21st Century Water Systems: Scenarios, Visions, and Drivers

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Urban water systems are in a period of stress and uncertainty, and will experience rapid and significant changes in coming decades. Water supply, stormwater management, and wastewater treatment systems face threats and opportunities created by developments within the water management sector, and by forces from outside the water sector, beyond the control of water system managers.

Scenario building and visioning exercises are valuable tools for understanding change and planning strategies for the future. The first is a "what if?" technique that portrays different ways forces beyond ones control could play out. The second typically portrays desired outcomes as goals for planning and action. Both must assess a variety of forces, or "drivers," that will shape the future. This paper presents the results of a water systems scenario building project conducted by Rocky Mountain Institute for the U.S. Environmental Protection Agency in 1995; outlines a "soft path" vision for sustainable urban water resources infrastructure; and discusses selected drivers that could force or enable the development of a new urban water management paradigm.

Water 2010: Four Scenarios for 21st Century Water Systems

Scenario planning is a formal process increasingly used by corporate and government strategists. It offers a creative, flexible way of preparing for an uncertain future (Schwartz 1991; van der Heijden 1996). The technique throws out the notion of prediction—a risky business at best—and instead focuses on identifying the most critical dimensions of uncertainty. By assuming various outcomes for those uncertainties, scenario planners can then envision several different but equally plausible futures, which help reveal the interlinking trends and factors that will shape whatever future finally unfolds. As people working with community water systems—large or small; public or private; supply, wastewater, stormwater, or combined—we can use scenarios to better understand how the trends and events unfolding around us, often beyond our control, will create problems, risks, and opportunities.

Scenarios are presented as "stories" about the future. By using the narrative form, scenario builders can capture the complex interactions of many factors and forces, provide contextual richness that helps give meaning to potential developments, and engage the reader in ways that encourage new and sometimes startling ways of looking at the future. Such scenarios can help us evaluate whether different strategies or decisions are robust—that is, if they hold up in a variety of different futures. If the future develops in one direction, how do we fare? What if it goes a different way?

In 1994, the Future Studies Office of the U.S. Environmental Protection Agency asked Rocky Mountain Institute to build a set of scenarios of general interest to managers, policy makers, and citizens concerned with community water systems. This effort, completed in 1995, focused on issues relevant to water supply and wastewater treatment infrastructure in urban,

suburban, and small city settings. With the help of a 36-person expert panel, RMI evaluated over 70 factors and forces that could affect the future of community water and wastewater systems. We identified a number of "critical uncertainties"—that is, factors that were deemed both very important and very uncertain or unpredictable. We chose to build the scenarios around two that seemed especially critical to the evolution of community water systems in coming years.

The first concerned the federal government's role in water quality and quantity management. RMI chose this dimension of uncertainty in order to explore questions concerning the federal government's future regulatory, policy-making, and managerial powers and responsibilities. Directions for the federal role were especially unclear at the time the project was underway, as a result of the dramatic shifts in Congress brought about by the 1994 election. RMI characterized one potential outcome as a continuation and intensification of the trend toward an increased federal role in water management experienced over the past several decades. (The federal role in this outcome was labeled "dominant" as shorthand in the scenario set.) RMI characterized another potential outcome as a landmark reduction in the federal role, as advocated at the time by many conservative politicians.

The second uncertainty central to the scenarios concerned the financial support for water systems. Developments in financial markets and the economy raised many questions about the availability and cost of capital. In 1995, the path of the economic expansion was far from clear, and the federal deficit seemed an intractable problem. Many would say those questions remain pertinent today, when considered in the long view. Furthermore, ratepayers' willingness to support investments in system maintenance, expansion, and improvement was and is a critical question. RMI characterized one possible result as a weak financial environment, in which capital markets are tight and ratepayers are reluctant to support investments. Conversely, markets, governments, and the public could turn out to be more supportive.

Naturally these outcomes are oversimplified. This is in part a deliberate strategy in any scenario-building effort—the assumed outcomes for the central drivers of the scenarios must be different enough to highlight risks and opportunities inherent in the vagaries of the future. Figure 1 identifies the four scenarios created by combining these outcomes for the main axises of uncertainty. Many additional factors were woven into the scenarios in ways that seemed internally consistent with the potential playing-out of each combination of central driver outcomes. The names of the scenarios were chosen to convey the overall "gestalt" of each.

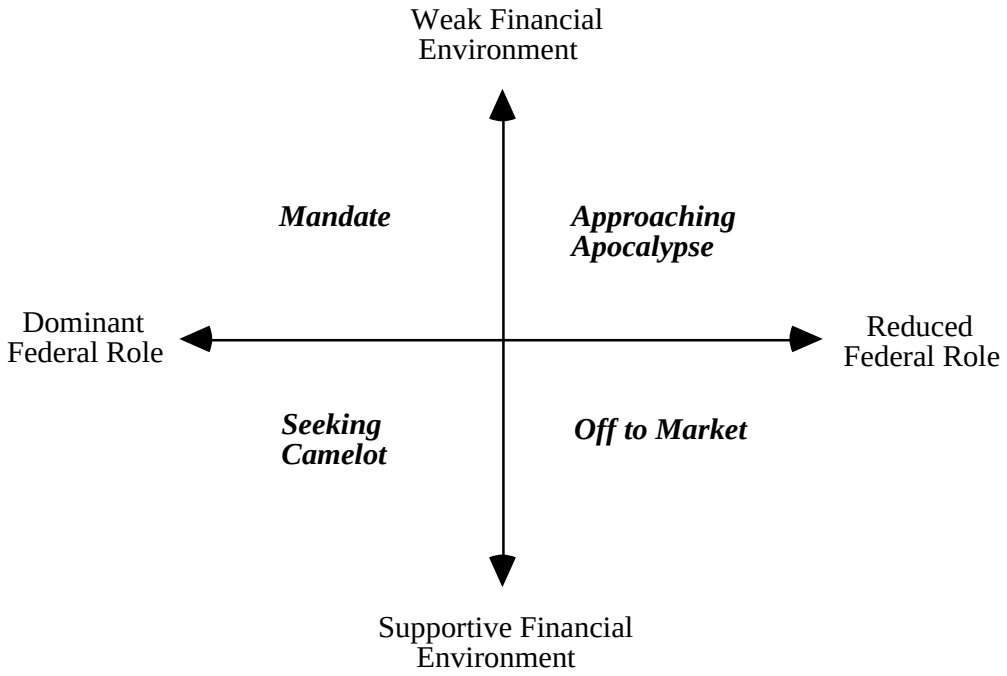

Figure 1: Scenario Matrix from the Water 2010 Study.
Source: Pinkham and Chaplin 1996.

The scenarios present four thought-provoking narrative images of water systems in the year 2010. Each scenario is a roughly 1300-word "story" of a different future. Here are synopses.

Approaching Apocalypse. In this scenario, the federal government's role in managing water has been greatly diminished. At the same time, considerable troubles in the economy have tightened state and local government purse strings, and ratepayer revolts have prevented many water utilities from implementing the rate increases necessary to finance infrastructure improvements. This is a future of widely varying standards across the country, and widely varying water system performance: the rich have good water, the poor suffer. But no water managers have it easy. Screaming headlines fan widespread worries that the latest contamination problems are not isolated. A health-conscious population increasingly takes water purification into its own hands with new point-of-use and point-of-entry technologies. One result: some supply utilities are crying "uncle." They strike deals with state regulators to bypass most centralized treatment, and provide customers instead with home treatment systems and essentially raw water.

Off to Market. Now imagine what might happen if a reduced federal role co-evolves with a much more supportive financial environment. Consolidation and privatization of water services is the rage in this future. Resulting profit opportunities are attracting new investment dollars, helping to finance infrastructure improvements in many areas. But money stays away from communities where badly declining infrastructure, vandalism, lawsuits resulting from poor water quality, and other problems increase perceived risks to investors. Environmental water standards vary from state to state. Where environmental protection is politically

popular, strong biological integrity goals are helping redress many problems. Local watershed councils play a major role in many areas. But in others, environmental goals and results have been weakened by those who promote their states as more friendly to industry.

Seeking Camelot. What might the future hold with a strong leadership role for the federal government and a supportive financial environment? The stage could be set for such a scenario by a series of environmental disasters that make the environment and public health top political priorities. As a result the EPA is elevated to cabinet status, and its new Environmental Resource Assessment Service is responsible for coordinating sophisticated computers, satellites, and all other federal environmental data assets with state, local, and private efforts. New regional water agencies, some growing out of 20th century interstate water compacts and river basin commissions, facilitate the resolution of water conflicts. Federal funds are available to help troubled water systems, and citizen support for system improvements encourages backing from private capital markets. The downside: curbing the federal tendency toward bureaucracy, control, and perceived waste of money on centralized technologies such as desalination is a continual struggle.

Mandate. Finally, combine a dominant federal role and a weak financial environment. Now what does 2010 look like? In this scenario, the American people rely on the federal government as the guarantor of healthy drinking water and clean rivers and lakes. Politicians are quick to please, passing tough new laws. But the economy is stagnant, the deficit is growing, and funds for new programs are short. Water managers in most areas suffer headaches and heartaches trying to comply with new requirements. Many find they can delay expensive capacity expansions by strongly promoting conservation, but most have little wherewithal for improving their systems with new treatment technologies. Only with extensive efforts to educate the public about the technological requirements and costs of providing clean water are some utilities gaining ratepayer support to move forward.

None of the scenarios summarized above was presented as most likely in RMI's report. To do so would short-circuit the examination and dialogue that the scenarios were designed to engender. Each scenario in a scenario set should be quite plausible, and each will generally have surprising aspects. The goal of scenario building is to challenge assumptions about the future and provide a framework for evaluating decisions and strategies. One result is a set of imagined future environments in which one can play out the likely results of a decision being made today. Another result is an increased general understanding of the business environment, and an increased ability to recognize the import of new developments.

The scenarios described briefly above are available in a Rocky Mountain Institute report entitled *Water 2010: Four Scenarios for 21st Century Water Systems* (Pinkham and Chaplin 1996). Some elements of the scenario narratives are now somewhat dated, while others still raise important questions about the future of community water systems. Companies and agencies that use scenario building as part of their strategic planning processes typically revisit and rebuild scenario sets every year or two, and build focused scenario sets as particular strategic threats and opportunities present themselves.

A Vision of Future Water Systems: The Water Soft Path

Visioning exercises develop desired futures, setting out positive future environments as goals. While scenarios typically address the question "what could happen to us?" visions typically address the question "what do we want to make happen?" In this time of stress and challenges for urban water resources infrastructure, a new vision of sustainable water systems is needed.

Methods used by industrialized societies to manage water supply, wastewater, and stormwater were essentially established in broad outline a hundred or more years ago. These methods were highly successful in addressing development and sanitation objectives, but today their functional and economic effectiveness in fulfilling environmental, quality of life, and other objectives is often questioned. Conventional methods are rapidly improving, and will continue to evolve. At the same time, new technologies, and old ones in newly refined forms, are emerging that present new options for water systems. Institutional and managerial innovations are likewise emerging at a rapid rate. It appears that development of a new "paradigm" for urban water systems is both necessary and likely.

The old paradigm and the emerging paradigm are broadly characterized below. These are simplifications of course, and many systems are in transition, but the rough differences in approach are instructive.

The Old Paradigm	**The Emerging Paradigm**
Human waste is a nuisance. It is to be disposed of after the minimum required treatment to reduce its harmful properties.	*Human waste is a resource.* It should be captured and processed effectively, and put to use nourishing land and crops.
Stormwater is a nuisance. Convey stormwater away from urban areas as rapidly as possible.	*Stormwater is a resource.* Harvest stormwater as a water supply, and infiltrate or retain it to support urban aquifers, waterways, and vegetation.
Build to demand. It is necessary to build more capacity as demand increases.	*Manage demand.* Demand management opportunities are real and increasing. Take advantage of all cost-effective options before increasing infrastructure capacity.
Demand is a matter of quantity. The amount of water required or produced by water end-users is the only end-use parameter relevant to infrastructure choices. Treat all supply-side water to potable standands, and collect all wastewater for treatment in one system.	*Demand is multi-faceted.* Infrastructure choices should match the varying characteristics of water required or produced by different end-users: quantity, quality (biological, chemical, physical), level of reliability, etc.
One use (throughput). Water follows a one-way path from supply, to a single use, to treatment and disposal to the environment.	*Reuse and reclamation.* Water can be used multiple times, by cascading it from higher to lower-quality needs (e.g. using household graywater for irrigation), and by reclamation treatment for return to the supply side of the infrastructure.
Gray infrastructure. The only things we call infrastructure are made of concrete, metal and plastic.	*Green infrastructure.* Besides pipes and treatment plants, infrastructure includes the natural capacities of soil and vegetation to absorb and treat water.
Bigger/centralized is better. Larger systems, especially treatment plants, attain economies of scale.	*Small/decentralized is possible, often desirable.* Small scale systems are effective and can be economic, especially when diseconomies of scale in conventional distribution/collection networks are considered.
Limit complexity: employ standard solutions. A small number	*Allow diverse solutions.* A multiplicity of situation-

of technologies, well-know by urban water professionals, defines the range of responsible infrastructure choices.	tuned solutions is required in increasingly complex and resource-limited urban environments, and enabled by new management technologies and strategies.
Integration by accident. Water supply, stormwater, and wastewater systems may be managed by the same agency as a matter of local historic happenstance. Physically, however, the systems should be separated.	*Physical and institutional integration by design.* Important linkages can and should be made between physical infrastructures for water supply, stormwater, and wastewater management. Realizing the benefits of integration requires highly coordinated management.
Collaboration = public relations. Approach other agencies and the public when approval of pre-chosen solutions is required.	*Collaboration = engagement.* Enlist other agencies and the public in the search for effective, multi-benefit solutions.

Rocky Mountain Institute refers to the emerging paradigm as a "soft path" for urban water infrastructure. The terminology borrows from the energy soft path foreseen by Amory Lovins in 1977 (Lovins 1977). The energy soft path is characterized by highly efficient end-use technologies and widespread use of small-scale renewable energy resources—photovoltaics, wind power, biogas, hydrogen fuel cells, etc.—in contrast to continued proliferation of large, centralized fossil fuel and nuclear power plants, and continued reliance on fossil fuels for motive power. As discussed later in this paper, movement of the energy industry toward the energy soft path is accelerating rapidly.

The water soft path is similarly characterized by wide use of diverse, often decentralized systems. Water supply, treatment, sanitation, and runoff management systems would be situation-dependent, but in general would be highly integrated physically and institutionally. They would take much greater advantage of local hydrologic resources (e.g. urban rainwater/stormwater harvesting and aquifer storage recovery systems versus distant surface supply and storage facilities); use the treatment capacities of urban watershed soils and vegetation to much greater stormwater management effect ("green infrastructure"); and use all manner of wastewater treatment and reclamation/reuse systems (including "new" technologies such as sand filter systems and robust constructed ecological systems: treatment wetlands, Living Machines™, etc.).

The water soft path, like the energy soft path, places a strong emphasis on greatly increased efficiency in end-use, precise management systems to avoid system losses, and matching of system components to the exact quantities and qualities required for appropriate classes and locations of end-use. Regarding this last point, supply and treatment systems would not be sized to provide drinking quality water for landscape irrigation, nor probably for toilet flushing and other less quality-intensive uses. It is also possible to imagine how diverse methods and scales of supply and treatment could provide water of varying character—amount, chemical and biological quality, reliability of supply, and perhaps even temperature and other qualities—more cost-effectively than current systems. On the downstream side, a variety of wastewater treatment systems and scales could efficiently match the characteristics of the water produced by different end-uses, and make it available for nearby or regional reuse opportunities.

Figure 2 sums up the water soft path in one line: a combination of end-use efficiency, system efficiency, stormwater harvesting, storage innovations, and reuse strategies would reduce water demand (measured most importantly as water withdrawals from the environment for human use) to levels far below most recent projections, and conceivably well below current demand.

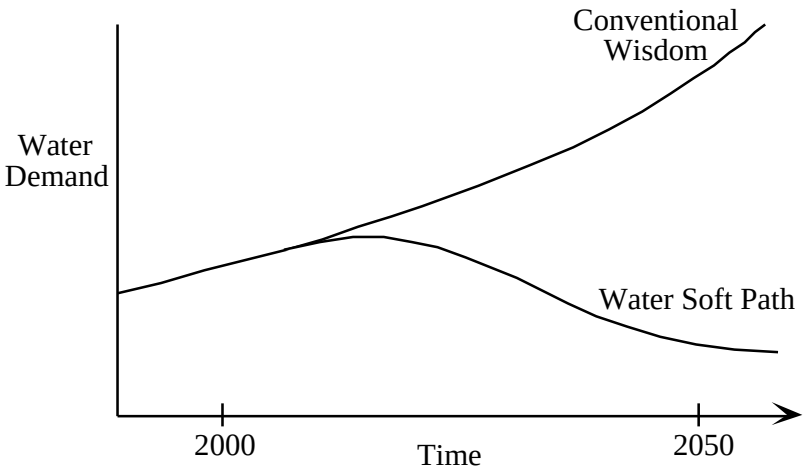

Figure 2: The Water Soft Path

This vision of the water soft path may seem impossible to some, but several points indicate its attainability. First, the "conventional wisdom" about water demand overestimates future demand with extraordinary frequency. Figure 3 compares projections of world water withdrawals in the year 2000, made by eight important studies from 1967 to 1996, versus the path of actual withdrawals. Similar graphs showing historical overestimates of demand could be constructed for very many nations, states, and cities.

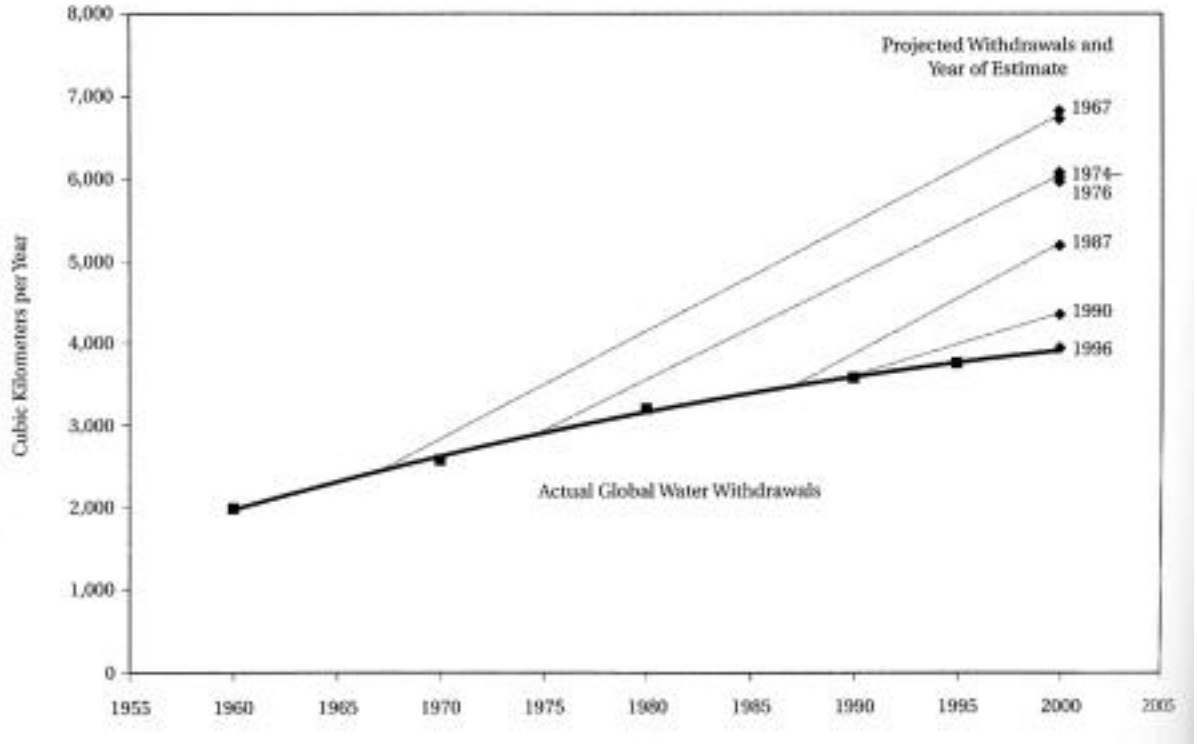

Figure 3: Projected Global Water Withdrawals for the Year 2000.
Source: Gleick 1998, p. 14.

A second indicator of the attainability of the water soft path is recent trends in U.S. water withdrawals shown by United States Geological Survey data. Since 1980, total withdrawals, and withdrawals for the thermoelectric power use, agricultural irrigation, and self-supplied industrial sectors have been decreasing. Only public supply withdrawals (for community water systems) have continued to increase in absolute terms. However, public supply withdrawals are now decreasing on a per capita basis (Solley, Pierce, and Perlman 1998) . Figure 4 shows trends in U.S. water withdrawals.

Into the foreseeable future, it is reasonable to expect irrigation sector withdrawals to continue declining due to losses of agricultural subsidies, retirement of marginal lands, and transfers to the urban sector and to instream environmental uses. Industrial withdrawals are likely to continue declining due to increased efficiency and increased reuse, driven by cost factors and by efforts to reduce regulatory exposure from industrial discharges. Thermoelectric power use may decline precipitously in coming decades as centralized power plants become uneconomic, an emerging development discussed below. The future of public supply withdrawals is the least clear. However, conservation efforts have only just begun to affect overall water use in this sector, and the prospects for large gains in reuse within community water systems are good.

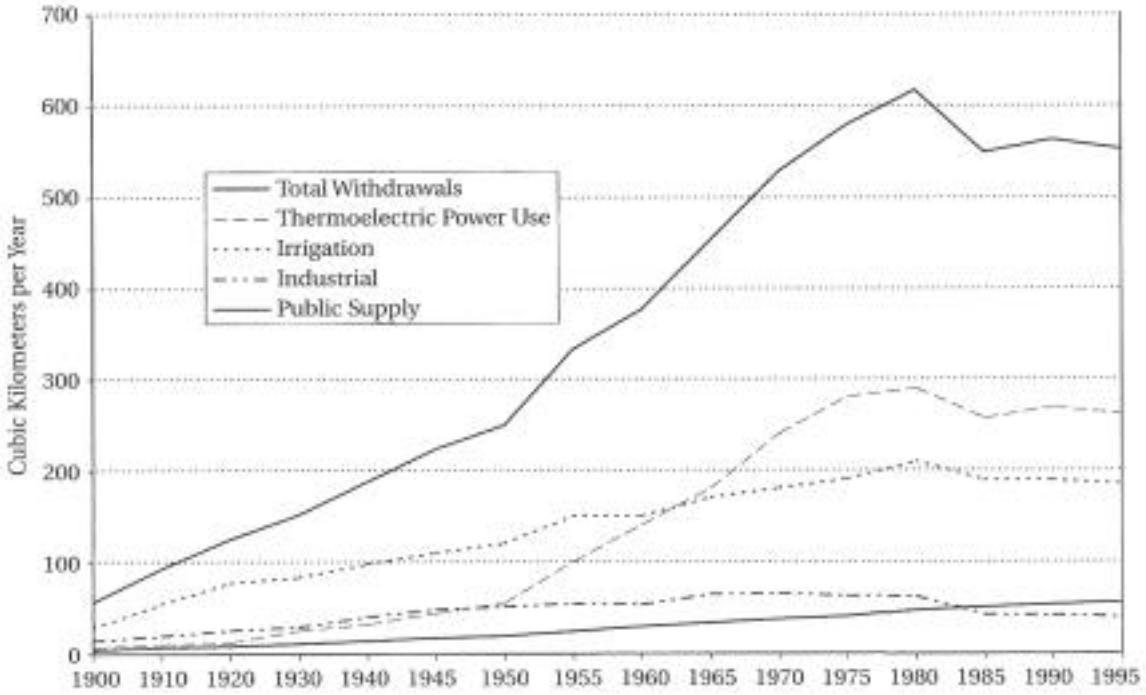

Figure 4: Water Withdrawals in the United States, 1900 to 1995
Source: Gleick 1999, p. 11.

Driving Forces of the Water Soft Path

A variety of developments within and outside of the water sector will affect future directions for urban water infrastructure. A comprehensive survey of these factors and forces is beyond the scope of this paper. Instead, several current and emerging developments that may enable attainment of the water soft path are discussed below.

Demand Management Opportunities

Infrastructure planning must begin with careful analysis of end uses of water and available end-use efficiencies. It would be unwise to size system components without first taking advantage of all cost-effective opportunities to increase the efficiency of water uses. End-use efficiency is doubly important because it affects “both ends of the pipe”—the water supply side, and the wastewater treatment side.

Water conservation professionals have only just begun to tap available efficiencies. For instance, Figure 5 shows data for average residential indoor water use from the North American Residential End Use Survery, sponsored by the American Water Works Association Research Foundation. Differences between conserving and non-conserving homes are shown. This study corroborates common judgments by water conservation professionals that savings of about one-third are achievable. Notably, the study also shows that the “penetration” of efficient fixtures and appliances into North American homes is still quite low: 35 percent for showerheads flowing at 2.5 gallons per minute (gpm) or less, 15 percent for toilets that use 1.6 gallons per flush (gpf) or less, and under 3 percent for high efficiency clothes washers (Waterwiser 1999a). Clearly, the residential indoor use sub-sector can become considerably more efficient using current fixture standards.

Potential savings go even further. The conserving home water use levels shown in Figure 5 do not account for additional savings from the best available technologies, all of which perform effectively, without sacrificing level of service: 1.5 gpm or less showerheads, 1.0 gpm or less bathroom faucets, dual-flush toilets (which use less water for urine flushes), state-of-the-art leak detection systems, and the best high-efficiency clothes washers and dish washers. Graywater use for toilet flushing, an emerging technology, would reduce indoor residential use still further. Total potential savings could rise to 50 percent or more with full implementation of the best technologies. For many water systems, pursuing this aggressive level of conservation will become increasingly cost-effective as supplies tighten in coming decades.

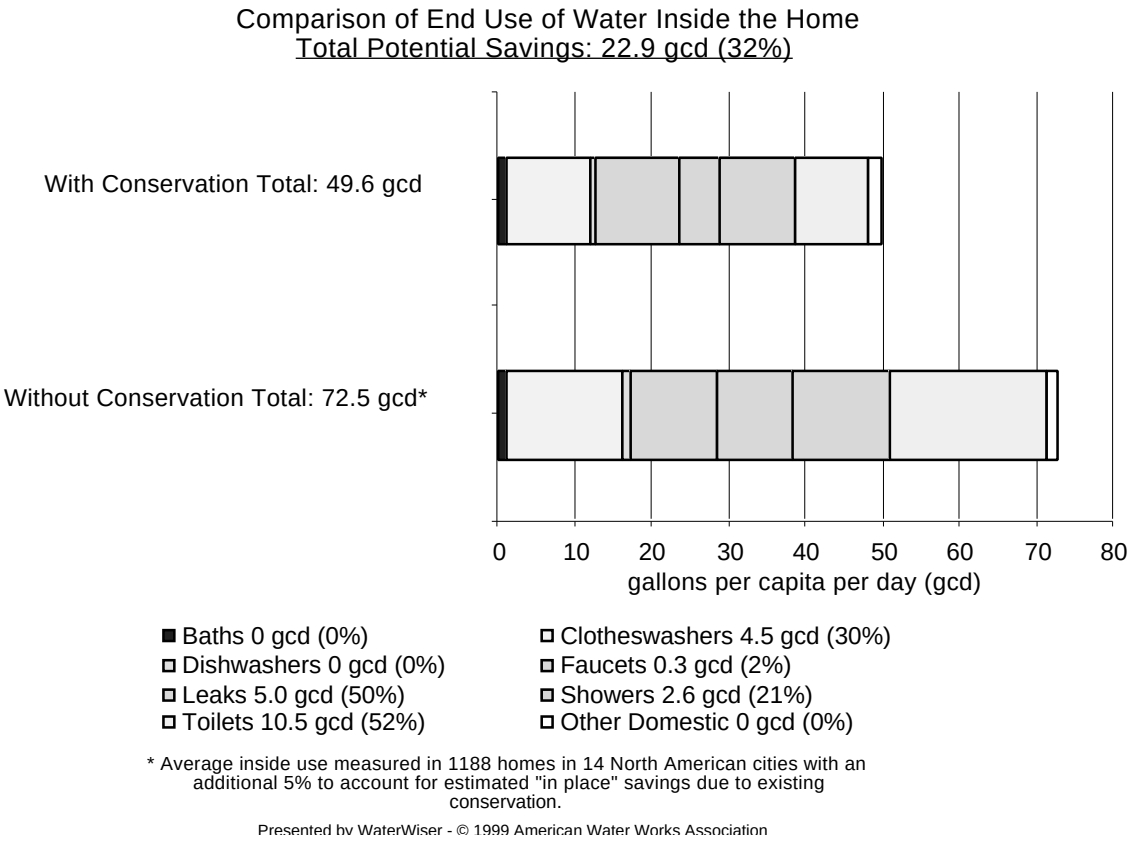

Figure 5: Comparison of End Use of Water Inside the Home
Source: WaterWiser 1999b. Based on data from the North American Residential End Use Study as interpreted by Jon Olaf Nelson Water Resources Management.

Potential efficiencies in the commercial, industrial, and institutional sectors are also great. Water conservation professionals are increasingly turning attention to assisting "CII" facility managers with conservation audits, water management advice, and modification or replacement of inefficient fixtures, appliances, machines, and processes. A recent audit program by the Metropolitan Water District of Southern California made recommendations to 900 CII customers for easily-achievable savings, with average savings of 23 percent. The recommendations were mostly basic, and the cost-effectiveness assumptions conservative. Higher water-efficiency potential is probably feasible (Wilkinson and Wong 1999). High potential for efficiencies in the CII sector is corroborated by the many impressive results of more ambitious efforts to retrofit equipment and re-design processes. Savings of 30 to 60 percent or more, and large quantities of water, are not uncommon (Wilkinson, Wong, and Owens-Viani 1999; Hawken, Lovins, and Lovins 1999).

Enormous savings in landscape irrigation are possible. Improved irrigation equipment and scheduling practices often produce savings of 40 percent or more for a given residential or CII landscape (Chaplin 1994). Savings of up to 100 percent are possible with redesign of landscapes to reduce turf grass and emphasize drought-tolerant vegetation. Such landscapes can be very beautiful and functional. Property owners are increasingly accepting them.

In addition to customer-based efficiency measures like those noted above, utility-based measures available to water and wastewater system managers are many and offer important savings opportunities. These include leak detection and repair in water mains and lines, conservation price structures, watershed management activities to reduce storage losses from reservoir siltation, and water reclamation. The latter strategy—treating wastewater for reuse—has terrific potential across a wide range of scale of treatment systems, and is now receiving considerable attention by water resource professionals.[1]

Waterless Sanitation

Waterless toilets and urinals represent the ultimate in water-efficient sanitation. Waterless urinals using liquid-repellant coatings and a special lighter-than-urine biodegradable trap fluid to prevent odors (e.g. Waterless Co.) are gaining in popularity in the U.S. Composting toilets have long had niche applications at highway rest stops, military bases, and other remote locations. Now, waterless toilets are receiving increasing attention for broader application. Modern designs being pioneered and installed in Sweden feature a two-compartment bowl to separate urine, which contains most of the nutrient value in human waste, from feces. It is then relatively straightforward to collect and treat or field-apply the urine, and to dry, compost, or otherwise treat the small volume of feces (Hawken, Lovins, and Lovins 1999; Drangert, Brew, and Winblad 1997). The collection infrastructure for such systems would be very different from conventional sanitation systems, but the enormous reduction in volume in waterless systems may offer attractive advantages. Waterless systems will continue to evolve in coming decades through entrepreneurship and by necessity. In Sweden alone, 50,000 dry systems have been sold in 42 models from 22 manufacturers. Over 2.6 billion people worldwide lack access to adequate sanitation (World Health Organization 1996). It will be hydrologically and economically impossible to provide even a large portion of these people with water-based sanitation.

Green Infrastructure

Green infrastructure refers to techniques and systems that use to human advantage the natural capacities of soil and vegetation to absorb and retain water, and to take-up, transform, or otherwise treat pollutants in water. Green infrastructure is an important approach to urban stormwater management, and offers potential for management of some types of wastewater.

In the stormwater field, green infrastructure techniques include infiltration swales; bioretention cells; surface and subsurface infiltration basins; porous pavements; tree plantings; diversion of roof and pavement drainage from storm sewers to vegetated surfaces; protection and restoration of natural drainageways, streams, and wetlands; and careful urban design to reduce the amount of impervious surface. The functionality and cost effectiveness of these techniques is well-proven in many new development applications (Wilson et al. 1998, 141-46). Recently, agencies and proponents in some areas have begun to envision and implement retrofits of these measures into established urban areas. Prince George's County, Maryland and the non-profit

[1] Reclamation/reuse is often considered a supply measure, but can also be considered water conservation because recycling of water within a community water system, like end-use and system efficiency measures, reduces initial withdrawals of water from the environment.

Low Impact Development Center are examining the potential of such techniques for management of combined sewer overflows (Coffman and Weinstein, pers coms 1999). Multiple agencies in the Los Angeles River basin are supporting projects, initiated by the nonprofit organization TreePeople, to infiltrate and capture rain water for flood control and water supply. These landscape-based projects also bring important energy use, air quality, and solid waste management benefits (Condon and Moriarty 1999). And in Pittsburgh, Pennsylvania, rehabilitation of the urban landscape is proposed to cut the costs of controlling combined and sanitary sewer overflows, reduce erosion of local stream channels, and leverage redevelopment activities for multiple environmental, economic, and social benefits (Ferguson, Pinkham, and Collins 1999)

Daylighting of Culverted Waterways

Perhaps the most radical expression of the green infrastructure concept is the practice known as "daylighting." This term refers to the restoration to the surface of a stream or drainageway previously buried underground in a culvert or pipe.

While efforts to restore degraded surface streams are common, re-surfacing buried streams is a fairly new activity in the United States. Interest in daylighting is growing rapidly, due to the water quality benefits of exposing water to air, sunlight, and vegetation; the resulting creation of riparian habitat and improved fish passage; the aesthetic and recreational opportunities daylighting presents for urban and suburban areas; increased property values and commercial activity from creating proximity to running water; and a deep desire on the part of many people to "set right" alterations humans have made to the environment in the past. Research now underway for the U.S. Environmental Protection Agency has identified 20 daylighting projects completed in the U.S. since the early 1980s, and another 20 projects now under consideration (Pinkham 1999 forthcoming). It is conceivable that over a period of many decades, as redevelopment and civic amenity projects proceed, cities could plan and achieve the "retreat" of development from buried or degraded waterways, reestablishing more natural drainage systems in many areas—systems that would likely be more environmentally and economically sustainable.

Most of the daylighting projects implemented or envisioned in the United States to date are fairly small in scope—a few hundred feet here, a thousand feet there. Some European cities have much more ambitious programs. In Zürich, Switzerland, authorities are implementing their "Bachkonzept" (Brook Concept) for drainage and combined sewer overflow management. Engineers are rerouting spring water, clean runoff, buried streams, and some roof runoff from old pipes into new channels that run to the Limmat River. Many of the new brooks are naturalized, vegetated channels, others are contained drainageways running along streets through densely built-up sections of the city. Since 1988, the city has created nine miles of new brooks that together divert an average flow of 3.5 million gallons per day from the city's two wastewater treatment plants. (Dry weather flows to these plants total 71 mgd.) Eventually this program will re-create over 18 miles of surface streams.

Rainwater/Stormwater Harvesting

The precipitation falling on urban areas is a much-neglected potential water supply. Capturing some of this precipitation for supply purposes would also contribute to urban wet weather management.

Harvesting and storing rooftop runoff in cisterns is widely practiced in many countries for both non-potable and potable uses. Texas is now encouraging rainwater harvesting (Texas Water Development Board 1997), and interest is growing in other areas. Some agencies are motivated by the stormwater management benefits; for instance, the city of Toronto, Ontario's "Recycle Your Rain" program offers selected homeowners rain barrels, as part of the city's extensive program to disconnect roof downspouts from combined sewers.

Recently, urban water budget studies and analyses of the potential for integrating supply, stormwater, and wastewater infrastructures have outlined even more ambitious schemes for harvesting stormwater. Clark, Perkins, and Wood (1997; see also Clark 1997), using the city of Adelaide, Australia as a case study, propose collection of urban surface runoff in dispersed treatment wetlands, with subsequent additional treatment and introduction of the water to supply aquifers or directly into the water supply distribution infrastructure. Heaney, Pitt, and Field (1999) examine the feasibility of increased stormwater harvesting in the U.S. The initial results of these studies indicate that the economically optimal size of integrated systems may be closer to the neighborhood scale than the city/sub-city scale of conventional supply and wastewater systems. Small-scale systems avoid diseconomies of scale in piping, the largest single cost in urban water infrastructure.

Hybrid-Electric Motor Vehicles

Many developments outside the water resources field will constrain, enable, or otherwise affect options for water infrastructure. One development of particular importance for water quality is the coming transition to hybrid-electric motor vehicles. Among other things, this transition will increase the viability of urban runoff as a water supply.

Hybrid-electric vehicles use a small power unit—a gas or diesel internal combustion engine or Stirling engine, a natural gas turbine, or a hydrogen fuel cell—optimally sized to run an electric generator. An electric motor drives the wheels, and provides electromagnetic braking (recovering some power in the process). Mechanical brakes are only engaged for extremely quick deceleration. Some power is stored in a battery, flywheel, or ultracapacitor, providing a power buffer for acceleration and hill-climbing. Sophisticated electronics manage power generation, wheel drive, regenerative braking, and other functions. Advanced hybrid-electric vehicles feature substantial load reduction through use of lightweight bodies, aerodynamic design, thermally efficient windows, low rolling-resistance tires, and other measures. Fuel efficiency is improved severalfold with the best designs.

In many ways, hybrid-electric vehicles will be more comfortable and perform better than conventional automobiles, buses, and trucks. For this reason, these vehicles are in rapid development and the early stages of commercialization. The Toyota Prius is a four-door, Corolla-sized sedan with a hydrid-electric drive and a conventional steel body; its fuel-efficiency is 55-60 miles per gallon. Over 18,000 have been sold in Japan since its recent introduction there. The U.S. release is scheduled for the year 2000. Honda has announced a December 1999

U.S. release for the Insight, a two-door, aluminum-bodied hybrid that achieves 70 miles per gallon. Many other manufacturers and start-ups are advancing the new technology package as well (Cramer pers com 1999).[2]

The water resources implications of hybrid-electric vehicles are many. In particular, as these vehicles replace the current vehicle fleet over the next several decades, the quality of urban runoff will improve as automotive pollutant sources are reduced or eliminated for the following reasons:

- Lighter vehicle weight and electromagnetic braking reduce deposition of brake wear particles.
- Lighter vehicle weight and low rolling-resistance tires reduce deposition of tread wear particles.
- Optimization (smoother duty cycles for generating power vs. driving wheels directly) or elimination of internal combustion engines, and elimination of mechanical transmissions, reduce motor vehicle oil use, leakage, and burning.
- Cleaner on-board power plants reduce or eliminate atmospheric deposition of internal combustion byproducts.

Hybrid electric vehicles will create further opportunities in the water sector—though more indirectly—by accelerating the development of micro technologies for electric power production, especially fuel cells.

Hydrogen Fuel Cells

Hydrogen fuel cells generate electricity by disassociating the protons and electrons in gaseous hydrogen. They use the electrons to run an electric load, then recombine the electrons and protons with oxygen from the air, producing warm water as their only emission. Hundreds, perhaps thousands, of fuel cells are in service around the world, providing power to a variety of commercial, institutional, and industrial buildings. A number of companies are rapidly advancing the technology, reducing the cost and the size of fuel cells.

Fuel cell development has received considerable impetus from the motor vehicle industry. Prototype fuel cell buses are already in service in Chicago and some other cities. In 1997, Daimler-Benz announced a $230 million investment in Ballard Power Systems, with the intent of bringing 100,000 fuel cell cars to market by 2004. Ford subsequently matched the Daimler-Benz investment in Ballard. Meanwhile, Toyota is pursuing its own fuel cell initiative, and says it will beat Daimler-Benz to market (Williams pers com 1999).

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[2]See http://www.hypercarcenter.org/go/new1go.html for a chronology of activities among the major automakers and other companies. Ultimately, advanced polymers will probably make up most of the body of hybrid-electric vehicles. Use of advanced composite materials for hybrid-electric vehicles offers significant lightweighting opportunities while allowing for design of substantial crush zones and other features to address safety concerns. Composite body manufacturing also avoids the huge capital costs of steel body part stamping, which will allow smaller companies to develop hybrid-electric vehicles. Rocky Mountain Institute, a Colorado-based non-profit research center, has recently spun-off a for-profit company that aims to bring to market the Hypercar™, a composite-bodied hybrid-electric vehicle. See http://www.hypercar.com. The implications for U.S. and international industrial structure of likely changes in the manufacturing technologies and marketing channels for such vehicles are enormous (Lovins and Lovins 1995).

Development of fuel cells for the huge automotive market will drive costs down substantially. This opens up tremendous opportunities for cost-effective installations in buildings, potentially even individual residences. Contrary to popular belief, widespread deployment of fuel cells for cars and buildings can proceed without creation of a whole new "hydrogen infrastructure"—hydrogen can instead be produced cost-effectively at the neighborhood and building scale using, a) the existing electric power infrastructure (produce hydrogen through electrolysis of water), and b) the existing natural gas infrastructure (produce hydrogen by reforming natural gas). Fuel cells offer important power quality and reliability advantages over the electric power grid, increasing their attractiveness to building owners. It is likely that developments in the automotive and building sectors will co-evolve over the near and long terms, advancing the viability of widespread fuel cell use in both sectors (Lovins and Williams 1999).

The water implications of fuel cells are many:

- Water is required for producing hydrogen via electrolysis or reformation of natural gas.
- Fuel cells produce chemically pure water (at 70˚C, ideal for heating, cooling, and dehumidifying buildings) as their only emission.
- The mass flows of water inputs and outputs are small relative to other classes of urban water end-use, but could be significant locally and at the margin.
- Hydro-electric dams could be re-operated in ways potentially beneficial to instream flows and water supplies. Instead of producing power according to the timing of demands and resources on the electric power grid, hydro-electric plants could be run to produce hydrogen by electrolysis at times that are convenient for other water uses. The energy of falling water would be thereby captured for later use, rather than instantaneous use.
- Fuel cells will accelerate and broaden the "distributed resources revolution" in the electric utility industry.

The Distributed Resources Revolution in the Electric Utility Industry

Economies of scale in power generation are rapidly changing. While economies of scale increased from the 1930s to the 1980s, introduction of cheap, combined-cycle gas turbine plants in the 1990s radically decreased the economically optimum size of power plants, as shown in Figure 6.

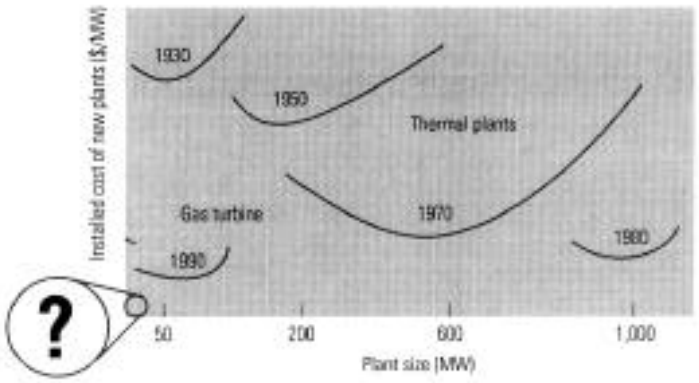

Figure 6. Changing Economies of Scale In Electric Power Production
Source: Cler and Shepard 1996.

Figure 6 hints that even more interesting things are happening with very small-scale power generation technologies. Fuel cells, microturbines, Stirling engines, and other technologies at the home and building scale are increasingly competitive with larger power plants, especially when integrated into service packages that offer customers enhanced power reliability and power quality (ESOURCE 1998 and 1999a). Savvy electric utilities increasingly use small-scale technologies, also including photovoltaics, to address localized demand growth and grid congestion problems—deferring or avoiding expensive central power plant and transmission/distribution system capacity expansions by employing a concept known as Local Integrated Resource Planning (Lenssen 1995).

The economic advantages of small-scale technologies are even greater than commonly realized. A new Rocky Mountain Institute study catalogs 70 ways in which the size of devices that make, save, or store electricity affects their economic value (Lovins and Lehmann 1999).[3] Ultimately, many energy analysts believe that electric power systems will transform into interconnected networks of distributed, relatively small-scale generation units that more closely match the size, power quality, and reliability requirements of end-use loads than present large-scale plants. The once-clear distinctions between suppliers and end-users will blur, and utilities will become managers of distributed systems, using communications networks and smart meters to remotely dispatch generators and loads (Hodge and Shepard 1997).

The bottom line of all these changes is that the electric power industry will become extremely sophisticated in techniques for valuing, planning for, operating, metering, pricing, maintaining, and otherwise managing distributed systems of small-scale technologies. This expertise will spill over to management of water systems, improving the viability of smaller-scale supplies (e.g. rainwater/stormwater harvesting) and drinking water and wastewater treatment technologies. This spill-over will happen both indirectly, as water managers absorb techniques and strategies from the electric utility industry, and directly, as energy utilities seek new markets by expanding into water sector services.

[3] Rocky Mountain Institute anticipates preparing another study that will examine the application of these concepts in the water, stormwater, and wastewater sectors.

Competitive Restructuring of the Electric Utility Industry

Electric utilities are in an era of rapid change due to regulatory restructuring. This restructuring is designed to increase competition in the provision of energy services. The strategies of companies in the transforming energy markets are diverse. Some companies are focusing on efficient operation of the distribution wires, others are offering lower-cost or special-quality power generation to customers. Many new companies are emerging to service various energy needs. Some companies are pursuing aggressive mergers and acquisitions, within and outside of the electric utility sector. Some pursue the "multi-utility" concept, gaining efficiencies through combined management of electric, gas, cable, and water services, which can produce cost savings in customer care of 45 percent (E SOURCE 1999b).

In the end, those companies that succeed will likely be the ones that offer not just a good price, but excellent customer service. They will cut customer's bills by offering assistance in end-use efficiency, and they will carefully match energy offerings to the power quality and reliability requirements of customers. They will respond quickly and effectively to emergencies, billing matters, and evolving customer needs.

Across many infrastructure and commercial sectors—energy, telecommunications, financial services, and more—consumers are expecting ever higher levels of service and value for their money. To date, the water sector—supply, stormwater, and wastewater management—has been relatively insulated from these expectations and pressures. It is not unlikely that consumers will come to expect more from the water sector too.

It is instructive to examine the British experience, where water supply services have been privatized. Many in the U.S. have heard of British citizen complaints about excessive profits and poor service under the new regime. Now, the monopoly power of the private companies is increasingly in question, and many observers anticipate the opening of supply and distribution services to competition, envisioning an era in which customers could choose their service provider, and the distribution system would be open to "common carriage," allowing various suppliers to introduce water to the system at new points. Such proposals challenge many notions of how water systems should be designed and managed, and if enacted would represent a revolution in the infrastructure and institutions of water management.

Conclusions

Scenarios can help water system managers and policy makers explore different pathways the future may take. Visions provide goals to shoot for. Both tools are necessary in order to make sense of the many forces that will drive or enable changes in water infrastructure. Some of those "drivers" will come from within the water sector. Others will come from outside, from developments beyond the control of water managers.

It is critical to bear in mind that water, wastewater, and stormwater service requirements can be disaggregated into many quantity, quality, and reliability attributes. Different end-uses, customer classes, and locations have varying "bundles" of needs that current "one size fits all" infrastructure does not always meet effectively or efficiently. There are many more technological and institutional ways to satisfy the various bundles of needs than current infrastructure systems and institutions provide.

Consumers and policy makers will increasingly make connections between growing customer needs or expectations and the potential of new systems. Whether these realizations lead to increased pressure for privatization of water systems, or for reform within the now largely publicly-owned sector for water, wastewater, and stormwater services, is unclear at this time. What is clear is that important changes—physical and institutional—are coming for urban water infrastructure.

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