Trends in dual water systems

Peter D. Rogers and Neil S. Grigg

ABSTRACT

Concerns about aging infrastructure, pressure on water supplies, and increasingly stringent wastewater discharge regulations have led water providers to consider new and innovative approaches. One such approach involves the distribution of reclaimed water through a dual distribution system in which the piping is separated into two separate and independent networks. One network is used exclusively for potable water, the other for non-potable water. This paper summarizes the results of a recently completed study sponsored by the Water Research Foundation in which a retrospective assessment of the performance of existing dual water systems was performed. Criteria for the performance assessment were established through an extensive literature review, the development of 37 case studies, site visits, feedback from workshop participants, and the creation of a classification framework that enables comparisons among similar dual systems. The study concluded that the primary motivators in using dual systems are to extend water supplies and provide more options for wastewater management. While dual systems can provide benefits such as extending the lives of existing potable water systems and deducing risk from drought, there are many issues such as storage for non-potable supplies, rate-setting, and true costs accounting that remain to be resolved.

Key words | dual systems, reclaimed water, water management

Peter D. Rogers (corresponding author)
Department of Civil Engineering and Construction Management,
Georgia Southern University,
P.O. Box 8047,
Statesboro,
GA 30460-8047,
USA
E-mail: *progers@georgiasouthern.edu*

Neil S. Grigg
Department of Civil and Environmental Engineering,
Colorado State University,
B207 Engineering Building,
Fort Collins,
CO 80523,
USA

INTRODUCTION

Background

The aging condition of the nation's water infrastructure, findings from a 2006 National Research Council report linking drinking water safety and the physical, hydraulic, and water quality integrity of distribution systems, and a 2001 study by Craun and Calderon (Craun & Calderon 2001) addressing outbreaks caused by distribution systems, indicate the need to pay more attention to the quality of water in distribution systems. As a result of these concerns, the US Environmental Protection Agency (2007) developed a research plan that focused on improving distribution water quality at the same time that infrastructure and financing issues are addressed. It identified the need for research projects to probe the performance of in-service dual systems and how they might be used in the future.

This paper presents the findings of the retrospective analysis which developed an inventory of cases where dual systems have been implemented; formulated a protocol to identify claimed benefits, costs and risks; collected quantitative and anecdotal data to assess performance; and presented the results at workshops attended by stakeholder groups. It also introduces several new elements to the knowledge bases of water reuse and water distribution systems. It presents an expanded definition of dual water systems and how they are used for distribution of non-potable supplies, it presents data and statistics to demonstrate the current status of dual systems use in the USA, it summarizes data on water quality in dual systems, and it identifies a range of experiences that provide lessons learned for utilities seeking to begin or expand the distribution of reclaimed supplies.

Defining dual systems

On a conceptual basis, it is important to identify the point-of-view to take when discussing dual water systems. One point-of-view is to focus on the distribution infrastructure,

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where two separate systems are used. Another point-of-view is to focus on a system to distribute reclaimed water, which might or might not be a dual system. Figure 1 shows the general concept of two separate and independent distribution networks. One network conveys potable water and the other conveys lesser quality non-potable water. If raw or reclaimed water is transported in the non-potable water system, the distribution system is considered as 'dual'. If raw or reclaimed water is distributed directly to a user, it is known as 'direct use of raw or reclaimed water' and is not considered a dual system. While this may seem like a fine point, it creates an important management issue of how you view the system for distributing reclaimed water. Is it a bona fide part of the distribution system, which will enable a utility to create a more efficient total water management scheme for the future; or is it simply a limited add-on to the system to distribute a limited quantity of reclaimed water?

As utilities experiment with the distribution of reclaimed water they may create dual systems incrementally. For example, consider a scenario in which the utility has a dedicated reclaimed water line from a wastewater treatment plant to an industrial customer. As the utility gains experience, it decides to expand reclaimed water distribution to other industries and irrigators and eventually evolves further to include applications such as commercial buildings and fire-fighting. This system did not develop from a single decision to implement a dual water system, but evolved into a dual system in order to meet emerging needs. In a case like this, the utility may find itself managing a complex dual system when it did not plan to do so in the beginning.

Study of dual systems

Water reuse, as it relates to water treatment systems, water quality, and water safety, has been studied extensively and the study focused on the body of knowledge about the infrastructure used to distribute it. The literature review identified how dual systems have evolved, issues associated with their performance, and the relevant rules and regulations with their operation. Topics covered water quality and public health aspects of dual water distribution; experience with water reuse systems; distribution system asset and operations management; and economics and institutional arrangements of dual distribution systems.

A database of dual systems for the USA and other countries was developed in order to evaluate published claims about the number of systems in existence as well as to identify systems to be later used as case studies. The WateReuse Association's database (Water Reuse Association 2011) was used as a starting point and each facility in the database was checked independently using online sources to verify its status as a dual water system rather than a direct use system. This revealed that many facilities were not dual water systems but were direct use systems to isolated users. The database indicated that most water reuse was practiced in Florida and California. Since the data were limited and from voluntary reporting, the project team used published and online sources to identify additional utilities across the USA and in other countries. This activity resulted in a project database with 335 dual systems in the USA and 87 systems in other countries.

As shown by Figure 2, some 37 case studies were used to verify the trends and conclusions in the published literature,

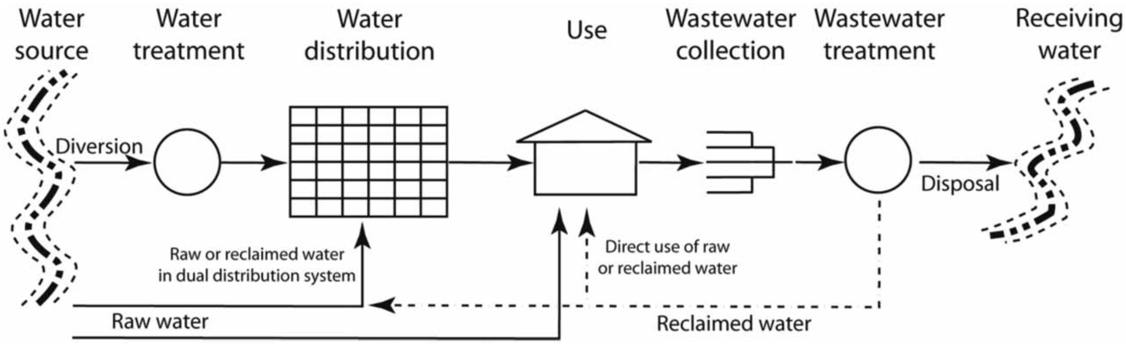

Figure 1 | Schematic of a dual water system.

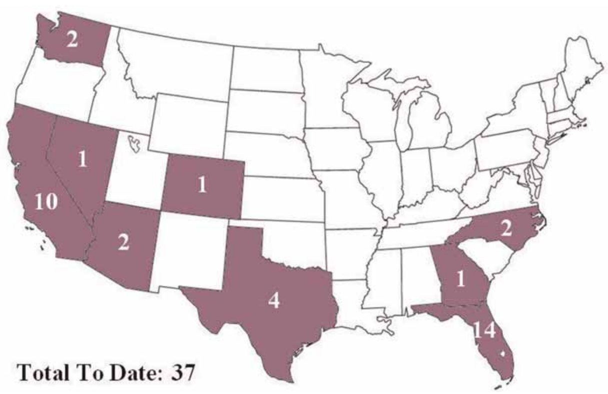

Figure 2 | Locations of case studies in the USA.

provide new insights into the performance of dual systems, and test the performance categories and assessment methodology. These were selected from different states with unique features such as using reclaimed water for fire protection or toilet flushing. Most are in California and Florida because those states are the most active in distribution of reclaimed water. Regional workshops were held in Florida and California and site visits were conducted at several utilities. Using information from the literature review, case studies, site visits, and the workshops held in Tampa and Oakland, the team developed a classification system for dual systems and evaluation protocol to assess their performance.

CLASSIFICATION SYSTEM

The previous definition of dual systems explains their use for the distribution of non-potable supplies but a classification system is needed to compare and evaluate them. Based on pipeline mileage, dual water systems comprise only a small percentage of all water distribution systems and no classification system for them has been developed by US Environmental Protection Agency (USEPA) or other organizations.

A starting point in creating a classification system is provided by the set of water and wastewater classification systems that were developed for national needs studies conducted by USEPA. These are used in the Safe Drinking Water Information System (SDWIS), the Community Water Systems Survey (CWSS), and the Clean Watersheds Needs Survey (CWNS) (US Environmental Protection Agency 2010a, b, c). For example, public water systems are either Community or Non-Community systems. Wastewater systems are collection, treatment, or combined systems. The CWSS and the SDWIS contain information about the potable water distribution systems and the CWNS has a Category X that addresses the distribution of recycled water (RW). This reveals that reclaimed water distribution systems are generally classified under the wastewater category rather than the water supply category, even though their distribution may be handled by water supply workforces. The division of water supply and wastewater classification systems indicates that classifiers for dual potable and non-potable water distribution systems must be hybrids of water and wastewater.

Given the dual nature of the distribution systems and the fact that they transport both water and wastewater, it is likely that the water and wastewater industries could not adopt a classification scheme and it is also not clear whether such a classification system is needed for management or policy purposes. Presently, the use of a classification system might be limited to helping local governments explain their systems and for research and policy studies. The classification scheme developed is shown in Figure 3. Starting from the top, it illustrates the division of all systems into those with or without residential connections. This turned out to be an important issue that affected management of dual systems in fundamental ways. The variables A, P, L, S, D, and R are defined in the following sections.

Dual system operators explained that whether the reclaimed water system serves residential customers is an important variable that impacts the utility's operations and maintenance programs. Service to residential customers generally consists of reclaimed water for landscape irrigation but in some cases, it includes indoor use. For the 37 systems used as case studies, only nine (24.3%) did not provide service to residential customers (see Table 3).

Ownership of water and wastewater supplies and the distribution infrastructure is an important classification variable. These classifiers are used for ownership (Table 1): Category A (all) systems where the components of the potable and non-potable systems are completely owned and supplied by the utility; Category P (partial) systems where either the potable or non-potable system relies on an external party for infrastructure and/or source water; and

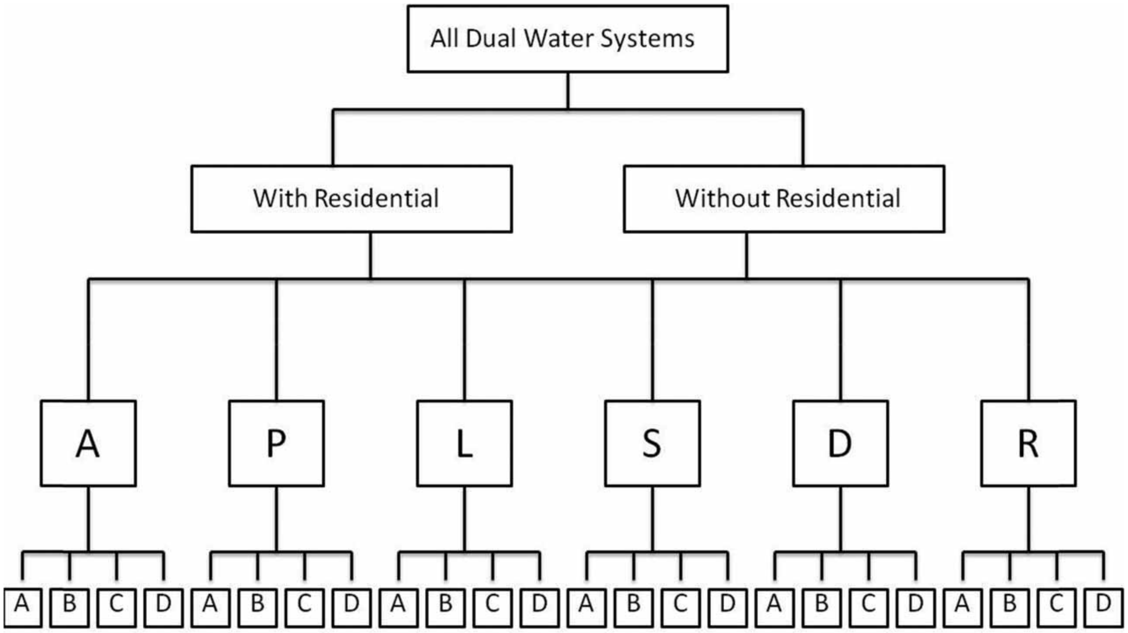

Figure 3 | Overall dual water system classification scheme.

Category L (limited) systems where both the potable and non-potable systems are dependent to some degree on another utility. The S, D, and R (supplier, distributor, and regional) categories capture the wholesaler–distributor relationship that is common to potable water systems. Some utilities obtain treated potable and/or RW from other utilities. This scheme also takes into account that some utilities have regional functions to serve other utilities (counties, water districts, and municipal utility districts). As examples, the system in Yelm, WA is Category A since it owns the dual water system infrastructure and provides its own supplies of potable and non-potable water. In the case of Pittsburg, CA, since the recycled system is owned and operated by another utility, it is classified as a Category P.

While classifying utilities based on their service category serves as a starting point, it has limitations, mainly that not all utilities can be classified into a single category. Some would be placed in several categories (P, R, L, or D) because they partner with other utilities for one or both of the systems. For instance, Santa Rosa, CA is a managing partner for the sub-regional wastewater treatment plant which provides treatment, disposal, reclamation, industrial waste inspection, and laboratory services to Santa Rosa, Rohnert Park, and other locations. Santa Rosa contributes about 73% of the sub-regional operating budget. Another weakness of this approach is that classifying utilities into service categories does not take into account the degree to which a utility is a P or an L. For instance, some utilities (such as Tampa) are a P because they obtain an emergency source of water from another utility on a seasonal basis whereas others such as Largo, FL receive potable water supply from an external provider continuously.

While service categories allow for comparisons of utilities with similar source water and infrastructure ownership characteristics, the classification system also includes a measure of the degree of system duality. This is based on a normalized infrastructure measure (percent reclaimed water main mileage to total water main mileage) and an operational performance measure (percent reclaimed water production relative to total water production). Depending on the percentages of reclaimed water main mileage and reclaimed water production within a service category, a utility is assigned a performance class designation (A, B, C, or D) as shown in Table 2.

Figure 4 illustrates the variation between capital intense (high percentage of infrastructure with low percentage of reclaimed water use) utilities and utilities with high

Table 1 | Service categories

Category	Description
A (all)	The utility owns the infrastructure and water supply for both systems
P (partial)	The utility owns the infrastructure and water supply for one system but not entirely (or not at all) for the other system
L (limited)	The utility is partially or entirely dependent on others for its infrastructure or water supply for both systems
S (supplier)	The utility supplies potable and/or RW to other utilities
D (distributor)	The utility distributes potable and/or RW obtained from others
R (regional)	The entity is a cooperative that supplies recycled and/or potable water

Table 2 | Performance class descriptions

Class	Description
A	Low percent RW mileage, high percent RW use; these represent developing systems with high non-potable use
B	High percent RW mileage, high percent RW use; these represent developed systems
C	Low percent RW mileage, low percent RW use; common to emerging systems
D	High percent RW mileage, low percent RW use; these are infrastructure-intensive reclaimed water systems

operational efficiency (low percentage of infrastructure with a high percentage of reclaimed water use) for the 37 case studies. The figure shows that the majority of the case study systems are classified as Class C or emerging dual systems.

The performance class boundaries shown on the diagram are at the 10% RW use and the 25% RW line levels. While the original boundaries were selected visually based on the distribution of the 37 case study data points, their appropriateness was confirmed using feedback collected from system operators attending regional workshops in California and Florida (Grigg *et al.* 2013) and follow-up questionnaires sent to operators from various states (Edmiston 2011). These boundaries enable a division of the systems into the four performance classes. Given that most systems are in the emerging category, it will take additional experience to determine success factors for their performance. This is especially the case when systems are considered where the motivation is to save water or meet regulations, rather than to gain performance or financial advantages.

Most of the systems utilize dual water systems in which less than 10% of the total water demand is met by reclaimed water and where less than 25% of the pipe mileage is for RW. Figure 5 provides additional detail regarding the distribution of RW mains and reclaimed water production within this class (Class C). The figure illustrates that even within this single category, most of the utilities have small amounts of RW line, compared to their overall distribution mileage, and there is a wide variation in water production.

Table 3 summarizes the residential use, service category, and performance class designations for all 37 systems used as case studies.

PERFORMANCE ASSESSMENT

The performance model is based on past reports in the literature, US Environmental Protection Agency's (2007) identification for policy information, and the classification system just explained. Five categories of performance indicators were developed:

(1) water safety and public health protection;
(2) effectiveness in meeting system goals including water conservation;
(3) total cost (of potable and non-potable systems);
(4) risk and reliability;
(5) implementation and operational results.

Given the tentative and evolving status of dual systems, it was apparent that definitive data for all systems across all categories would not be available. In some cases it was possible to develop objective and quantitative measures, but in other cases only qualitative and descriptive data were required. Even when numerical data were available, it could not always be used directly for assessment. For example, the number of reported violations of standards would make a good indicator for water safety/public health category but the reporting of violations is not standardized or quality-assured. Another statistic might relate to

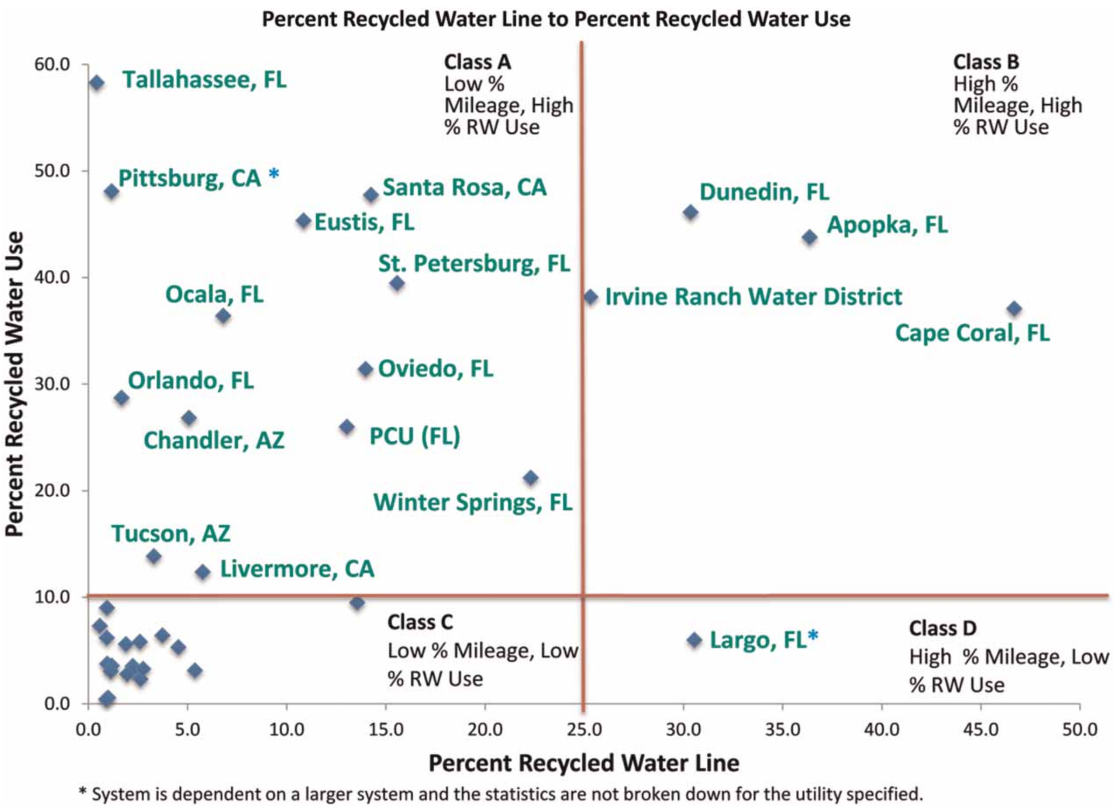

Figure 4 | Percent RW line versus percent RW use.

financial performance but numerical data are difficult to obtain and interpreting it can be misleading.

Given the challenge to make an assessment of a complex program, a multi-criteria performance model was required to span both objective and subjective measures. The following discussion explains the performance categories and the process used in assessing dual systems.

Water safety and public health protection

Since the US Environmental Protection Agency (2007) research plan was focused on the safety of drinking water, the research team sought indicators that provide some measure of risk of contamination and the compromise of security of water safety. Initially, the metric for this category was based on the number of cross connections and illnesses due to reclaimed water. However, illnesses are rarely reported and difficult to correlate with reclaimed water use. The literature review identified few reported cross connections and in all cases examined, the water provider resolved the problem immediately. It was determined that utilities that remediated any cross connection issues should not be ranked lower than those that never had cross connections to fix. In some cases, the presence of cross connections caused utilities to implement stricter public health and safety measures than those that never had cross connections.

Since the effects of reclaimed water systems with respect to public health are difficult to quantify, two preventative measures were used for assessment; utility engagement with the public and the public's engagement level. Utility engagement with the public was measured by whether it provides general information to the public, if it has an active educational campaign, whether it offers workshops to participants, and whether it requires training as a prerequisite for a non-potable water connection. Public engagement levels were assessed by system managers by considering three factors: overall public interest in conservation programs and reuse, community compliance with ordinances, and public participation in training workshops. Refer to Edmiston (2011) for further details. Once again, a

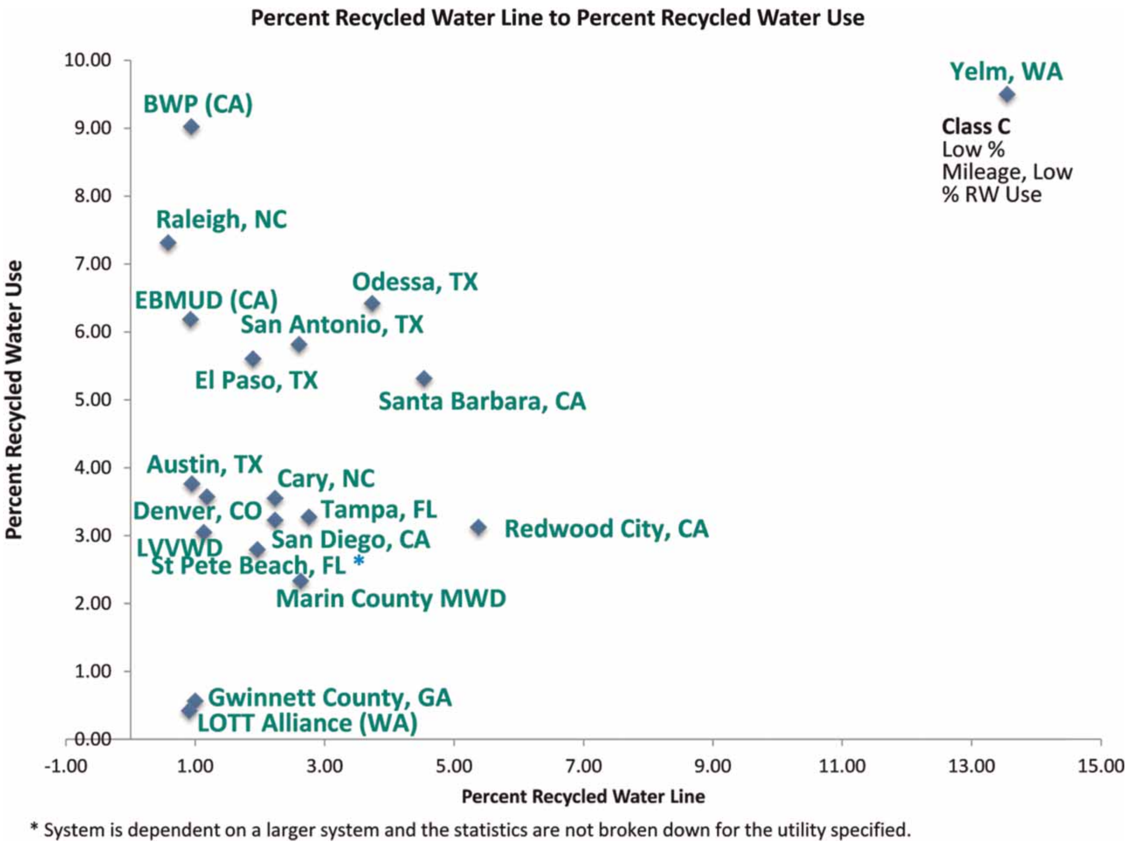

Figure 5 | Percent RW line versus percent RW use (Class C).

quantitative measure such as whether a utility has a program or does not seems too simplistic to be credible as a statistic.

Effectiveness in meeting system goals

The primary challenge in evaluating a dual system's effectiveness in meeting system goals is that the metric changed. Contrary to US Environmental Protection Agency's (2007) original vision of using dual systems as a mechanism to improve water quality, as the project evolved, it became apparent that dual systems are being used to extend water supplies and improve the management of wastewater. As such the category was expanded to three parallel goals:

1. deliver higher quality potable water at lower cost and at greater reliability;
2. extend water supplies and reduce impacts on source waters;
3. improve management of wastewater.

As it relates to the classification system discussed above under performance assessment, if effectiveness is defined as the percent recycled mileage of the dual system versus the percent RW demand, then the performance classes (A, B, C, and D) can be used to quantify effectiveness. Under this approach, systems with performance classes A and C would rank higher than systems with performance classes B and D since they require less infrastructure to meet the RW demands. A similar approach is applied for conservation where performance classes A and B rank higher than classes C and D since they have a larger percentage of RW use.

Total costs (of potable and non-potable systems)

Cost is a challenging criterion to measure because operators have different approaches in accounting for operational and maintenance costs. While a few utilities separate the reclaimed water system costs from the wastewater system

Table 3 | Summary of the residential use, service category, and performance class designations for the case study systems

Utility	With residential	Without residential	Service category	Performance class
Apopka, FL	X		A	B
Austin Water, TX		X	S	C
Burbank Water and Power, CA		X	P	C
Cape Coral, FL	X		A	B
Cary, NC	X		P	C
Chandler, AZ	X		P	A
Denver Water, CO	X		P	C
Dunedin, FL	X		P	B
East Bay MUD, CA		X	S	C
El Paso, TX	X		R	C
Eustis, FL	X		P	A
Gwinnett County, GA		X	R	C
Irvine Ranch Water District, CA	X		D	B
Largo, FL	X		P	D
Las Vegas Valley Water District, NV	X		R	C
Livermore, CA	X		P	A
LOTT Alliance, WA		X	S	C
Marin Municipal Water District, CA		X	R/D	C
Ocala, FL	X		A	A
Odessa, TX	X		P	C
Orlando, FL	X		D	A
Oviedo, FL	X		P	A
Pinellas County Utilities, FL	X		D	A
Pittsburg, CA		X	P	A
Raleigh, NC	X		S	C
Redwood City, CA	X		L	C
San Antonio Water System, TX	X		A	C
San Diego, CA	X		D	C
Santa Barbara, CA	X		P	C
Santa Rosa, CA		X	L	A
St Pete Beach, FL	X		L	C
St Petersburg, FL	X		A	A
Tallahassee, FL		X	R	A
Tampa, FL	X		P	C
Tucson, AZ	X		D	A
Winter Springs, FL	X		A	A
Yelm, WA	X		A	C

costs, the majority accounts for only the total cost of the potable, reclaimed, and sewer systems. It would, of course, be possible to do cost studies to partition these costs but this would require great effort and be equivalent to a rate study for each case study.

Although some data on cost of non-potable systems are available, it was apparent from the beginning that the data would not in general enable the partitioning of operating and capital costs into potable and non-potable categories. As utilities were interviewed, and based on feedback from the participants at the project workshops, it became clear that the main cost to be evaluated is total water and wastewater cost with and without the reclaimed water system.

Risk and reliability

Risk and reliability issues include operational (short term) reliability and long-term availability, especially in the case of drought. The most common risk issues encountered during the case study process were water storage for potable and non-potable water systems, diversity of water supply, and diversity of reclaimed water customers. Examples of systems with storage problems include the two case studies in WA in which the system in Yelm recently had to install new above ground storage tanks to address the problem while the system for the LOTT alliance is still experiencing storage problems. Examples of case study systems facing water supply diversity issues include the system at Gwinnett County Georgia which relies solely on Lake Lanier and the system serving Santa Barbara, California where the water rights to its primary source, Lake Cachuma, are being contested. An example of a system facing challenges relating to a low diversity of reclaimed water users occurs with the system in Odessa, Texas which, having two industries cease from using reclaimed water, saw its total reclaimed water demand cut by half.

Based on these observations, the selected measures for risk and reliability were diversity of service and availability of reserves. While the diversity of service can be measured by the ratio of number of customers to total reclaimed water production, storage must be based on capacity relative to need.

Implementation and operational results

Implementation and operational results form a broad performance category that measures the overall performance of dual systems in categories other than safety, effectiveness in meeting goals, costs, and risk management. Based on the case study investigations, project visits, and input from water industry professionals attending the regional workshops, the project team identified a number of issues that fall into this group including:

- strategic advantages in meeting goals such as reducing discharges or water withdrawals, extending the lives of potable water systems or wastewater treatment, reducing peak demands, or improving fire protection;
- unexpected loss of revenue after implementing non-potable system;
- management difficulty and complying with more regulations and mandates;
- requiring more and different storage and adding to infrastructure burden;
- added risks, such as projected demands that do not materialize;
- public image effects.

These different considerations fall into the general category of institutional issues, and some of them overlap into the other categories. They were handled through descriptive text rather than trying to assign objective criteria to them.

SUMMARY AND CONCLUSIONS

The results of the study support the goals outlined in USEPA's plan for 'Innovation and Research for Water Infrastructure for the 21st Century' by providing a retrospective assessment of the performance of dual water systems. Dual water systems were identified in the plan as a potential strategy to improve water safety while addressing the gap between needed and current funding levels.

One of the principle findings is that improving water safety and addressing the infrastructure investment gap are not the primary goals being pursued by agencies with dual water systems. The primary motivations associated with distributing reclaimed water are to supplement potable water supplies, particularly in drier climates or in coastal areas, and to offer more options for the management and disposal of wastewater. In this light, dual systems are serving as useful additions to water resource management portfolios but are not being implemented in order to deliver higher quality potable water supply at a lower cost and improved reliability.

The study identified several other key findings related to dual system performance:

- Neither the literature review nor the case studies identified major public health problems in the USA from the distribution of reclaimed water. This does not mean that reclaimed water systems are free of water safety risks but it suggests that well-managed systems can avoid public health problems.
- Water storage for non-potable supplies is a reliability issue because non-potable water systems normally require seasonal storage.
- The study found that utilities do not prepare the necessary rigorous accounting required to assess the true costs of dual systems. While reclaimed water systems do add capital and operating costs, an accurate assessment would have to factor in the avoided costs across all sectors, including wastewater management.
- Rate-setting is difficult and a work in progress. Some utilities must ration reclaimed water while others must work to encourage its use. Cost accounting and rate-setting systems for reclaimed water distribution need additional development.
- The use of dual systems can be beneficial to water agencies by extending lives of potable water systems, delaying expansion of wastewater treatment facilities, reducing peak demands on potable water systems during dry seasons, and avoiding environmental pressures and court decisions about water imports.

- Dual water systems may be used to reduce the cost of treating and distributing potable water especially if the potable water source initially has poor water quality or if the location of the potable source makes the use of reclaimed water less expensive to deliver.
- Determining which reuse projects will enjoy greater success, depending on how success is defined, will be a function of drivers that include cost and availability of water, public attitudes, and regulatory constraints. This is evident from the larger numbers of systems in states where these drivers favor reuse, notably California and Florida.

On an overall basis, the finding is that dual water systems are a work in progress and many issues remain to be resolved. As water supplies become scarcer and water efficiency is emphasized, dual systems to recycle treated wastewater become more attractive. Regulatory controls are mainly at the state level and require attention and guidance to normalize and evaluate them. Utilities need guidance for a range of technical, financial, and management issues, so distribution of reclaimed water through dual systems promises to become a more active field of practice in the future.

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REFERENCES

Craun, G. & Calderon, R. 2001 Waterborne disease outbreaks caused by distribution system deficiencies. *J. Am. Water Works Assoc.* **93** (9), 64–75.

Edmiston, S. 2011 Evaluating the Performance of Dual Distribution Systems. MS thesis, University of Texas at Tyler.

Grigg, N. S., Rogers, P. D. & Edmiston, S. 2013 *Dual Water Systems: Characterization and Performance for Distribution of Reclaimed Water-Report 4333*. Water Research Foundation, Denver, CO. Available from: www.waterrf.org/PublicReportLibrary/4333.pdf (last accessed 3 September 2014).

US Environmental Protection Agency 2007 Innovation and Research for Water Infrastructure for the 21st Century: Research Plan. April 30.

US Environmental Protection Agency 2010a Safe Drinking Water Information System (online). Available from: http://www.epa.gov/enviro/html/sdwis/sdwis_query.html (accessed 24 September 2012).

US Environmental Protection Agency 2010b Community Water Systems Survey (online). Available from: water.epa.gov/aboutow/ogwdw/cwssvr.cfm (last accessed 3 July 2012).

US Environmental Protection Agency 2010c Clean Watersheds Needs Survey: 2008 Report to Congress (online). Available from: www.epa.gov/cwns (last accessed 26 September 2012).

WaterReuse Association 2011 National Database of Water Reuse (online). Water Reuse Association. Available from: www.watereuse.org/info/nwrdb (last accessed 7 September 2012).

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