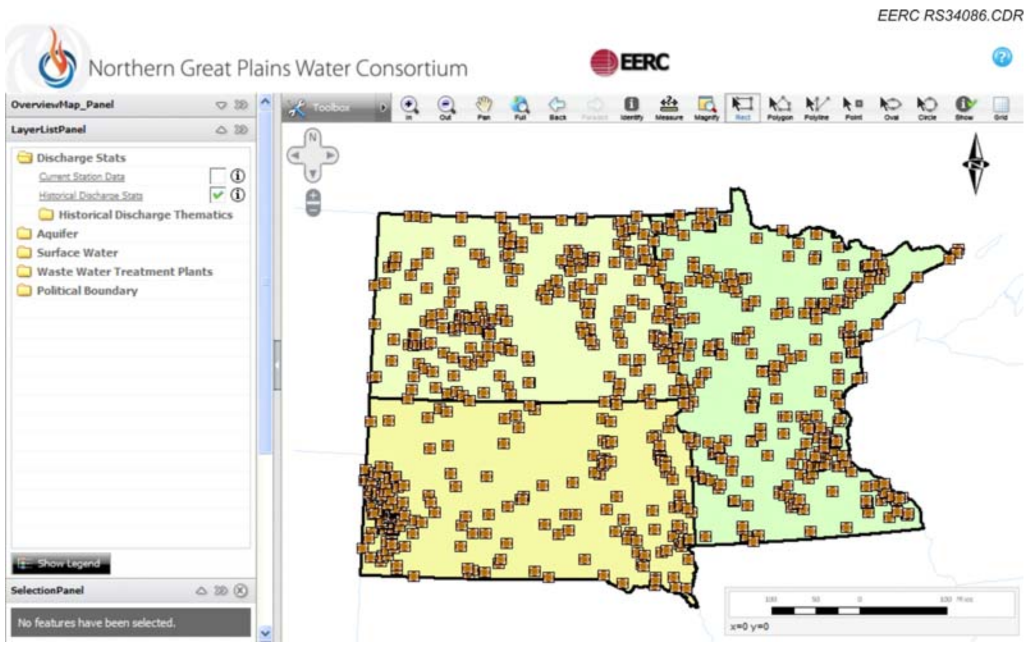

Figure 7. Historical discharge statistics gauging stations map.

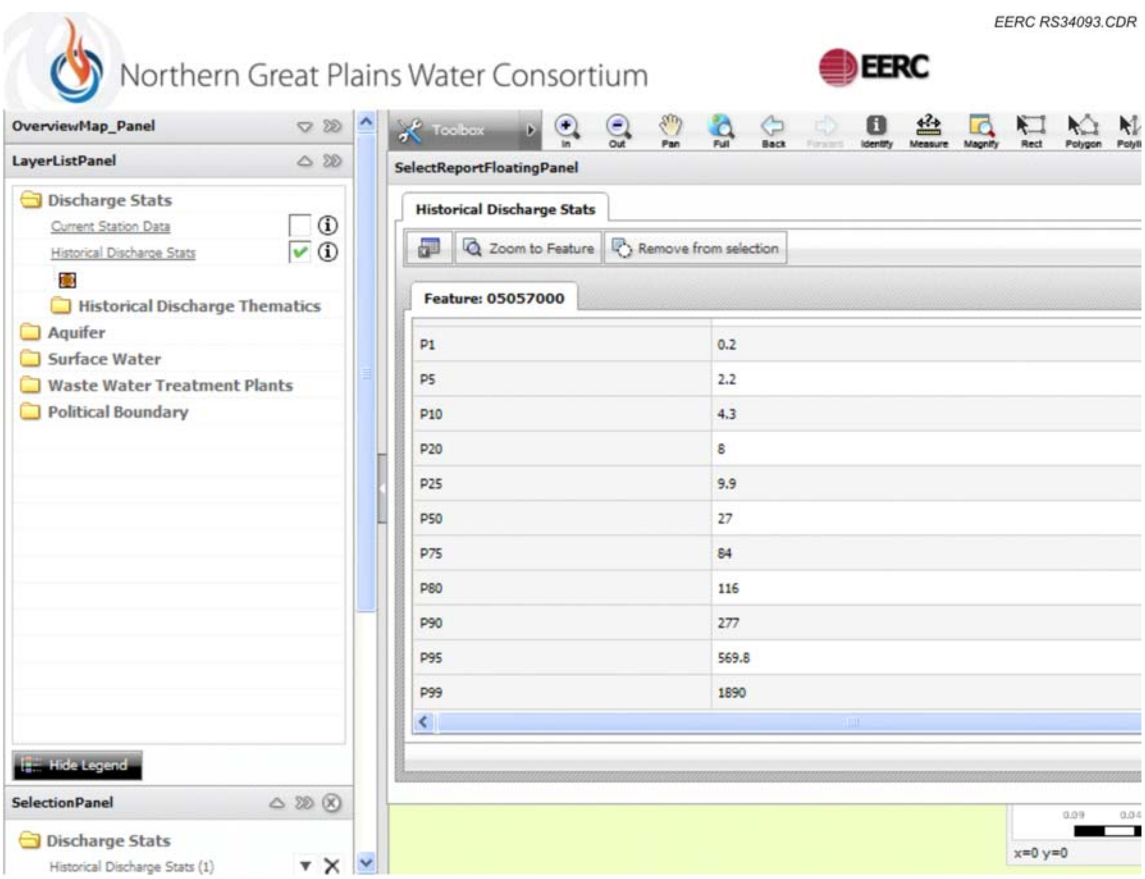

Figure 8. Historical statistical flow data for a USGS gauging station.

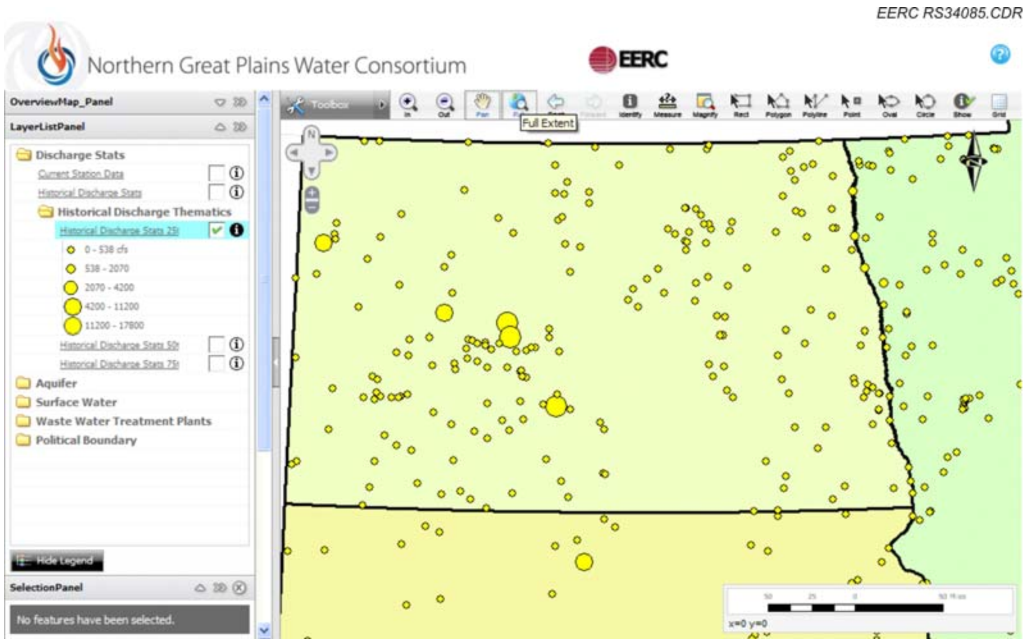

Figure 9. Historical discharge thematic data, in this case displaying a circle proportionate to the total discharge at USGS gaging stations within the region.

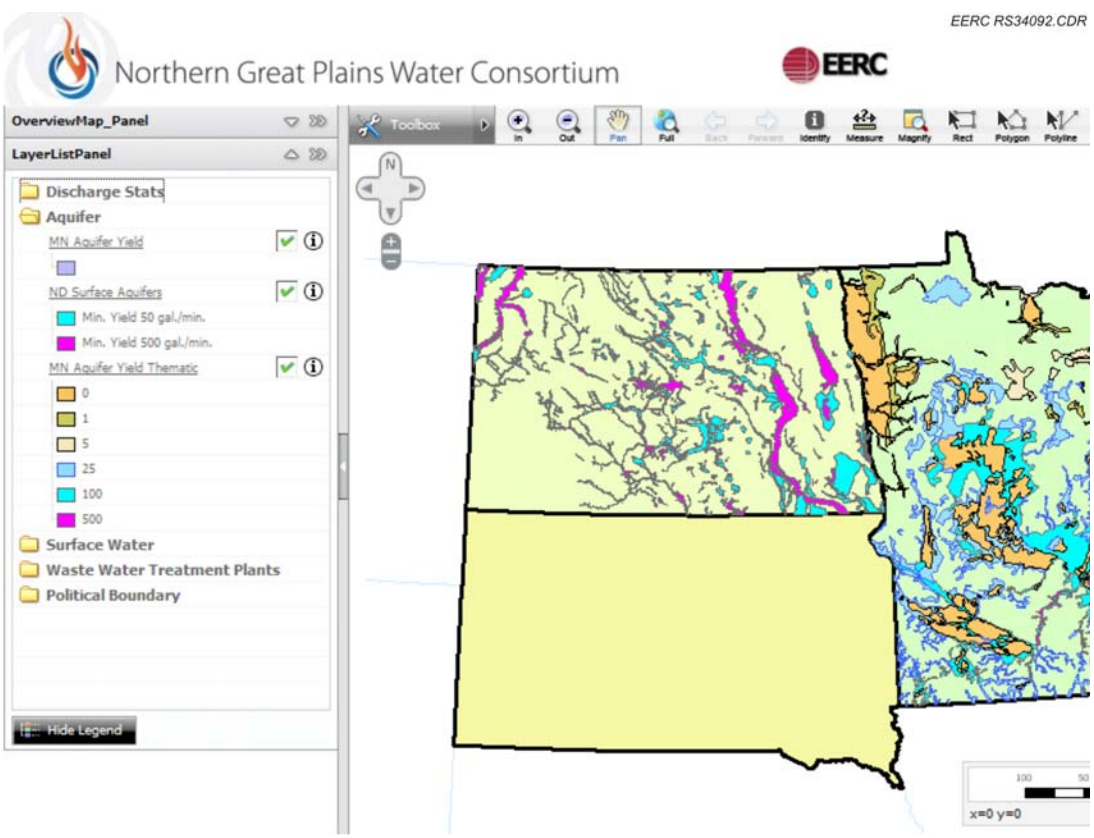

Figure 10. Glacial aquifer thematic maps with color-coded yield.

EERC RS34084.CDR

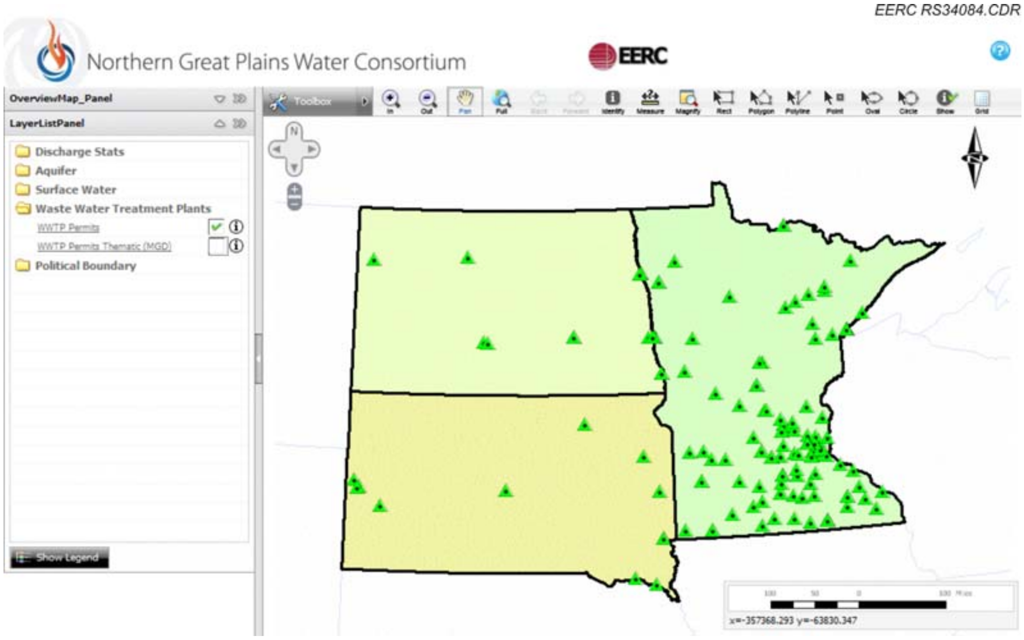

Figure 11. The location of wastewater treatment plants with effluent volumes greater than or equal to one million gallons a day.

EERC RS34083.CDR

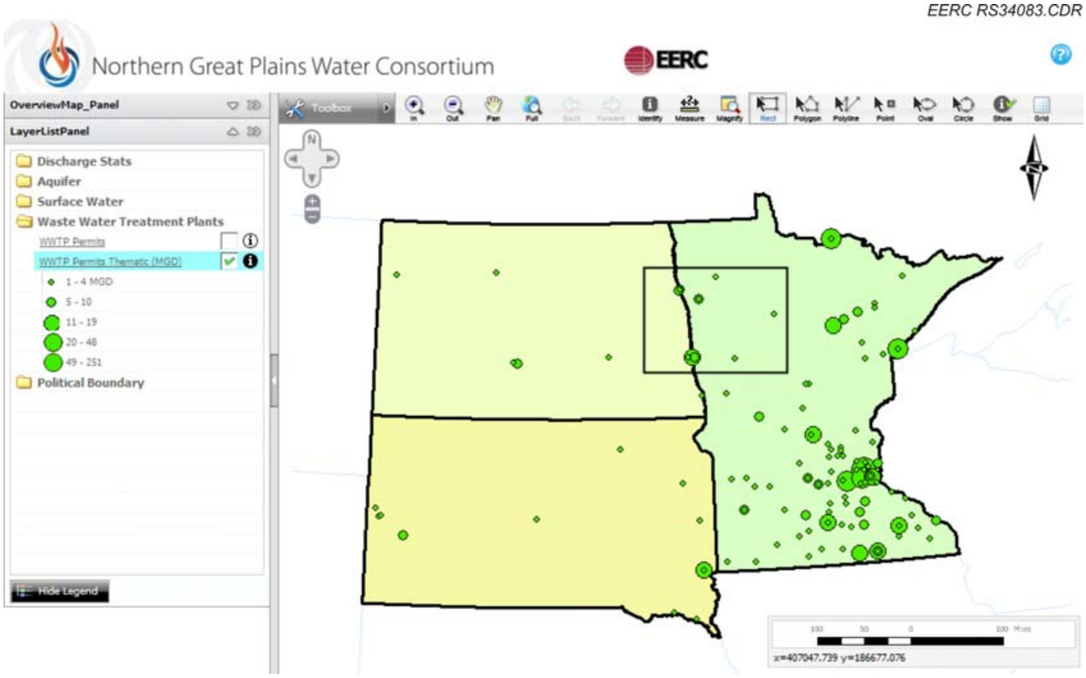

Figure 12. WWTP thematic map with rectangle selection of permits.

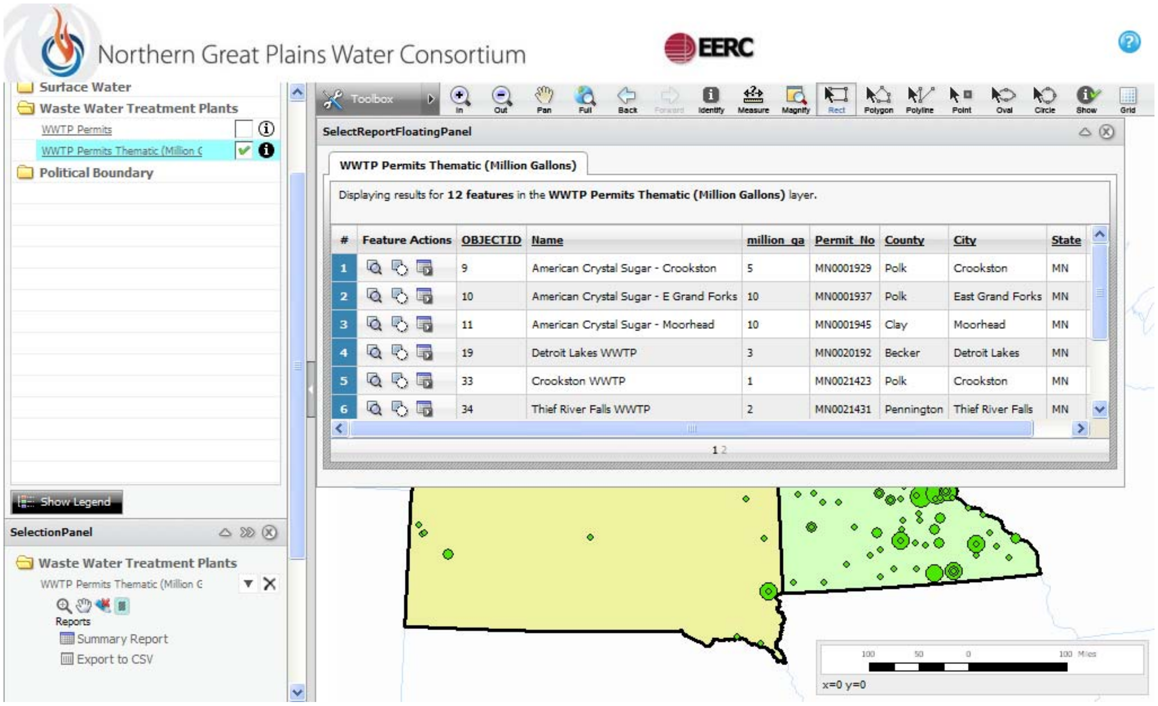

Figure 13. The permit data for those WWTPs selected by the rectangle shown in Figure 12.

Conventional Water Treatment Technologies

Conventional water treatment processes are designed to remove particulates and unwanted chemicals from water. Common physical processes include coagulation, flocculation, sedimentation, filtration, and activated carbon adsorption. Common chemical processes include lime softening, ion exchange softening, and disinfection (10).

1) Coagulation – The process of using chemical and/or physical techniques to promote particulate settling by reducing net electrical repulsive forces between particles.

2) Flocculation – The process of agglomerating particles in water or wastewater to promote settling by using high molecular weight materials such as starch and multiple charged ions.

3) Sedimentation – A process that allows the flocculated or coagulated particles time to settle by gravity in a sedimentation tank. Typically, a hydraulic residence time of 4 hours is desired to allow sufficient time for settling. Sedimentation is common in wastewater treatment and water pretreatment.

4) Filtration – A process that involves removing solids from the water by passing the water through a porous medium. Coarse, medium, and fine filters can be utilized depending on the degree of treatment. Two types of filters that are used are gravity and pressure filters.

a. Microfiltration – This membrane has pore sizes ranging from 0.03 to 10 µm and is used to remove sand, silt, clay, algae, and bacteria.

b. Ultrafiltration – This membrane has pore sizes ranging from 0.01 to 0.03 µm and is used to remove sand, silt, clay, algae, and bacteria.

c. Nanofiltration – This membrane has pore sizes as small as 0.001 µm or 1 nm. Nanofiltration removes hardness, natural organic matter, and synthetic organic chemicals from water.

d. Reverse Osmosis – This membrane removes virtually all contaminants from water (11).

5) Activated Carbon Absorption – A physical process typically applied as tertiary treatment to remove low concentrations of contaminants from water that are difficult to remove by other means. Activated carbon has been processed to make it extremely porous, thereby increasing the surface area that is available for adsorption of contaminants. Activated carbon may have a surface area of as large as 1500 m^2/g (7.3 million ft^2/lb) (12).

6) Lime Softening – A process that involves a series of chemical reactions that change the soluble calcium and magnesium compounds in water into insoluble calcium carbonate and magnesium hydroxide. These are the least soluble calcium and magnesium compounds and will precipitate from solution at relatively low concentrations. For example, calcium carbonate will precipitate from water at concentrations greater than 40 mg/L (13).

7) Ion Exchange Softening – The process of using either natural or synthetic ion exchange resins to remove hardness from water. The resins exchange nonhardness-causing sodium ions for hardness-causing calcium and magnesium ions. The water becomes enriched with sodium and depleted in calcium and magnesium, while the resin becomes enriched with calcium and magnesium and depleted in sodium. Hardness in water can lead to scaling of the metallic piping and plumbing equipment (14).

8) Disinfection – The purpose of disinfection of water is to destroy organisms that cause disease. Common water disinfection methods include chlorination, ozonation, and ultraviolet radiation.

a. Chlorination – A water treatment method that destroys harmful bacteria, parasites, and other organisms. Chlorination also removes soluble iron, manganese, and hydrogen sulfide ions from the water (15).

b. Ozonation – A water treatment process that destroys harmful bacteria and other microorganisms through an infusion of ozone. Ozone (O_3) is a gas that results from oxygen molecules subjected to high electrical voltages (16).

c. Ultraviolet (UV) Radiation– A disinfection process for water and wastewater treatment that involves passing ultraviolet light through the water or wastewater. UV light inactivates microorganisms (17).

Innovative Water Treatment Technologies/Synergies

Several innovative technologies such as forward osmosis, bank filtration, and freeze–thaw evaporation (FTE) have been successfully demonstrated in water treatment applications and have potential for providing improved water quality:

1) Forward Osmosis – A nonpressurized treatment technology that uses a semipermeable membrane to separate water from dissolved solutes. The semipermeable membrane acts as a barrier, allowing water to pass through but blocking larger molecules such as starches, sugars, salts, proteins, and bacteria (18).

2) Bank Filtration – A filtration treatment that involves passing water from streams, rivers, or lakes through the natural banks of the water body. Suspended solids, bacteria, and other contaminants are removed or attenuated by this process (19).

3) FTE – A treatment process that provides the opportunity for cost-effective treatment of brackish or contaminated water, wastewater, or produced water. Feed water is subjected to outdoor subfreezing conditions (−32°F). Freezing water creates a matrix of water molecules, excluding contaminants that do not fit into the crystal matrix. The contaminants are subsequently concentrated into brine, which is drained from the ice to a separate pond. Meltwater from the ice pile is of relatively high quality and suitable for reuse (20).

Wastewater Treatment

Industrial and municipal wastewaters often contain chemical, biological, or human waste contaminants that require removal or attenuation prior to discharge to a receiving water body. Three major stages of treatment are typically implemented to adequately treat wastewater: primary, secondary, and tertiary. Primary treatment involves physical and/or chemical processes to remove large solids and suspended solids. Much of the organic load may also be removed during primary treatment. Secondary treatment employs biological processes in which microorganisms convert contaminants in the wastewater to CO_2, H_2O, and other end products. Tertiary treatment can be a physical and/or chemical process that can include final clarification, filtration, adsorption, and disinfection.

Wastewater Treatment – Primary Wastewater Treatment

Primary wastewater treatment techniques remove entrained and suspended solids from wastewater by various means.

1) Bar Screen – Removes large objects (such as wood, stones, rags, etc.) prior to the water entering the grit chamber (21).

2) Grit Chamber – Sedimentation tanks are designed to slow down the water flow, allowing heavy solids, grit, and sand to settle out, preventing downstream damage to pumps, pipes, and other equipment (22).

3) Primary Clarifier – Tanks with a large hydraulic retention time provide a quiescent zone for settling solids from an influent stream. Settled solids are removed from the tank and are usually sent to anaerobic biological treatment processes, while tank overflow is directed to secondary biological treatment. These clarifiers often incorporate surface skimming devices to remove oils, greases, and other floating material (23).

4) Centrifugation – The use of centrifugal force to promote accelerated settling of particles in a solid–liquid mixture (24).

Wastewater Treatment – Secondary Wastewater Treatment

Secondary wastewater treatment processes use microorganisms to biologically remove contaminants from wastewater. Secondary biological processes can be aerobic, anoxic, or anaerobic, each process utilizing a different type of bacterial community. Aerobic biological processes are common in municipal wastewater treatment, while anaerobic processes may be used to treat high-strength industrial and agricultural wastewaters. These processes may be suspended-growth or attached-growth, depending on configuration. In an aerobic system, the organic contaminants are converted to carbon dioxide, water, additional microorganisms, and other end products. Anaerobic treatment processes are typically employed to treat high-strength wastewaters. The metabolic end products of anaerobic treatment are carbon dioxide, methane, and other end products. Coupled anaerobic–aerobic processes may also be employed under certain circumstances.

Aerobic Secondary Treatment

Common examples of aerobic secondary biological processes include aerobic lagoons, activated sludge, rotating biological contactors, and trickling filters.

1) Aerobic Lagoons – Lagoons are typically large, shallow earthen basins that provide adequate residence time to be treated naturally by both bacteria and algae (25).

2) Activated Sludge – A suspended-growth aerobic biological process in which microorganisms remove carbonaceous matter from wastewater in an aerobic environment (26).

3) Rotating Biological Contactor (RBC) – An attached-growth process consisting of a series of closely spaced, parallel discs mounted on a rotating shaft that are partially submerged in the wastewater being treated. Microorganisms grow on the surface of the discs where aerobic biological degradation of the wastewater pollutants takes place (27).

4) Trickling Filter – An attached-growth process where wastewater is distributed over a fixed bed of media such as rocks, gravel, plastic substrate, etc. The wastewater flows

downward over the media surface where microorganisms form a layer of biomass and consume contaminants in the water (28).

Anaerobic Secondary Treatment

Anaerobic biological treatment processes employ organisms that function in the absence of molecular oxygen. Anaerobic processes convert organic contaminants to a biofuel gas composed of carbon dioxide, methane, and other end products. Anaerobic processes are generally used to treat high-strength wastewaters where it is impractical to utilize aerobic processes or where producing a biofuel gas is desired. Anaerobic processes also use considerably less energy than mechanical aeration processes. Anaerobic processes are loosely organized as either suspended or attached-growth systems.

Wastewater Treatment – Tertiary Wastewater Treatment

The purpose of tertiary treatment is to provide a final, polishing treatment stage prior to discharge or reuse of the wastewater. Common tertiary treatment operations include filtration, disinfection, and carbon adsorption. Filtration may be used to remove suspended solids. Disinfection can be accomplished using a variety of techniques, including chlorination, UV radiation, and ozonation. Ozonation, along with activated carbon adsorption, may be used to remove biorefractory organic compounds from secondary effluents. Ion exchange may also be used as a tertiary treatment option to remove inorganic compounds.

1) Multimedia Filtration – A depth filtration filter, similar to a sand filter, that uses more than one media for improved filtration (29).

2) Chlorination – A water treatment method that destroys harmful bacteria, parasites, and other organisms. Chlorination also removes soluble iron, manganese, and hydrogen sulfide ions from the water (15).

3) Ozonation – A water treatment process that destroys harmful bacteria and other microorganisms through an infusion of ozone. Ozone (O_3) is a gas that results from oxygen molecules subjected to high electrical voltages (16).

4) UV Radiation – A disinfection process for water and wastewater treatment that involves passing UV light through the water. UV light destroys microorganisms and can reduce dissolved organic material (17).

5) Activated Carbon Absorption – A physical process that is typically applied as tertiary treatment to remove low concentrations of contaminants from water that are difficult to remove by other means. Activated carbon has been processed to make it extremely porous and, therefore, with a very large surface area available for adsorption of contaminants. Activated carbon may have a surface area of as large as 1500 m^2/g (7.3 million ft^2/lb) (18).

6) Ion Exchange – Ion exchange is a reversible chemical reaction used to removes ions from waters and wastewaters. An ion from solution, such as ammonium, sodium, copper, nitrate, and many others, is exchanged for a similarly charged ion attached to an immobile solid ion exchange particle. These solid ion exchange particles are either naturally occurring inorganic zeolites or synthetically produced organic resins (30).

Legal Considerations

Water law deals with the ownership, control, and use of water as a resource. Laws enacted by each state govern water use. States employ two water law doctrines to govern water use: prior appropriation which is endorsed by western states (generally those states west of the 97th Meridian – approximately the border of Minnesota and North Dakota) and riparian rights which eastern states use. In the eastern United States, where water is more plentiful, the "Doctrine of Riparian Rights" water use system developed. In a riparian rights system, water users are entitled to make reasonable use of accessible water. However, in the drier western United States, a system has developed based on the "Doctrine of Prior Appropriation." The prior appropriation system allows water users to construct works to move water over long distances and provides a water use priority date for assignment. Indian reservations' water use is governed separately from the states in which the reservation is located by Indian reserved water rights, also known as the Winters Doctrine.

Western Water Law – Prior Appropriation Doctrine

The use of water in many of the states in the western United States is governed by the doctrine of prior appropriation, also known as the "Colorado Doctrine" of water law. The prior appropriation doctrine, or "first in time – first in right," developed in the western United States in response to the scarcity of water in the region. The essence of the doctrine of prior appropriation is that, while no water user may own the water in a stream, all persons, corporations, and municipalities have the right to use the water for beneficial purposes. The first person to use the water (called a "senior appropriator") acquires the right (called a "priority") to its future use as against later users (called "junior appropriators"). In order to ensure protection of senior water right priorities and to maximize the use of this scarce and valuable resource, many states have adopted detailed schemes for the determination and administration of water rights. These state regimens define the water right to a large extent. According to the rules of prior appropriation, the right to the full volume of water "related back," or had the priority date of the time when the water was first diverted and put to beneficial use. In other words, water users with the earliest priority dates have the right to use the diverted amount of water over other users with later priority dates.

Unlike a riparian right, an appropriative right exists without regard to the relationship between the land and water. An appropriative right is generally based upon physical control and beneficial use of the water. These rights are entitlements to a specific amount of water, for a specified use, at a specific location with a definite date of priority. An appropriative right depends upon continued use of the water and may be lost through nonuse. Unlike riparian rights, these rights can generally be sold or transferred, and long-term storage is not only permissible but also common.

Eastern Water Law – Doctrine of Riparian Rights

The use of water in many of the states in the eastern United States is governed by the doctrine of riparian law. This law gives each owner of land bordering on a stream a right to make reasonable use of the water and imposes a liability on the upper riparian owner who unreasonably interferes with that use. This right exists whether or not the downstream riparian owner is actually using the water. Non-riparian landowners have no rights to the use of surface water. Riparian water rights, therefore, occur as a result of landownership. A landowner who owns land that physically touches a river, stream, pond, or lake has an equal right to the use of water from that source. The water may be used as it passes through the property of the landowner, but it cannot be unreasonably detained or diverted, and it must be returned to the stream from which it was obtained. The use of riparian water rights is generally regulated by "reasonable use." Reasonable use allows for the consumptive use of water, but what actually constitutes reasonable use has varied widely from state to state and continues to evolve (31).

Minnesota Water Law

Riparian rights are property rights arising from owning shore land. They include the right to wharf out to a navigable depth; to take water for domestic and agricultural purposes; to use land added by accretion or exposed by reliction; to take ice; to fish, boat, hunt, and swim; and to such other uses as water bodies are normally put. The riparian owner has the right to make use of the lake over its entire surface (32).

It is the duty of the riparian owners to exercise their rights reasonably, so as not to unreasonably interfere with the riparian rights of others. Riparian owners cannot dike off and drain, or fence off, their part of the water body. It is a public nuisance and a misdemeanor to "interfere with, obstruct, or render dangerous for passage waters used by the public."

South Dakota Water Law

The doctrine of prior appropriation is South Dakota's method of managing its water resources. A permit to appropriate water is needed for all water uses in South Dakota except for certain domestic uses of water. Domestic use is the highest use of water and takes precedence over all appropriative uses. All water within the state is the property of the people of the state, but the right to the use of water may be acquired by appropriation as provided by law. Water needs to be put to beneficial use at least once every 3 years or all or any part of the appropriation not used is subject to cancellation. In 1972, a provision was added to the state's water rights laws concerning management of groundwater. This provision prevents withdrawal of groundwater in excess of the average estimated annual recharge to the groundwater source (33).

North Dakota Water Law

The doctrine of prior appropriation is North Dakota's method of managing water resources. A right to appropriate water can be acquired for beneficial use as provided by the North Dakota Century Code. Beneficial use shall be the basis, the measure, and the limit of the right to the use of the water (34).

Indian Reserved Water Rights

The doctrine of Indian reserved water rights, also known as the Winters Doctrine, holds that when Congress reserves land for an Indian reservation, Congress also reserves water to fulfill the purpose of the reservation. When this doctrine is applied to the water laws of the western states, tribal rights to water are almost always senior to other claimants. Therefore, in order for western water officials to effectively plan for a stable allocation of water on which all parties can rely, they must find a way to satisfy the water claims of local Indian tribes (35).

Other Sources of Information

Web links are provided to additional information on produced water, DOE Water/Power Interface, Department of the Interior Water for America initiative, Sandia Energy – Water Nexus, a municipal wastewater treatment primer, and water and wastewater treatment manuals (36–41).

Challenges

Some difficulties were encountered in acquiring the data needed to build the DSS, mostly related to groundwater resource evaluation. While North Dakota and Minnesota have good delineation of aquifer boundaries and depths, reliable aquifer yield and total resource data are often inadequate. South Dakota also has very limited data available on aquifer yields or recoverable volumes. This makes it difficult to evaluate groundwater resources during the decision-making process.

Wastewater source data were very easily obtained for Minnesota via Internet access to NPDES permits. NPDES permit data for North Dakota and South Dakota were obtained by lengthy Internet searches of city Web sites and EPA's Web page, as well as interviews with city and state officials. A more extensive investigation into discharge requirements for individual NPDES permittees will need to be added in the ongoing improvement of the DSS. Lagoon-based wastewater treatment plants usually discharge at a rate and time frame regulated by the appropriate state agency. Although the average daily discharge for a lagoon may be attractive for a reuse scenario, the actual real-time discharge rate may be many times larger in volume. Often, the discharge may take place over a month or two, several times a year, rather than on a continuous basis.

CONCLUSIONS

The DSS is a very useful tool that enhances water-related decision-making by eliminating the time-consuming effort associated with gathering information from disparate sources. The initial focus of the DSS was to allow users to rapidly assess critical water issues for power generation, including the availability of adequate supplies of suitable water for new generation facilities or the assessment of supplemental water supplies at existing power plants. However, the DSS benefits not only those involved in the power generation industry, but users from other industries, agriculture, and municipalities who are seeking new water resources or potential options for treatment and reuse of existing water supplies.

The DSS is currently undergoing internal review and testing to enhance the utility of the user interface. It will be made available under the Northern Great Plains Water Consortium page of the EERC's Web site, located at www.undeerc.org. In addition, the DSS is being expanded to encompass the eight-state region shown in Figure 14. This will allow the EERC to not only expand the region encompassed by the DSS, but to address some of the current data gaps within the existing system.

REFERENCES

1. U.S. Department of Energy, 2006, DOE estimates future freshwater needs to meet thermoelectric power demand.

2. University of North Dakota Energy & Environmental Research Center, 2009, Plains CO_2 Reduction Partnership: www.undeerc.org/pcor (accessed 2009).

Figure 14. Expanded water resource DSS region.

3. U.S. Environmental Protection Agency, 2009, STORET database access: www.epa.gov/storet/dbtop.html (accessed 2009).

4. U.S. Geological Survey, 2009, USGS real-time water data for the nation: http://waterdata.usgs.gov/nwis/rt (accessed 2009).

5. Minnesota Pollution Control Agency, 2009, Environmental data access—water quality: http://www.pca.state.mn.us/data/edaWater/index.cfm (accessed 2009).

6. American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1975, Standard methods for the examination of water and wastewater, 14th Ed.: Washington D.C., American Public Health Association.

7. Grady, Jr., C.P. Leslie, and Lim, H.C., 1980 Biological wastewater treatment—theory and applications: New York, Marcel Dekker, Inc.

8. Reynolds, T.D., 1982, Unit operations and processes in environmental engineering: Wadsworth Inc.

9. Reynolds, T.D., and Richards, P.A., 1996, Unit operations and processes in environmental engineering: 2nd Ed.: Boston, MA, PWS Publishing Company.

10. Cyberspace Chemistry, 2009, Water treatment: www.science.uwaterloo.ca/~cchieh/cact/applychem/watertreatment.html (accessed 2009).

11. National Academy of Sciences, 2009 Safe drinking water is essential: http://drinking-water.org/html/en/Treatment/Membrane-Processes-technologies.html (accessed 2009).

12. Energy Technologies, 2009, Absorption and adsorption: http://tristate.apogee.net/et/ewtwaca.asp (accessed 2009).

13. Mountain Empire Community College, 2009, Lime softening: http://water.me.vccs.edu/concepts/softeninglime.html (accessed 2009).

14. Skipton, S.O., Dvorak, B.I., and Niemeyer, S.M., 2003, Drinking water treatment—water softening exchange: University of Lincoln, Nebraska, revised October, 2008. www.ianrpubs.unl.edu/epublic/live/g1491/build/g1491.pdf (accessed 2009).

15. North Dakota State University, 2009, Treatment systems for household supplies: www.ag.ndsu.edu/pubs/h2oqual/watsys/ae1046w.htm (accessed 2009).

16. Southern Nevada Water Authority, 2009, Ozonation: www.snwa.com/html/wq_treatment_ozonation.html (accessed 2009).

17. Canada Mortgage and Housing Corporation, 2009, UV treatment.

18. www.cmhc-schl.gc.ca/en/co/maho/wawa/wawa_002.cfm (accessed 2009).

19. Teoh, M., Wang, K., Bonyadi, S., and Chung, N., 2009, Forward osmosis and membrane distillation processes for freshwater production: Innovation Magazine, World Scientific Publishing, www.innovationmagazine.com/innovation/volumes/v8n1/coverstory3.shtml (accessed 2009).

20. University of Hawaii, Water Resources Research Center, 2009, Bank filtration for water treatment, www.wrrc.hawaii.edu/bulletins/2000_08/filtration.html (accessed 2009).

21. University of North Dakota Energy & Environmental Research Center, 2009, Freeze thaw: www.undeerc.org/centersofexcellence/waterfreeze.aspx (accessed 2009).

22. www.lenntech.com/wwtp/wwtp-overview.htm (accessed 2009).

23. Lenntech, 2009, Screening: www.lenntech.com/screening.htm (accessed 2009).

24. Bowling Green Municipal Utilities, 2009, Wastewater treatment: www.bgmu.com/water5_process2.htm (accessed 2009).

25. Environmental Leverage, Inc., 2009, Primary clarifiers—how they often impact the process negatively when they are overlooked: www.environmentalleverage.com/Primary%20Clarifiers-%20Problem%20Areas.htm 9accessed 2009).

26. Lenntech, 2009, Centrifuges and centrifugation: www.lenntech.com/Centrifugation.htm Accessed 2009).

27. Lagoon Systems in Maine, 2009, Design, operation, and regulation of lagoons in Maine: www.lagoonsonline.com/desopreg.htm (accessed 2009).

28. University of California, Los Angeles, 2009, Microorganisms and their role in the activated sludge process www.college.ucla.edu/webproject/micro7/studentprojects7/Rader/asludge2.htm (accessed 2009).

29. Eimco Water Technologies, 2009, Copa RBC – rotating biological contactor: www.glv.com/WATER/Municipal_Wastewater/Biological_Treatment/Copa_RBC__Rotating_Biological_Contactor/ProductDescription.aspx (accessed 2009).

30. Mountain Empire Community College, 2009, Trickling filters: http://water.me.vccs.edu/courses/ENV149/trickling.htm (accessed 2009).

31. Itasca, 2009, Media Filtration: www.itascasystems.net/support/waterTreatment}MediaFiltration.php (accessed 2009).

32. Remco Engineering – Water Systems and Controls, 2009, Ion exchange reations: www.remco.com/ix.htm (accessed 2009).

33. National Science and Technology Center, 2009, Western states laws: www.blm.gov/nstc/WaterLaws/appsystems.html (accessed 2009).

34. Minnesota Department of Natural Resources, 2009, Minnesota water statutes and rules: www.dnr.state.mn.us/waters/law.html

35. South Dakota Department of Natural Resources, 2009, Summary of South Dakota water laws and rules: www.state.sd.us/denr/des/waterrights/summary.htm (accessed 2009).

36. North Dakota State Water Commission, 2009, North Dakota water laws and policies: www.swc.state.nd.us/4dlink9/4dcgi/GetCategoryRecord/Water%20Laws%20and%20Policies (accessed 2009).

37. Brooks, N., 2005, Indian reserved water rights—an overview: CRS Report for Congress, Congressional Research, The Library of Congress, www.policyarchive.org/bitstream/handle/10207/1917/RL32198_20050124.pdf?sequence=1 (accessed 2009).

38. U.S. Department of Energy National Petroleum Technology Office, 2006, A guide to practical management of produced water from onshore oil and gas operations in the United States: 2006, www.all-llc.com/IOGCC/PDF/PWGuideFinal-LowRes.pdf (accessed 2009).

39. National Energy Technology Laboratory, 2009, Produced water management system: www.netl.doe.gov/technologies/PWMIS/techdesc/index.html (accessed 2009).

40. National Energy Technology Laboratory, 2009, Innovations for existing plants: www.netl.doe.gov/technologies/coalpower/ewr/water/index.html (accessed 2009).

41. Sandia National Laboratories, 2005, The energy–eater nexus: www.sandia.gov/energy-water/ (accessed 2009).

42. U.S. Environmental Protection Agency, 2009, Primer for municipal wastewater treatment systems: Washington D.C., www.epa.gov/OWM/primer.pdf (accessed 2009).

43. U.S. Army, 2009, Army engineering publications: www.army.mil/usapa/eng/index.html (accessed 2009).