

United States of America

Cityscape of Chicago, the loop area office buildings and the Chicago River. Photo credit: ©iStock.com/Arpad Benedek.



"In the United States urban water supplies are adequate and water borne illness is rare. Yet, the problems of deferred maintenance, the need for future renewal, deteriorating water quality and intensifying water scarcity, if left unmanaged, will make additional water supplies hard to obtain and contribute to the deterioration of quality in existing supplies. These problems can be effectively addressed with a combination of demand management policies and the use of new and innovative technology. Wastewater recycling and desalination will likely become more common. Solutions will be costly, however, and the political will to bear those costs will have to be developed through enlightened leadership"

An Overview of Urban Water Management and Problems in the U.S.A.

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Summary

The urban water problems of the United States are problems of maintenance and renewal of water systems, continuing deterioration of source water quality and water scarcity which impedes the development of new supplies to support urban growth. These problems are technological, institutional and political. There is a clear need to invest in the maintenance and upgrading of urban water facilities but the political will to bear the necessary costs of doing so is absent. Although current water supplies are largely adequate and waterborne illness is quite rare, the U.S. is a good example of the “water paradox of developed nations” because without substantial new, innovative and costly efforts its urban water supply systems will be in jeopardy. There are a number of ways in which the problems can be addressed. Demand management strategies include actions to manage water consumption more carefully, reduce wastage and maintain levels of reliability. Some of the elements of demand management strategies are water rationing, education, pricing and the development of water marketing arrangements thru which additional supplies might be acquired. Pricing reform will be particularly important because current pricing practices cover only a fraction of the true cost of the water which includes the scarcity value of water, treatment costs, and transport and disposal costs. The intensifying competition for public funds makes it unlikely that they would be as readily available as they were in the past to support these activities. Another general category of actions to address the problems of scarcity involves the use of technology and other supply augmentation strategies. Waste water recycling is attractive in certain situations where water quality regulations require that any wastewater discharged be treated to a high level of quality. However, the technology needed to upgrade qualitatively degraded water supplies is expensive and wastewater recycling is usually attractive only in instances where the costs of alternative sources

of supply are quite high. Desalination is another potentially attractive technology but the costs are quite high; the technology is energy intensive; and, it can lead to environmental problems which may themselves be costly to mitigate. Policy reforms to promote demand management strategies appear to be the least costly way to address urban water problems and induce water conservation which is demonstrably the cheapest way to augment supplies. Where demand management policies are insufficient the adoption of new technology and other supply augmenting strategies maybe helpful despite the fact that they are bound to be very costly.

1. Introduction

An overview of urban water management and the problems which urban water managers face in the United States suggests that the general water picture could be characterized as “post modern.” Virtually the entire urban population of the United States has access to generous supplies of healthful, clean water and access to good sanitation facilities. Although waterborne disease occurs occasionally, it is very much the exception. Yet, the problems faced by urban water managers throughout the country are in many ways as daunting as those faced by countries that must address problems of inadequate water supply and sanitation services. Although existing supplies for most urban areas in the U.S. are more than adequate the availability of new supplies to support urban growth is problematical in many regions as general water scarcity intensifies. The quality of urban water supplies is also threatened by the continuing emergence of new chemical contaminants and biological agents associated with the development of new industrial processes and products. Additional threats to the availability and quality of water supplies and sanitation services are posed by an aging water service infrastructure. Despite the age of the nation’s water infrastructure, little investment or provision is being made to renew and update it.

The urban water situation of the United States thus stands in contrast to the situation in much of the rest of the Americas. The problems faced by the U.S. are problems of maintenance and renewal of water systems, continuing deterioration of source water

quality and water scarcity which is particularly prevalent in regions where urban growth tends to be concentrated. These problems are both technological and institutional and if they are to be solved research, political will and public resources will need to be available in significant quantities. It is somewhat ironic that the problems fit into the same categories as those of developing countries: infrastructure, lack of government commitment, inadequate financial support, a need for effective institutions including regulatory institutions and the need for improved and updated technology.

The remainder of this chapter is organized in four sections. First, the general urban water supply situation in the U.S. is described. Second, the problems of water scarcity and the available solutions are described, discussed and evaluated. Third, potential solutions to the problems of maintaining and protecting urban water supplies and sanitation services are reviewed and analyzed. The final sections contain some concluding remarks and recommendations for action.

2. Urban Water Supplies and Sanitation Services in the U.S.: an Overview

In 2005, the latest year for which comprehensive water statistics are available, withdrawals for urban water use totaled approximately $61.1 \times 10^9 \text{ m}^3/\text{year}$ in the United States. Of this total, two thirds came from surface water supplies with an additional one-third contributed by ground water. Urban water uses accounted for approximately 21.1% of withdrawals for consumptive uses in the U.S. in 2005. The comparable figure for 1950 was only 9.7%. The growth in urban uses after 1950 was accounted for by increases in population, which doubled, and increases in per capita use, which grew by a little less than 50%. Growth in per capita consumption was accounted for largely by increased water use for irrigation of landscaping, largely in the arid climates of the western U.S. (Kenny, et al., 2009). Despite the growth in population and in per capita rates of usage most urban areas have had generous supplies of high quality water for domestic purposes.

The explanation lies with the high levels of public and private investment in water storage and distribution facilities that prevailed during most of the twentieth century. Graf (1999) shows, for example, that reservoir storage capacity increased nearly one-hundred fold over the course of the century. Currently, very few water storage and supply projects are under construction and/or contemplated. There are several reasons for this. First, most of the good storage sites have already been developed and those that remain tend to be expensive and difficult to develop or remote from places of use. Second, water projects now have to compete with multitude of other public services for financing. This was not the case throughout much of the twentieth century. Third, the costs of public works have risen disproportionately faster than the costs of other goods and services. This increase in relative expense has made them less appealing on economic and financial grounds. Thus, although the recent history of urban water provision seems an unqualified success, there are reasons to suspect that future circumstances will be very different and the provision of adequate supplies will be more complicated than simply developing and operating additional water storage and conveyance facilities.

In addition to the physical and financial difficulties of augmenting surface water storage, there are a host of other reasons for believing that the problem of obtaining additional water supplies to support urban growth may be far more difficult in the future than in the past. The first of these is a locational reason. Scarcity of naturally occurring water supplies is more acute in the arid and semi arid American West than it is in other parts of the nation. Yet most of the population of this area of the country is concentrated in urban areas. Moreover, these urban areas which include Los Angeles, Las Vegas, Phoenix, Denver and Salt Lake City are among the fastest growing in terms of population. Linked to the demographic growth are significantly growing demands for additional urban water supplies. The problem is compounded by the fact that existing water supplies are already fully allocated among a variety of uses under the prevailing systems of water rights. Indeed, the growth of urban water demands comes on top of the fact that water is physically scarce and the competition for available supplies is especially acute. It should also be noted

that shortages are also occurring in the more humid eastern regions of the country both because of population growth and because of the unreliability of accustomed supplies (Feldman, 2007; Feldman, 2008).

The implications of climate change for the availability of urban water supplies in the U.S. are unclear. Increases in temperature will increase the environmental demand for water resulting in additional consumptive losses from both increased evaporation and transpiration. Possible changes in the timing of available supplies may also serve to reduce supplies *de facto*. Many western urban areas rely on melt from snowpack to see them through the warm summer and early fall seasons. The possibility of higher snowlines and earlier spring snowmelt could change the pattern of supply both by reducing accustomed supplies absolutely and by altering the timing of availability of water. Climate change is likely to have different effects in different regions and it is difficult to draw firm conclusions about possible impacts on any specific region or on the country as a whole. The predicted increase in extreme weather events is likely to have adverse impacts on water quality as well as on the availability of supplies (Bates et al., 2008).

Added to all of this is a serious infrastructure problem. Infrastructure for both water supply and sanitation is aging. In 2013 the American Society of Civil Engineers (2013) reported that the drinking water systems in the United States face an annual shortfall of \$USD 11 billion to replace aging facilities and comply with current and future federal water regulations. The report also noted that the costs of treating and delivering drinking water are in excess of the funds available to sustain such systems. This concern extends not just projects which can be federally underwritten but also to local utilities which continue to have operating deficits. The current unwillingness of elected politicians to appropriate funds to replace and sustain both drinking water and sanitation infrastructure seems destined to create a situation in which the reliability of such systems in protecting public health and delivering critical public services will be increasingly in jeopardy (American Society of Civil Engineers, 2013).

The picture with respect to water quality is very much the same. During the twentieth century the quality of urban water supplies in the U.S.

was the equal of the any place in the world. In the early years, the advent of disinfection and other improved sanitary practices sharply reduced the incidence of water borne diseases such as cholera and typhoid. In the last half of the century those diseases were virtually eliminated as were other waterborne diseases and threats to public health from inadequate sanitary facilities and wastewater management. In the latter half of the century new protections were added in the form of the 1972 Federal Water Pollution Control Act Amendments – known as the Clean Water Act (P.L. 92-500, 33 USC 1151 et seq) and Safe Drinking Water Act of 1974 (P.L. 93-523) as amended.

Broadly stated, the Clean Water Act afforded protection to the quality of the nation's surface waters by stipulating the minimum levels of ambient quality of those waters that must be achieved and regulating through discharge permits the point source pollutants entering those waters. The Clean Water Act also provided significant funding support for the construction of public wastewater treatment facilities. Such facilities ensure that wastewater is treated to the secondary level or higher. On the other hand, the Safe Drinking Water Act regulated the quality of drinking water by stipulating the establishment of National Drinking Water Standards which are legally enforceable and to which all public water systems must comply. Under the provisions of this act some 91 contaminants including, chemical, biological and radiological contaminants, are regulated. The Act also provides for processes through which additional contaminants can be added to that list. These laws have served the nation well in protecting drinking water quality and in cleaning up and protecting the quality of the nation's surface waterways. Nevertheless, there are signs that the protection of general water quality as well as of drinking water quality may also be jeopardized in the future.

New potential contaminants appear in the environment almost every day. These come from industry, agricultural, pharmaceutical chemicals, coal mining and natural gas extraction. Following the provisions of the Safe Drinking Water Act these potential contaminants are listed on Contaminant Candidate List. Furthermore, the Act mandates research to assess the health risks associated with each contaminant. The research is intended to serve

as the basis for deciding whether the contaminant should be regulated and, if so, at what levels. The Act requires a decision to regulate or not be made on at least five contaminants in each five year period. Venkataraman (2013) documents the fact that the number of contaminants on the Contaminant Candidate List is growing faster than the capacity of the Environmental Protection Agency to evaluate them. Thus, without additional funding, the backlog of contaminants awaiting decisions about regulatory action will continue to grow.

The picture that emerges is one in which existing processes for identifying and evaluating new contaminants are inadequately scaled and funded. There is also no way to control for the number of new contaminants that may emerge since that is a function of economic growth and innovation, the details of which are largely unregulated. Despite this fact and the facts surrounding the available quantities of water supply the public appears to be relatively unaware of the threats that they pose. Venkataraman (2013) reports the results of a number of polls show sharp declines in public concerns about the quality and availability of water supplies. He attributes this lack of awareness to the fact that threats to the availability and healthfulness of water supply are largely hidden from view. In addition, he notes that prices paid by consumers of water supplies and wastewater treatment service in the U.S. are very small, averaging in the U.S. just 0.3% of disposable income, leading to an outcome in which user costs cover only a small proportion of what is required to treat and deliver a safe water supply.

The urban water supply and sanitation situation in the United States provides a good example of the "The Water Paradox in Developed Nations" (Venkataraman, 2013). Historically, plentiful amounts of high quality water have been available at low cost in virtually every urban area. Similarly, technologically advanced wastewater treatments facilities have helped to ensure that the nation enjoyed full sanitation services which were the equal of any in the world. The quantity and quality of these services is now very much in jeopardy. Fundamental water scarcity, an aging water supply infrastructure and inadequate plans to replace and maintain it, public apathy and an apparent unwillingness of users to pay a significant portion of the capital and operating costs of such systems threatens the future

adequacy of urban water supplies in a very real way. The proliferation of new chemical and biological (and radiological) contaminants threatens the quality of urban water supplies in the future. This is because current processes are inadequately scaled and funded to handle the sheer numbers of contaminant candidates which are growing annually. In addition, the aging of wastewater treatment and sanitation facilities coupled with inadequate funding for renewal and maintenance poses a threat to the quality of urban water supplies in the future. (See box on The Big California Drought).

3. Addressing the Problems of Water Scarcity: Managing Water Demand

Urban water users have only recently begun to confront the reality of intensifying water scarcity. While existing water supplies appear to be adequate to serve existing levels of population in most instances the forces of economic and population growth fuel demands for additional water supplies to serve growing populations and regional economies. In the face of these growing demands, supplies in many areas remain static or are in decline. The supply situation is rendered uncertain by the specter of global climate change and the consequences of such change for water supplies across the regions of the nation. Although water scarcity is present to some extent throughout the country, it is most intense in the arid and semi-arid western regions of the country where the extent of urbanization and the rates of growth are the highest in the nation. Historically, urban water supplies were extensively developed in the face of population growth by constructing dams and canals to capture and store water and transport it to the urban areas in question. The strategy of developing new supplies in this manner is no longer viable both because the costs have risen and because available supplies in most basins are fully appropriated and unencumbered water is unavailable. There are nevertheless a number of means to address urban water scarcity. These involve both supply augmentation and demand management strategies. Demand

management strategies which include rationing, education, pricing and the creation of water markets will be considered first.

Rationing: Rationing is most commonly practiced in developing countries and in places where water is extremely scarce. Thus, for example, water supplies are rationed in Amman, Jordan which has very limited rainfall and limited ground water. Weekly water deliveries can be augmented by purchasing additional water but the fact that supplies are delivered in fixed quantities once a week has the effect of limiting use (Zou'bi, 2011). Rationing tends to be most effective in limiting outdoor uses and it is particularly well suited to the management of drought situations. Where water is delivered through a distribution system that is constantly active the enforcement of rationing schemes can be problematical since indoor uses of water are particularly difficult to regulate. Yet, as the example suggests rationing can be tailored to a variety of circumstances. Thus, it can be made to work in the longer run where available water is stored at the site of usage and it is the quantity of storage that is rationed. In addition, as the Jordanian example shows, the tendency for rationing to beget black markets can be countered by creating legitimate markets through which users can augment available supplies through purchase. It is obviously undesirable to employ rationing in circumstances where basic needs for drinking, cooking and sanitation may be jeopardized.

Education: There is clear evidence showing that water use tends to decline when consumers know where their water comes from and how much they use. Further, evidence suggests that the more consumers know about the origin, nature, treatment and costs of the water on which they depend, the more careful they are in economizing on use. Bruvold (1988) shows that metropolitan water consumers in California who are well informed about all aspects of their water supply will economize on its use. The Bruvold analysis was extended to major communities in the western United States by Michelsen, et al (1999) with similar results.

In major metropolitan areas, utilities sometimes attempt to educate people about where water comes from, the impacts of drought, the quality of water supplies and the impacts of treatment and disinfecting systems. Such efforts may be only partly

The Big California Drought, 2011...?

Beginning in 2011, California which is the largest state in terms of both population and economic activity, has been beset by one of the most severe droughts of modern times. The calendar year 2013 was the driest year in recorded history and early in 2014 the Governor declared a drought emergency. By August, 2014, nearly 100% of the area of the state was in the grips of a severe drought with 80% of that area classified as experiencing extreme drought. Extreme drought is defined as entailing major crop losses and widespread water shortages and water use restrictions. Residents and business in the state's major urban areas were subject to mandatory water rationing (San Francisco) and other types of water use restrictions. All state residents and business were subject to steep fines for wasting water and violating drought management regulations. Agriculture has been particularly hard hit with 2014 economic losses estimated to be USD\$2.2 billion and job losses expected to top 17,000 (Howitt, et. al., 2014). Many rural communities were similarly hard hit with water supplies projected to last only for a few short months and emergency measures in place. Although water supplies available to major urban areas have been sharply curtailed the entire water system appears flexible enough to forestall extreme hardship for the foreseeable future. In the meantime, restrictions and regulations will require curtailed water use. This will entail more than simply inconvenience as urban damages from less than accustomed levels of water availability continue to mount.

While the drought is currently more prominent in the public eye, it differs fundamentally from the longer term urban water security problems that are the focus of this chapter. The difference between longer term water security and drought is the same as the difference between scarcity and shortage. Scarcity is a persistent phenomenon that must be managed over the longer term. Drought is usually a much shorter term phenomenon which must be managed with flexible and adaptive techniques that may not be effective in the longer run. Thus, rationing is frequently employed to manage drought and it is effective because it is broadly understood to be a short term measure. When used as a tool to manage demand over the longer run rationing risks the development of black markets and almost always implies that water itself is not persistently scarce. Urban water management organizations customarily address drought in advance by developing supplies systems that have very high degrees of reliability so they have the capacity to deliver water even when the physical resource is scarce. This tends to avoid extreme hardship during drought though it really does not address the longer term problems that constitute the "Paradox of Developed Nations."

In August, 1914 two large and widely publicized breaks in water mains within the City of Los Angeles starkly illustrated the need to attend to longer term problems of water security. The breaks caused millions of liters of water to spill into the street and flood some adjacent buildings. That this was precious water dearly needed in a time of drought was only a part of the story. The water distribution system in the City of Los Angeles is over 100 years old and has come close to the end of its physical life. Estimates of the costs of rehabilitation are in excess of USD\$1.0 billion. It is unclear where this money is to be found and there is no transparent planning effort underway to address a problem that does pose a threat to future urban water security in Los Angeles. For the moment the physical drought is serving as a distraction from the longer term problem which may well be a man-made drought brought about by the neglect to focus on the longer term issues of urban water security in a major metropolitan area.

successful, however. Thus, for example, traditional methods of reporting water consumption tend to make it difficult for consumers to understand exactly what their use levels are. Frequently, use levels

are reported on utility bills in terms of unspecified and undefined "billing units" These provide most consumers with no understanding whatsoever of how much they are using. Alternatively, when

consumption is reported in terms of gallons per day or some similar and familiar measure consumers have a better understanding of consumption levels and tend to use less than fellow consumers who lack this information. Educational programs such as these are low cost and simple. They often lead to early reductions in water consumption that are characteristic when people first learn about their levels of usage. They are also helpful in facilitating response to drought conditions. This is particularly true when special pricing or rate rules are imposed during drought periods in an effort to reduce consumption. Consumer education is one of the least costly means of inducing economizing in water use (Michelsen et al, 1999).

Public education may be very important in responding to the general problem of water scarcity. While there is evidence of a decline in public concern about urban water availability and quality there are several recent polls that indicate that pollution of drinking water remains one of the top public concerns over environmental issues. Thus, the Xylem Value of Water Survey (2012) found that 9 in 10 respondents considered water an important service while the Circle of Blue (2009) survey found that more than three quarters of the respondents across nations believed that it is important that all people have access to safe, affordable drinking water. This latter survey also found that a majority believed that the public needed more information to protect their water supplies. These results suggest that there is substantial public concern about water issues and that there is also substantial public receptivity to efforts to further educate the public about the current array of water problems and potential solutions to those problems.

Pricing: The price of water for urban areas is virtually always based upon the costs of impounding, treating and delivering it. Frequently, even these costs are not fully reflected in the price of water (Note: in some instances the price of water includes a sewerage charge to cover part or all of the costs of wastewater treatment services.) . More significantly, the price of water virtually never includes a component of scarcity value. That is, the water itself has an implicit scarcity price of zero. Such a price signals that the commodity in question – water in this case – is freely available. Yet, the scarcity of water

is a fundamental problem and in the face of such circumstances policies that suggest that water is widely and freely available are perverse. Additionally, policies which require inclusion of a scarcity value in the price of water virtually always induce conserving or economizing behavior by consumers thereby making additional water available to serve new users or alternative uses.

The price responsiveness of the demand for water has been clearly established. As the price of water increases the quantity of water demanded or used will decrease. The measure of this response is referred to as the price elasticity of demand. Typically, the demand for urban water is relatively more price inelastic than the demand for agricultural water. Inelasticity means that the impact on the quantity taken in percentage terms is less than the percentage increase (or decrease) in price. The evidence suggests, however, that by assigning even a modest scarcity value or scarcity price to water will likely result in modest reductions in water use (Hanemann, 1997; Schoengold et al, 2006).

Water can be priced administratively or through the unfettered interaction of the market forces of supply and demand. In the United States, water prices are typically established administratively. It would be a relatively straightforward matter to include a scarcity value or a proxy scarcity value in an administered price. The scarcity value could be inferred or estimated and would be an approximation of the true value. Water utilities and other purveyors typically establish water rates to reflect the average costs of capturing, treating and distributing the water. This is done to ensure that the costs which the utility faces – not including the scarcity cost or value – can be fully defrayed with available revenues. Clearly, it would be straightforward just to include in this rate an average scarcity value.

Simultaneously, it should be recognized that the use of average cost pricing has at least two shortcomings. In many circumstances today, the incremental cost or value of water is much higher than the average value. Thus, for example, the desalinated water which the San Diego County Water Authority will acquire and which will account for 10% of its supply when fully developed may cost as much as four or five times more than the average cost of current supplies. However, when the cost of

this water is averaged in with the cost of the other 90% of the supply that are much lower the price increase of this new supply will be very much less than its relatively high incremental cost (NRC, 2008). This lower rate signals consumers that the water is much more plentiful than it is in fact. It also requires existing users (and uses) to subsidize new users (and uses) because historical users see their bills rise to help defray the costs of the expensive new supply that is only needed because of new users who then end up paying less than the full costs of the new supplies which they require. Incremental costs are sometimes difficult to estimate but increasing block rates, which are frequently employed by electric utilities, can approximate incremental costs and provide incentives for economizing behavior that are very similar to that which would occur if actual incremental costs were used. Incremental pricing for urban water supplies results in more efficient water use in the urban sector. Efficient allocation means that water is devoted to its highest valued uses within the sector in question.

The scholarly literature suggests that appropriate pricing of water probably needs to be at least a part of any strategy for managing water scarcity (see, for example: Baumol and Oates, 1979). Prices that are approximately accurate send important information to consumers about the relative scarcity of water and induce economizing. The pricing system does not always work perfectly and hence there may be circumstances where a mixed strategy that includes pricing may be more appropriate. Prices have the advantage of restraining excessive and wasteful use of resources and this is an essential part of any effort to manage water scarcity (Baumol and Oates, 1979). This fact together with the fact that current water prices rarely cover more than a small fraction of the amount expended and almost never reflect the scarcity value of water make a compelling case for the employment of more enlightened water pricing policies in managing water scarcity and in facilitating the efficient provision of sanitation services (Venkataraman, 2013).

Water Markets: Appropriate water pricing policies ensure that water is efficiently allocated within a single sector where they are used. Thus, appropriate pricing policies for urban water supplies can ensure – or help to ensure – that urban water

is efficiently used. Water markets, by contrast, can ensure that water is efficiently allocated between various water using sectors, urban, industrial, agricultural and environmental. In addition, water prices generated by well-functioning markets almost invariably reflect the scarcity value of water. Markets work by facilitating the exchange of water from relatively low valued uses to relatively higher valued uses. It is important to recognize that market transactions are strictly voluntary and thus both buyer and seller are made better off from such exchanges. The buyer benefits by purchasing water that is cheaper than any alternative source and because the price of water acquired through markets is lower than the value which the buyer can obtain by putting it to the desired use. The seller benefits because the sales price exceeds the value which the seller could obtain by putting the water to its most valuable uses. All of these conditions are met when water is traded successfully in markets.

Market transfers in the water sector are not confined to the trading of water rights. Water can be sold in spot markets for one time transfers; it can be leased for specific periods of time; and, it can be made subject to contingent contracts where a potential buyer pays a potential seller a fee for the opportunity to purchase the water when needed. In this latter case, an additional price must be paid if and when the water is actually transferred. Thus, for example, the Metropolitan Water District of Southern California, a major supplier of urban water to the Los Angeles conurbation, has executed contingency contracts with several agricultural water districts that would help to ensure that urban supplies remain available during times of drought.

When water markets work well, the resulting allocation of water among the various use sectors is efficient. That is, there is no alternative allocation among sectors that would lead to a higher aggregate value of water in and between uses. Experience shows that most exchanges occur either within the agricultural sector or between the agricultural and urban sectors. In fact, agriculture is sometimes thought of as “the supplier of last resort”. In such exchanges the price that the agricultural seller receives plus the costs of transport and treatment are exactly equal to what the urban buyer pays. The existence of water markets helps to ensure that

water can be transferred from low valued to high valued uses. Without markets many low valued uses can continue to be served even while water is unavailable to support higher valued uses (National Research Council, 1992).

Water markets are neither perfect nor a panacea. Without special arrangements, environmental uses of water, which are generally non-consumptive, cannot compete on the same bases as urban, industrial and agricultural uses which are consumptive. Environmental uses of water, which provide environmental services and environmental amenities, are appropriately viewed as public goods. That is, when one individual is provided with an environmental service it is not possible to withhold that service from others even if they refuse to pay. The result is underinvestment in the development of an environmental service because a purveyor is unable to capture the value cannot be captured from consumers who ride free. There are a variety of remedies that include: 1) special or designated funds, which might be publically appropriate, that can be used to buy water for environmental purposes; 2) a tax on the proceeds of other water transfers that can be used to purchase additional water for environmental purposes; and 3) special legislative protections or designations which protect environmental water from market facilitated transfers to serve other uses (National Research Council, 1992).

There are some additional problems that need to be addressed in the design of water markets. These include adverse impacts on people who are not parties to the transfer negotiation. For example, people downstream of a transfer who depend upon accustomed river flows for their own supplies may suffer from an upstream transfer to which they are not party because of a resulting reduction in flows. Market transfers could also have adverse effects on water quality because the dilution capacity of the stream is reduced. Markets then need to be designed and supervised to ensure that environmental uses are accommodated; that third party impacts are small or absent; and that there are not other unanticipated or unaccounted for impacts. Like prices, markets may be particularly effective when they are used as part of a mixed strategy for resolving scarcity. In the case of transfers to the urban sector

from the agricultural sector the supplies of urban areas may be increased absolutely with associated increase in the total value of scarce water across the various uses.

4. Addressing the Problems of Water Scarcity: Technology and Supply Augmentation

The historic U.S. supply augmentation strategy of constructing storage and conveyance facilities is no longer a viable means of addressing scarcity. The lack of unallocated water, the absence of physically and economically desirable impoundment sites and the competition for funding reinforce this conclusion. However, modern technology coupled with the escalating costs of alternative sources of water mean that waters of impaired quality can be treated and upgraded to levels of quality suitable for most uses. Household (and industrial) wastewater that is discharged to centralized sewer systems can be recycled and reused depending upon the desired level of treatment and the costs of achieving it. In the United States relatively stringent surface water quality standards and discharge regulations (requiring a discharge permit) means that wastewater from sanitary (and in some cases, storm water) sewers must be treated to meet these standards. The costs of reuse are properly calculated as the costs of making the water suitable for reuse above and beyond the costs of meeting the discharge and receiving water quality standards. In some instances, treated wastewaters can be used for landscape irrigation and other non-potable uses in which little or no additional treatment is required beyond what discharge standards call for.

The importance of cost consideration is well illustrated by examining current trends in industrial water use. The quantities of water diverted for industrial purposes in the United States declined significantly following the enactment of national surface water quality standards and the associated controls on discharges. The explanation lies with the fact that once firms have treated wastewater to meet discharge standards, the additional costs

of restoring the water to a quality where it can be reused are quite modest. The consequence was that many firms found it economical to reuse treated wastewater as feed water for industrial processes. In this way the advent of water quality protection and regulation provided incentives for industry to economize and reuse its water inputs.

Modern wastewater treatment technology is now advanced enough so that household and industrial wastewater can be treated so as to meet the standards for potable reuse. Thus, for example, the Orange County Water District in southern California produces significant quantities of water, from wastewater, which is recharged to local aquifers. The water is ultimately extracted to serve household needs. The unique circumstances of the Orange County Water District are discussed elsewhere (see Box). The District uses a number of technologies including membranes in reverse osmosis processes prior to injecting the water directly into the underlying aquifer. The more advanced of these technologies are costly and can be utilized economically only under certain conditions (Mills, 2010).

It is important to recognize that the ability to employ the sorts of advanced technologies discussed here is unlikely to be present everywhere. The technology itself is expensive both in terms of capital cost and the costs of operation and maintenance. Operation of the technology requires a relatively skilled workforce which also entails higher costs. And, perhaps most importantly, the performance of the technology must be constantly measured and monitored to ensure that it is performing at the promised level. In short the options discussed here are likely to be attractive only in circumstances in which alternative sources of supply are very expensive and there are ample resources and expertise available to build and employ technologically advanced wastewater treatment systems.

Wastewater Recycling: Approximately 35% of the municipal wastewater effluent discharged each day in the United States goes to an ocean or an estuary. Reusing these coastal discharges would augment available water resources by 6% of total U.S. supply or 27% of public supply (National Research Council, 2012). The absolute quantities discharged to coastal waters are significant, amounting to 45.4

million m³/day. There may also be opportunities for reuse of inland effluent discharges but care must be taken to avoid harm to downstream users though flow reductions. Water reuse for non-potable uses is well established in the United States. Potable reuse is far less extensive and some of it is incidental and has not been quantified (National Research Council, 2012). Nevertheless, in arid and semi-arid coastal regions where water supplies are limited the opportunities for reuse are substantial as is the range of uses that could be served.

The vast majority of water reuse in the U.S. is for non-potable purposes. Thus, for example, landscape irrigation, irrigation of golf courses and freeway landscape irrigation are all purposes in which reclaimed water plays a significant role. Reclaimed water is also made available in some circumstances as industrial cooling water. Although circumstances will vary from location to location the likelihood is that non-potable will reuse will increase in coming years. This will be attributable both to the growing demand for water for non-potable uses and the fact the additional costs of rendering treated wastewater that meets discharge standards suitable for non-potable uses are frequently quite modest. The historic development of non-potable reuse has been helpful in exposing a sometimes skeptical public to the benefits of reuse. Those benefits include an augmented more reliable water supply which provides protection against drought for certain uses (National Research Council, 2012).

The current and future extent of potable reuse is hard to predict. This is because the extent of incidental reuse – also called *de facto* reuse – is not known and could grow significantly in the future. Incidental reuse occurs because some treated wastewater (which meets national standards) is discharged to surface waterways upstream of the water intakes. In the course of its journey in the stream this effluent is diluted and its quality is improved. Such water ultimately makes up some proportion of the downstream water supply which may be devoted to non-potable or potable use (reuse). The U.S. National Research Council (2012) reports that in many instances the degree of treatment of discharged effluent that becomes incidental reuse is less than that accorded to supplies that come from planned reuse projects. The fact that the extent of incidental reuse is unknown means that it is unclear

how many people are exposed to the contaminants contained therein and the current concentrations of those contaminants. Clearly, it will be very important in the future to have better information on the extent of incidental reuse, on the locales where it occurs and on the risks that such reuse poses to water consumers.

It is important to compare the risks associated with potable reuse supplies with the counterpart risks associated with water supplies that are presently used. In some instances, the risks associated with planned potable reuse are less than those of conventional supplies. There are instances in which water consumers have rejected proposals for planned potable reuse even where it could be shown that the risks associated with potable reuse were demonstrably lower than risks associated with continued use of existing supplies. In addition, design objectives for reuse systems should include criteria of reliability and robustness. Redundancy typically enhances the reliability of contaminant removal while robustness has to do with the ability to respond effectively to a wide variety of contaminants. It does appear that the risks associated with planned potable reuse can be reduced to acceptable measures but the costs of doing so may be high. Again, the economic and financial feasibility of such projects will depend importantly on the costs of alternative sources of water.

The costs of water reuse are highly variable from site to site and situation to situation. The size of the facility, its location, and the quality of the feed water, the need for storage, energy costs, interest rates and the costs of complying with regulatory and permitting processes vary across a wide range of domains and make it quite difficult to generalize about likely costs. As a generalization, it appears that potable reuse costs are frequently higher than most water economizing options and lower than seawater desalination costs. In the case of reuse for nonpotable purposes, product costs can be quite modest given that treatment requirements over and above those needed to meet wastewater discharge standards may be quite modest. In these instances, the costs of distributing the water are likely to predominate. This may be particularly true where water for non-potable, outdoor household uses can be accommodated because dual plumbing systems will be required (National Research Council, 2012).

There are pricing problems with reuse water for both potable and non-potable purposes. As already noted, potable reuse costs may be quite high and not competitive with the costs of alternatives. The rates charged for non-potable reuse water frequently do not cover the total costs of acquiring the water; treatment, if any; and the capital and operating costs of the distribution system. Subsidies and other artificial means of lowering costs are sometimes employed to make reuse supplies attractive and financially competitive. However, as the demand for reclaimed water increases in the future it is likely that the costs of these supplies will rise. This fact serves to reemphasize the importance of pricing and the need to be realistic about costs and prices of water supplies of all sorts are to be managed efficiently and effectively (National Research Council, 2012).

Public acceptability is an important element in the successful prosecution of any potable reuse project. A number of otherwise justifiable potable reuse project proposals have failed because of public opposition. These include projects proposed for construction in Los Angeles and San Diego in which public opponents became arrayed against local water purveyors in circumstances where effective communication seemed all but impossible. Such opposition is frequently based on misinformation or lack of accurate information (Equinox Center, 2010; Ingram et al. 2006). There are nevertheless numerous examples of successful potable reuse projects and these seem to share characteristics of early public involvement and transparent communication of scientific and policy information on a continuing bases. These experiences underscore the importance of extensive and continuing public communication on water issues in urban areas. Public knowledge and understanding of water issues are now known to be increasingly important in the formulation of water supply and management alternatives in urban areas and in various decision making processes related to water (Ingram et al., 2006; National Research Council, 2012).

Desalination: Desalination processes typically treat seawater or brackish waters to produce a stream of freshwater and an associated stream of concentrate water that contains the salts that have been extracted from the freshwater. The fact that such a large portion of the Earth's water endowment is in seawater and the fact that brackish

Orange County Water District, California

The Orange County Water District is located in the Santa Ana River watershed south of the City and County of Los Angeles and north of the City and County of San Diego in California. Its service area is coastal Orange County that, in the period following World War II, experienced explosive population growth which transformed it from an agricultural area into a densely settled urban and industrial area. Historically the area relied on ground water to a disproportional extent and ground water overdraft began to become significant in the first half of the 20th century. With population growth, overdraft became more severe and one serious consequence was the intrusion of seawater into the aquifer, threatening the quality and sustainability of the basic water supply. To address the problem the Orange County Water District devised a program and constructed the needed facilities to permit injection of water reclaimed from an advanced wastewater treatment facility known as Water Factory 21. The injection of reclaimed water began in 1976 and served the purposes of creating a seawater intrusion barrier and as an augmentation to the local potable supply.

In the first decade of the 21st century Water Factory 21 was replaced with a large Groundwater Replenishment System which consists of an advanced wastewater treatment facility, the seawater intrusion barrier and several spreading grounds. Current production is 200,000 m³/day with an ultimate capacity of 490,000 m³/day. The source water for the advanced treatment facility is secondary effluent from the Orange County Sanitation District Plant # 1. This plant is located immediately adjacent to the Water Districts' facilities. Half of the product water is injected directly into the seawater intrusion barrier after treatment with reverse osmosis. All of the treated water is accorded advanced oxidation and microfiltration. The half not directly injected is transported to the spreading grounds and undergoes soil/aquifer treatment as it is percolated to the underlying aquifer. Extraction wells are spatially removed from the spreading basins by over a mile and retention time underground prior to extraction is estimated to be in excess of six months. From a public health perspective the project has been unblemished for nearly 40 years.

The groundwater is supplemented by remote surface waters that are brought from northern California and from the Colorado River. These are expensive supplies, in part, because of the sizeable amounts of energy needed to pump and convey from remote locations. In this example, then, technologically sophisticated and large scale wastewater recycling and reuse is economically attractive because the costs of the least cost alternative supply are relatively high and because the Metropolitan Water District of Southern California, which imports the surface supplies offers subsidies to customers who develop alternative sources of supply to meet at least a portion of demand.

This case illustrates that potable reuse can be successful over the long-run if the resources and expertise needed to design, build and operate the facilities are available. It illustrates also the importance of the costs of alternative sources of supply in determining the economic attractiveness of the project. The technical sophistication, high costs and complicated financing arrangements make clear that projects with this level of expense and technical sophistication are unlikely to be attractive on a widespread basis though they can be highly successful given the appropriate circumstances.

Sources: Crook, 2007. Mills, 2010.

ground waters are found nearly everywhere in United States (Feth, 1965) makes desalination a potentially attractive technology for augmenting fresh water supplies. There are two distinct types of desalination technology sometimes characterized

as distillation technologies and membrane technologies. Distillation technologies were among the earliest developed and rely on different processes which separate pure water dissolve solids though distillation. Such technologies tend to be very

energy intensive and today are found almost exclusively in the countries of the Persian Gulf where energy is relatively inexpensive. Membrane technologies first appeared around 1970. These technologies entail the application of pressure to salty water to force it through a membrane which screens out and separates dissolved solids. These technologies tend to be less energy intensive and the costs of membranes have declined over recent years making such technologies economically and financially more attractive than the distillation technologies. Virtually, all of the recent desalination plants and those that are in the planning stage are of the membrane type and include electrodialysis, reverse osmosis, nanofiltration, ultrafiltration and microfiltration (National Research Council, 2008).

The advantages of these systems is that they permit new sources of freshwater supply to be developed from waters that tend to be plentifully available – depending upon location – but are qualitatively degraded. There are two principal disadvantages to such systems. First, the costs tend to be very high compared with the costs of many other modern sources of water including conservation and some reuse and reclamation schemes. Second, the environmental impacts of the concentrate stream are harmful and in many instances the need to mitigate or prevent them will increase costs even more. The two largest components of cost are the capital costs (annualized) and the energy costs. It has been estimated that for a seawater reverse osmosis plant with a capacity of 189,000 m³/day each of these costs would account for one-third of the total. The fact that energy costs are disproportionately large is also a cause for concern because energy costs have exhibited significant instabilities from time to time.

The unit costs of producing freshwater from seawater are reported to range upward from \$0.64/m³. Many estimates of unit cost tend to be understated because of a failure to account fully for all costs, because the role of subsidies is neglected or because other financial arrangements may involve forgiveness of some costs or hidden subsidies (Miller, 2003). Distortions in cost are frequently difficult to identify as irregularities in financing terms such as artificially low interest rates and perturbations in payback schedules are not uncommon and are far from transparent. Questions of cost are further

confused by pricing practices that distort the true cost of the water in order to enhance affordability or for other reasons. One example is the case cited earlier in which the San Diego Water Authority intends to average the relatively high costs of desalinated seawater which, when the facilities are complete and operational, will contribute 10% of the total water supply. A hypothetical case illustrates what happens when average cost pricing practices are employed.

Suppose that the existing cost of water is \$0.20/m³. Suppose further that the cost of the desalinated supply is four times that amount, \$0.80/m³. The new water supply is composed of 90% of supply costing \$0.20/m³ and 10% of the supply costing \$0.80/m³. The average cost of the combined supplies is \$0.26/m³. So, instead of charging users of the desalinated supply the cost of the supply (\$0.8/m³) all users are charged the new average cost of \$0.26/m³. In this example the addition of 10% to the supply, costing four times as much as the base supply and averaged over all users causes everybody's water cost to rise by \$0.06/m³ or 30%. The implications of average cost pricing are mixed. This pricing practice ensures that water remains reasonably affordable and that the price increase is relatively modest when compared with the price increase of the additional increment. However, the practice of average cost pricing buffers consumers from the sharp price rise of the new supply and simultaneously conveys erroneous information about the scarcity value of the water. The underpricing of the water sends a signal to consumers that water is more plentiful than it is in reality and thereby provides an incentive to use more water than is warranted under the prevailing scarcity circumstances. This additional use is, by definition, wasteful. It is the result of perverse policies which encourage wasteful use of a scarce resource.

As indicated earlier the exact magnitude of cost depends upon local circumstances. It is known, however, that with membrane technologies the costs of desalting are sensitive to the salinity content of the water, meaning that brackish waters are almost always less costly to desalt than seawater. This means that both inland and coastal supplies of brackish ground waters may be more competitive sources of supply than seawater. It is also important

to recognize that seawater desalination will almost always occur at sea level and the need to pump product water uphill to points of use will increase the cost, usually significantly. With inland desalting of brackish water conveyance costs can also be significant as can costs of extracting the brine from aquifers. Additionally, the second major shortcoming of the technology which is the cost of environmental impacts can also have adverse impacts on total costs.

The diversity and seriousness of environmental problems will vary locationally, technologically and with the scale of the specific desalination facility. Moreover, there is limited knowledge and thus substantial uncertainty about the environmental impacts of desalination. There are nevertheless three generic types of environmental problems that will have to be addressed in the planning, construction and operation of virtually any facility. They are impingement, entrainment and concentrate management. Impingement entails the pinning or entrapment of large organisms such as fish against the intake screens of the desalination facility. Entrainment occurs when relatively small organisms are taken in and killed by temperature or crushed against membranes. These problems can be attenuated to some extent by co-locating intakes with those of power plants. In some circumstances impingement and entrainment can be minimized by utilizing subsurface intakes or deep water intakes. With surface intakes fish handling systems and traveling screens can be used to minimize impingement. The need to address impingement and entrainment problems will increase both the capital and operating costs of a desalination plant (National Research Council, 2008).

The other generic environmental problem relates to the need to manage concentrate which is the waste product of desalination. The desalination process effectively partitions the feed water into a freshwater stream and a concentrate stream. The latter contains salt and residuals from the treatment process. The chemical constituents in concentrate pose complex problems. Thus, for example, it is thought that membrane cleaning chemicals should be disposed of separately rather than with the concentrate. Similarly, there are environmental hazards associated with the disposal of concentrates. Such hazards may be inimical to individual species or to entire classes of organisms. Disposal of contaminants falls under the provisions of the Clean Water Act and the Safe Drinking Water Act so that disposal processes and regimes must meet regulatory requirements. Inland desalination may exhibit different sorts of environmental problems. Ground water overdraft and associated subsidence is one example. Threats to the quality of existing surface waters are also a possibility.

The incremental costs of desalination are high even where environmental impacts are relatively modest. Those costs do not compare favorably with the costs of many of the available alternatives. It is clear that the least cost alternative source of water for urban areas in the United States is conservation (Equinox Center, 2010). It seems fair to assert that pricing policies that lead to marginal cost pricing of supplies from desalination and expensive reuse projects would themselves induce substantial quantities of conservation. It is ironic that in such an event the quantities of conservation would itself outstrip the quantities to be supplied by the new, high-cost technologies thus rendering them unneeded.

5. Conclusions

The picture of urban water management – current and future – that emerges for the United States is characterized by the water paradox of developed countries. Virtually the entire population of the country has access to healthful water supplies and fully adequate sanitation services. Yet, urban residents and water managers are faced with an array of future water management problems that appear to be just as daunting as those faced by countries which are not fully served. Water scarcity is intensifying, especially in the arid and semi-arid western parts of the country where urban growth is the highest. Water quality problems are also intensifying as new contaminants appear frequently and the institutional and policy apparatus for responding to them grows increasingly inadequate. Urban water supply and sanitation infrastructure is aging. The planning and financing needed to maintain and renew this infrastructure is inadequate and with time the inadequacy grows. The public appears apathetic to these problems largely because they are unaware of them.

Intensifying water scarcity is caused by a combination of factors. Growth in water demands is fueled by population growth in urban areas. This growth is occurring at a time when water supplies to serve it are static or shrinking. New quantities of supply from accustomed sources are not available since most river basins have been fully allocated and because supplies in some regions are not reliable. Future deterioration in water quality could shrink such supplies further. Water scarcity is made worse by the failure of political leadership to educate the public about the nature of the problem and garner support for addressing the various manifestations of it. Water pricing policies are focused on recovering the costs of supply and treatment and virtually never include or reflect the scarcity value of the water itself. Water prices which convey a scarcity value of zero to consumers signal that water is freely available. These pricing policies

are perverse and contribute to public ignorance of the water scarcity problem.

While accustomed sources of new supply are largely unavailable modern technology can be employed to augment water supplies through water reclamation and reuse and with desalination technologies. The latter technologies produce freshwater from seawater or brackish waters which are thought to exist as ground water in much of the inland United States. The difficulty with these technologies is that they are very costly and especially so when compared with the cost of existing supplies. Current pricing policies mask this fact by averaging the high costs of the new supply in with the lower (frequently much lower) costs of the existing supply. This signals consumers falsely that the newer supplies are much less costly than they are in fact and leads to excessive –and wasteful – use of these supplies.

It is well documented that the cheapest source of additional water is conservation or economizing on the use of water. It is also well documented that the demand for water is price responsive. Higher prices induce consumers to economize and conserve. The failure to include the scarcity value of water in its price and the use of pricing gimmicks to mask the real cost of new supplies from reuse and desalination seem self-defeating. By underpricing water – on both counts – consumers are sent a signal that water is more plentiful than it is in actuality. That is, prevailing policies are aimed at understating or misstating the true extent of scarcity. Thus part of the response to the challenges confronting urban water managers is to fashion pricing and allocation policies and engage in programs of education which emphasize the reality of water scarcity rather than masking it. Such policies should also make provision for modern and adequate assessment of emerging contaminants in an effort to maintain or even enhance source water quality.

For situations where policy reform is insufficient to provide adequate quantities of water of appropriate quality water reuse schemes and, where feasible, desalination efforts can be considered important. Such supplies should be priced at approximately their marginal costs to signal consumers about scarcity and cost and to minimize or avoid altogether wastage of scarcity

supplies. The experience of electric utilities with increasing block rate pricing structures has been very successful and provides a model which the “water industry” in the developed world should consider emulating. To some significant extent the problems of water scarcity faced by urban areas in the United States are self-inflicted. There is no reason why this should be so.

6. Recommendations

1. The three threats to urban water security in the United States – water scarcity, inadequate and aging water supply and sanitation infrastructure and a rapidly growing number of potential contaminants – should be addressed in an integrated fashion. Addressing a single threat but not the others is unlikely to result in sustained states of water security. Moreover, different levels of government will be required to act in consonance if the issues are to be successfully resolved. The problems of contaminant identification, characterization and management are appropriately problems for the national government. Problems of water scarcity and inadequate infrastructure are best addressed at lower levels of government. Thus, the problems themselves need to be considered in an integrated fashion but effective responses will require collaboration between different levels of government – intergovernmental integration.
2. Water pricing policies will need to be reformed to account for the scarcity value of water and to reflect the increasing costs of new supplies. Assigning water itself a scarcity value and reflecting that value in pricing strategies will result in water economizing and also has the potential for augmenting revenues that will be needed to finance rehabilitation, operation and maintenance of water and sanitation infrastructure. Such reforms in water policy will likely to be central to any effective strategy for protecting water security.
3. Purveyors of water supply and sanitation services should initiate and support robust programs of education and communication. The purposes of such programs should be the development of informed users groups and an informed public. Users and the public should develop solid understandings of the nature of water scarcity, the financial implications of an aging infrastructure and the problems of identifying and managing contaminants.
4. The national government needs to authorize and provide funding support for programs of evaluation and regulation of contaminants and potential contaminants. Failure to accomplish this task will adversely impact both the safety and reliability of the nation’s urban water supplies in the future.
5. New technology and supply augmentation strategies should only be employed only after careful analysis of the costs of new supplies and services and a comparison of those costs with the costs of other options.

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