The Role of Water in Efficient and Sustainable Communities

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ABSTRACT

In most communities, sourcing, treating, and distributing potable water and collecting, treating and reclaiming wastewater – what may be called the water enterprise – is a large user of electricity. The water enterprise uses 3 to 4 percent of total electricity in the United States. With increasingly stringent standards and declining water availability, many in the water and wastewater community predict that the energy intensity of the water enterprise could rise significantly in coming decades. This trend may be avoided by improving the energy efficiency of pumping and of treating potable water and wastewater and by supporting the entry of alternative technologies that are inherently more energy efficient. If we rethink the accepted technologies for water and wastewater and understand how they were supported by inexpensive electricity, we are likely to find alternatives that could reduce energy use, improve environmental performance, and extend service in the water sector.

This paper will review current municipal water and wastewater practices and their related energy use, look at the state of art, the state of the infrastructure, energy efficiency opportunities and alternative technologies and models. The energy and sustainability implications for communities of choosing these alternative paths will be discussed.

Introduction

The provision of potable water and the treatment of wastewater are critical services that a community must provide to ensure the economic health and well being of its residents and to safeguard the future viability of the community. The water and wastewater industries in the United States are undergoing significant changes due to growing service populations and increasing demand for services, the promulgation of more stringent environmental regulations, the impacts on watersheds, the need for sustainable water supplies, and concerns about escalating capital and operating costs (WIN 2000). Among the pertinent changes are: (1) the installation of new and innovative equipment, controls, processes, technologies and facilities to upgrade, expand and replace existing equipment, controls, processes, technologies and facilities; (2) the construction of new water and wastewater facilities to meet population growth; (3) the installation of new and innovative facilities to meet increasing environmental standards; (4) wider application of water conservation measures under non-drought conditions; and, (5) budgetary constraints that affect the cost of constructing and operating these water and wastewater facilities.

Water and sewerage facilities are essential infrastructure, yet historically they have been both capital-intensive and energy-intensive when conventional technologies, processes and system models are used. In many communities, the cost of sourcing, treating, and distributing potable water and collecting and treating wastewater is one of the largest energy expenditures represent as much as one-third of a municipality's energy bill (EPA 2005). As energy prices continue to increase, the more energy-intensive systems will cost more to operate placing a burden on already strained operating budgets.

For the most part the water and wastewater communities approach the provision of these services with a set of well accepted technical paradigms because communities in the United States have successfully provided these services for decades and in some cases for more than one hundred years. As a result the approaches to solving these problems are frequently viewed as static. Conventional thinking and conventional technologies, especially those used for secondary treatment, were developed in an era when energy prices were relatively cheap. If we are to realize real reductions in the energy requirements for these essential services we must rethink how we approach water and wastewater provision and treatment. Taking a piecemeal approach may not actually produce real energy savings. For example, biogas produced during anaerobic primary wastewater treatment may be used to generate energy. However, if downstream secondary and tertiary stage treatments use energy-intensive processes, the energy requirements for secondary and tertiary treatment may exceed the power generation potential from a conventional separate sludge digester. Choosing a more energy-efficient non-conventional technology path may significantly reduce total energy requirements in the wastewater side of the water enterprise. Separate sludge digesters developed in the late 1900s allow for the recovery of biogas from the anaerobic digestion and stabilization of primary sewage solids so that these biosolids may be more easily dried allowing transport and disposal of residual sludge biosolids.

As our country revisits its investments in water and wastewater infrastructure, it is appropriate to revisit these well accepted technical paradigms such as centralized treatment and hydraulic transport. To change our path it is essential that water and wastewater industries explore, develop and employ alternative models that can meet increasing environmental regulations with less capital investment and with less energy use, improving the economy and reliability of these essential infrastructures. This paper will identify several key issues facing society and suggest alternative models that might be considered.

Role of Water and Wastewater in Community Energy

Between 3 and 4 percent of the total electricity generated by the electric power industry in the U.S. is consumed by the water and wastewater industries (Burton 1996; Carns 2005). Electricity is used to power equipment such as pumps, screens, fans and blowers, mixers, centrifuges, sludge presses, ozone generators, membrane bioreactors, chemical dosing equipment and disinfection processes, such as ultraviolet (UV) light. Burton (1996) projected that using current technology models, the market for water and wastewater electricity would be expected to grow by over 20 percent by 2010 relative to mid-1990s practice as greater volumes of water are treated and to tighter environmental standards. Recent literature suggests that we are seeing the trends predicted by Burton actually occur (Elliott 2005 and EPA 2005).

The challenge, therefore, becomes how to accommodate the requirements for increased water and wastewater services while improving energy management and efficiency. Improved energy efficiency can be achieved through improved operations, better energy management and the incorporation of technological changes and innovation. Some equipment may be operated around-the-clock, while operation of other equipment and processes may be shifted to off-peak hours or interrupted during periods of peak electric demand to improve overall electric system efficiency and reduce costs.

There are approximately 54,000 community water systems, but just seven percent of those systems (3,797) serve 81 percent of the people (EPA 2004). Recently promulgated water quality regulations will have significant impact on energy consumption in water treatment because many water utilities will install energy-intensive technologies such as ozonation, UV disinfection and membrane filtration. New and improved filtration facilities will also be required to treat existing surface supplies that currently are not treated. Most existing drinking water treatment facilities will also need to be upgraded if they do not already meet new requirements for disinfection (Carns 2005).

Approximately 71 percent of the U.S. population (or 176 million people) are served currently by publicly owned treatment works. Over 90 percent of the municipal wastewater in the United States will be generated by communities having populations in excess of 10,000 people. About 3,000 wastewater treatment facilities (out of a total of nearly 16,000) each treat one million gallons or more of wastewater per day (Burton 1996).

While there is growing interest within the water industry for new, more energy-efficient technologies that may provide equal or better treatment, water quality and reliability and process control, there is a growing burden being placed on the industry due to unprecedented infrastructure needs. When aging water and sewer lines, pumps and motors, and large storage and treatment tanks have exceeded their useful life, they must be replaced. This need is magnified by the growing awareness of the needs to improve the management of storm drainage and sanitary sewage or combined collection systems in order to protect valuable surface water supplies. The economic challenge for this undertaking is staggering. *Clean & Safe Water for the 21st Century* (WIN 2000) reports this unprecedented financial problem: "…over the next 20 years, America's water and wastewater systems will have to invest $23 billion a year more than current investments to meet the national environmental and public health priorities in the Clean Water Act and Safe Drinking Water Act and to replace aging and failing infrastructure."

Future Energy Trends in Water

Many in the water and wastewater community predict that the energy intensity and overall energy consumption in the sector could rise significantly in coming decades (Elliott 2005). Increasingly stringent standards, increasing demand, and declining water availability and quality, are all driving increased energy demand.

For the most part, energy consumption by water enterprises is largely flow-related. Energy consumption in the collection, conveyance, and treatment of both water and wastewater are positively related to the volume and timing of water use and wastewater flows. Most, thought not all, capital costs are flow-related as well. For drinking water utilities, capital improvements pertaining to source water protection and collection, treatment, storage, and distribution are positively related to water demand, average and peak demand, and time of demand. For wastewater utilities, expenditures for improved wastewater collection systems and improved primary, secondary, and tertiary treatment are positively related to the volume of wastewater being treated. While these relationships are not always linear, reduced water demand will tend to reduce the capital costs of these types of works (Osann & Young 1998). Thus one option is to reduce the water demand through conservation and water recycling, which in turn will reduce energy demand by the energy that would have been used to collect, treat and distribute the conserved drinking water and to collect, treat and disposal, or reuse, the conserved wastewater.

To address the need for better water quality, advanced treatment technologies will be needed to treat lower quality water to drinking water standards as higher quality sources become fully tapped. Electric based technologies and processes, such as membranes and UV disinfection, offer promise of a greater degree of control and monitoring that conventional filtration and disinfection techniques, but at the cost of increased energy use (Elliott 2005 and Burton 1996).

Thus conveyance and treatment systems will continue to use more energy if conventional technologies and system models remain dominant. Thus, it is important to assess trends in the energy intensity of the water enterprise on a per customer basis, as well as on a per unit (gallon, ccf, mgd) basis, since several key strategies for reducing energy intensity will involve reducing water throughput while maintaining acceptable levels of service for all customers. And as noted, water efficiency measures also allow for better management of capital costs, which should be well received by decision-makers throughout the country.

Alternative Paths for Water and Wastewater

Increasingly energy intensity does not necessarily have to be the future path that we embark upon. If we rethink the accepted models for water and wastewater we are likely to find alternatives that could lead to a lower-energy, more-sustainable future. These will likely involve both – using less water and using less resource-intensive treatment approaches – although they must be assessed in a holistic manner by comparing life-cycle costs and environmental impacts.

Centralized versus Decentralized Models

The current centralized model for water and wastewater treatment focuses on achieving “economies of scale.” In reality, as the volume and geographic area of coverage increases, the cost and energy associated with water collection and distribution and wastewater collection and disposal or reuse increase dramatically as compared with decentralized systems. By treating more locally and at smaller scales, much of the energy required to transport the water can be avoided and less energy intensive systems can be used. In addition, the level of treatment can be adjusted more precisely to the level and nature of contaminant concentrations, and more opportunities will exist to match reclaimed water quality to reuse end-uses.

Water resource management in the U.S. has been dominated by “hard path” centralized, capital intensive and energy intensive infrastructure solutions (Elliott 2005). These solutions include centralized distribution systems and filtration plants in the water sector, and large diameter gravity combined storm water and sanitary sewage collection systems and electro-mechanically intensive wastewater treatment processes since the advent of the activated sludge process, and its many variations, for wastewater treatment. Urban creeks and rivers have been channeled, and dams have been constructed for flood control, irrigation storage and power generation. Permitting, funding, and management responsibilities of these interrelated water and wastewater systems have been delegated to separate agencies, rather than integrated into a holistic watershed management framework, and the regulatory goals have attributed little, if any, significance to energy use concerns. Operators are judged primarily on compliance with regulations, with limited regard for broader sustainability.

This reliance on centralized solutions does not fully consider the broader watershed and groundwater forces at work in the ecosystem and has cumulatively led to unintended consequences and environmental damage. Sewer collection systems and point-source discharges, by moving locally supplied water and infiltration/inflow water great distances, to point-source discharges have led to depleted local aquifers, allowing saltwater intrusion in the coastal zone, and reduced stream flows.

Sewer systems have also promoted growth and development, accompanied by large-scale increases in stormwater runoff. Leaking sewer pipes now constitute a major source of drinking water contamination. Stream channeling to control floods has also led to disruptions in natural wetland that have played an important role in surface water purification. And finally, failure to fully utilize cost-effective water efficiency and distributed water reuse measures exacerbates the surface and groundwater impacts on water supply systems.

In recent years, much progress has been made in developing alternative decentralized or distributed approaches to water resource protection. These approaches hold great promise to achieve water resource protection at substantially lower energy and capital costs than the traditional centralized technologies. In particular, these approaches can entail far fewer adverse public health and environment impacts when considered within an integrated framework. In contrast centralized approaches that can disrupt these natural systems, these distributed, "green" solutions to sewage and stormwater treatment rely on and integrate with natural surface water and groundwater systems. Among the key element of these "soft path" approaches are:

- Smaller service areas
- Lower overall energy intensity
- Lower water collection, treatment and distribution costs
- Lower wastewater collection, treatment and reuse costs
- Greater resource recovery from wastewater, including water, energy and nutrients
- Better community aesthetics though ease of integration into community open spaces and wildlife habitats
- Multiple functionality of system elements

"Soft path" infrastructure solutions are appropriate both for new areas of housing development and for remedial "fixes" when urban centralized water or wastewater infrastructure are in need to expansion or rehabilitation. Using soft path elements can cost-effectively complement an existing centralized system, reducing loads on the central system and avoiding costly system expansion investment. Soft path infrastructure can also produce other benefits for communities, including:

- Financial savings to communities by spreading investments out over time (avoiding borrowing costs), and by integrating projects into road, park, and public building budgets
- Targeting wastewater and stormwater solutions to existing problems, without creating the infrastructure for rampant, uncontrolled growth
- Restoration and preservation of open space that may be used for treatment as well as provide recreational open space and wildlife habitat amenities
- increased property values for those who live near this "green" infrastructure

Challenges to Alternative Technologies

"Hard path" infrastructure solutions to water resource protection and services have become conventional practice supported by government regulatory agencies, equipment manufacturers, professional education and practice, and numerous barriers exist to the promotion of "soft path" approaches. The water resource management field has many "sectors" and utilizes many "disciplines", including decentralized wastewater, drinking water, distributed stormwater, low-impact development, non-structural flood control, to mention but a few. Integrated water resource management means that planning for each of these sectors is conducted within the context of all other sectors. Too often, facility planning fails to take account of all the direct and indirect impacts on other sectors. In this context, soft path approaches will often have distinct advantages over centralized infrastructure, since there is less impact on natural processes and better assimilative and treatment capacity.

Typically, comparisons of the construction and maintenance costs of water and wastewater infrastructure are at the forefront of investment decisions. But often the range of choice is constrained and soft path alternatives are excluded as unproven or experimental. When they are included and are fairly presented, comparisons will often show distributed, decentralized and nonstructural system approaches to be less costly.

By shifting from a centralized model to a decentralized model, more energy efficient alternative technologies may emerge. However, often these energy-efficient, alternative technologies and approaches are less capital intensive and therefore result in lower design fees for engineers, a disincentive for most large engineering firms who are usually entrusted to select the best technology by the water and wastewater utility for whom they consult (Elliott 2005). Regulators may be inherently reluctant to approve alternative technologies because of the potential risks to public health of what may be perceived as unproven technologies. Some in the engineering community take advantage of this regulatory reluctance to either ignore or disparage alternatives that might threaten their bottom line. As the water and wastewater markets become more international, this argument of an alternative technology being "unproven" may be counter intuitive when the climate and social contexts are actually more favorable than in the countries where the alternative technology was first developed and proven.

In addition, basic secondary effluent water quality indicators used in discharge regulations, such as biological oxygen demand (BOD) and total suspended solids (TSS), when universally applied without discerning the nature of the BOD and TSS disadvantage engineered natural systems. For example microalgae used in engineered natural systems for secondary treatment to provide dissolved oxygen via photosynthesis and nutrient assimilation (Oswald 1988a; Oswald 1988b, Oswald 1990) are often viewed by regulators as the same as the BOD and TSS of primary sewage solids and/or secondary aeration biosolids. Treated wastewater effluent BOD and TSS concentrations are often viewed in the U.S. as universal indicators of effluent quality without scrutinizing the type of suspended solids or the type of BOD. Bacterial solids do indeed exert an oxygen demand, and a pathogen load, to receiving water, whereas, microalgae are microscopic plants, primary productivity biomass, that are net oxygen producers in a receiving water, contrary to the results of the standard dark incubation, five-day BOD test. In Europe, the effluents from wastewater pond systems are allowed to contain much higher TSS concentrations than are mechanical wastewater treatment plant effluents because they are primarily algal TSS and BOD. In a restricted irrigation reuse scheme that uses secondary effluent containing mostly algal suspended solids, the irrigation water will also carry a more stable form of organic nitrogen and phosphorus that is slowly released over time as soil bacteria decompose the algae conveyed by the reclaimed water (Oswald 1995, Green et al. 1995, and Green et al. 1996).

Restraining Energy Intensity through Water Efficiency

In a well-run water enterprise, demand management is a continuing process of seeking out *cost-effective opportunities* to make *beneficial reductions* in water use. The cost-effectiveness of conservation measures is best gauged by both their reduction in annual operating costs and their potential effect on the timing and scale of capital improvements. Beneficial reductions connote changes in water use that maintain functionality, economic opportunity, quality of life, and customer satisfaction. The dynamic nature of water use technology and the scalability of most conservation measures ensure that demand management is a continuous process, rather than a static objective.

Rates, fees, and customer billing are fundamental efficiency tools. Price signals can play a crucial role in demand management for water and wastewater service. Timely and rational price signals are enabling strategies for all other conservation measures, and typically highly cost-effective in their own right due to relatively low out-of-pocket costs.

- ***Tiered water rates***. Nationwide surveys since 1996 have shown a gradual shift away from declining block, or promotional, rate designs for water service. Nevertheless, uniform and declining block rates remain widespread, even though the strong seasonality of water consumption (and the costs that are properly allocated to such peak usage) would support seasonal and/or increasing block rates. (AWWA and Raftelis 2004). Revisions to these non-conserving rate structures would allow more customers to see bill savings from additional efficiency improvements, such as efficient plumbing, high efficiency clothes washers, and advanced irrigation controllers.
- ***Volumetric wastewater rates***. While most cities bill customers for wastewater service by volume, many customers in California, Oregon, Washington and elsewhere, pay for sewer service with flat rates, obviating any effective price signal. Where water and sewer services are provided by separate entities, water suppliers need to work with their respective sewer agencies toward the adoption of volumetric pricing for sewer services. Secure data transfer and billing system compatibility are key issues to resolve.
- ***Monthly billing and AMR***. Monthly billing is crucial for sending timely signals to customers, particularly during the peak months of outdoor water use. (AB 2717 Landscape Task Force 2005) Automatic meter reading (AMR) technology is evolving rapidly, and can greatly facilitate monthly billing, while offering other functions that enhance water conservation efforts, such data handling accuracy, elimination of estimated bills, more granular views of customer usage, and near real-time identification of potential leaks.
- ***Connection Fees***. While the assessment of connection fees to new development is widespread, few water enterprises structure such fees to encourage greater end-use efficiency. Without significantly depressing revenue, enterprises can establish criteria for deep discounts from the average fee for those new connections that employ breakthrough technologies and permanent conservation practices. The bar should be set high enough so as to limit qualification to 10 to 20% of new connections. Such a

program can showcase innovative efficiency measures, and periodic review of the criteria will encourage further advances.

In addition, local regulations can capture low-cost savings, while providing incentives to customers for efficiency investments:

- ***Retrofit-on Resale or Transfer of Service requirements***. Communities such as Los Angeles and San Diego have adopted ordinances that accelerate the rate of replacement of inefficient pre-1992 plumbing products. Some of the ordinances are structured as retrofit-on-resale requirements, with fixture replacement required before or within a set time after the transfer of a building's title. Others are found within a utilities own service regulations, where fixtures mist be upgraded upon the transfer of service from one account holder to another. Both approaches have their merits, and can soon be expanded to include clothes washers and even higher efficiency toilets (less than 1.3 gpf).
- ***Water-Efficient Landscape Ordinance***. California has had a model local water efficient landscape ordinance applicable to new construction for more than a decade, with mixed results. Recently, a state chartered task force has made recommendations for improvements. Effective local ordinances that capture one-time opportunities in new construction can be critically important tools for achieving greater end use efficiency throughout the country.
- ***Clothes washers and ET controllers*** are likely to be among the most productive areas for product rebates in the near term. ET controller programs will benefit from the recent completion of the Smart Water Application Technology (SWAT) testing protocol and the eventual establishment of performance standards.[1] Clothes washer programs nationwide will benefit from proposed efficiency standards by the California Energy Commission and by the newly revised *Energy Star* criteria for clothes washers, which incorporate a water factor for the first time.
- ***Incentive Delivery***. Achievement of penetration goals for water efficient products, especially among commercial and institutional customers, can be problematic. Alternatively, a water enterprise may devise an RFP process to attract performance contractors with the staff and experience needed to reach CII customers. Measurement and verification protocols are key determinants in the success of performance contracting.[2]

The final element in a water efficiency program is insuring that as much of the water treated is delivered to customers for use. All pressurized water systems leak, some more than others, and the loss of treated water prior to delivery to the customer is quite clearly a loss of the energy embedded in the water's collection, treatment and in part its distribution. There is a revolution underway in water accounting, and new guidance will be available in 2006 in the form of a new AWWA *M-36 Manual* for conducting water system audits. This new approach will dispense with reference to "unaccounted for" water, in preference for a "water balance" that maps all water uses and assigns appropriate levels of confidence to all estimated quantities. Methods and strategies for determining economically recoverable levels of apparent losses and real losses are provided.

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[1] See the Irrigation Association's Smart Water Application Technology page at http://www.irrigation.org/swat.

[2] For the latest publicly available M&V protocol with a water efficiency component, see www.ipmvp.org.

The performance of a system water audit following this new methodology requires a commitment from utility management, coupled with sustained interdepartmental collaboration. In addition to water conservation program staff, information technology, billing and adjustment, metering, rights-of-way maintenance, and engineering personnel all must be involved.

Implications for Energy and Sustainability

At the 2004 water and wastewater road-mapping workshop (Elliott 2005) a consensus emerged that current models and paradigms for plant design and operation needed to be revisited by the community. The main areas for reconsideration of current practices include:

- The hydraulic model for both plant and system design
- The dominance of aerobic processes in sewage treatment over anaerobic processes
- The dominance of centralized versus decentralized treatment models

More broadly, a rethinking of how water and wastewater systems fit into the overall community is warranted. Interest has increased in generating energy from anaerobic digestion of wastewater solids. A potential exists to integrate wastewater with other organic solids, either high-organic content agro-industrial or putrissable municipal wastes to increase the energy output from anaerobic digestion processes and facilities, making sewage treatment plants net-energy exporters. In addition, these integrated waste management facilities could be used to extract salable products from the waste streams. With conventional energy intensive tertiary wastewater treatment in the wings, this may not be possible for conventional separate sludge digesters that only recover a fraction of the biogas potential before sludge residues are removed, dewatered, processed, transported and land applied.

In the bigger picture, sustainability must be considered as the primary goal of communities and their water and wastewater systems, of which energy efficiency is a critical component. In this context, using renewable energy produced during the course of wastewater treatment to in part operate water and wastewater systems rather easing the reliance upon non-renewable energy resources and materials, such as chemicals, may become the norm. For example, using slightly more energy-intensive technologies such as ultraviolet and ozone disinfection, powered by a renewable energy resource rather than purchased chemicals, may become the preferred path. In the revised scheme of operation, energy use in the system might increase over current normal consumption even after the energy efficiency practices are implemented, but externally procured energy (both fuels and chemicals) might decrease, perhaps even to zero.

Ultimately this balance requires steps to address short-term infrastructures needs while maintaining the flexibility in the system to allow for future innovations.

Need for Future Research

As noted above, energy use in the water and wastewater industry has received only cursory attention in recent years as is evidenced by use of the 1996 EPRI report (Burton 1996). If we are facing a period of unprecedented water and wastewater infrastructure investment, we need to have a better understanding of energy use in those industries and of the technical and market paradigm options that are available. For example, another paper at this conference

(McCarthy et al. 2006) looks at how water issues should be integrated into community development. To these ends, a concerted research effort is needed to address the following issues:

- Need to better understand energy use in the water and wastewater industries;
- Need to better understand the energy implications of new water regulations;
- Need to better understand the water quality, public health and environmental objectives behind the regulations;
- Need to better understand the energy implications of alternative models and technologies both in terms of economic and environmental advantages and penalties;
- Need to develop better life cycle cost and environmental assessment tools and methods;
- How these alternative models can be integrated into urban planning and regulations;
- How can alternative thinking be included at the initial facilities planning stage when a full range of choice is being considered through a fair and comprehensive alternatives analysis process?

These efforts will help to define the path upon which the U.S. will embark as it responds to the infrastructure challenges identified in WIN report (2000).

Conclusions

Energy use in the water and wastewater industry is underappreciated by many energy, municipal planning and water and wastewater professionals. As with so many issues within community planning, the driving issue for water and wastewater utilities is less about energy efficient technology, and more about regulatory compliance. If we continue on our current path, we may well condemn ourselves to a capital, resource, and energy intensive future in which fewer, not more, people will have their water and wastewater needs met. Growing water scarcity, declining water quality and increasing energy costs will continue to challenge coming generations unless we are able now to rethink the dominant "hard path" paradigms and begin to plan and manage our water resources in a more holistic and integrated manner.

If we step back from the current "hard path" disconnected paradigms of water resource management and look at designing more "organic" systems, we may be able to chart a path that is both more sustainable and less capital, resource, and energy intensive, one that will allow our communities to meet their water and energy needs closer to home using more decentralized "soft path" approaches. These approaches will be critical to establishing more sustainable communities.

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