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Distributed optimal technology networks: an integrated concept for water reuse

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Abstract

The mounting necessity for recycle and reuse of water presents global challenges to our abilities to meet ongoing needs for water suitable for human consumption. Coupled with this is the reality that current practices of treating the total water demands of communities to levels required for human consumption are not indefinitely sustainable. Viable alternative strategies that integrate more effective water recovery for potable reuse with improved means for production and delivery of higher quality water for human consumption are thus essential. Given the inherent advantages of flexibility and responsiveness associated with decentralization of complex functions and operations, the strategic dispersal of flexible advanced treatment and control technologies throughout water transport and storage networks is one logical alternative to consider. Integration of advanced technology satellite systems with cost-critical components of current water infrastructures would facilitate optimal cost-effective applications of highly sophisticated advanced technologies within the context of existing treatment and distribution/collection systems. Most importantly, it would provide markedly enhanced “personal water” quality and significant potential for energy recovery.

Keywords: Potable water; Energy recovery; Advanced technologies; Infrastructures; Strategies

1. Introduction

Water demands throughout the world currently exceed the ability of Earth’s natural hydrologic cycles to replenish adequate fresh supplies of this resource. Water must therefore be recycled and reused many times over the course of each period

between its extraction from and return to those cycles. The net effect of constantly increasing reuse of water is that distinctions between natural waters, water supplies and wastewaters from municipal, agricultural, and industrial sources are becoming increasingly blurred. The reality we

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now face with respect to a continuum of water quality was evident on the horizon more than three decades ago [1]. The specifics of the reality are more broadly evident and increasingly urgent now, however, and the earlier perspectives on the necessity for water recycle and reuse more widely accepted [1–6].

The position taken and held in this conference keynote, which is based in large measure on a recent publication by the author [7], is that the technologies and systems we develop to address multiple water recycle must incorporate highly sophisticated treatment and control technologies and be operable under policies and within infrastructures designed to facilitate their optimal use in ways compatible with urban values and social mores. The distributed optimal technology network (DOT-NET) concept described here envisions a revolutionary approach to infrastructures employed for potable water supplies. For implementation in existing urban communities, which in most cases present a more difficult problem than

providing adequate supply systems in new urban developments, DOT-NET is designed to lever in-place water treatment and distribution infrastructures. It engages in-place central treatment facilities and distribution networks in innovative ways that make it cost effective to employ the most highly advanced technologies for production of potable water of the highest possible quality. This is a particularly important feature of the concept in that the alternative of completely replacing such infrastructures would be highly disruptive and costly.

2. The role(s) of existing infrastructures

The conditions and potential functional roles of existing treatment and distribution collection infrastructures are critical considerations in any plan to upgrade existing water systems. A schematic characterization of the major components of traditional systems for providing potable water and collecting wastewaters from urban population centers is presented in Fig. 1.

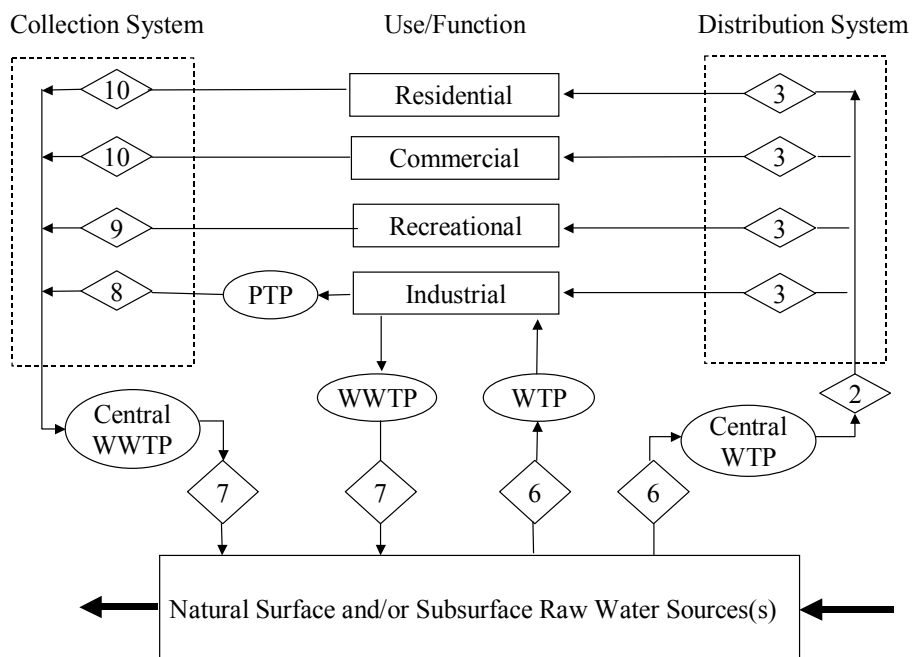


Fig. 1. Schematic representation of a traditional water infrastructure [7].

The code numbers in the diamond shaped boxes shown in Fig. 1 are defined in Table 1. They refer to arbitrary levels of water quality at different stages of production, propagation, and use within the infrastructure illustrated, and are intended here simply to suggest relative values.

Traditional strategies for public water supply and wastewater treatment and disposal in densely populated environments are inherently fixed by the huge centralized water and wastewater treatment plants and endless miles of high capacity distribution and collection networks depicted in Fig. 1. Attempts to upgrade water quality in such systems are often frustrated by the inherent inflexibility of the infrastructures involved, and by the enormous efforts and costs required to rehabilitate or rebuild those infrastructures. The distribution and collection networks are particularly problematic because they are generally buried beneath buildings, roadways, and other superstructures. The magnitude of the problem is evident in the sizes of the water production, propagation, collection, treatment and disposal systems of large urban densely populated areas. Most of these systems and facilities have been built to process many millions, and even billions, of cubic meters of water per day.

3. Technology needs, availability, and feasibility

The fact that both source-water quality and product water value are significantly impacted by increased recycle and reuse of water raises formidable challenges to our ability to ensure potable water of higher and higher quality in response to legitimate societal demands. Water quality challenges have been met successfully through research and development of more competent technologies, and there are in fact existing advanced processes capable of reducing very high levels of contaminants in source waters to the most stringent of existing use-based standards. In short, we are not now nor will we likely be in the future constrained by technology *per se*.

There is however an overriding problem with respect to providing high quality water from low quality sources cost effectively, for processes of the type cited above generally involve prohibitive costs for full-scale, stand-alone use. It is thus necessary in water supply practice to select combinations of unit operations that provide required levels of treatment at total costs that are less per unit volume of water treated than the perceived “value(s)” of the water produced. Time and space constraints here do not allow detailed discussion

Table 1
Water qualities at various stages of production, propagation, and use [7]

| Class | Use category | Quality in category | Human risk | | Ecological risk | |
|-------|---------------|---------------------|------------|---------|-----------------|---------|
| | | | Acute | Chronic | Acute | Chronic |
| 1 | Potable | Premier | N | N | N | N |
| 2 | Potable | Good | N | P | N | N |
| 3 | Potable | Marginal | P | P | N | N |
| 4 | Non-potable | Excellent | P | P | N | N |
| 5 | Non-potable | Good | P | P | N | N |
| 6 | Non-potable | Acceptable | Y | Y | N | N |
| 7 | Recoverable | Good | Y | Y | P | Y |
| 8 | Recoverable | Acceptable | Y | Y | Y | Y |
| 9 | Recoverable | Marginal | Y | Y | Y | Y |
| 10 | Waste | Poor | Y | Y | Y | Y |
| 10* | Energy source | Acceptable | N | N | N | N |

P = Potential, N = No, Y = Yes

of “true” *vis-à-vis* perceived and adopted costs and values, but that subject is in itself one of the keys to viable future water supply strategies and practices [5,6,8]. Multi-stage arrangements of processes in large central processing systems usually involve correspondingly large associated construction times, efforts, costs, and amortization periods. The implementation of such systems in timely manner to meet evolving treatment needs is extremely difficult, and once implemented they rarely can be flexible enough to respond to needs other than those for which they were specifically designed and constructed.

From the perspective of economic feasibility alone, one must conclude that it is no longer reasonable to believe we can afford to treat all of the water we use to the level of quality we desire for drinking and other personal uses; i.e., for uses that involve regular long-term exposure by ingestion and/or inhalation. Moreover, even if the treatment of all water to such high levels were somehow to become economically feasible, it would be pointless in the context of typical in-place urban water supply infrastructures (e.g., Fig. 1) to do so. In all likelihood and in most cases, such high quality water would be degraded in quality shortly after its release to and during its transport through deteriorating distribution networks between central treatment plants and users’ taps in densely populated urban environments. It may eventually become technically possible and economically feasible to upgrade massive central plants to produce water of the quality we desire for drinking and personal use. It is doubtful, however, that it will ever be technically possible and economically feasible to replace all existing distribution networks with systems having comparable hydraulic capacities and long-term abilities to maintain the integrity of that water quality.

4. Distributed optimal technology networks

The DOT-NET strategy for complete water recycle and reuse calls for bold departures from

traditional visions and charter practices of most water and wastewater institutions and industries. The concept is characterized schematically in Fig. 2, with the designations of water quality again being as defined previously in Table 1. Key elements of the proposed concept include two different types of pluralized satellite or point of use/discharge treatment systems designed for advanced water treatment (AWT) and energy extraction processes for black water treatment (EXP). The distribution and strategic placement of relatively small and highly effective treatment systems at specific locations in existing water supply and collection networks is a signature element of DOT-NET. The satellite AWT and EXP systems would be strategically located to serve the water use and waste processing needs of population clusters, such as housing subdivisions, apartment and condominium complexes, commercial districts, and industrial parks and districts. It is particularly important to note in Fig. 2 that the concept levers existing infrastructures in a manner that fundamentally enables cost-effective implementation of the most sophisticated optimal technologies; i.e., places them exactly where and when they are required for production of “personal” potable water of markedly and consistently higher quality. The satellite EXP systems for beneficial processing of segregated black water also provide for removal of this organic-rich waste from the recycle loop, and for point-of-use energy recovery (i.e., “distributed energy”).

The satellite AWT systems would process relatively low flows and would employ off-the-shelf treatment technologies of the most advanced nature (e.g. supra-selective foul-resistant membrane separations, customized polymeric adsorbents and molecular sieves, supercritical water oxidation, etc.). Technologies of this calibre would not normally be affordable for application to the processing of all water distributed in typical urban systems. These dedicated personal water treatment processes would cost-effectively eliminate all current microbial, chemical, and physical

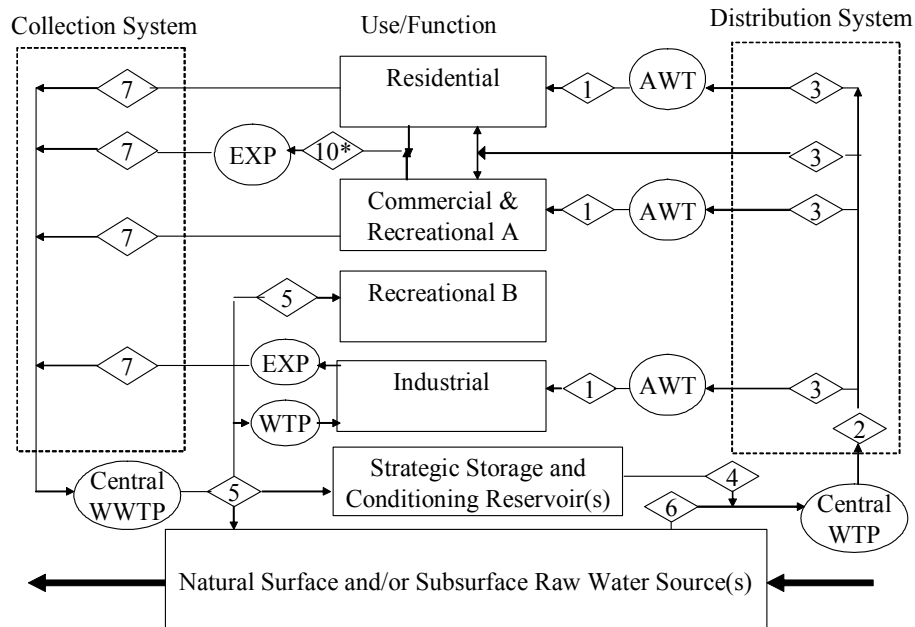


Fig. 2. Schematic representation of a DOT-NET based water infrastructure [7].

contaminants from water regularly used for human consumption and direct exposure. DOT-NET would erase concerns for the known and unknown by-products of water disinfection, for example, and alleviate fears about the broad spectrum of emerging trace contaminants appearing increasingly in urban water systems. The advanced treatment processes could be monitored regularly and controlled by micro electrical-mechanical systems, capable of wireless on-line data interpretation and real-time feedback control.

Self-contained black water treatment and energy extraction process (EXP) systems are currently not as readily available in off-the-shelf mode, but significant advances are being made every day in such applicable areas as advanced biooxidation technologies, membrane separations, and integrated bio-membrane systems. The major purpose of segregated black water treatment is to reduce the disproportionate water quality burden this material imposes on the much larger volumes of less contaminated waters collected and routed

to existing central treatment systems. Additionally, however, the way in which the black water processing units are configured in DOT-NET opens a broad spectrum of opportunities for recovery of some of the energy and nutrient value(s) of the concentrated wastes; i.e. optimal technology distributed for energy production as well. Opportunities for implementation of such cost reduction/recovery measures are lost once the resource-rich black water is dispersed in a large collection network. In reality, segregated EXP systems are in most cases likely to be less an issue of technology and resource recovery than an issue of public acceptance. Factors relating to this issue have been discussed by Lens et al. [9].

Many of the physical components of the system concept described above should lend themselves to: i) standardized and modularized design and construction; and ii) privatized vendor installation, maintenance, and operation. These features are not unlike those offered in commercially available water softener and conditioning services

today. The potential for technology innovation and commercialization of public drinking water products and services is beginning to be recognized broadly, even in developing countries (e.g., [10, 11]). This realization is evolving from compelling evidence that water is becoming a tradable commodity of significant market value, and it will continue to grow as a major factor in international industry, commerce, and policy in the years ahead.

5. Closure

It is necessary to rethink current approaches to water and wastewater collection, processing, and distribution in the densely populated urban environments of the world. Concepts that have served us well in the past must be reexamined with respect to their appropriateness now and in the future. We have markedly improved the competency of treatment technologies over the past few decades, but have done little to improve companion systems for resource and product collection, storage, and distribution. Measurable further advances in the overall management of water and wastes in urban environments will require that we raise the performance bars applied to the latter operations to those already achieved in the areas of treatment technology.

Can we afford to do this? Not unless we are creative in our thinking. Simply forging ahead with business as usual will not get us where we want to be with respect to viable and sustainable water systems. In addition to the issues and concepts discussed above, we must, from an affordability point of view, begin to think about turning some of our “cost centers” into “profit centers”. This means, among other things, reconsideration and appropriate adjustment of product values and redistribution of roles between public utilities and for-profit supply and research institutions.

We can be reasonably confident of our abilities to use current technologies more effectively and develop more effective and demand-responsive technologies as necessary for producing enough

water of sufficiently high quality to meet societal needs and demands. To do so, however, will require that new and innovative infrastructures in which such technologies can be implemented more sensibly, effectively, and affordably be devised. DOT-NET presents a promising first step in that direction.

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