A Water / Energy Best Practices Guide for Rural Arizona's Water & Wastewater Systems

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Introduction

In Arizona, water is one of the keys to economic development and quality of life. Arizona's water and wastewater systems use significant amounts of electrical energy, and the generation of that energy often generates greenhouse gases (GHG) that have been associated with global warming. Water is also closely tied to Arizona's industrial sector where substantial amounts are used for cooling at power plants, agriculture, and for mining and manufacturing operations. Arizona's water infrastructure is both extensive and diverse, with systems that range in size from complex water supply facilities, run by entities such as the Central Arizona Project, to smaller water systems operated by rural communities, state and federal agencies, tribes, and private entities.

According to the U.S. Census 2000, approximately 25% of Arizona's population lives outside of the urban centers in Maricopa, Pinal and Pima counties. Typically, these rural communities have populations of less than 50,000 people. A report by the University of Arizona Water Resources Research Center (Gelt, 2000) suggests that many of these communities lack the management resources to administer effectively their water resources. While urban utilities have a highly-trained cadre of water professionals, small communities often must rely on a patchwork of national, state and regional agencies for technical expertise. At the same time, the inadequate tax base of many rural communities hampers their ability to commission evaluations of their operations, systems and needs. According to the report, these problems "leave rural officials without the means to contract needed expertise and services to support water management efforts".

Given these challenges, this "best practices" guide was developed to help rural Arizona managers and operators of public and private water and wastewater systems meet future water and energy challenges in the most effective manner possible. The authors have investigated the "best practices" for innovative water and energy utilization by small- to medium-sized water and wastewater systems in the United States, Europe, and elsewhere, to identify, evaluate, and prioritize technologies and strategies that can be used by rural Arizona providers to conserve water, to reduce energy usage and related expenditures, and to minimize GHG emissions. In short, this guide is designed to help "green" the water infrastructure of rural Arizona, and assist rural water and wastewater providers in their efforts to meet ongoing and future water and energy challenges in the most effective manner possible.

The best practices in this guide are organized under four themes:

- Water Management and Policy
- System Design and Engineering
- Operations and Maintenance
- Renewable Energy

In addition, this report provides summaries for seven case studies (Appendix 3) completed on small water and wastewater systems in rural Arizona. These case studies are intended to illustrate the possible applications to real Arizona water and wastewater systems of concepts and practices presented in this guide.

Background

The United States Environmental Protection Agency (USEPA) considers “small” water systems to be those systems serving between 500 and 3,300 individuals. Similarly, “very small” water systems typically serve 500 people or less. Collectively, there are nearly 147,000 such small and very small systems in the U.S. serving nearly 40 million individuals, or nearly 13% of the population.

In Arizona, nearly 1,600 drinking water systems are permitted through the Arizona Department of Environmental Quality (ADEQ). About a dozen of these are for towns and cities that serve populations in excess of 10,000. Thus, most Arizona systems serve populations of fewer than 500, and many serve less than 50. Similar trends hold true for the nearly 900 wastewater systems permitted through ADEQ (personal communication, Bill Reed, ADEQ, 6/30/2008). In addition to ADEQ-permitted systems, there are many small systems, including many systems that exclusively serve school populations, in the numerous sovereign Native American communities across the state. It is these small rural Arizona water and wastewater systems that are at the focus of this guide.

There are a variety of rural system operators/owners in rural Arizona. Some examples include:

- Towns and cities, such as Benson, Winslow and Tuba City;
- Improvement districts, such as Coconino County’s Kachina Village Improvement District (KVID);
- Private entities, including developments such as Forest Highlands near Flagstaff;
- Private water and wastewater utilities such as Arizona Water Co and Global Water Co.;
- The Bureau of Indian Affairs (BIA), dedicated tribal utilities such as the Navajo Tribal Utility Authority (NTUA), and sovereign nations, such as the Ak-Chin Indian Community;
- Water councils and other organizations in small communities, such as Sipaulovi Village on the Hopi Reservation;
- Industrial and mining systems (Chemical Lime Company in Nelson near Peach Springs; Phelps Dodge’s Morenci and Clifton mines, etc.);
- Arizona State Parks and Arizona Department of Transportation rest area systems;
- Department of Defense facilities, such as Fort Huachuca, Luke Air Force Base, and the Yuma Proving Ground;
- National Park Service (NPS) systems, such as those operated at Grand Canyon National Park;
- State and federal correctional facilities.

Rural Arizona Water and Wastewater System Attributes

Water and wastewater facilities in rural Arizona have several defining characteristics:

- Though there are some exceptions, Arizona wastewater treatment facilities generally rely on proven simple processes that require a low or minimal level of operations and maintenance (O&M);
- Wastewater treatment often is based on facultative lagoons, some aerated and some not, or utilizes oxidation trenches/ditches;
- In some places, lagoons are permitted to discharge directly to waterways (e.g., White River, Arizona);
- A common wastewater treatment process is package plants that use activated sludge;
- Where utilized, disinfection is typically achieved using liquid/tablet chlorination (UV disinfection is uncommon at small treatment facilities);
- Raw water, with some important exceptions (e.g., Page, CAP water consumers), is generally supplied by groundwater sources;
- In some instances, groundwater sources are deemed to be under the influence of surface water, and filtration is required;
- Typically, water treatment consists solely of disinfection;
- Less often, groundwater supplies are treated to achieve: fluoridation; fluorine reduction; taste / odor control; arsenic reduction; herbicide / pesticide reduction; or nitrate reduction.

(*The above is a synthesis developed from conversations on 6/30/2008 with Bill Reed of ADEQ and on 7/3/2008 with Vern Camp of the Arizona Small Utilities Association.*)

Direct and Embedded Energy Demands

There are several accounting methods used to track energy when considering its utilization in water and water systems, its cost, and its conservation.

Direct energy is the result from an accounting which takes into consideration energy that exists, is delivered, is purchased, is sold, etc., in the form of: chemical energy (gasoline, diesel fuel, natural gas, propane, methane from wastewater treatment plant sludge digestion); electrical energy; or thermal energy (a certain amount of material, such as air, water, iron, etc., at a certain temperature).

Embedded energy is the result from an accounting which quantifies the total energy used to extract, manufacture, transport and dispose of a product or service. For example, if an organization purchases sodium hypochlorite for use in water disinfection, the cost paid for that product presumably includes the energy expense incurred by the manufacturer when it created and packaged the product, and the energy expenses of transport and storage before it came into the user's possession. There may be embedded energy in a product for which one does not pay the supplier. For example, part of the the cost of a new service vehicle is for the energy expended as part of production, assembly and transportation to the dealer. As another example, the coal burned at an electrical generating station contains energy supplied, millions of years ago, by the sun, which aided photosynthesis by plants, which were, subsequently, over geologic time, converted into coal.

Water that is purchased from a wholesaler, or utility, such as the Central Arizona Project (CAP), has embedded energy. Part of the cost to a buyer of CAP water is used by CAP to defray expenses for energy and other expenditures incurred to store (e.g., in Lake Pleasant), lift (pump stations), or transport (via canals) the water. The energy expenditures come about principally for operating pump stations, and, to a lesser extent, for heating, cooling, and lighting of facilities, and powering vehicles used by employees, etc. Other expenditures arise due to employee salaries, employee benefits, etc. If an organization pays $250 for an acre-foot (43,560 cubic feet, or 325,000 gallons) of CAP water, some significant portion of that $250 is for energy expended by CAP to deliver that water to the user.

The same concept applies to water provided by a small rural Arizona water utility. If a household pays $7.50 per 1000 gallons of potable water, a significant portion of the $7.50 is for the energy expenditures to lift, pressurize and treat the water.

Similarly, treated effluent that is discharged by a wastewater utility has embedded energy, due to the pumping, treatment, aeration, and other processes that require energy inputs. The fee to a commercial enterprise for disposing of its wastewater into the utility's collection system covers the cost of the energy. Often, wastewater fees and water fees are lumped, since it is easy to meter water deliveries and less so to meter wastewater discharges!

Energy Usage in Water and Wastewater Systems

As a nation, the United States devotes nearly 4%, or 164 million Mega-Watt-hours (MWh), of our electrical energy generation, to handle, lift, move, pressurize, distribute, and treat our water. Typically, this energy usage, or *energy intensity*, may be expressed either in terms of kilo-Watt-hours (kWh) per acre-foot of water (kWh/ac-ft) or in terms of kWh per 1,000 gallons of water (kWh/kgal).

A comprehensive study (Cohen et al., 2004) concluded that the average energy intensity for California water usage from source through the end use and continuing through discharge from a wastewater treatment plant is approximately 7000 kWh/ac-ft (21 kWh/kgal). *End use energy* – which includes the energy required to heat or cool water in homes and industry – requires 3900 kWh/ac-ft (12 kWh/kgal). *Source / conveyance* energy uses 2040 kWh/ac-ft (6.3 kWh/ac-ft), while distribution uses 330 kWh/ac-ft (1.0 kWh/kgal). *Wastewater treatment* uses approximately 570 kWh/ac-ft (1.7 kWh/kgal), while *water treatment* requires 60 kWh/ac-ft (0.2 kWh/kgal).

According to these values, in California, the end use energy intensity accounts for more than 50% of the total. According to the United States Geological Survey (USGS) (Solley et al., 1998), residential usage accounts for nearly 26% of the water used in the United

States. Dependent on locale, single family and multi-family dwellings use between 50% and 80% of billed water demand, and the average household uses 100 gallons, per capita, per day. Approximately, 68% of residential water is used inside the home, while 32% is used outside to irrigate plants and lawns.

Other studies, with a focus purely on water and wastewater utilities / systems, have considered only the energy intensity embedded in the water delivered to the end user, and the energy intensity embedded in wastewater after its release by the end user to the wastewater utility. For example, a study (Elliott et al., 2003) of Wisconsin drinking water facilities revealed that the median value of energy intensity was about 1.5 kWh/kgal, considering both surface-water-using and ground-water-using facilities. (The State of Wisconsin [Cantwell, 2008] has an entire program, *Focus on Energy*, that offers energy information and services to Wisconsin utility customers.) EPRI (1996) reported results from an investigation of water supply and treatment facilities and found that surface-water-supplied plants use on average 1.4 kWh/kgal while groundwater-supplied facilities used, on average, 1.8 kWh/kgal. deMonsabert and Liner (1996) studied federal facilities and reported approximate energy demands of 2 kWh/kgal for water treatment and 3 kWh/kgal for wastewater treatment plants.

Water Used in Energy Production

While not the focus of this guide, it is nonetheless important to keep in mind that large amounts of water are used in the production of electrical energy. According to the Energy Information Administration (EIA), in Arizona nearly 104.4 million MWh of electrical energy was generated in 2006. Of that total, the breakdown by energy sources is as follows:

- coal: 38.7%;
- natural gas: 31.5%;
- nuclear: 23.0%;
- hydroelectric: 6.5%;
- petroleum, renewables other than hydroelectric, and pumped storage: 0.3%.

Across the U.S., electrical energy generation averages over 2 gallons of water usage for every kWh generated (Torcellini et al., 2003). Pasqualetti (personal communication, 2008) has estimated that, for electricity produced from Arizona hydroelectric sources, water usage for those facilities can, on average, be as high as 65 gallons/kWh. However, because most of Arizona's electrical generating capacity is thermo-electric (coal, gas, nuclear) the average water use at Arizona electrical generating facilities is near 8 gallons/kWh (Torcellini et al., 2008). This is four times higher than the national average.

Basic Energy and Water Uses in Water and Wastewater Systems

In water and wastewater systems, energy is used to lift (overcome gravity), move / transport (overcome friction), heat, cool, pressurize, and treat water. Actual treatment consists of pressurization, transport/lifting, filtration, addition and removal of chemicals, aeration, etc. Additionally, energy is used to heat, cool, or pressurize air. Finally, energy is used for lighting, heating, ventilating, air conditioning (HVAC), and telecommunications at wastewater facilities, as well as for transportation of employees, equipment, etc.

For the purposes of this guide it is useful to use the the following elements to describe the water and energy usage of of water supply systems: supply/source; transmission, distribution, and storage; pumping; treatment; end use(s).

Similarly, this guide uses the the following elements to describe water and energy usage in wastewater systems: collection; pumping; storage; treatment; reuse / discharge.

Greenhouse Gas Emissions

Users and producers of energy through the combustion of fossil fuels recognize that reducing emissions of GHGs is increasingly important. Voluntary reductions of carbon dioxide emissions are now encouraged, but rapidly developing state, regional, national, and international policies will mandate reduced emissions of GHGs. Thus, meeting Arizona's energy needs will become increasingly expensive.

In general, a savings of 1 kWh of electrical energy translates to a reduction of nearly 1.5 pounds of greenhouse gas emissions (Arizona Climate Change Advisory Group, 2006; Dones et al., 2003).

Best Practices for Water and Energy Conservation

In preparing this guide, we have focused on energy and water conservation practices for small rural water and wastewater systems, about which little has been written. On the other hand, there are many studies, investigations and reports concerning larger systems, from which generalities have emerged. The results on larger systems were used to identify processes, systems and components for initial review and consideration.

Concerning larger water supply systems, Berry (2007) reports that the most promising areas for intervention are: improving pumping systems; managing leaks; automating system operations; and, regular monitoring, with metering, of end use. For larger wastewater systems, Elliot (2003) found that aeration, sludge treatment, and pumping offer the greatest potential for reducing energy costs.

We expect that a similar set of best practices will yield the most bang for the buck when it comes to small rural water and wastewater systems, although that premise is untested. Therefore, it is essential to complete a cost analysis (best practice #3, below) before proceeding with any major improvement or adjustment.

Water Management and Policy

1. Balance Revenue and Expenses when Operating Water and Wastewater Systems

To provide baseline data, utilities should strive to track expenses and revenues associated with current operations and maintenance, and assess the success of best water and energy conservation practices after implementation.

As part of this practice, it is essential to review routinely and, if necessary, adjust water and wastewater rates. Rate setting can be politically charged, but it is critical for long-term, and possibly short-term viability of a water or wastewater utility, whether private or public. The subject of rate setting is mostly beyond the scope of this guide, but the American Water Works Association (AWWA, 2000) has issued a manual that provides guidance; and there are many other references on this topic. Consult Best Practice 6 in this guide,for information on water budget-based rate structures.

Success with this and any other rate-related practice requires periodic communication with end-users so they: 1) are aware that efforts to conserve water and energy do result in reduced demand for both renewable and non-renewable natural resources – which benefits all; and, 2) help to reduce future user expenses by reducing the need for ever-greater amounts of water and wastewater system infrastructure. End users also need to be informed that rate reductions, if they occur at all, are only a secondary benefit that may arise when best practices are implemented.

2. Understand How Energy and Water are Utilized in Water and Wastewater Systems

In order to reduce energy and water use in any system, it is important to understand the 'where', the 'why', and the 'when' of that usage.

For example, aeration in wastewater treatment typically consumes a significant fraction of overall facility energy usage. Aeration is required to facilitate aerobic decomposition of waste products in the wastewater; and large amounts of energy are required to power the blowers / compressors that supply the air necessary for aeration in conventional wastewater treatment plants, or to power mixing equipment in aerated lagoons. In many plants, the blowers or compressors operate at full capacity all of the time, whether or not it is necessary. It may be feasible to monitor dissolved oxygen (DO), or another indicator, in aerated waters and to adjust mechanized equipment operations accordingly.

The University of California at Davis (UC Davis) implemented aeration control using continuous DO monitoring at their campus wastewater treatment plant. Paraphrasing and quoting from the 2005 report by Phillips and Fan:

> The original design for the 2000 UC Davis Wastewater Treatment Plant (WWTP) relied on manual aeration control to maintain desirable dissolved oxygen (DO) levels in the oxidation ditch. Given the large daily variation in flow and wastewater strength, WWTP operators found it difficult to maintain stable DO levels. As a result, operators typically erred by providing too much oxygen, and the ditch was often found to be in an over-aerated state. Thus, the control strategy wasted energy and promoted unstable biological conditions. In January 2004, UC Davis installed a new system for continuously measuring DO in the oxidation ditch and automatically controlling aeration:
>
> Over a 12-month period the use of Variable-Frequency Drives (VFDs) for oxidation ditch aeration in conjunction with DO feedback-loop control reduced WWTP electrical consumption by an average of 23% or 0.755 kWh/kgal. The project was found to have a 1.2 year payback at the prevailing municipal electrical rate of $0.09/kWh. Beyond energy efficiency, the ability to maintain DO at prescribed levels in the oxidation ditch has afforded operators a higher degree of biological process control. Effluent quality has improved as a result. The sludge volume index (SVI) increased from an average of 84 to 99. Ammonia as nitrogen has consistently remained below 0.5 mg/l after implementation.

In many water treatment facilities, backwashing of filters utilizes significant quantities of water. At a minimum, backwash rates and procedures should be reviewed for possible changes to lower water use. Also, to the greatest extent possible, overflows from basins and storage tanks, as well as leakage from such, should be eliminated.

In Ruidoso, New Mexico, the water utility has implemented backwash recycling at its water treatment plants in order to conserve water used in plant operations (Brand and Wilt, 2003). The "wet" water savings, due to backwash recycling at a new water treatment plant, were estimated at 30 ac-ft./yr. This represents 3% of total water deliveries to the plant.

For public health reasons, reuse of backwash water in a potable water facility must be approached carefully; it may not be allowed by the regulating authority, which in Arizona is ADEQ or USEPA (for tribal systems). Even if backwash water cannot be recycled as potable water, there may be other potential uses, such as dust control, construction water for soil compaction, etc.

The Cedar Rapids, Iowa, water utility (Iowa Association of Municipal Utilities, Year unknown A) has an energy efficiency management program that addresses the needs of public, commercial and industrial users. The program consists of the following elements:

- Maintaining electrical usage records and developing analytical methods to review the record data;
- Monitoring and management of peak-demand power and the power factor(s);
- Equipment for real-time monitoring of power usage;
- Variable speed/frequency drives for pumps;
- Participation in the electrical provider's power interruption management program;
- Citywide energy management system.

In all of these examples, a thorough understanding of how, where, and why energy and water were being utilized was needed before conservation strategies could be formulated and implemented.

3. Develop a Cost Analysis and Implement Capital Improvement Planning

Before making any significant investment requiring either money (capital) or labor, complete an economic evaluation that takes into account the annual cost of maintaining the status quo (an existing system configuration) in comparison to making improvements. This is often referred to as alternatives analysis. For example, it may appear, on the surface, that a facility could utilize renewable energy to support part of its energy demand. A complete analysis will consider all costs of implementing renewable energy: any borrowing cost(s), purchasing the equipment, installation, permitting, maintenance, operations, etc., in addition to the savings likely to be gained. This analysis will take into account capital costs, energy and other costs, interest, inflation, depreciation (possibly), operations and maintenance expenses, labor costs, etc. This type of analysis is typically completed by an engineer with expertise both in the water or wastewater systems under consideration and in engineering economics.

If an alternatives analysis requires resources beyond those readily available, it may be possible to seek out the experiences and expertise of individuals who work for water or wastewater utilities that have completed such an analysis before they proceeded, or declined to proceed, with an upgrade similar to the one being contemplated.

Once an alternatives analysis has been completed, it can serve as the basis for either staying the course, or making a change.

The State of Washington offers energy life-cycle cost analysis (ELCCA) guidelines, spreadsheets and reports that address buildings. Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems is a detailed life-cycle cost (LCC) guide developed by the Hydraulic Institute, Europump, and the U.S. Department of Energy's Office of Industrial Technologies (OIT).

4. Implement a Water Conservation Program

Based on U.S. Census data, the U.S. population will grow by 30% over the next thirty years. In growing regions like the Southwest, large and small utilities will need to expand their operations. As noted earlier, end use or supplying water to homes and businesses is energy intensive, and, as demand and power costs rise, small utilities will be challenged by rising costs. Fortunately, the most cost-effective way to reduce water costs is to simply use less. As a result, water conservation programs are often the most cost-effective way to lower energy bills for both consumers and utilities (Cohen et al. 2004).

Conservation can provide other system benefits as well. When utilities reduce the water that has to be pumped and treated, they reduce their water production and chemical expenses. Because conservation reduces the demand for water, a conservation program can also effectively increase system capacity, reducing the need for costly upgrades or expansions of existing facilities.

Unfortunately, reduced water usage also means lower revenues for a utility. For water or energy conservation to be attractive to water and wastewater utilities, the implementation of best practices must be accompanied by parallel efforts to adjust rates so that expenses will continue to be met by revenue. Similarly, revenues to the system should not necessarily be an incentive to expand production.

Generally, there are five approaches that utility managers can use to create effective conservation programs:

- Water audits/& leak detection programs;
- Water budget/rate programs;
- Financial incentives;
- Ordinances/codes;
- Education.

The State of Texas has developed an excellent comprehensive guide that outlines several conservation strategies in each of these areas (Texas Water Development Board, 2004).

5. Develop Water Audits and Implement Leak Detection

An old saying suggests, "what gets measured, gets done." To implement a conservation program, often the best place to start is with a comprehensive water audit. Typically, a water audit uses a two-step approach where the system is looked at from the top down and then, from the bottom up. The top-down approach compares the utility's production data with billing records to help determine a picture of the total system water losses. The bottom-up approach looks at utility management practices to determine exactly where water losses occur. For instance, some water losses can be attributed to line flushing, fire department usage, or street-cleaning operations. Other water losses can be attributed to meter errors, water theft, and pipe leakage due to excess pressure. The American Water Works Association (AWWA) publishes a comprehensive manual (Water Audits and Leak Detection M36) that can be used to develop a preliminary or comprehensive water audit.

Water audits also can be used by utilities to understand the water usage characteristics of individual users. For instance, many larger utilities offer water audit services to their industrial, commercial, institutional (ICI) users to help their largest customers understand their water usage trends and detect system inefficiencies. Once created these audits can help customers save money through reduced water usage, and create good will between customers and utilities. Water expert Amy Vickers has written a comprehensive book on water conservation that includes water audit checklists for both residential and ICI customers (Vickers, 2001).

Typically, a large part of the bottom up approach is a comprehensive leak detection program. Leak detection is a systematic search for leaks within a utility's infrastructure. An effective program uses electronic equipment to locate leak sounds and pinpoint the exact location of leaks. Because leaks can develop at any time, these programs should be used on a regular basis.

An effective program can yield several benefits. Generally, there is an immediate savings in pumping and treatment costs. Additionally, once leaks are discovered they can be scheduled for repair, eliminating the need for costly emergency repairs. A leak-detection program can also identify trends with faulty equipment. For example, one study found that most of the leaking fire hydrants in the city were purchased from the same manufacturer. Using this information, the utility manager developed a replacement plan for the leaking parts, and changed to the city's specification for new hydrants (Wright, 2008).

A leak detection program can generate significant savings in utility operating costs. One Florida study (Wright, 2008) uncovered four water main leaks that were responsible for 240,000 gallons per day in losses. Once the leaks were repaired, the water utility realized a reduction of $3,000 a month in water production costs, and a significant improvement in water main pressure. The higher water pressure also eliminated the need to replace a main that had previously failed to meet firefighting requirements. Another large leak detection/ remediation program in Georgia resulted in estimated annual savings of $650,000 for the utility (Pennington, 2007).

Developing a leak detection program can be costly. Private contractors charge up to $120 per mile for leak detection services, and in-house programs require training and costly equipment. This can be problematic for smaller utilities with limited staff. But, because leaks can account for up to 10% or more of system losses, implementation costs can be often be quickly recovered through reduced production costs and increased system efficiency.

6. Implement Water Budgets and Rate Structures

According to a recent study by the American Water Works Association (Mayer et al, 2008), "As populations increase and climate uncertainties place heightened demand and stresses on water systems, more utilities are seeking new tools for water conservation and drought response." One effective management tool that utility managers can use to meet these challenges is a water budget rate structure (WBRS), which is a management system that uses a water budget together with an incentive-based rate structure.

Utilities can develop water budgets for different classes of water customers, such as single-family residential, restaurants, etc., by reviewing historical records for those customers, and by analyzing water budgets that have been developed by other regional utilities, or by developing their own water budgets. The data are then used to establish a level of efficient water use or "targets" for the different types of customers. For instance, in Boulder, Colorado, a water budget of 7000 gallons per month is established for single-family. In an effort to curb landscape water usage (see landscaping section below), exterior water budgets are developed on a sliding scale where 15 gallons / square foot (gal/sf) are allotted for the first 5,000 sf of landscape area, 12 gal/sf for the next 9000 sf, and 10 gal/sf for areas that exceed 14,000 sf. Utilities can also use a similar approach to establish budgets for multi-family users and commercial, industrial, and institutional users.

The second part of the WBRS usually makes use of an increasing block-rate pricing structure, by means of which water rates increase when customers exceed their water budget.

This kind of program has several benefits. Water budgets help utility customers understand their usage patterns, and the sliding rate scale provides monetary incentives for customers to stay within their water budget. Utilities that have adopted a WBRS have also created substantial conservation savings. One study that reviewed several programs in California, reported up to a 37% reduction in water consumption. These reductions have stabilized demand and made it easier for utilities to set rates that can meet cost of service requirements, improving their revenue stability (Pekelney and Chesnutt, 1997). Reduced demand also generates savings in the form of reduced energy usage.

A recent report (Mayer et al., 2008) provides a comprehensive look at how WBRS programs are created and managed. According to the study, implementation costs for a WBRS can vary widely. Generally, the existing customer billing system can be modified to meet the demands of a variable block rate structure, however software revisions may require outside expertise. Even with limited resources, utility staff can research historical trends, develop cost of service models, and review other systems' operations to learn of the effectiveness of such programs, where they have been adopted. The AWWA study cites several programs that implemented WBRS programs in less than twelve months with existing staff resources. A recent report (Mayer et al., 2008) provides a comprehensive look at how WBRS programs are created and managed.

7. Create Financial Incentives for Water Customers

Because the success of conservation programs is dependent upon the end user, many utilities have developed financial incentives such as rebates, vouchers, or incentives to encourage customers to change their water usage habits. Some examples include rebate programs for installing new water conserving fixtures, financial incentives for utilizing water efficient techniques like xeriscaping, and incentive-based rate structures (see discussion above).

Landscaping Programs

For many Americans, the image of the ideal home includes a lush, well-maintained lawn. Unfortunately, the American obsession with green acres has significant water and energy consequences. According to the U.S. Geological Survey, 7.8 billion gallons of water are used every day, largely to irrigate our lawns and flower beds (Solley et al., 1995). Nationally, this accounts for approximately 30% of all residential water usage, and, in arid climates like Arizona, the numbers for landscape usage are much higher, sometimes accounting for 50-75% of total daily usage. These water demands often pose significant challenges to small utilities. During hot summer months, many water suppliers experience demand that is 1.5 to 3.0 times higher than the winter demand, and in smaller communities, this peak demand often approaches the operating capacity of the water system.

Given these issues, several innovative utilities have focused their incentive efforts on reducing the outdoor water demand by creating landscape water conservation programs. These programs can generate several benefits. Vickers (2001) reports that the city of Albuquerque reduced outdoor water usage (which accounts for 50% of the city's residential usage) by ten percent after mandating a water wise landscaping program that included rebates of $250 for reducing turf usage. Besides water usage and associated energy costs, a landscape water conservation program can also reduce the need for water infrastructure (storage, wells, pumping facilities), and reduce energy costs associated with pumping and treatment. These reductions can help stabilize a utility's cost of service and improve long-term revenue stability.

Several utilities offer landscaping incentive programs to help customers convert their existing water-hungry "turfed" landscapes to low-water-use xeriscapes. Here, the utility offers a monetary incentive to customers to convert irrigated turf landscapes to water-efficient "xeriscaping." For instance, the City of Flagstaff (2008) turf replacement program offers rebates of up to $3,000 for replacing water-intensive landscapes with approved xeriscaping. The rebates are calculated on the square footage of turf removed from service. Other programs offer incentives for approved high-efficiency irrigation components such as rain-sensitive shutoff devices and drip irrigation systems.

Toilet Replacement Programs

Toilets account for almost 27% of the water usage in an American single family home, using more water than any other household fixture or appliance. On average, each person uses a toilet 5.1 times per day, and each flush averages 3.48 gallons per flush, or gpf (Mayer et al., 1999). Toilets are also one of the main sources of leaks in a typical residence. Aging flapper valves, poorly sized replacement parts and malfunctioning contribute to a large piece of the water consumption pie. The AWWA estimates that up to 25% of American toilets leak, and these losses average 9.5 gallons per day per fixture (AWWA, 1993).

As a result, many utilities have implemented toilet rebate or replacement programs to help conserve water. For instance, the city of Santa Monica, California, implemented a toilet rebate program in 1993 that effectively replaced 60% of older toilets with more efficient 1.6 gpf models. According to utility officials, this reduced water and sewage flows within in the city by 15%. These usage reductions resulted in the avoidance of significant capital improvement costs, and reduced energy usage for the city.

Toilet replacement programs are generally sponsored by water utilities that use a credit or rebate to get their customers to update their fixtures. These programs vary widely. Some programs utilize an "incentive" fee program, where each customer is charged $2 a month to help fund the program, and the fee is removed once a customer's toilet has been replaced. Other utilities offer a rebate of $50 - $150 to replace an old toilet. In Santa Fe, New Mexico, a recent law requires builders to replace an aging toilet in order to obtain a building permit for new construction. While federal law governs new toilet performance at 1.6 gpf, research indicates that toilet performance varies widely. As a result, utility managers should look to replace toilets with products that carry the EPA's *Water Sense* logo.

Showerhead Exchange Program

According to the study "Residential End Uses of Water" (Mayer et al. 1999) showers account for almost 17% of a typical household's water use. Because modern showerheads are more efficient than older programs, water providers can effectively reduce water consumption by establishing a showerhead exchange program. Users exchange their current showerheads for replacement fixtures (2.5 gallons per minute, or gpm, at 60 psi) provided by the utility. This ensures that water efficient showerheads are installed and inefficient fixtures are recycled. Recent research suggests that an effective showerhead exchange program can reduce household water consumption by between 5.7% and 10%, and, when fully implemented, a showerhead exchange program can save significant amounts of water (Vickers, 2001).

The showerhead replacement program should also be marketed to non-residential users with high water usage profiles. These include hotels and motels, schools, dormitories, hospitals, gymnasiums, and athletic clubs. In one Massachusetts athletic facility, thirty-five high-flow showerheads were replaced with a low-flow model. The initial cost of the program was only $300; the annual savings from reductions in water, sewer and water heating energy costs was $3,300. The effective payback period for this program was one month (Vickers, 2001).

8. Adopt Water Efficient Ordinances and Codes

Municipal ordinances and building codes are often one of the most cost-effective tools for accelerating water conservation within a community. Over the past several years, drought-like conditions in the Southwest have forced municipalities to draft ordinances that limit excessive exterior water usage. Faced with rapidly declining supplies, and explosive growth, the City of Las Vegas developed ordinances that limited lawn watering, banned the use of turf on new projects, and mandated water conservation techniques in all new building projects. These aggressive ordinances reduced water consumption in the City of Las Vegas by 20% in one year (JP Morgan, 2008).

The City of Tucson requires the use of rain-shutoff devices (devices that turn off irrigation systems before and after rain events) on all new irrigation systems. Other cities, including Phoenix and Albuquerque, have created ordinances that mandate summer watering restrictions, and prohibit the wasteful use of water. Users who fail to comply with the ordinances are fined (Vickers, 2001).

Building codes also can be used to help utilities conserve water. While building codes are often focused more on public safety than on water efficiency, they can usually be modified to mandate water conservation within a community. For instance, federal regulations stipulate that showerheads use less than 2.5 gallons per minute, but most building codes do not limit the number of showerheads that can be used in any one shower. This can be remedied by adopting a code variation that limits the number of showerheads per square foot of shower area. Other adaptations to the code allow for the usage of “waterless” urinals in public and commercial facilities (Pape, 2008).

The “green” building movement can also be used to help utilities manage water demand. One of the areas of emphasis in most green building initiatives is the “efficient usage of water”. Cities that adopt green building requirements like the United States Green Building Council’s LEED initiative (see www.USGBC.org), can use these programs to mandate water efficiencies in new and existing buildings. The Alliance for Water Efficiency (AWE) maintains a website (www.allianceforwaterefficiency.org) that outlines several useful code variations and water ordinances.

9. Create Water Education Programs

The effectiveness of any conservation program will usually depend upon a utility’s customers. For this reason, it is important to educate utility customers on “why” water conservation is important. Education can take many forms. The City of Albuquerque maintains a website (www.abcwua.org/content/view/70/60/) that shows customers how to create efficient rainwater gardens, and provides designs for drought-tolerant landscapes. In Australia, one utility uses an education program that features a water mascot, similar to those used at sporting events. The mascot appears at public events, shopping malls, and parades where he generates enthusiasm for the utility’s water education efforts. The water mascot also appears at grade schools where he introduces the water conservation program to young students.

According to a Texas study, school education programs can be particularly effective at gaining the public’s trust for new conservation programs. Here, water conservation is introduced to the students, who, in turn, introduce the concepts to their parents. The Texas study suggests creating an advisory board of educators and utility operators, who can assist in choosing and developing a curriculum. One curriculum features a science experiment where students are asked to measure the flows of their showers, toilets, and faucets. When the data are returned, students are given low-flow faucet aerators and showerheads, which they then use to retrofit their homes. In the final part of the project, students determine the water savings for the house. In this case, a science project not only trains students and parents about the economics of water conservation, but it also helps reduce the water usage with the local utility (Texas Water Development Board, 2004).

One resource for Arizona educators is Project WET (Water Education for Teachers) Project WET Arizona, is a state affiliate of National Project Wet, which was developed by the U.S. Bureau of Reclamation. The University of Arizona's Water Resources Research Center and the College of Agriculture Cooperative Extension 4-H Youth Development jointly administer the program. Project WET provides water education resources and assistance to educators, who are broadly defined as public and private school teachers, 4-H leaders, Boy and Girl Scout leaders and others in teaching or leadership positions. WET resources are appropriate for all ages, although the project's priority is to provide teaching aides for K-12. Much of the educational information specifically relates to Arizona, including water conservation, water pollution, and water rights.

System Design and Engineering

10. Review System Plans, Specifications, and Records

Plant operators and managers who are well-acquainted with the design and the intended operation, as well as with the current and historical operation of their facility, are best situated when it comes to evaluating how their systems are performing and how those systems might better perform if improvements or changes are made.

If new management or operators seek to gain familiarity with the system(s) for which they are responsible, consider inviting a 'circuit rider' from the Arizona Small Utilities Association (ASUA), which can provide:

- *On-site Technical Assistance*, which may include, but not be limited to: development of operational and equipment preventive maintenance plans, identification of operational deficiencies, corrective maintenance plans, system enhancement project planning and financing, and water quality sampling for analysis.

- *Training*: organized by certified water and wastewater professionals with qualified trainers having expertise and knowledge of the water and wastewater industry.

- *Source Water Protection*: ASUA professionals work with water systems to develop Wellhead Protection Programs (WHPs).

- *Regulatory and Legislative Advocacy*: With the help of member systems, ASUA develops positions on legislative and rule-making activities. ASUA legislative representatives will work with Congress, the state legislature and state departments to communicate positions.

11. Take Measurements, Evaluate the Data, Make Decisions

Water and wastewater system operators and managers need to be able to measure, or have access to individuals or equipment that can measure: pressure; elevation; flow; electrical voltage and current, or power; temperature; rotational pump speed.

These measurements are necessary to assess the present operating condition of systems and system elements, and to provide answers to questions such as:

- what is the load factor (see AWWA, 2003) for a given piece of equipment?
- what is the average inflow of influent?

- how does potable water production vary over the course of an hour, a day, a month, or a year?
- what is the energy loss between two given points of a water / wastewater system?
- how much energy is a pump adding to a flow?
- Where on the pump curve is a given pump operating and what is the efficiency of that pump's operation?
- Is a motor operating efficiently?

Also, these measurements provide the data that allow operators and managers to assess whether a given change or improvement has had the intended effect.

Guidance on open-channel flow measurements is available from the U.S. Bureau of Reclamation (USBR, 2001). For pressurized systems, there is not a single guide that covers all possibilities, however, manufacturers of power, flow, level and pressure meters / transducers / sensors typically provide their own guidance.

While the above types of measurements are the most common in water and wastewater systems, on occasion, other measurements (see Sullivan et al., 2004) may be useful – particularly with regard to evaluating the energy consumption and energy efficiency of equipment and machinery: oil analysis; temperature measurement (for example, using thermal imaging); vibration measurement and analysis.

When deciding to collect data, consider that:

- Good data are better than no data;
- No data may be better than bad data;
- Too much information can overwhelm an organization's ability to manage the data;
- There are expenses associated with collecting and managing data, so plan strategically to collect useful data and to archive that data for future needs.

12. Evaluate Different Available Water Sources and Their Costs

A recent study (Olsen & Larson, 2003) indicated that the energy cost associated with groundwater production and treatment is typically greater than for surface water production and treatment. In the cited study, which considers systems in the Madison, Wisconsin area, energy costs are estimated at 1.3 kWh/kgal for surface water and 1.7 kWh/kgal for groundwater. While groundwater treatment costs are often relatively low, the energy cost for lifting water from considerable depths to the surface is not.

An economic analysis to decide between ground or surface water sources requires consideration not only of energy costs, but must also take into account any necessary infrastructure, such as for water treatment, water rights or procurement, and O&M costs. This sort of analysis also must consider issues such as security, whether the supply can be sustained (drought and other impacts), etc., and these issues may well trump energy costs.

13. Reduce Leakage through Pressure Management

Consider reducing the water system pressure when possible to reduce leakage and to reduce stress on distribution system and user piping. There may be additional opportunities to reduce pressure during periods of lower demand, which will be at night for most systems.

With pressure management, not only will leakage be reduced, but system energy requirements also may be reduced, depending on how pressure is reduced. If pressure reducing valves (PRVs) are used to reduce pressure, there will be no energy savings. However, if pumps operated by variable frequency drives (VFDs) are used to manage pressure, there will be energy savings.

A series of relevant articles, including a case study of one Australian water distribution system pressure management, are provided on the Pacific Water Efficiency website. In one such article (Mistry), the author reports that:

> Basically, a higher pressure will result in a greater frequency of bursts and more water lost through leaks and burst pipes. Installation of computerized, flow-sensitive pressure control valves or the retrofitting of electronics on to existing pressure reducing valves can be used to reduce unnecessary high nighttime pressures and minimize the problem of fluctuations in pressure which weaken pipe systems and reduces their asset life.

14. Reduce Energy Losses in Pumps & Fans

Pumping systems use substantial amounts of energy. For instance, an Electric Power Research Institute study (EPRI, 1996) found that with groundwater based water supply systems, the vast majority (nearly 99%) of energy goes for well pumping and booster pumping. With surface-water-based water supply systems, most (in excess of 95%) of the energy used is for raw and treated water pumping.

There are fairly standard methods and technologies for assessing the efficiency and operation of pumps, and software is available for evaluating the effectiveness of proposed improvements. The objective is to reduce hydraulic energy losses in the pump and electrical energy losses in the driver (motor) and to maximize overall system efficiency in the process. The closer the match between the power input to the pump and the power transferred to the water, the greater the efficiency.

Two common strategies are to operate constant-speed pumps as near as possible to their point of maximum efficiency, and to utilize variable-speed pumping to achieve the same objective when the flow or pressure that must be supplied by the pump varies considerably during the period(s) of pump operation.

Best energy management practices for pumps (USDOE, 2008) are a series of tip sheets have been detailed by the U.S. Department of Energy's Energy Efficiency and Renewable Energy program, which has also prepared a pump energy sourcebook (USDOE, 2006) that addresses improving pump efficiency, and a fan energy sourcebook (USDOE, 2003) that addresses fan efficiency. Additionally, pump energy efficiency (USDOE, 2008a) and fan energy efficiency (USDOE, 2008b) assessment software are available from the Department of Energy. The trade magazine Waterworld has a monthly column, Pump Tips & Techniques that offers guidance for operators and managers (Budris, 2008).

15. Reduce Friction Losses in Production Wells

As noted previously lifting and pressurizing groundwater requires considerable energy. Depending on design and operating conditions, there may be considerable energy losses incurred as water is extracted from aquifer storage.

Related best practices include design for high efficiency extraction, with consideration given to the aquifer, the gravel pack and the well screen, and through maintenance or rehabilitation to restore efficiency lost due to normal aging processes (Drake, 2008; McGinnis, 2008).

The commonly used measure of well (not pump) efficiency is specific capacity, which is the volume of water produced (gallons) divided by drawdown (feet). The larger the volume that can be produced at a given drawdown, the greater the well efficiency; as drawdown increases, the required lift will increase, as will the required energy input.

On a parallel track, pumping systems for water production wells, such as vertical turbines with the electrical motor at the surface, or submersible pump and motor configurations, need to be designed, operated, and maintained for maximum efficiency.

16. Reduce Friction Losses in Valves

Valves of all types (check, stop, regulating, control, altitude, etc.) have the proven potential to cause energy losses in water systems. This is especially a concern for systems that are pressurized by pumps. Even when valves are operating correctly, the energy loss associated with one valve type could be ten times that of another valve. If your system has only a few valves, this will not be significant. However, if a system has tens or hundreds of valves, the associated energy costs can be significant. Valves that are operating in a partially closed position can give rise to large hydraulic energy losses; if pumps pressurize the system, then large electrical energy losses will be incurred.

17. Reduce Friction Losses in Pipes

It takes energy, supplied either by pumps or by elevated storage, to overcome pipe friction in transmission and distribution system piping. Since frictional resistance to the flow of water is present in any pipe, all one can do is minimize friction losses. This is an optimization problem that requires consideration of the value of existing pipe runs, the cost of rehabilitation or replacement, and the tradeoff between projected energy cost reduction(s) and the costs of improvements.

Plastic pipe friction losses are relatively low in new pipe and can be treated as fairly constant over time. For metal pipes, no matter whether in a water transmission or water distribution system, friction losses will generally increase over time. The growth of tubercules in many types of metal pipe both increases friction and reduces the area of pipe available for transmitting water.

Best practices for reducing pipe friction consist mainly of pipe cleaning (AWWA, 2003), pipe lining (Muenchmeyer, 2008), and pipe replacement (with or without an increase in pipe diameter).

18. Adequately Ventilate or Sunshield in Warm Weather

Electrical resistance increases with temperature. As a result, exterior motors should be shielded from the sun. Motors at wellheads need to remain accessible for repair or removal and shields need to be removable.

19. Use Gravity to Move Water

Most hydraulic systems provide for the exchange of energy between elevation, or gravitational potential energy, velocity, or kinetic energy, and energy of pressurization. In some operations, water flows from a higher to a lower elevation under the action of gravity and then, due to a design flaw or another reason, the water must be returned to a higher elevation with a pump. The objective of this practice is to utilize gravitational potential energy wherever possible, rather than pumps, to promote the flow of water from one location to another.

20. Automate System Operation

The utilization of Supervisory Control and Data Acquisition (SCADA) systems is widespread in larger water and wastewater utilities but not so in smaller rural systems. SCADA systems allow not only for monitoring, but for control and more sophisticated automated decision making and real-time adjustment of pumping rates, process parameters, valves, etc. A recent overview is provided by Schroeder et al. (2008).

21. Generate High-Quality WWTP Effluent

Adequately treated wastewater (effluent) is a water resource of increasing value. If treatment is to sufficiently high quality, which vary across the nation but are generally uniform across a given state, such as Arizona, the effluent can be reused for irrigation, industrial applications, groundwater recharge, power plant cooling water, etc. The wastewater treatment process(es) in use, or selected as part of redesign, or for design of a new facility, can have a great influence on effluent quality. As an example, a membrane bioreactor (MBR) process, in comparison to an activated sludge process, may offer considerable advantage in removing endocrine disrupting contaminants (presently unregulated) that exist in most WWTP influent streams (Arizona Water Resource, 2008).

Mankato, Minnesota's new wastewater reclamation facility was recognized by Minnesota APWA (American Public Works Association) for its high-quality effluent, which will be used for power plant cooling water at the nearby Calpine power plant (Water World, 2008). The new plant was constructed by means of a public-private partnership amongst the City of Mankato, California-based Calpine, and the Minnesota Pollution Control Agency (MPCA).

22. Consider Hydroxyl Ion Fog for Wastewater Odor Control

A relatively new technology is the hydroxyl ion fog odor control system by Vapex. The hydroxyl ion fog system offers the potential for reduced energy and capital costs where odor control is routinely required: headworks, scrubbers, holding tanks, lift. stations, wet wells, etc. The hydroxyl ion fog reacts with odorous hydrogen sulfide gas, reduces the corrosion associated with the gas, and breaks down grease. The system can be considered as an alternative, or supplement to carbon, biological, and chemical scrubbers.

Operations and Maintenance

23. Manage Air in Pressurized Water and Wastewater Systems

The presence of air in pressurized water or wastewater systems can cause excessive energy consumption in pumped systems, including possible damage due to hydraulic transients (water hammer). The underlying cause is a loss in cross-sectional area of flow with accompanying flow reduction and increased friction losses.

Pressure pipe runs need to be evaluated by an engineer with expertise in water transmission. Common remedies include strategic placement of air release valves.

24. Utilize Off-Peak Power Usage Strategies

Electrical power demand by residential, commercial, institutional, and industrial users varies considerably over the course of a 24-hour day. Furthermore, the demand over a 24-hour period will vary according to the season. Electrical power providers need to respond to this variable demand and their expenses, and consequently, the cost of purchasing power, is usually greatest when demand is at its peak. As a result, the rate for electrical power, particularly for users with large electrical demands, will vary, depending if the use is on-peak or off-peak. For users with significant electrical power needs, often there are cost advantages to shifting power use from on-peak to off-peak periods. The threshold for electrical power pricing, according to such a program, is different for each electrical power provider.

With water treatment, raw / source groundwater supply pumps are used to lift water from wells to the surface and into storage, often with minimal treatment. In small systems, these well pumps usually operate intermittently. It may be advantageous to operate the well pumps at off-peak periods when electricity is less expensive to purchase.

The North Liberty, Iowa, water utility saves energy and reduces expenses with off-peak groundwater pumping into ground storage, in conjunction with variable frequency drive (VFD) pumps to move water through treatment and into elevated storage (Iowa Association of Municipal Utilities, Year Unknown A). In this instance, a key requirement is *adequate storage,* so that pumps can be operated during the off-peak time period. Otherwise, the pumps would have to operate in synchronization with demand, regardless of power pricing.

The water utility department in the City of Fresno has several hundred well pumps. Fresno uses a SCADA system to monitor and control pumps for operation, to the greatest extent possible, at times when power costs for each particular pump location is at a minimum (City of Fresno, 2008).

25. Optimize Treatment Processes to Reduce Water and Energy Consumption

Poor water quality may necessitate treatment that has significant associated energy costs. This is certainly the case for wastewater, but it is also true for potable water. Certain water treatment processes, for example, reverse osmosis (RO), consume both energy and water. Each treatment process generates a waste stream, which could be small, as in the solid waste generated from water disinfection using bottled sodium hypochlorite, or it could be much more significant, as in sludge generation at a WWTP.

While laws and regulations typically dictate the allowable water quality for treated potable water or wastewater, e.g., the Safe Drinking Water Act (SDWA) and Clean Water Act (CWA), compliance with the laws, regulations, and standards often requires one or more additional processes. These processes not only have capital and O&M costs, but they also require energy, and they may require a water input.

Blending water supplies may, in some instances such as meeting the SDWA arsenic standard, allow a water utility to reduce or eliminate the treatment necessary to meet regulatory criteria.

Alternative processes may consume less energy; however, one needs to take into account all costs, not only capital or energy costs.

26. Coordinate Water Production / Delivery with Treatment Process Capacity

High rates of raw water production / delivery for short periods of time may result in over-sized water treatment infrastructure with correspondingly high energy use, embedded energy use, operations and maintenance expenses, etc. For example, if a new arsenic treatment system has to be sized for 300 gpm water well production and the well only runs for a few hours a day, it may be prudent to downsize the production well pump and go with a lower-capacity treatment system, presumably one that is scalable as demand grows over time. Wastewater facilitiesthat have no little or no storage at the front-end and are sized primarily for peak periods of inflow, tend to have processes and equipment that must be operated under peak inflow conditions, even during periods of off-peak inflow.

27. Retrofit Facilities with Energy-Efficient Lighting

A good general reference, extensively quoted here, is: Energy Reduction Techniques for Small and Medium Water and Wastewater Systems (Florida Rural Water Association, 2007). Proven practices include:

- Utilize natural lighting when and where possible (need to consider HVAC costs and benefits as well);
- Use high efficiency ballasts for fluorescent lighting (retrofit/new purchase);
- Use high-reflectivity reflectors (retrofit/new purchase);
- Replace incandescent bulbs with compact fluorescent bulbs (use same fixture);
- Consider high or low pressure sodium over incandescent bulbs;
- Consider low pressure sodium over high pressure sodium;
- Consider LED lighting, which has the best efficiency of all lighting;
- Consider, time-based, occupancy-based, or photo-cell-based lighting controls;
- Consider task lighting instead of overhead lighting;
- For outdoor lighting, make sure lighting is directed onto the ground or task area instead of up into the sky.

28. UV Disinfection Systems Best Practices

Ultraviolet light-based effluent disinfection currently is not common in rural wastewater systems. However, these systems are increasingly used, and some attention to their operation and maintenance is warranted.

A first strategy is to reduce the electrical energy lost (as heat) in low efficiency ballasts, which are electrical devices that limit current flow through the UV lamps. Implementation of this practice will require evaluation of the existing system and ballasts, and consultation with the manufacturer. For an overview, consult Lupal (2001). The Princeton, Indiana WWTP recently has implemented the use of high-efficiency ballasts (Princeton, 2008).

The quartz sleeves that enclose the UV lamps foul over time and there is an accompanying decline in UV intensity, with reduced disinfection. Automated systems will assess UV light intensity attenuation over time, but that is no substitute for regular visual inspection of operating conditions.

Larger UV disinfection systems with multiple flow channels and banks of UV disinfection lamps may be candidates for modified operation by means of which flows pass through a single channel during periods of low flow, reducing the need for simultaneous and energy-wasting operation of lamp banks in two or more channels. Philips and Fan (2005) provide a case study of implementation at the UC Davis WWTP, where it was found that annual UV system energy dropped by nearly 25%; bulb lives were extended by a similar amount; and, payback, based on energy savings alone, took only four years.

29. Increase Electrical Motor Efficiency

This a widely-used practice and consists primarily of replacing lower efficiency motors with higher-efficiency models. This reduces electrical losses in the driver. It may be cost-effective to not replace motors until they are near the end of their design life. If appropriate, single-speed motor operations should be upgraded to variable-frequency drives. Additionally, it may be feasible to switch from single-phase to three-phase power. Three-phase motors are generally more efficient in their use of electrical power. Finally, motors should be evaluated for inefficient operation due to miscoupling / misalignment or due to poor mounting. Electrical losses are reduced because electrical energy will no longer be converted to unnecessary, potentially damaging, and energy-wasting mechanical vibration (see practice 11).

30. Operations and Maintenance (O&M) Guides and Education & Training

When new systems or components are procured, specify that the designer or supplier is to provide written and illustrated operations and maintenance (O&M) guides and on-site O&M training, possibly with a requirement for professional videography of the initial on-site training. These reference and training materials, if used and followed, will help to promote O&M consistent with the intent of the designer or vendor. Anticipate that, over time, seasoned and knowledgeable operators may improve and amend O&M practices.

Additionally, overall education and training for operators is essential so that they can understand utility policies, management and operations, be aware of energy supplies and uses and costs and understand the basis for successful application of best practices for water and energy conservation (Cantwell, 2008).

Renewable Energy

Because water and wastewater systems have regular and continuous power demands, there are excellent opportunities for using renewable energy sources. Renewable energy sources such as photovoltaic panels and wind turbines can be used to help meet day-to-day energy needs. Given the significant recent and ongoing investment in renewable energy, technologies are becoming more efficient and cost effective. In Arizona, where there are ample sun and significant wind resources, renewable systems can be effective at reducing expensive peak power demand placed on conventional providers.

Other renewable sources include sludge digesters that produce methane. The methane is captured and used to power a gas engine generator or a micro-turbine system. These systems utilize the methane gas produced in anaerobic treatment processes, reducing the GHG emissions of the wastewater treatment plant. To date, these kinds of systems have been limited to plants that exceed a threshold of 5-10 million gallons per day (Mgd).

31. Wind Energy

Wind has long been used to help pump, distribute and treat water. In the early 20th century, the development of the steel windmill and reciprocating pump provided water to farms, ranches, and railroads in the rapidly developing American west. This technology is still used to pump water worldwide. According to a report from the National Renewable Energy Laboratory (NREL), there are over one million windmills in the United States, Argentina, and Australia alone (Argaw, 2001). However, wind-powered mechanical pumps have limitations. Because of their reciprocating pump design, these pumps need to be installed directly over a well head. This poses problems because groundwater is often tapped in low-lying valleys, and these locations are not usually optimal for available wind energy.

Given the above location constraints on windmill / reciprocating pump installations, an electric wind turbine offers greater versatility. These turbines are designed to generate electricity (AC or DC) that can be used to operate a variety of electrical devices. Wind power can be used effectively to power pump motors, fans, lights, controls, and convenience power for small utilities. In pumping operations, the turbine can be coupled with an AC motor, which then drives the pump at varying speeds. This eliminates the need for costly batteries and inverters. Because electricity is easily transported, the turbine can also be placed in locations that will allow for the most efficient wind energy harvesting. Electrical wind pumps are twice as efficient as traditional windmills and are often a cost-effective alternative to traditional power supplies (Argaw, 2001).

In relatively recent applications, wind-energized aeration of both potable water reservoirs and wastewater lagoons and ponds has been implemented and evaluated in a range of settings (Horan et al., 2006; Anonymous, 2008; Brzozowski, 2008).

32. Solar Energy

Given the escalating cost of energy, several large municipalities have started to integrate solar power into their operations. The Alvarado water treatment plant in San Diego (120

Mgd) recently installed a solar power system that saves the utility nearly $70,000 in costs annually.

Many smaller municipalities will have difficulty funding the upfront costs associated with renewable systems. In this case, it may make sense to utilize a "power purchase agreement." Here, a development partner acts as an intermediary between the municipality and its power utility. The development group provides all of the upfront costs, design, installation and financing costs required for the project. In turn, the municipality signs a power-purchase agreement that allows them to buy power at a specified rate for 15 to 20 years. Generally, this fixed rate can be 15% to 25% less than the utility's typical cost per kilowatt hour. The advantage here is that utilities can lock in power rates for an extended period at a reduced cost. As power prices are escalating at an average of 5% a year, a fixed rate can substantially reduce future costs (Public Works, July 2008).

The most cost-effective method is to install a renewable energy system behind the electric utility's meter at the site. In this way, the water or wastewater utility can use the energy produced to augment power usage without a contractual agreement from the electric utility. This is particularly appropriate for small renewable systems like wind turbines and smaller photo-voltaic (PV) systems. If possible, it is best to size the renewable system to provide 75% of the power requirement of the facility. This allows the water or wastewater utility to generate a significant fraction of its power requirements, but still allows for a backup connection to the electric utility.

If the renewable energy is installed in front of the electric meter, then a power purchase agreement will have to be negotiated with the local electric utility. In this case, the green credits are sold to the local electric utility, and a power agreement is established between user and provider. Again, because the rate is fixed, the inflation risk is reduced.

Another idea is to form a collective that can pool small users to purchase bulk power from utility groups. Small collectives may also be able to pool enough small projects to generate the interest of a solar investment partnership.

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Appendix 1 – Design Best Practices Checklists for New Water and Wastewater Facilities

Excerpted from Roadmap for the Wisconsin Municipal Water and Wastewater Industry (Wisconsin, 2002). There is considerable overlap with the best practices identified in this guide.

New Water Treatment Facilities

- ☐ Provide ample storage capacity and flow flexibility to accommodate variable demand.
- ☐ Specify high efficiency motors and pumps.
- ☐ Include control systems and software.
- ☐ Consider low-energy backwashing system options.
- ☐ Optimize chemical requirements.
- ☐ Install baffled flocculation tanks instead of mechanical flocculators.
- ☐ Use staged, load-adjusted, small air compressors for air-fed ozone systems.
- ☐ Consider alternative solution mixers that are non-mechanical (static or hydraulic jump).
- ☐ Consider minimal energy concept, with respect to spatial layout of a new water extraction / treatment system to minimize pump distance and head requirements
- ☐ Select water treatment system technology that reflects the best life-cycle economics, with respect to environmental compliance
- ☐ Use lower friction pipes (estimated 6-8 percent energy savings)

Apply not-quite-potable, treated wastewater to:

- ☐ Recharge aquifers.
- ☐ Support industrial processes.
- ☐ Irrigate certain crops.
- ☐ Augment potable water, when and where appropriate.

New Wastewater Treatment Facilities

- ☐ Use attached-growth type of secondary treatment (trickling filters or biological contactors) in lieu of activated sludge for medium-sized plants to reduce energy costs.
- ☐ Provide ample storage capacity and flow flexibility to accommodate variable demand.
- ☐ Specify high-efficiency motors and pumps.
- ☐ Include control systems and software.
- ☐ Employ initial removal of large debris in lieu of comminutors to avoid increased secondary treatment costs.
- ☐ Consider low-energy backwashing system options.
- ☐ Optimize chemical requirements.
- ☐ Apply baffled flocculation tanks vs. mechanical flocculators.
- ☐ Use staged, load-adjusted, small air compressors for air-fed ozone systems.
- ☐ Consider alternative solution mixers that are non-mechanical (static or hydraulic jump).

- ☐ Apply fine-bubble aeration instead of coarse bubble aeration.
- ☐ Consider UV for disinfection, instead of chemical or ozonation systems.
- ☐ Minimize infiltration of groundwater and rainwater into sewage collection system to reduce pumping requirements (seal joints, lining, PVC pipe, bypasses, etc.).

Appendix 2 – Funding Sources, Renewable Energy Specialists, and Other Resources

Funding Sources

WIFA – Water Infrastructure and Financing Authority (Arizona)

http://www.azwifa.gov/

Clean Water State and Safe Drinking Acts (State Revolving Fund Program)

http://www.epa.gov/safewater/

DOLA, CDPHE, CWRPDA
National Water Program Strategy (Response to Climate Change)
Direct and Leveraged Loans
Disadvantaged Community Loans

Colorado Water Resources and Power Development Authority

http://www.cwrpda.com/Programs.htm

Small Hydro Loan Program (Colorado only)
Water Resources and Power Development Authority
Engineering up to $150K per year, $15,000 per local government
Up to $2 million per borrower, 2% for 20 years
SRF – Planning and Design Grants have been a success

Energy Efficiency and Conservation Block Grant Program (EECBG)

http://www.usmayors.org/climateprotection/documents/eecbghandout.pdf

U.S. DOE
68 % to Municipalities (30,000+)
28% to States
2% to Tribes

USDA Section 9006 Energy Programs

http://epa.gov/region09/cleanup-clean-air/pdf/az-waste-energy/renewable-energy-efficiency-pgm-farm-bill-sec.pdf

Section 9007 in new farm bill
AG producers and rural small business

25% grant

Water / Energy Partnerships

Solar Investment Partnership
Solar Development Companies

Sol Equity
IEG – Independent Energy Group – ASU developer
Camilla Strongin (602) 346-5054
Code Electrical
Mark Holahan (602) 438-0095
Sun Edison – (solar systems 50 KW or bigger)
Deer Path – (Boston)

Renewable Energy Specialists

Barbara Lockwood – APS (602) 250-3361
Tom Hansen – TEP (928) 337-7322
Lori Singleton – SRP (602) 236-3323
Terry Hudgins – Green Ideas (480) 620-4795 (mobile)
Ken Starcher – Alternative Energy Group – (806) 651-2296
Tom Acker – Department of Mechanical Engineering – Northern Arizona University (928.523.5200)

Other Resources

Agricultural Pumping Efficiency Program
http://www.pumpefficiency.org

National Environmental Services Center
http://www.nesc.wvu.edu/index.cfm

USEPA Small Water Systems
http://www.epa.gov/OGWDW/smallsystems/index.html

Consortium for Energy Efficiency
http://www.cee1.org/

WATERGY – Water and Energy Efficiency
http://www.watergy.org/

Focus on Energy – State of Wisconsin
http://www.focusonenergy.com/