THE ROLE OF WATER RECLAMATION IN WATER RESOURCES MANAGEMENT IN THE 21ST CENTURY

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ABSTRACT

In recognition of the existing and impending stress to traditional water supply, water planners must look beyond structural developments and interbasin water transfers to secure supply into the future. In this process, it is becoming evident that various issues related to water must be integrated into a whole system approach, including water supply, water use, wastewater treatment, stormwater management, and management of surrounding water environment. In bringing disparate water assets together, alternatives to traditional water supply should arise. Integrated water resources management can provide a realistic framework for examining the feasibility of water reuse. This paper evaluates how water reuse can become a strategic alternative in water resources management. The key challenges that limit water reclamation as one of the key elements in integrated water resources management scheme are discussed, including limitations with typical centralized wastewater treatment systems and public health protection, particularly the implications of trace contaminants. The key considerations to address these challenges are presented including (1) selection of appropriate treatment processes and reuse applications, (2) scientific and engineering solutions to emerging concerns, (3) consideration for cost effective and sustainable system, and (4) public acceptance. Recent water reclamation projects are presented to illustrate the response of the engineering community to the challenges of making water reclamation and reuse a real and sustainable solution to water supply system management planning.

KEYWORDS

advanced treatment, decentralized, integrated water resources management, reclaimed water, reuse, satellite, sustainable, trace contaminants

INTRODUCTION

Water supply security and water quality are at the forefront of politics in many states. Water is receiving equal attention in the international arena exemplified in the work of many inter-governmental bodies and international agreements. Partnerships and development goals have been forged to combat water scarcity and improve sanitation on a global scale. According to the Dublin Principles and Bonn Recommendations for Action, water is an economic as well as a social good that should be treated as a valuable and finite resource and should be equitably and sustainably allocated (UNESCO, 2005). These principles also mandate that owners and managers of water assets fulfill an obligation to conduct business in a socially, environmentally, and ethically acceptable manner. While multinational organizations and industries can mobilize significant financial and other resources to meet these worthwhile goals in regions of the world, the sustainable management of water on a local level can pose several challenges to municipalities and the communities they serve.

Integrated environmental management is based on the belief that environmental regions (defined by the boundaries of catchments, bioregions, or other criteria) need to be managed holistically and is a response to "much of the traditional natural resource management, which has been largely reactive, disjointed, and for narrow or limited purposes" (Margerum, 1999). Integrated water resources management (IWRM) is a subset of this concept and seeks to unite management and planning for water, wastewater and storm water management for a region – water assets for which management is normally fragmented and for which decisions are usually made independent of one another. The emergence of IWRM is in fact a logical development to deal with common stresses and impacts of inefficient water management, as shown in Table 1. In recognition of these factors management schemes must look beyond traditional water supply strategies such as interbasin water transfer and structural development. IWRM can provide a realistic framework for incorporating water reclamation and reuse into planning for future water supply. By integrating the use of reclaimed water into water management, water purveyors can achieve more cost-effective solutions for meeting short term water needs and improving long term water supply reliability.

Table 1. Common stresses on water resources and resulting impacts

Stress on Water Resources	Impact
- population growth	- increased demand for water
- development & sprawl	- increased stress on distribution systems
- inefficient water allocation	- transfer of water and wastewater out of watershed basins
- inefficient water pricing	- disincentive for water conservation
- over-allocation of groundwater	- over-pumping, subsidence and deterioration of groundwater quality

Historically, water reuse has been a single purpose solution to either water shortage (water quality, quantity, and institutional capacity) or stringent wastewater discharge requirements (adoption of total maximum daily loads and revision of state pollution discharge elimination systems). Within the integrated approach, in contrast, water reuse can play multiple roles by increasing water supply reliability, reducing the waste discharge to receiving water, and maintaining quality of drinking water sources. However, these strategies require a multiple-objective planning approach to arrive at the optimal solution.

This paper examines how water reuse can become a strategic alternative in integrated water resources management. The key challenges to water reuse are identified including technological, scientific, and institutional constraints. Solutions for successful implementation of water reuse programs are discussed using some of Metcalf & Eddy's projects.

IDENTIFYING CHALLENGES

Limitations of Conventional Approaches

Most urban areas in the United States, comprising nearly 80 percent of the total population, are served by public, centralized wastewater collection and treatment systems (U.S. EPA, 2002). In a typical centralized system, water reclamation processes are added either within or adjacent to the existing wastewater treatment plant and distribution systems are installed to carry reclaimed water to all points of use. A major drawback of this approach is that it often requires extensive distribution systems to fragmented and remote sites that are mostly at higher elevations than the wastewater plant. The cost of constructing and operating the distribution system may be prohibitive. In fact, water reuse projects often seek government funding to be cost competitive. Another limitation of centralized reclamation facilities is that many existing wastewater treatment processes are not designed and optimized for water reclamation and reuse. For example, newly developed wastewater treatment system designed for water reuse may achieve secondary effluent total suspended solids at lower than 5 mg/L, whereas many older plants are designed only to comply with the discharge requirement, 30 mg/L. The difference in the performance of secondary treatment will greatly affect the operation of tertiary treatment.

Aside from large centralized WWTPs, the solution to wastewater treatment in less urbanized areas has been onsite treatment and disposal systems such as septic tanks, wastewater stabilization ponds and leachfields. A major drawback with onsite systems is the land area requirements; many onsite systems require substantial land area. Many traditional onsite systems also suffer failures due to inappropriate siting, design or maintenance, and caused contamination of groundwater and surface water (Nelson, 2005). Recent development of membrane technologies, however, is pushing the concept of decentralized system to forefront of future wastewater treatment and reuse systems.

As centralized WWTPs approach the end of their useful design life and are faced with issues such as interbasin transfers and stringent water quality standards and as individual sewage disposal systems become obsolete in fast-growing communities localities must determine whether decentralized treatment with community or satellite treatment for a group of homes or businesses will be a more effective and sustainable wastewater treatment solution.

Public Health Protection

The purpose of all regulations pertaining to wastewater treatment is to protect both public health and the environment. These concerns increase in the context of water reuse, where the pathway of potential exposure to humans is more direct. Protection of public health in water reclamation projects achieved by (U.S. EPA, 2004):

1. reducing or eliminating concentrations of pathogenic bacteria, parasites, and enteric viruses in the reclaimed water,
2. controlling chemical constituents in reclaimed water, and/or
3. limiting public exposure (contact, inhalation, ingestion) to reclaimed water.

Pathogens and chemical constituents can be controlled using appropriate treatment technologies; however, the reliability of those systems is key to producing safe reclaimed water. Filtration and disinfection systems, added to existing secondary treatment, can reduce pathogens to acceptable levels for unrestricted irrigation and non-potable urban uses. Micro- and ultrafiltration can further reduce pathogen levels by removing suspended particles from reclaimed water. Chemical constituents in reclaimed water pose a health risk primarily in cases of long-term ingestion, as with indirect potable reuse via groundwater recharge. To reduce dissolved chemicals remaining in secondary treated effluent, reclamation processes will usually require highly advanced treatment such as nanofiltration (NF), reverse osmosis (RO), advanced oxidation (AOP) and carbon adsorption.

Public exposure to reclaimed water can be controlled through the selection and management of reuse applications. As shown in Table 2, the State of California requires different treatment levels for various water reuse applications (landscape irrigation is shown as an example) according to the likelihood of human exposure. In addition to restricting water quality and irrigation methods, many state regulations specify monitoring and setback distance requirements to ensure proper management of reclaimed water system and to minimize human exposure.

Table 2. Reclaimed water uses for landscape irrigation and irrigation methods in California[a]

	Reclaimed water conditions in which use is allowed			
Uses	Disinfected tertiary	Disinfected secondary 2.2	Disinfected secondary 23	Undisinfected secondary
Parks, playgrounds, school yards, residential yards, and golf courses associated with residences	Spray, drip or surface	Not allowed	Not allowed	Not allowed
Restricted access golf courses, cemeteries, freeway landscapes	Spray, drip or surface	Spray, drip or surface	Spray, drip or surface	Not allowed
Ornamental plants for commercial use	Spray, drip or surface	Spray, drip or surface	Spray, drip or surface	Not allowed

[a] Adapted from Metcalf & Eddy (2003).

Trace contaminants

While regulations for reuse provide standards for conventional wastewater constituents, the existence of trace concentrations of organic contaminants in reclaimed water can eclipse scientific justification of water reuse and acceptance of water reuse projects. In particular, the chemicals categorized as endocrine disrupting compounds (EDCs) are of primary concern. The main concern with these chemicals is that they may affect wildlife and human health at extremely low concentrations. EDCs can disrupt communication between a hormone and its receptor by mechanisms including: mimicking, stimulating, blocking, or destructing a message (Birkett and Lester, 2003). The actual human health effects of some of these chemicals at low concentrations are not clear to date, even though the potential for health effects is recognized through toxicological examinations (Tsuchihashi et al., 2002). The lack of scientific certainty makes risk assessment for these chemicals particularly difficult.

Figure 1 below illustrates the potential pathways for trace contaminants to enter the environment via wastewater treatment. It also highlights the role that WWTPs can have in mitigating or removing concentrations of these compounds. This raises the question about the ultimate fate of these contaminants and the potential risk to the environment.

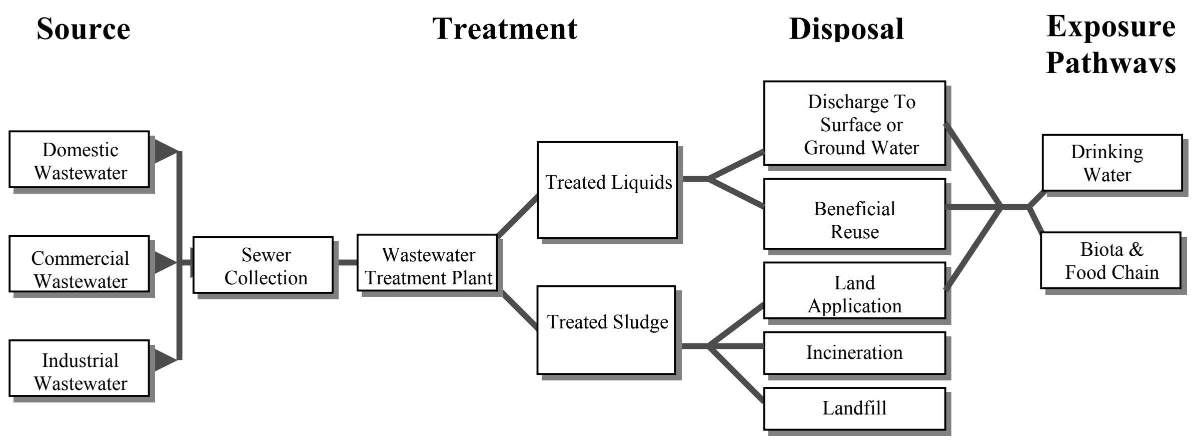

Figure 1: potential pathways for ECs to enter the environment via wastewater treatment

In the context of water reuse, planned and unplanned (*de facto*) indirect potable reuse is the primary exposure pathway. USGS scientists recently found that while drinking water treatment reduced many compounds to undetectable concentrations, several compounds were still found in the polished drinking water (Stackelberg et al., 2004). Non-potable reuse applications, such as agricultural irrigation, pose a low risk of exposure to trace contaminant; however, very limited information is available on the uptake of trace organic contaminants by food crops or on associated human health effects from consumption of crops irrigated with reclaimed water.

KEYS TO SUCCESSFUL IMPLEMENTATION OF WATER REUSE

Selecting Appropriate Treatment and Reuse Applications

In the United States, agricultural and landscape land irrigation are the primary uses of reclaimed water. For agricultural irrigation of non-food crops, secondary treatment is considered sufficient to protect public health. As human contact with reclaimed water increases, further treatment such as chemical coagulation, sedimentation, and filtration with higher level of disinfection is required as illustrated in Figure 2. It should be noted that treatment goals depend on the reuse application. For example, reclaimed water treated with RO, even though it is extremely clean, is not necessarily suitable for some of reuse applications that require only secondary or tertiary treatment. Extremely low levels of dissolved solids may result in poor water infiltration on irrigated land and desorption of contaminants from soil. Chemical addition will be necessary if the RO treated water is used for irrigation.

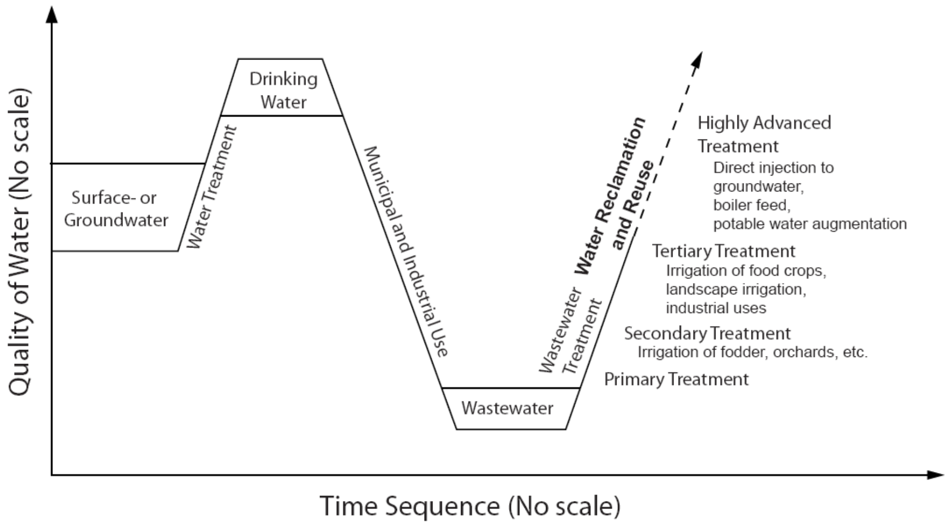

Figure 2. Quality change of water in water/wastewater systems (Adapted from Asano, 2002)

Nonpotable reuse applications, such as agricultural and landscape irrigation, industrial and commercial uses, and some urban uses, have been widely implemented and accepted in many states. Typically, highly advanced treatment is not required for nonpotable applications

Although the implications of trace contaminants weigh more heavily with indirect potable reuse projects, water supply constraints have led several water agencies to develop indirect potable reuse projects in the US, many of which have been operating for at least several years. Groundwater recharge is the most common way to augment potable water sources, either by surface spreading or direct injection. The Upper Occoquan Sewerage Authority Water Recycling Project in North Virginia augments surface water upstream of water treatment intake. These applications require much higher levels of treatment than what is required for nonpotable applications. Awareness of trace contaminants is leading to adoption of multiple barriers with highly advanced treatment processes such as RO and AOP.

Scientific Approach: Metcalf & Eddy-USGS Collaborative Research Program

Conventional biological and physical-chemical wastewater treatment processes were not designed to treat the complex and persistent trace contaminants that are now being detected. The engineering community must assess, optimize and innovate treatment technologies in response to growing concerns of the occurrence, fate and transport of trace contaminants in water systems. Many known trace contaminants and endocrine disrupting compounds are highly complex with numerous physicochemical, structural and electrostatic characteristics affecting their behavior in a WWTP.

In 2003 the USGS and Metcalf & Eddy (M&E) devised a multi-disciplinary collaborative research program to investigate concentrations of over 80 trace contaminants at four WWTPs (operating a wide range of treatment processes) and their associated water bodies utilizing analytical methods developed by USGS scientists. The WWTPs discharge to streams that contribute to the Croton or Catskill/Delaware Reservoir Systems which provide drinking water to New York City and thus potentially contribute to overall concentrations of trace contaminants in the City's water supply system. The study characterized concentrations at influent and effluent points as well as upstream and downstream of each WWTP. Samples were collected from these points multiple times each year to account for seasonal variability and to verify results. Intensive sampling was also conducted throughout the treatment train of each WWTP to assess where removals were taking place. Overall, the research indicated that concentrations in WWTP effluents and receiving streams vary in response to three main factors: size of the receiving stream (dilution factor), technology and operation of the WWTP, and chemical characteristics of the influent wastewater. The program identified potential treatment technologies and process optimization strategies that can be cost effectively implemented at existing wastewater treatment facilities to mitigate contaminant discharges into the environment and set a clear direction for future research activities. A major finding was that the majority of reductions occurred in the biological process, specifically in activated sludge treatment units.

Engineering Approach: Groundwater Recharge Demonstration Project

With advances in membrane technology, increasing numbers of water reclamation plants are utilizing membrane such as micro- or ultra-filtration. One of the advantages is that membrane filtration is extremely effective at reducing the suspended solids, especially larger particles. Membranes are widely used as either a process to enhance disinfection efficiency or as a pre-treatment for advanced treatment such as RO, carbon adsorption and an advanced oxidation process (AOP). The current state of the art for new indirect potable reuse projects is microfiltration (MF), reverse osmosis (RO), and an AOP. The evolution of disinfection away from chlorination is indicative of the engineering community responding to public health concerns with regard to disinfection byproducts such as NDMA.

After the 2002 drought the NJ Department of Environmental Protection (NJDEP) took proactive steps to safeguard the state's water supplies by soliciting proposals from more than 450 water purveyors, wastewater dischargers and agricultural users for projects that would best supplement New Jersey's water resources through reuse (NJDEP, 2005). M&E in partnership with Logan Township Municipal Utilities Authority proposed and won funding in the amount of over $4 million to implement one of the most innovative demonstration projects: indirect potable reuse via groundwater recharge. High growth rates and potential in southern NJ coupled with the need for additional potable water to meet demands underscored the importance of the project. This innovative project, based on a multiple-barrier approach, will incorporate membrane bioreactors (MBRs), RO and an AOP prior to injection of reclaimed water into the local groundwater aquifer via a series of injection wells. The advanced oxidation process was added in response to the concern for low molecular weight organics, including emerging contaminants.

Consideration for Decentralized and Satellite Systems

With rapid advances in membrane technologies and subsequent cost reductions in the last several years, membrane bioreactors (MBRs) coupled with water reuse applications have become cost effective alternatives. The MBR process is particularly attractive for decentralized and/or satellite wastewater treatment systems as it requires a small footprint while achieving effluent water quality often exceeding the levels of conventional tertiary treatment systems.

A major benefit of a decentralized treatment and reuse is the potential to reduce costs of wastewater collection and reclaimed water distribution systems. Connecting new outlying areas to centralized sanitation systems can require significant capital investments and can result in strain on the capacity, compliance and integrity of pre-existing downstream systems (Katehis and Mantovani, 2003). Decentralized systems also have the advantage of limiting the wastewater source, thereby reducing difficult-to-treat pollutants.

In Koloa, Kauai, the Kukui'ula development is incorporating a decentralized wastewater reclamation system for its new upscale community. The community will be located where no centralized sewer collection and treatment system exists. To reliably accommodate water demand and minimize the wastewater discharge, water reuse will be incorporated in their water supply system. Domestic wastewater from the entire community will be collected and treated at a state-of-the-art treatment facility within the community boundary, and reclaimed water meeting requirements for unrestricted irrigation will be used for landscape irrigation of some communal areas. Because of the restricted footprint and to address esthetic concerns, a flat panel MBR process with UV disinfection is proposed, and the entire facility will be housed in a building looking like a plantation manager's house. The unique feature of the development is that it will use three different types of water: potable water, non-potable water from reservoirs (which used to be used for sugar cane irrigation), and reclaimed water. This project is a good example of how well water reuse can be incorporated into the whole water management strategy, especially when it is incorporated into the initial design.

Satellite systems are attracting attention from water reuse engineers due to some benefits that are unique to its connection to the existing centralized wastewater system including (Katehis and Mantovani, 2003):

- alleviation of overburdened sewer systems
- facilitation of localized reuse with decreased transmission costs
- simplification of process flow by providing only liquid stream treatment via redirection of solids back to the main sewer line.

M&E provided Forsyth County, GA with full design-build-operate services for an advanced water reclamation facility in Cumming, GA. This project was initiated to facilitate the rapid development the area, 20 miles north of the Atlanta metropolitan area, was experiencing. This is an example of a hybrid sewer mining/cluster system in that wastewater was collected from new developments as well as from the sewer line of the centralized WWTP in order to meet the minimum flow requirements to justify a reclamation facility (Katehis and Mantovani, 2003). The facility incorporates treatment of 2.5 mgd wastewater with ultrafiltration membrane bioreactors and UV disinfection, a 6 million gallon reclaimed water storage tank, 11 miles of reclamation pipes and year round drip irrigation on 150 acres, one of the largest of its kind in the US. The reclaimed water is used for irrigation of parks and recreation fields and there is a goal of implementing indirect potable reuse with future discharge into the watershed for Lake Lanier, the potable water supply for Atlanta.

Cost effectiveness

The primary limiting factor in the cost effectiveness of water reuse systems is often the infrastructure costs associated with the reclaimed water distribution system. The costs of the distribution system are essentially the determining factor for the project feasibility when reclaimed water system is installed in an urban area, where centralized water and wastewater systems are already constructed and the area is fully developed. When water supply and wastewater treatment infrastructure are newly constructed in an area, the cost of installing dual distribution transmission lines from a WWTP or community treatment system back to a beneficial use will be less significant. The cost of treatment system is the next important element. The reduced cost of membrane technology is opening the opportunity for innovative water reuse applications.

System reliability

Both centralized and decentralized systems have their own benefits and drawbacks. In terms of system reliability, larger systems tend to be easier to achieve reliable treatment performance due to robustness of the treatment process itself and the variation of incoming wastewater quality and quantity. For water reuse applications with increased probability of human exposure, acceptable variability in reclaimed water quality is much narrower than discharge to receiving waters to ensure public health protection. The design of the treatment process must account for variability of incoming wastewater quality and the system redundancy for unexpected system failure. The concept of multiple barriers must be incorporated in the system design. In addition to multiple barrier treatment, reclamation projects can benefit from continuous online monitoring.

Public perception and acceptance

Public acceptance has been one of the most important issues for successful implementation of water reuse projects. As shown in Table 3, there is no doubt that public is concerned about both water supply and the environmental effects of pollutants in water. When it comes to water reuse, misunderstandings often exist that the public is being forced to drink treated wastewater. With increasing concerns about trace contaminants, even non-potable water reuse applications, which have been demonstrated to be safe, are sometimes denied because of public health concerns.

Key considerations for gaining public acceptance include:

- Involve stakeholders in the early stage of planning
- Evaluate the value of treated wastewater effluent as an alternative water source
- For the values of reliable water supply and environmental protection, use water reuse as an asset for the community rather than impose its use on an unwilling public
- Consider non-potable application as primary option
- Consider indirect potable reuse to be the last resort
- Address concerns over potential effects of trace contaminants in reclaimed water and minimize the potential risk to public health

Table 3. Public concerns over environmental issues

Issues	concerned public
Pollution of drinking water	64%
Pollution of rivers, lakes, and reservoirs	58%
Contamination of soil and water by toxic waste	58%
Contamination of soil and water by radioactivity from nuclear facilities	49%
Air pollution	48%
The loss of natural habitat for wildlife	48%
Damage to earth's ozone layer	47%
The loss of tropical rain forests	44%
Ocean and beach pollution	43%
Extinction of plant and animal species	43%
Urban sprawl and loss of open spaces	35%
The "greenhouse effect" or global warming	33%
Acid rain	28%

Source Copyright 2001 - The Gallup Organization

IS WATER REUSE PART OF AN ENVIRONMENTALLY RESPONSIBLE PATH?

Even though there seems to be no universal definition, the term "sustainability" is becoming a key word for any kind of development and management, including water management. Water reuse is often considered as a solution for the future of water resource management without in-depth analysis of the projects. In current engineering practice, sustainability of water reuse projects is judged primarily by economic feasibility. With increasing environmental concerns and the more holistic approach of integrated water resources management, however, various factors affecting the sustainability of water reuse projects must be evaluated.

Unplanned vs. Planned Indirect Potable Reuse

Unplanned indirect potable reuse occurs whenever a water supply is withdrawn for potable purposes from a natural surface or groundwater source that is fed in part by effluent discharged from a wastewater treatment plant. While planned indirect potable reuse projects are subject to intense scrutiny and research, unplanned indirect potable reuse occurs with little or no control.

This is the case in New York whereby the state has invested significant funding to upgrade wastewater treatment infrastructure in sensitive and vital watersheds. All WWTPs located in the Catskill/Delaware Watershed had to be upgraded to include phosphorus removal, nitrogen reduction, disinfection, microfiltration, and sand filtration. In addition to efforts to improve effluent quality in northern parts of the state to protect vital watersheds, New York City has also embarked on an ambitious nitrogen removal program to reduce nutrient discharges to the Long Island Sound, a sensitive estuarine water body. These significant investments in effluent water quality might retrieve additional benefits, including cost recovery, if the highly treated water was reclaimed for beneficial reuse under an integrated water resources management plan. There are only a few reuse projects in the state, mostly reclaiming water for golf course irrigation, and there are no guidelines or regulations for reuse in NY. Currently, both the Senate and the House of the New York Assembly are advancing bills to add a new Water Efficiency and Reuse section to the State's Environmental Conservation law to promote the reuse of reclaimed wastewater for nonpotable uses. In addition to improved effluent quality in centralized WWTPs there are many small towns in the watershed regions that have historically depended on septic systems for their wastewater treatment and are eligible either for new sewage treatment infrastructure, community wastewater systems. In these towns beneficial reuse would offset discharge of effluent to sensitive watershed protection areas.

Long-Term Effects of Salts

The effect of prolonged application of reclaimed water must be assessed for a long-term sustainability of water reuse. Reclaimed water is suited for irrigation because nutrients in reclaimed water (without nutrient removal) can reduce the need for chemical fertilizers. In addition, reclaimed water supply provides farmers in arid regions with much-needed water security. Since salts are not removed by water reclamation processes for irrigation purposes, there is concern that salts in reclaimed water will accumulate in irrigated soil. Accumulated salts put stress on crops and, unless removed through a drainage system, may leach to underlying groundwater. For example, a typical irrigation rate for a golf course with about 100 acre of irrigated area in California is about 90 million gallon per year (276 acre-foot per year). If the average dissolved solids level is 1000 mg/L, about 340 tons of salts will be added to the golf course every year. Salt accumulation may not be an issue in most water rich regions as rain water will leach out excess salts from the root zone without significantly affecting the groundwater quality underneath. In arid regions, however, appropriate management of salt by leaching and drainage is essential to ensure long-term sustainability of irrigated land.

CONCLUSIONS

Due to water quality and supply constraints recognition of the need to bring disparate water assets together in many regions is growing. The main challenge of a holistic approach to water resources management will be integrating decision making and planning for water, wastewater, and stormwater to secure reliable water and sustainable water supply in the short and long term. Several papers now address basic frameworks for IWRM yet there is a general consensus that priorities are localized, thus water managers must incorporate the rhetoric of IWRM into the reality of localized water needs and conditions (Rahaman and Varis, 2005 and Margerum, 1995). IWRM can result in adoption of innovative strategies that allow water supply and treatment needs to be met in a more cost-effective and sustainable way. In the absence of an integrated framework some alternatives, particularly water reuse projects, might be not be considered due to perceived infrastructure, water quality and public health constraints.

Historically wastewater has been collected and treated to a centralized wastewater treatment facility that discharges effluent to an adjacent water body. While there is an opportunity to reclaim water from these facilities several factors limit reuse potential including costs associated with transmission to reuse sites and necessary retrofits as well as the risk of effluent toxicity from mixed wastewater sources. Decentralized wastewater treatment, with either satellite of cluster systems, allows for more cost-effective flexible treatment configurations with innovative technologies to reclaim water. To ensure public health protection, design of multiple treatment barriers must become the foundation of protection of public health from known and unknown health risks. Since trace contaminants are ubiquitous in everyday life, source control will prove extremely difficult. Thus, the scientific community must direct attention to treating these contaminants at the WWTP, prior to discharge to water bodies where aquatic organisms will be exposed to potentially harmful concentrations and where persistent contaminants may be incorporated into drinking water sources. Technologies exist that provide a high level of treatment for known contaminants and as new contaminants in reclaimed water, especially endocrine disruptors, and associated health implications are identified, further research into the removal efficiency of treatment technologies will be needed.

There are few areas on the globe that will not have to grapple with what the World Bank refers to as "the grim arithmetic of water" in coming years (Montaigne, 2002). While water reuse is just one element of water management, it can serve the important purpose of offsetting demand for potable water by allowing for use of water that has already been extracted, thus closing the loop between water supply and disposal, while allowing for continued economic viability and social well-being. By working to overcome the challenges outlined in this paper, water reuse will play an increasing role in water resources management as part of a sustainable water future.

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