EDITORIAL

MANAGEMENT OF URBAN WATER: INTRODUCTION

An ever-increasing proportion of the world's population lives in cities. About half of the world's population already live in cities, and by the middle of the 21st century, close to 90% of the then 10 to 12 billion people could be living in cities. Continued urban development poses challenges to water resources management. Presently about two-thirds of freshwater usage is for agriculture (over 90% in some countries), but the proportion used by cities will increase with time. Competition for water between cities and other users—in some places agriculture, in others instream requirements for nature—will continue to escalate.

Cities change the hydrological cycle, usually in ways that detract from the quality of water and cause harm to the environment. It is worth considering how urban development might be planned and executed in a way that minimizes negative effects and presents opportunities for improved water management.

To plan for a better future, and to stimulate visions for a better future, conventional approaches to urban water management must be challenged. Most of the world's population lives in countries that are actively seeking improved water supplies that are affordable. In the developing world's cities with minimal or inadequate water infrastructure, there are opportunities to implement good ideas without entrenched resistance to change. In the developed world there is a need to rehabilitate aging systems and institutions that no longer provide satisfactory service and fail to meet tightening standards. For the future of water management, in both worlds, innovation is important.

URBAN DEVELOPMENT: THE PAST

Urban areas often develop near water—on a river, an aquifer, or near a lake. As cities grow, the nearby water sources are used, often to the limit of their capacity. Pollution from the urban area eventually threatens the sources, and then new supplies are sought further away. Many cities import water from tens or even hundreds of kilometers away. As in ancient Rome, imported water makes possible unbridled urban growth. The successful proponents of aqueducts, pipelines, and river diversions are credited with foresight and entrepreneurship. Tenacity is required also, because bringing water from remote sources is expensive, and complicated by permit and licensing procedures. The Aqua Vita of ancient Rome took 100 years to gain approval from the Senate. The situation is much the same today.

In ancient times many water supplies for cities also came from within, or close-by, and clever ways were developed to capture and to use water. The Nabateans in the deserts of the Middle East harvested the rainfall that fell on parts of their cities and directed the runoff into underground storage. Water was captured with an entry sill that allowed the cleaner part of the flow in and kept the debris and sediments out. Similar initiatives have been developed in recent decades. For example, urban runoff is stored in abandoned gravel pits in Denver to augment water supplies. In King County's new office building in Seattle, rainfall is captured on the roof for use in the building.

Management of floods is also an important feature of human settlements. In ancient Petra, in Jordan, floods arriving from upstream were diverted around the city by a control dam and tunnel scheme that still exists, and is a component of the present flood protection scheme for that popular tourist destination (Al-Weshah and El-Khoury 1999). The enormous Red River flood of 1997 overtopped levees and destroyed downtown Fargo, in North Dakota. Downstream at the larger city of Winnipeg, Canada, the levees were just barely protected by a project that diverted a portion of the river around the city. Burdened by institutional inertia, and lacking clear priorities, these three cities have wrestled with the task of identifying the appropriate flood protection criteria. In Fargo, the downtown has been abandoned. In Petra and Winnipeg, the studies continue.

Technology for water management within the urban areas has developed more slowly than practices for regional large-scale water storage and supply systems. This reflects an inappropriate imbalance of priorities. Annual investments in water infrastructure within cities, for water supply, sewage collection, treatment and disposal, and runoff control and drainage, exceed the costs for all other water facilities and systems. The urban water-management methodologies for monitoring and analysis taught in universities and practiced in cities have not kept pace with technologies for designing and managing hydroelectric power, irrigation, aqueducts, and other large-scale water systems.

With the rise in urban water demands and associated increases in the competition for resources, there should be less dependence on development of new sources. A different paradigm would favor efficiency in the use of local and distributed supplies, considering *all* waters in the urban area (including runoff, low-quality water, and wastewater) as potential sources, not nuisances. Consider the urban hydrologic and hydraulic cycles depicted schematically in Fig. 1, and visualize the institutional, technical, and engineering difficulties of implementing such an integrated system.

All components of the system must be planned, designed, and operated to provide a reliable supply, but reliability is a somewhat elusive subject, difficult to quantify and apply. Approaches and methodologies have been advanced by Shamir and Howard (1981), Wagner et al. (1988a,b), and Ostfeld and Shamir (1993, 1996) and applied in a few cases (Charles Howard and Associates, unpublished report, 1996), but they still have to find their way into common practice.

URBAN HYDRAULIC SYSTEM

Fig. 1 shows water supplies from remote and local sources. The hydraulic cycle includes water capture at remote and local sources, water conveyance, water treatment, water storage, water distribution, water collection, sewage conveyance, sewage treatment, sewage disposal, and sewage reuse.

Local sources can be the conventional ones—lake, ground water, river—as well as rainfall captured in the city. Some aspects of the urban hydraulic cycle have previously had little focus but are now becoming more important:

- Bottled water use is rising in Europe, North America, Asia—in fact throughout the world. In developed countries there is rarely a health reason for this; water delivered by the distribution network from a central source is usually as good, and sometimes of better quality, than bottled water. Moreover, water utilities almost everywhere are under stricter control than the bottled-water industry. Still, many people believe that bottled water is healthier and worth the price—which is high, many times more than the price of gasoline. The effect of using bottled water on the quantity of water required from sources is not significant, since only a small fraction of consumption is actually used for drinking. However, bottled water offers the potential for substantial new revenues for urban utilities, as demonstrated in Houston, Texas. The worldwide success of bottled water is a small chink in the paradigm of centralized

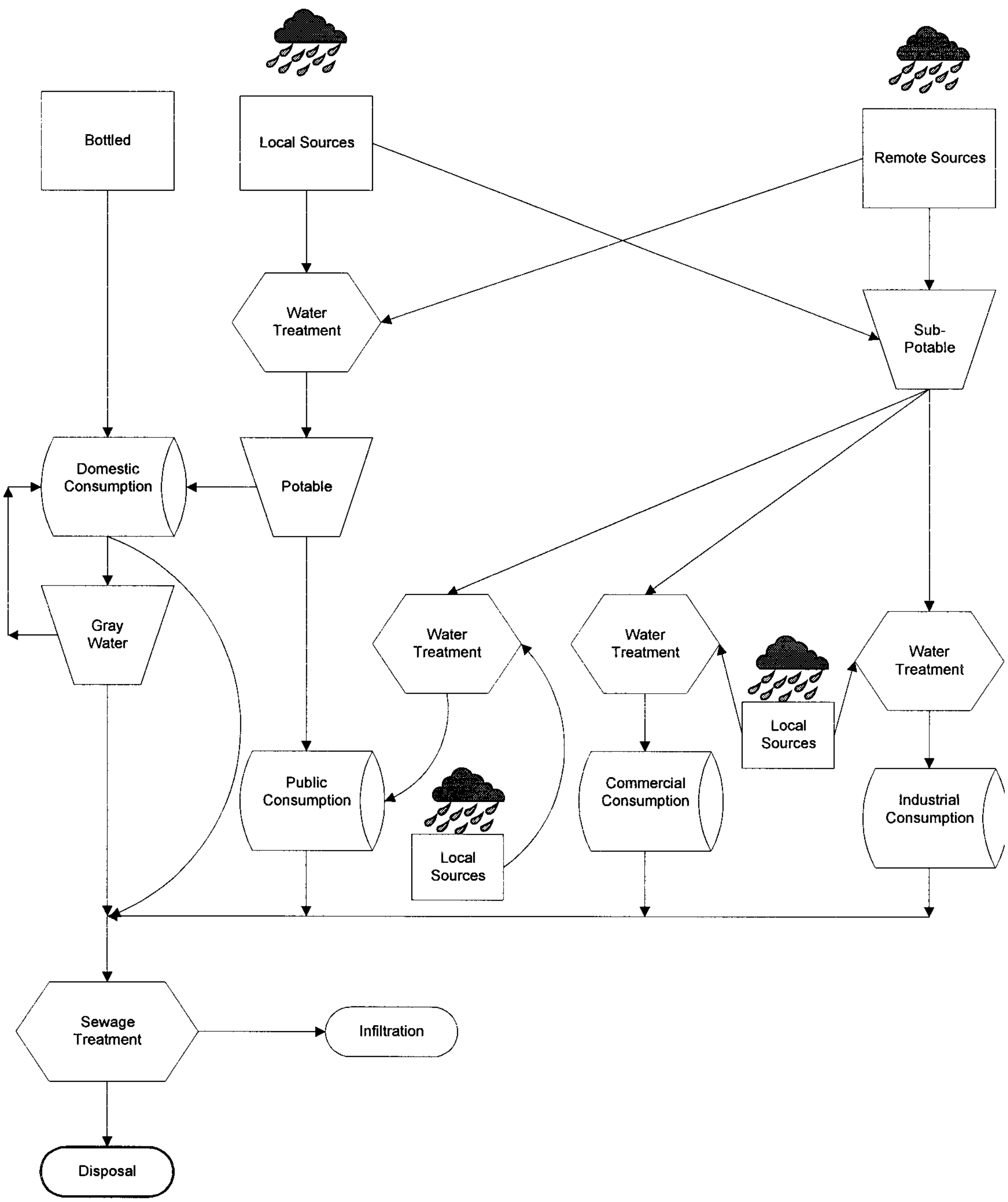

FIG. 1. Urban Hydrologic and Hydraulic Cycles Associated with Water Supplies from Remote and Local Sources

collection and distribution of urban water supplies. What will follow?

- Point-of-use treatment of water is a technically feasible option for potable water supply. With economies of scale from mass production and utility level maintenance, it is also potentially economical. In most modern cities, there is no indication that point-of-use treatment, like bottled water, is required as a health precaution, but many are convinced that it results in a superior product. There are also some dangers in using point-of-use treatment, since poor maintenance of devices will result in more harm than good. Large-scale, widespread point-of-use treatment deserves a thorough study and evaluation to identify site-specific opportunities. Too complicated, you say? The same could be said at one time for such electrical devices as the telephone, refrigerator, TV, washing machine, and computers, which are now commonplace. Is complexity the problem, or the inertia of interests vested in centralized treatment? Think again. Bottled water distribution is well suited to small independent producers. But, like telephones and electric power, the technical complexity of point-of-use treatment, supply, and maintenance is a natural service for the utility industry.

  Point-of-use treatment increases water management flexibility and opens up undeveloped sources. Point-of-use treatment will also probably result in overall cost savings, since not all the water distributed within the city needs to be treated to the highest standards. Like dual distribution systems, which already have their place, the technical, health, social, economic, institutional, and legal aspects of point-of-use treatment need to be evaluated in a holistic manner.
- Recycling and reuse of gray water in the home from the sink, shower, and bathtub is not a new idea, but it too should be fully examined in the light of modern monitoring and control systems. Approximately 40% of domestic

water use is for toilet flushing, for which gray water can be used if the pipes are properly fitted. In addition to reduced consumptive use, there are economic savings to be captured through reduced treatment costs. Agricultural and garden reuse of water is a common practice in many arid regions; urban uses are also possible with adequate attention to health hazards.

- Capturing, storing, and treating urban runoff currently are used for ground-water recharge and maintenance of in-stream flows for nature. This connects the hydraulic urban cycle to its hydrologic cycle.

URBAN HYDROLOGIC CYCLE

Urban development adds impervious surfaces, increases runoff, and decreases infiltration and ground-water recharge. Urban runoff is viewed as a nuisance, to be removed as quickly as possible, but it can be a resource. Conventional land development practices require rapid removal of the runoff, causing a loss of water for ground-water recharge. This past trend may be countered in the future by what has been termed water-sensitive urban planning (WSUP), which utilizes runoff as a potential resource, not merely as a nuisance (Carmon et al. 1997; Carmon and Shamir 1997).

Capturing and infiltrating runoff on-site reduces both the cost of drainage systems and the loading on the aquatic environment (*Water sensitive* 1989; Ferguson 1990; Herath et al. 1993; Harbor 1994; Konrad et al. 1995; Bettes 1996; *Low impact* 1997; Kronaveter et al. 2000). Rainfall harvested for use should be captured close to where it falls, before its quality becomes impaired. Use of rainfall and runoff, directly or after storage, should be evaluated jointly with the options provided by dual distribution systems and point-of-use treatment.

Capturing runoff in the ground, in detention and retention basins, reduces pollution of the receiving environment and the cost of drainage systems. This knowledge is now well established by urban storm-water management programs. But 25 years ago, only a few innovative cities allowed the use of infiltration and storage for control of urban runoff.

URBAN WATER POLITICS

The issue of water is often very low on the municipal political echelon. It lays dormant most of the time, and catches the public eye only when there is a shortage or a flood, or when water rates are raised. At the same time, water is frequently a municipal cash cow; the excess of water revenues over costs has been used to finance other programs and projects. In at least one Central American city, during the 1970s, water revenues were used to subsidize more visible bus fares. The result for the water system was an investment and maintenance backlog, and the system's performance deteriorated. Some remedy to this situation is found when municipal utilities are privatized. Cities that turn their water systems over to the private sector (in any of a variety of arrangements) include a requirement for maintaining the performance of the system over time. If the arrangement is free from politics and corruption, and structured properly, the result should be a professional service that is focused on the quality and integrity of the water supply.

Sewage treatment decisions are also not without fault. Sewage treatment upgrades for Boston, Seattle, and other coastal cities has cost hundreds of millions of dollars without assurance of significant detectable environmental benefits. Meanwhile, urban and rural point-source pollution is low on the list of priorities. Public discussion on the World Wide Web may help to improve regulatory decisions. Unnecessary expenditures will divert funds away from beneficial environmental purpose and will send negative cynical signals about the importance of science in environmental engineering and water management.

URBAN WATER TECHNOLOGIES AND CHALLENGES

Urban water systems for tomorrow's cities will see the introduction of new management policies and structures, and also innovative technologies. New technologies will come into practice quickly as the opportunities are identified by more progressive utilities. There is an urgent need to introduce a paradigm shift in education, without delay, to prepare a new generation of urban water engineers who have a different view of the issues and are not trapped in the traditional way of doing things. Several issues that future engineers must deal with are the following:

- New hydraulic hardware for efficient water use and waste reduction—see http://www.waterwiser.org—where savings of up to 30% in the domestic sector are reported by AWWA
- New materials coming into use for pipes and appurtenances
- Efficient and cost-effective high-level treatment technologies (e.g., membranes) that will be more widely used, with less emphasis on centralized control
- Several technologies that will be used for control and communication in water and sewerage systems, including smart local communications objects, distributed automatic control, and centralized decision support systems for emergencies

Demand management must be based solidly on technological, economic, regulatory, and educational means for influencing the total annual quantity used; its distribution over days, weeks, and seasons; and requirements for pressure, quality and reliability. The costs and benefits of currently accepted practices and their alternatives should be viewed broadly, not just from an economic perspective. Legal and institutional arrangements must be questioned to identify missed opportunities and hindrances to implementation of better systems for delivering water services. Long-range and sustained public involvement and education must be funded adequately to become part of every utilities standard repertoire.

Pressures to increase water imports should be reduced when appropriate by finding methods for increased use of local sources of rainfall, runoff, gray waters, and reclaimed wastewater.

Advanced water and waste treatment technologies should be continuously evaluated to identify opportunities for using distributed treatment of water and of wastewater, and the proper geographic scales at which this should be done. This includes point-of-use treatment for potable water and in-home and neighborhood treatment of sewage.

As recycling of water increases, there will be a need to develop methods that avoid accumulation of pollutants in water and soils. Use of gray water will recycle wastes and increase their ultimate concentration in the final effluent. Point-of-use treatment of water produces waste materials. Accumulation of waste materials (salt, heavy metals, nutrients) has been seen in systems, which recycle wastewater from urban areas for irrigation, especially with highly efficient irrigation technologies, such as drip, which reduce return flows and flushing. An urban materials balance must accompany an urban water balance.

Implementation of complex systems, such as dual-distribution or multiple-distribution systems, will require new technologies and a broad understanding of environmental and health implications.

Control technologies in the water industry already require a range of disciplines, including mechanical, electrical, communications, computers, control methods, and software. The challenge to plan, design, and operate urban water systems will become more difficult as more diverse systems come into practice.

The legal-institutional-economic-management structure(s) may evolve toward a self-contained, economically based, service-oriented sector removed from direct political influence.

As competition for water resources increases, there will be an increasing need for improved efficiency of water use in all demand sectors, including reduction of system losses.

Standard practice must develop methods for determining the optimal reliability, which properly balances benefits and costs of supply, and how best to achieve it.

Water-sensitive urban planning should be incorporated into urban development to minimize negative interference with the hydrological cycle and possibly improve hydrologic conditions compared with predevelopment, e.g., agriculture. Runoff should be examined for its potential as a resource, not merely a nuisance.

In addition to the grander schemes, incremental, robust, water supply, and sewage solutions should be sought aggressively as part of long-range plans to meet future needs. Utilities need to avoid becoming trapped in expensive inflexible schemes. Old rules of thumb will need to be examined. In the old East Germany, with heavy subsidies, water consumption was predicted (in 1980) to rise substantially, leveling out by the year 2020. In 1990, German reunification introduced Western water rates and per capita consumption dropped by 19% in one year.

Privatization of the water, wastewater, and drainage systems will challenge future engineers, as it becomes an increasingly attractive and practical alternative to inadequately funded public utilities.

APPENDIX. REFERENCES

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