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A Preliminary Study of Reclaimed Water Infrastructure Systems

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Abstract

Traditionally, fresh water has been considered a human right and its consumption went unregulated, thus some regions have nearly exhausted this natural resource. As a result, governments around the world have begun to increasingly regulate the allowable consumptive use of its freshwater resources. Meanwhile, reclaimed water systems have been built more and more as fresh water supplies have been placed under increased pressure as a result of growing human populations and environmental pressures. This has forced the utility infrastructure owners/operators to limit their consumption through conservation and use of reclaimed water. This research will attempt to document why reclaimed water infrastructure systems in use today, identify the systems' benefits to the communities, and develop a list of challenges of the construction of the systems.

Keywords

Construction, Infrastructure Systems, Potable Water, Reclaimed Water

1. Introduction

1.1. Background

As human habitation has increased, tremendous pressure has been placed on the quantity and quality of potable water available to sustain not only the growing human population, but shrinking natural environments on which we depend. To mitigate this trend and expand the amount of available potable water, utility systems have been building grey water piping systems which decrease the demand for virgin water. Recycled water is now used for a wide variety of purposes in some regions, such as landscape irrigation, agricultural irrigation, cooling, fire control, composting, toilet flushing, and environmental enhancement and construction purposes in Maui, Hawaii U.S.

Middle-East and North Africa (MENA) countries are facing the most severe water shortage problems in the world, with nearly 5% of the world population and only 1% of all renewable freshwater resources in the region. Water resources are being changed as a result of climate changes, population increases, economic considerations and environmental considerations (Droogers et al., 2012). As the most water-scarce area in the world, MENA region's population growth and economic development with associated irrigation for crops and landscaping are becoming more critical than the effect of climate change with respect to water shortages. As countries within the region continue to grow their populations, while water availability is constrained, it is estimated that by 2030 nearly 58% of the water in the MENA region will be used for food production (Droogers et al., 2012). In order for these countries to continue to sustain their human population and agricultural resource demands they will need to develop alternative methods to conserve water.

In areas of the world where rapid population growth and limited fresh water resources are present reclaimed water systems can have an immense effect on the available water resources available for use. Additionally the strain of climate change will force countries or regions to develop potable water from non-traditional sources such as desalination, water recycling and enhanced water conservation methods. As rapid continuous population growth occurs fresh water resources are being contaminated at an alarming rate (Pasqualino et al., 2010). To combat freshwater contamination and ensure the availability of potable water to growing populations Pasqualino recommends Government's promote reusing wastewater under safe conditions as much as is possible.

In order to realize the full potential of wastewater reuse in society, a study of residential use of water will be required. A major hurdle for this goal to be realized is combating public perceptions and health safety concerns. Public attitudes to utilizing in-house reclaimed water depending on different variables such as system design, system scale, system context and water conservation behavior (Jeffery, 2002). If a typical residential household utilized gray water for toilet flushing and landscape irrigation they could save approximately 93,000 gallons of freshwater per household per year, which would account for nearly 35% annual water savings (Alkhatib & Edgerly, 2006). If all households were required to utilize reuse water in this manner, the limited freshwater resources available would be extended to reduce the future challenges faced from population growth, climate change and dwindling freshwater resources. Figure 1 depicts how water is used in a typical residential dwelling in the U.S. Leaks make up nearly 14% of water use in a typical home; the reduction or elimination of leaks is a low hanging fruit that could be exploited through more proactive meter monitoring. Meters are the best source to warn homeowners whether or not they have a leak in their piping systems. Through education of the public regarding this issue a large amount of water could be saved.

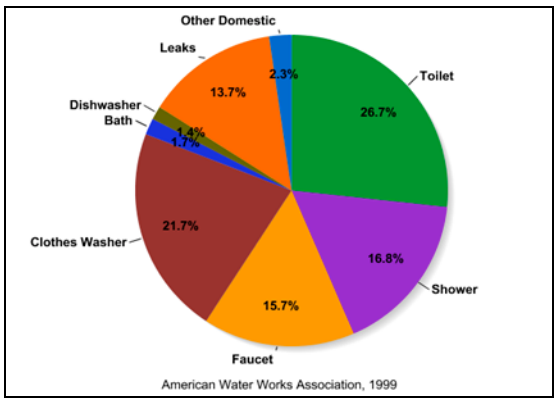

Figure 1: Typical household water use distribution in the U.S

1.2. Water re-use system infrastructure planning

The planning process can be extremely challenging for a community that is working towards the development of a new reclaimed water infrastructure system. In the United States, a comprehensive listing of reclaimed water system project has been developed to provide sources of statistics and knowledge to be used to promote the expansion of utilizing water reuse around the country (Bryck et al., 2008). This reference provides statistical data regarding reuse infrastructure systems in use in the U.S. and serves as a lessons learned database for communities beginning the process of developing their own reclaimed water systems. Time and effort spent in the planning phase has proven to reduce the challenges faced during construction of reclaimed water infrastructure systems. In particular, time spent with public coordination, researching existing utility systems, project coordination and proper coordination with permitting agencies will reduce the difficulties experienced when the construction actually commences (Turney, 2007). In order to combat public perception challenges faced with the introduction of reclaimed water systems to a community, the City of Scottsdale, Arizona hired a professional public relations firm. The public involvement and coordination throughout the process proved to be just as important to the success of the project as any of the engineering or technical challenges faced (Mansfield & Nunez, 2004).

The primary detractor for developers to incorporate reclaimed water systems is the capital costs incurred as a result of having to construct additional piping distribution systems. The capital cost of the construction of reclaimed water systems is the greatest impediment to implementation while schedule is determined to not be a factor (Varghese, 2007). From the results of Varghese's research, it can be interpreted that if water scarcity is not an immediate danger to a community then the implementation of reclaimed water systems will not be incorporated into the project. As a result communities delay incorporating reclaimed water systems and are forced to pay higher costs to retrofit these systems in the future when they are confronted by water scarcity issues. In order to reduce these costs it is imperative that reclaimed water distribution system routes are thoroughly planned with large volume users in mind as was the case with the Tucson Water System (Tucson, AZ) which utilized "anchor" golf courses to determine their distribution system routes and then sold additional taps along the routes to local small volume customers. To further optimize capital costs associated with the development of a reclaimed water system there is a benefit to constructing the water, sewer and reclaimed water systems simultaneously. In Melbourne, Australia; this theory was evaluated as part of a planned residential community consisting of 44,000 new homes to be constructed. The result was that the initial investment was still greater than not constructing them, however since all three systems were planned the developers were able to optimize each individual system and reduce construction costs (Dandy et al., 2009).

Additional considerations for planners of large scale reclaimed water systems may be to develop strategic partnerships with adjacent communities to provide uses for reclaimed water resources. In Tampa Florida, the feasibility of providing reclaimed water was dependent on finding alternative uses for reclaimed water. The primary users of reuse water in Florida has been landscape irrigation, however during the wet season, there was not a robust market for water to provide irrigation. In order to solve this dilemma an innovative partnership to maximize the beneficial use of reclaimed water in the Tampa Bay area was developed by adjacent communities to utilize reclaimed water for additional industrial and residential customers thus allowing additional freshwater to be added to the potable water supply. The overall concept was to augment river flows with reclaimed water in order to maintain minimum required stream flow volumes, which resulted in a system that was beneficial during the wet and dry seasons (Metcalf & Eddy, 2003).

The ultimate goal of reclaimed water infrastructure planning is to provide a reliable supplementary source of water to meet the demands of the community where it is planned to be developed. In the past, particularly in developing countries where confined wastewater treatment facilities are non-existent, wastewater has inadvertently provided an additional source of water and fertilizer (Asano, 2001). Utilizing untreated sanitary sewer is an unsafe practice to the health of the community and should be stopped. It is through the planning process that communities can determine if a reclaimed water system is feasible for development. Areas of concern that need to be evaluated are; economic considerations, potential uses for reclaimed water resources and local environmental requirements. It is through this type of integrated water resources planning that communities can determine whether or not the development of a reclaimed water system can respond to the short term water resource demands as well as increase the reliability of the community's long term water supplies (Asano, 2001).

The aim of this research is to investigate the current reclaimed water reuse systems in use today. In particular the research is focused on the reasons why communities develop reclaimed water systems, their benefits, and the challenges faced during the construction of the systems.

2. Literature Review

An extensive literature review of recent articles, journals, conference proceedings and web content was completed. The main topics explored in the literature review were; 1) primary reasons why communities develop reclaimed water, 2) benefits from the use of reclaimed water, and 3) challenges experienced during construction of reclaimed water systems.

2.1. Why reclaimed water systems?

There is very limited research available which analyzes the reasons why communities have developed reclaimed water infrastructure systems. It is believed that communities have developed plans to incorporate reclaimed water systems for the future into their developments in the hopes of not having to retrofit their communities as a result of population growth or to keep pace with economic development. This pre-planning will be of particular importance in fast developing countries around the world such as China and India. It is also believed the four main reasons for communities to develop reclaimed infrastructures are:

- *Environmental Considerations.* In Japan utilization of reclaimed water began in 1951. A paper manufacturing plant began to utilize reclaimed water industrial uses. In this instance the primary reasons for using reclaimed water were that the quality of water from a local river was not clean enough to utilize and groundwater was not economical as a result of excessive use, which caused salt water intrusion (Asano et al, 1996).
- *Population Growth.* In Florida population growth has exploded from the first census in 1830 of 34,730 to the latest census in 2010 of 18,801,301 people. This exponential growth has led to many logistical challenges for the communities of Florida. In regards to water resources, freshwater resources have been strained to meet the demands of this population growth. Since 1950 freshwater withdrawal has increased from 0.9×10^9 to 7.3×10^9 in 1996. In that same period of time the population of Florida grew from 2,771,305 to approximately 15 million (U.S. Census). As a result, regulatory agencies in Florida have promoted the development of reclaimed water resources and water conservation through regulations (Young & York, 1996).
- *Mandated by Environmental Regulations or Agreements.* Denver, Colorado began construction of its reclaimed water system as a result of the Blue River Decree which allowed the utility to extract water from the western slope of the continental divide but also required Denver to maximize its use of reclaimed water resources (Turney, 2007). The primary use of the reclaimed water system was for recreational irrigation of parks and golf courses.
- *Economic Development/Considerations.* The long-term economic vitality of the greater Tucson, Arizona area is defined by its destination resort golf industry. Historically irrigation for golf courses was taken from groundwater sources. After many years of exclusively using the aquifer for all water resources, the aquifer was in a depletion state. Local laws and regulations were enacted to curb groundwater use. In order for the golf course industry to continue to prosper the reclaimed water system was developed (Thomure & Kmiec, 2012). Major golf course users referred as “Anchors”, are the primary reason that the reclaimed water system is extended. Once the anchors agree to use a specified amount of reuse water for irrigation, the system operators develop the most advantageous routing for the piping extension, which provides the most secondary users with ease of connections. The planning that goes into the routing is a very important lesson for any community that is thinking about developing or expanding their reclaimed water system.

2.2. Benefits from the use of reclaimed water

Israel is a country that has very limited freshwater resources. In 2012 Israel reused more than 73% of its total domestic sewage production while for comparison, the United States only reuses 2.5% (Mission 2012: Clean Water). One of the major benefits realized as a result of using reclaimed water is its reliability. Reuse water production is relatively constant during the year since it is produced from municipal sewage. The fact that this resource is extremely reliable is credited with the increased investment in agricultural since the reuse water is widely used for irrigation in this industry (Friedler, 2001).

Capital improvement to the potable water systems can be delayed due to less pressure being exerted on those systems as a direct result of increased use of the reclaimed water systems. This is one of the added benefits experienced by Tucson, Arizona as its reclaimed water system has been expanded (Thomure & Kmiec, 2012).

Another benefit of use and development of reclaimed water systems is that LEED credits may be achieved (Varghese, 2007). LEED certified facilities are becoming more popular due to their sustainable nature and lower operation and maintenance costs. LEED rated facilities are also a marketing tool for developers who are trying to lease space in their facilities.

For communities where salt water is an available resource, desalination has been exploited to increase the amount of water available for use. Due to the high energy costs associated with the desalination process, the use of reclaimed water is always preferred to using desalinated water for non-potable applications (Pasqualino et al., 2010). As a result, it is highly recommended that reclaimed water resources be exhausted before desalination is considered as a viable option.

2.3. Challenges faced during construction of reclaimed water systems

The construction of Denver, Colorado's recycled water distribution system which consisted of over 80,000 linear feet of distribution piping at a cost of over $40 million faced many challenges. The primary challenge faced by the contractors during construction was the installation of the system amongst the already built environment. For example, the new large diameter pipelines (24"-54" in diameter) were to be installed in relatively older and densely populated areas of the city (Turney, 2007). Relocation of hundreds of existing utility infrastructure systems had to be completed which resulted in adding considerable cost and extending the time to construct the project. This example highlights the importance of infrastructure planning in developing areas and installation of reclaimed water systems as communities are being developed rather than retrofitting.

Initial capital construction costs are a huge challenge faced by communities working to develop reclaimed water systems (Varghese, 2007). The primary expense related to development of a reclaimed water system is the initial construction of the storage and distribution system. In order to combat this challenge Dunedin, Florida has funded it reclaimed water capital construction costs through the use of a city bond, one cent sales tax, state matching funds and tapping fees for residential customers (Rembold, et al., 2007). Other communities such as Tucson and Scottsdale, Arizona have financed their capital costs by selling water rights to large volume users, primarily golf courses.

The lack of applicable plumbing codes which address the use of reclaimed water systems was a drawback for some developers which prevented them from constructing reclaimed water systems in their facilities (Varghese, 2007). As a result of this some of the developers sought variances from the regulatory agencies while other abandoned the reclaimed water systems in total. As reclaimed water systems, particularly for residential applications are expanded building codes will have to be updated to protect the public interest.

3. Methodology and Results

3.1. Research data collection

The primary objectives of this research is to identify the reasons why communities have chosen to develop their reclaimed water resources, list the primary challenges faced during construction of the reclaimed water systems and list the benefits that these communities have realized as a result. Besides conducting a thorough literature review, the authors have also used a survey to collect qualitative data. This survey consisted of twenty-one questions related to the respondent's role, description of the reclaimed water system, challenges faced, benefits, uses and future developments planned. The survey was sent to owner operators of 12 selected large scale reclaimed water systems within the United States through e-mail in February and March 2013. These 12 owner operators were Maui Hawaii, Palm Beach County Florida, Hurlburt Field Florida, Fort Walton Beach Florida, Denver Colorado, Scottsdale Arizona, Tampa Florida, Los Angeles California, Tucson Arizona, Tampa Bay Florida, Austin Texas and San Francisco California. Only two locations completed the questionnaire; Maui Hawaii and Hurlburt Field Florida. Palm Beach County Florida and Los Angeles California responded to the questionnaire by providing documents which contained most of the information requested in the questionnaires.

3.2. Results and Analysis

Responses to the questions posed to the owner operators of the reclaimed water infrastructure systems are summarized. In addition to the responses received the research includes data retrieved from the literature reviews conducted. An analysis of each response is provided below the table for each question. Due to the page limit of this paper, the authors only presents the results of few selected questions below.

Q2 - Provide a brief description of the reclaimed water system in your community?

Respondent Location	Responses
Maui, Hawaii U.S.	R-1 (tertiary) recycled water is produced at regional wastewater reclamation facilities, stored in an in-plant reservoir, pumped to an elevated storage tank to develop pressure. The recycled water flows back through the main pipe line to smaller diameter transmission pipe lines and then through service laterals and water meters to each commercial property. (Parabicoli, 2013).
Palm Beach County, Florida U.S	Regional reclaimed water facility capable of providing 27 million gallons per day of reclaimed water and an 18 mile pipeline to connect the waste water treatment plant to the power generating plant. (McGrew and Tobon, 2012).
Hurlburt Field (Air Force Base), Florida U.S.	The system when complete will feed water to 16 different sites on base to be used for commercial/industrial washing/rinsing, irrigation, fire training and cooling tower make-up. (Tuominen, 2013).
Los Angeles, California, U.S.	The Sanitation Districts of Los Angeles County (Sanitation Districts) operate 11wastewater treatment facilities, 10 of which are classified as water reclamation plants (WRPs). These facilities serve approximately five million people in 78 cities and unincorporated areas within Los Angeles County. 258 miles of Reclaimed water distribution piping. (Hartling, 2013).
Scottsdale, Arizona, U.S. (Mansfield and Nunez document)	A 24 Million Gallon Per Day Water and Wastewater Treatment Facility and associated reclaimed piping distribution system throughout the City. (Mansfield and Nunez, 2004).
Denver, Colorado, U.S.	91,000 linear feet of large diameter reclaimed water distribution piping. (Turney, 2007).
Tucson, Arizona U.S.	Reclaimed water system with over 800 customers; piping distribution system that delivers approximately 14,000 acre-feet per year. (Thomure and Kmiec).
Austin, Texas, U.S.	Retrofit construction project to install reclaimed water piping system. (Stilwell et al., 2011).
Dunedin, Florida, U.S.	Sixty-six miles of pipelines and four elevated storage tanks which serve 2900 residential customers, 2 golf courses, 56 parks and playgrounds, three schools, two cooling towers and ninety-five commercial users. (Rembold et al., 2007).

The reclaimed water systems evaluated varied in size depending on the reason they were constructed and the age of the systems. The water systems who are the most stressed, such as Dunedin Florida, also require use of reclaimed water for landscape irrigation if connection to the system is available. The fact that they require use has allowed them to nearly saturate the market of use rate however the system is considerably smaller than a system such as Los Angeles.

Q4 - Why was the use of reclaimed water begun in your community?

All of the communities analyzed, with the exception of University of Texas at Austin, had begun to exploit their reclaimed water resources as a result of environmental requirements/considerations (see Figure 2 below). The University of Texas at Austin’s primary reason for developing their reclaimed water system was to reduce the amount of money they spend on purchasing potable water. Los Angeles had begun to reuse its wastewater to address environmental considerations due to saltwater intrusion and environmental regulations however they also saw a financial benefit to selling off their reclaimed water resources and delaying investments in new potable water system infrastructure.

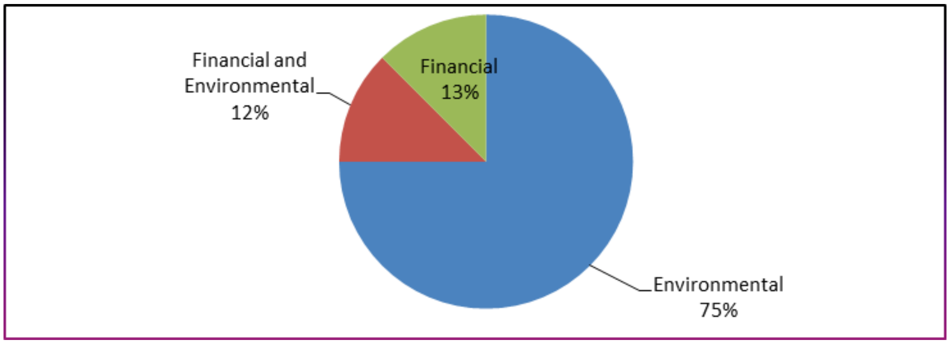

Figure 2: Reasons for communities to develop reclaimed water systems.

Q5 - What were the primary challenges faced by your organization in the construction of the reclaimed water infrastructure project?

The primary challenges faced by the communities in development of their reclaimed water infrastructure systems are; funding, avoiding existing utility systems during construction and permitting. Figure 3 provides a graphical description of challenges. All of the communities analyzed faced multiple challenges.

Due to the large capital costs of construction it is imperative that communities develop long term funding sources. The systems tend to have a typical lifespan of fifty years or more, so there is a long term to finance the construction, if required. In communities such as Tucson Arizona and Palm Beach County Florida where there are large volume commercial users who require large amounts of water have found that it is cost effective for them to fund these projects in return for a stable source of inexpensive reclaimed water over the long term. Communities who have similar opportunities for investment should exploit those resources to the fullest. Once the backbone of the system and distribution piping is in place there are many more users who can be added to the system to generate additional revenue for operation and maintenance.

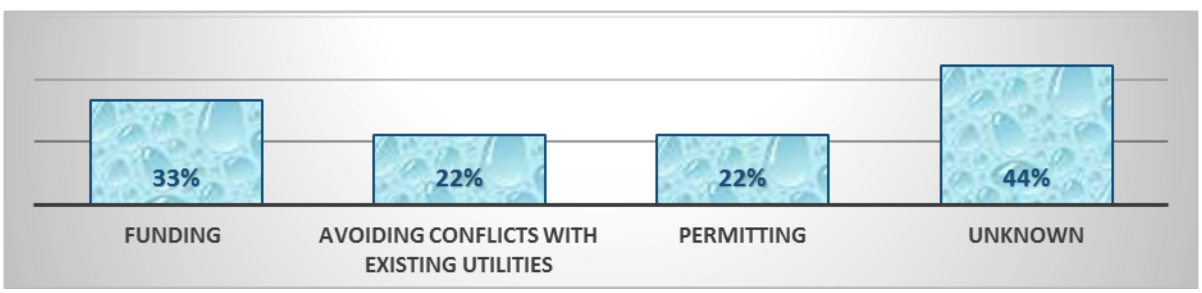

Figure 3: Challenges faced by the communities in development of their reclaimed water infrastructure systems.

Proper record keeping and detailed design procedures can reduce the inevitable conflicts with existing utility systems during construction of the new reclaimed water systems. The accuracy of as-built documentation of existing underground utility systems is an important asset when determining where to route the new reclaimed water piping system. Once the route is determined, it is imperative that the designers physically locate all existing utility systems by excavation to identify their exact location and type. These pre-planning activities can reduce or possibly eliminate the number of existing utility conflicts encountered during construction. This will allow the construction to remain on schedule and without significant cost increases for differing site conditions.

As reclaimed water systems expand to communities around the world the building codes will evolve to cover their construction requirements. As reclaimed water is used more extensively additional environmental regulation and building code attention will be provided. These improvements will allow for reduced complications with permitting the construction of these systems.

Q7 - What have been the primary benefits of utilizing reclaimed water?

The primary benefits realized by the communities analyzed from the development of their reclaimed water systems are: met environmental regulations, reduce operational costs of existing water and sewer systems, increased economic development and provided a dependable low cost water source (see Figure 4).

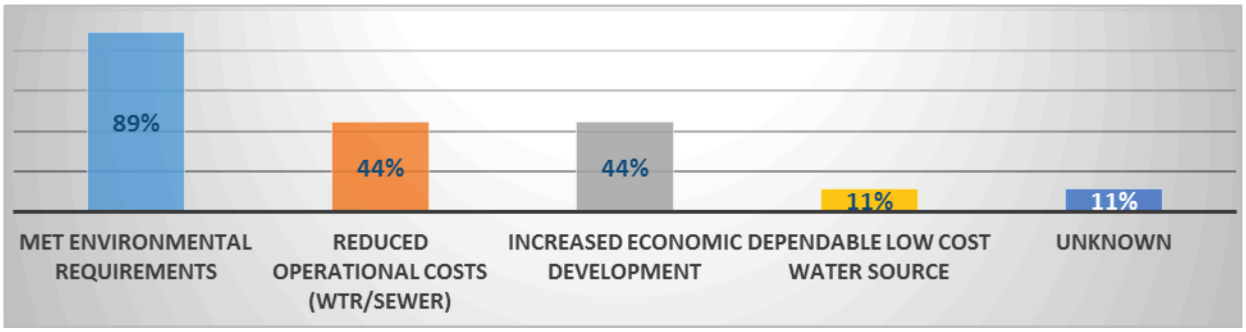

Figure 4: Primary benefits of reclaimed water infrastructure systems realized by their communities.

4. Conclusions

Traditionally, fresh water has been considered a human right and its consumption went unregulated, thus some regions have nearly exhausted this natural resource. As a result, governments around the world have begun to increasingly regulate the allowable consumptive use of its freshwater resources. Meanwhile, reclaimed water systems have been built more and more as fresh water supplies have been placed under increased pressure as a result of growing human populations and environmental pressures. This has forced the utility infrastructure owners/operators to limit their consumption through conservation and use of reclaimed water. This research recognized that the main reasons why reclaimed water infrastructure systems developed by communities are financial considerations, environmental considerations, pressure of population growth, and mandated by local environmental regulations or agreements. This research identified the primary benefits of the reclaim water systems to the communities. These benefits are: meeting the environmental requirements, relatively low operational and maintenance cost, improving economic development and its reliability. This study also unfolded the major challenges of constructing reclaim water systems, including high initial construction costs, retrofitting reclaimed water systems amongst other buried utilities, and the lack of applicable plumbing codes which specifically address the reclaimed water systems.

As climate change continues communities who have abundant water resources will be forced to develop alternative water resources at higher costs and with more challenges encountered during construction. The days of unlimited water resources being taken for granted are over for most communities. The research presented here makes the case for protecting the existing freshwater resources through promoting reclaimed water systems. Communities will have to exploit their reclaimed water resources to protect the environment and their citizens from future shortages of freshwater. The authors recommend that in the future reclaimed water systems should be developed simultaneously with water and sewer systems as a standard practice.

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