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POLICY ANALYSIS

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Management Experiences and Trends for Water Reuse Implementation in Northern California

Heather N. Bischel,[†] Gregory L. Simon,[‡] Tammy M. Frisby,[§] and Richard G. Luthy[*,†]

[†]Department of Civil and Environmental Engineering, Stanford University, Stanford, California 94305-4020

[‡]Department of Geography & Environmental Sciences, University of Colorado Denver, Denver, Colorado 80217-3364

[§]Department of Political Science and Hoover Institution, Stanford University, Stanford, California 94305-6044

Supporting Information

ABSTRACT: In 2010, California fell nearly 300,000 acre-ft per year (AFY) short of its goal to recycle 1,000,000 AFY of municipal wastewater. Growth of recycled water in the 48 Northern California counties represented only 20% of the statewide increase in reuse between 2001 and 2009. To evaluate these trends and experiences, major drivers and challenges that influenced the implementation of recycled water programs in Northern California are presented based on a survey of 71 program managers conducted in 2010. Regulatory requirements limiting discharge, cited by 65% of respondents as a driver for program implementation, historically played an important role in motivating many water reuse programs in the region. More recently, pressures from limited water supplies and needs for system reliability are prevalent drivers. Almost half of respondents (49%) cited ecological protection or enhancement goals as drivers for implementation. However, water reuse for direct benefit of natural systems and wildlife habitat represents just 6−7% of total recycling in Northern California and few financial incentives exist for such projects. Economic challenges are the greatest barrier to successful project implementation. In particular, high costs of distribution systems (pipelines) are especially challenging, with $1 to 3 million/mile costs experienced. Negative perceptions of water reuse were cited by only 26% of respondents as major hindrances to implementation of surveyed programs.

INTRODUCTION

California is at the forefront of recycled water use, treating municipal wastewater to a high enough degree that it can be returned to the water supply for a variety of beneficial uses including landscape irrigation,[1−3] agriculture,[4,5] ecosystem enhancement,[6] industrial cooling and processing,[2,7] groundwater recharge, and indirect potable reuse.[7−9] From 1970 to 2001, reuse of municipal wastewater more than doubled in California from 175,000 acre-ft per year (AFY, 11.7 m^3/s) to approximately 525,000 AFY (20.5 m^3/s). Yet this growth fell short of the state's goal to reuse 700,000 AFY by 2000.[10,11] California's goal to increase reuse by 2 million acre-feet (AF) by 2030 over 2002 levels[12] will require a portfolio of projects for a range of beneficial uses. Given multiple failures to attain statewide recycling goals (Figure 1), questions remain as to the sources of such difficulties as well as the feasibility of reaching near-term goals described in California's State Water Board Strategic Plan Update of 2008−2012.[13]

Despite efforts to encourage and support water reuse programs at the state and federal levels[10,12] not all projects are successfully implemented, and nonpotable reuse projects frequently fall short of planned delivery goals.[14,15] Exploration of reasons for failure of water reuse programs is incomplete. Public opposition has led to the suspension or abandonment of several large water reclamation projects for indirect potable reuse in California,[10,16] but a focus on lack of public acceptance of water reuse, as it is traditionally conceived, may be counterproductive to addressing issues such as inadequate institutional arrangements.[17,18] Given that water reuse can simultaneously address both water supply and wastewater disposal needs, how water reuse agencies perceive, and manage, recycled water − as a form of waste or an alternative source for water − remains open to question. Research regarding economics of water reuse and strategic cost recovery schemes is also limited. Considering the promise of recycled water for augmenting water supplies in the West and pressing water supply concerns related to dramatic population changes and climate change, assessment of past and current experiences in water reuse implementation is needed to more effectively promote, evaluate, and implement water reuse programs. The present study contributes to this task by evaluating the experiences and perspectives of water reuse managers in Northern California to understand major issues confronting recycled water projects in the region.

Specifically, our study seeks to document water reuse program growth and assess historical goals relative to actual performance in Northern California based on statewide surveys and policy-derived benchmarks; evaluate the roles of regulatory requirements that may

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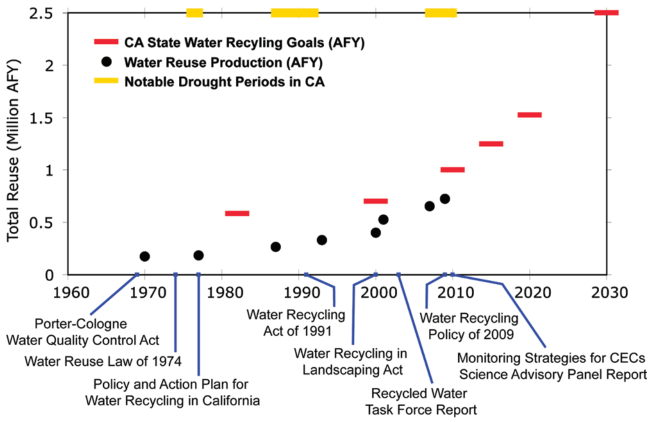

Figure 1. 50-year timeline of major statewide water recycling goals and production volumes, drought periods, and water recycling policies in California. Refer to the Supporting Information for a description of major laws and policies.

limit discharge relative to water supply and reliability needs in driving recycled water implementation through time; assess the importance of ecosystem enhancement or protection goals in water reuse decision-making; and elucidate the relative importance of economic factors among challenges to nonpotable water reuse implementation experienced by managers in Northern California.

METHODOLOGY

Data Sources. Primary data on water reuse agencies, practices, and management experiences were collected via an online questionnaire of Northern California water reuse managers conducted for the present study in 2010 (2010 Survey). Additional data on water reuse agency characteristics were obtained from the California State Water Resources Control Board (SWRCB) 2001 Water Recycling Survey released in 2002 (2001 Survey),[11] the National Database of Water Reuse Facilities (National Database),[19] and the 2009 California Municipal Wastewater Recycling Survey, a follow-up survey from the SWRCB released in April 2011 (2009 Survey).[20] Municipal water recycling agencies in Northern California (defined as the 48 counties northward of the southern boundaries of Monterey, Kings, Tulare, and Inyo counties) listed on the publicly available National Database and the 2001 Survey were invited to participate in the 2010 Survey.

Fieldwork Administration and Questionnaire. Data were collected online from February to April 2010 using electronic surveys sent to general managers or water/wastewater directors from 134 agencies. The questionnaire, which is described further in the Supporting Information and Table S12, was developed based on case study research, literature review, and site visits at agencies with water reuse programs for agriculture, landscape irrigation, industrial power plant cooling, and ecosystem enhancement. Respondents were asked a number of questions related to the drivers and challenges experienced in implementing their agency's water reuse program as well as responses to recent recycled water policy in California.

Categorization and Statistical Tests. The analyses conducted for 2010 Survey results provide quantitative confirmation of trends previously discussed and valuable insights into the characteristics of water reuse in Northern California. Results represent response data and are supported by qualitative descriptions of drivers and barriers experienced in program implementation. To assess relationships between categorical variables, chi square analysis was conducted on two by two contingency tables constructed from frequency results of specific drivers (Table 1) and hindrances (Table 2) to program implementation. The lists of specific drivers and hindrances were also consolidated into eight and nine categorical variables, respectively, and chi square analysis was performed (see Tables S1 − S8 for full results). Representative respondent quotes, extracted primarily from responses to two questions − the single most important driver or hindrance to implementation (Q10 and Q14, Table S12) − are presented (italicized in quotations) to provide context for the diversity of experiences evident throughout the results.

Respondent Information and Survey Limitations. A total of 71 distinct agencies, a 53% response rate, are represented by 2010 Survey responses. Because some parent utilities represent multiple recycled water facilities, a total of 81 unique production facilities are represented by responses; however, most agencies (83%) represent only one recycled water production facility, and another 7% represent a unique distribution facility coupled to a production facility. Respondents consist of internal public agency managers or utility staff. The survey completion rate, indicating the percentage of invited respondents who submitted a fully complete survey, was 40%. Therefore, the response fractions reported for each question indicate values for that particular question. Respondent agencies for the 2010 Survey were distributed widely across Northern California, with weaker representation for agricultural programs when compared to the 2009 Survey data (Figure S1 and Table S9). The median year of recycled water program implementation, based on self-reported implementation dates for 56 respondents, was 1991, with the earliest reported implementation occurring in the early 1960s.

ANALYSIS OF WATER REUSE IN CALIFORNIA

Recycled Water Distribution Falls Short of Statewide Goals. Figure 1 displays a timeline of statewide water recycling goals and production volumes.[10,11,15,20−22] According to the 2009 Survey, recycled water used in California in 2001 included 491,992 AFY (19.2 m^3/s) from municipal facilities (private facilities excluded).[20] The newest data from the California SWRCB indicate California municipal wastewater facilities recycled a total of 723,845 AFY (28.3 m^3/s) in 2009.[20] This represents an increase of more than 230,000 AFY (9.0 m^3/s) from levels in 2001 yet once again falls short of goals for recycling set by the State of California by nearly 300,000 AFY (12 m^3/s, Figure 1 and Table S10). Although the SWRCB 2009 Survey may underrepresent current reuse volumes due to a low survey response rate, the results underline a need to identify continuing challenges associated with implementation of recycled water programs, evaluate strategies to develop new programs, and expand existing distribution networks. In California, where applied freshwater usage was 39.2 million AF in 2005, recycled water represents a relatively small portion of dedicated or developed water supplies (e.g., water used for agriculture or urban uses).[23] However, only about 10% of available treated effluent was recycled in 2001, indicating important growth potential for this water source.[10]

Northern California Context. Our analysis shows that only 20% of the observed statewide increase in reuse between 2001 and 2009 occurred in the Northern 48 counties of California, where 120 municipal agencies recycled 127,000 AF (1.6×10^8 m^3) in 2001 and 143 agencies recycled 173,000 AF (2.1×10^8 m^3) in 2009. Recycled

Table 1. Percent of Respondents Indicating a Specific Factor As a *Driver* or One of the Three *Most Important Drivers*[a]

categorized factor	most impt. driver	driver	specific factor	most impt. driver	driver
wastewater discharge requirements	**51%**	65%	wastewater discharge volume requirements	51%	65%
water supply needs	**49%**	69%	water shortages due to reduced supply	42%	65%
			water shortages due to increased demand	17%	42%
			seawater intrusion	5%	6%
local, regional, or state policy and mandates	**45%**	68%	basin plan water quality objectives	25%	43%
			regional or local recycled water policy goals or mandates	20%	42%
			state recycled water policy goals or mandates	14%	31%
			climate change adaptation plans	0%	5%
institutional control	**29%**	58%	need for reliable water supply	26%	52%
			need for increased institutional control of water	3%	20%
economic/financial incentives	**26%**	51%	availability of federal/state grants or loans	18%	32%
			cost of alternative freshwater sources	9%	32%
ecological goals or requirements	**18%**	51%	ecological protection or enhancement goals	12%	49%
			ecological protection or enhancement requirements	6%	20%
influential stakeholders	**11%**	34%	large volume user(s)	6%	28%
			citizen initiative	5%	12%
technological advancements	**3%**	22%	technological advancements	3%	18%
other	**18%**	18%	other	18%	18%

[a] Responses ($N = 65$) were further categorized as shown and are sorted from top to bottom by the highest frequency categorized *Most Important Driver*.

Table 2. Percent of Respondents Indicating a Specific Factor As a *Hindrance* or One of the Three *Most Important Hindrances*[a]

categorized factor	most impt. hindrance	hindrance	specific factor	most impt. hindrance	hindrance
economic/financial disincentives	**87%**	94%	capital costs for construction of recycling plant facilities	56%	85%
			costs for pipeline construction	48%	80%
			ongoing operations and maintenance cost recovery	26%	61%
			availability of federal/state grants or loans	24%	54%
			cost of alternative freshwater sources	7%	26%
perceptions and social attitudes	**26%**	61%	perceived human or environmental health risks due to constituents of emerging concern	13%	48%
			social attitudes/public perception	13%	33%
			perception that recycled water will lead to more development	4%	22%
			perception that recycled water will reduce property value	4%	6%
who pays system costs	**20%**	59%	issue of who pays for program capital or operating costs	20%	59%
regulatory constraints	**15%**	52%	complexities/conflicts of water law and/or regulation	9%	37%
			slow regulatory process in permitting	7%	30%
water quality impacts	**13%**	48%	downstream water quality impacts/NPDES constraints	7%	31%
			detection of constituents of emerging concern	4%	33%
			effluent residuals (e.g., brine) disposal	2%	11%
user acceptance	**9%**	37%	user acceptance	9%	37%
institutional issues	**11%**	30%	institutional coordination	9%	28%
			loss of projected users	2%	6%
technical issues/treatment	**7%**	31%	technical issues/treatment processes	7%	31%
uncertainty over future recycled water uses	**4%**	13%	uncertainty over future recycled water uses	4%	13%
other	**9%**	11%	other	9%	11%

[a] Responses ($N = 54$) were further categorized as shown and are sorted from top to bottom by the highest frequency categorized *Most Important Hindrance.*

water programs in Northern California are generally smaller in volume (median = 347 AFY or 0.014 m^3/s in 2009) than programs in the ten Southern California counties (median = 1064 AFY or 0.042 m^3/s in 2009), where 82 municipal agencies recycled 365,000 AFY (14 m^3/s) of water in 2001, increasing to a total of 551,000 AFY (22 m^3/s) of water in 2009 by 104 agencies (Figure 2 and Figure S2). Water reuse programs are frequent across rural Northern - California and agricultural areas in the Central Valley (Figure 2), typically at much lower volumes than urban areas. Historically, agricultural water reuse predominated in California (Figure 3), occurring where farmland was located adjacent to wastewater treatment facilities.[10] Agricultural reuse was more common for older respondent agencies in the 2010 Survey, as determined by a chi square test with implementation dates before or after 1991 ($p < 0.05$). Significant population growth, particularly in the Central Valley, creates challenges for new or increased wastewater discharge in largely agricultural areas, especially for environments with limited assimilative capacity.[13] Though reuse in Northern California represents a lesser fraction of overall reuse in the state, challenges associated with the implementation of these programs are important to consider in developing the total portfolio of state projects. Several larger programs have been implemented over the past decade in Northern California, and more are likely to be developed in large urban centers. However, recycled water program size has remained relatively stable on average in Northern California.

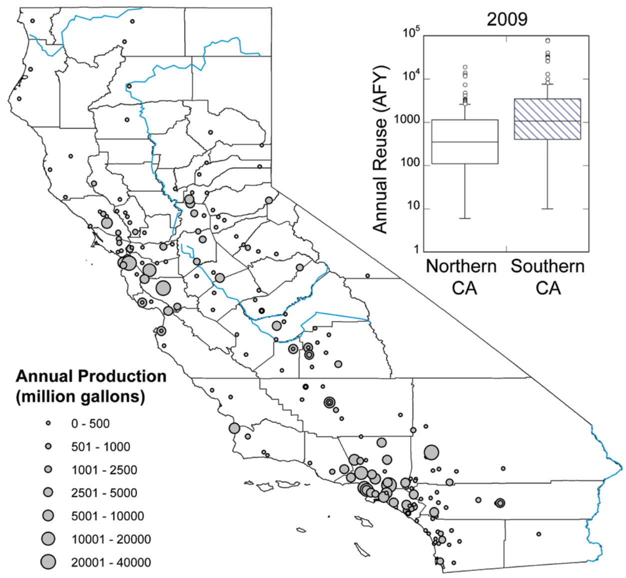

Figure 2. A snapshot of water reuse facilities in California from the National Database of Water Reuse Facilities (Annual Production, reported as *Facility Production Average Annual Actual* in million gallons) and the California 2009 Municipal Water Recycling Survey (Annual Reuse, reported as *Total Reuse* for 2009 in AFY). In the inset box plot, the boundary of the box indicates the upper and lower quartiles; a line within the box indicates the median flows (347 AFY and 1064 AFY); whiskers above and below the box demarcate 1.5 times the interquartile distance with outlying points also shown. The distributions of flows from the 2009 Survey differed significantly between Northern and Southern California (Mann–Whitney $U = 10080.5$, $n_1 = 143$, $n_2 = 104$, $P < 0.0001$, two-tailed).

DRIVERS OF WATER REUSE IMPLEMENTATION IN NORTHERN CA

Various social, economic, and environmental factors have been identified as drivers of water reuse by governments and stakeholders globally.[10,14,24,25] These driving forces include the following: drought, demand due to population and economic growth, wastewater management, ecological protection, availability near urban areas, and availability of proven treatment technologies.[14,25] To establish a forum for free-form responses regarding principal driving forces behind recycled water implementation in Northern California, respondents first considered the relative importance of several broad categories of drivers. The fraction of respondents indicating each broad category as a very important driver or a driver, respectively (Q8, Table S12), was as follows: regulatory requirements (0.59, 0.27), water shortages (0.49, 0.34), economic concerns (0.28, 0.37), recycled water policy (0.23, 0.49), and influential stakeholders (0.21, 0.33).

To further gauge the extent to which a range of specific factors motivated program implementation, respondents were asked to select from a list of 19 specific factors (Table 1). Altogether, 65% of respondents indicated "wastewater discharge volume requirements" as a driver of implementation, with 51% of respondents selecting this factor as one of the three most important drivers. "Water shortages due to reduced supply" was cited as a driver by 65% of respondents and by 42% of respondents as one of the three most important drivers of implementation. Together, these two factors were cited by 86% of respondents. Expressing a common experience for the most important driver of program implementation, one respondent described that their "*initial recycled water program was established as a wastewater disposal option out of concern for discharge capacity... Expansions to the recycled water system since 2005 were based on prudent use of water resources and extending the limited potable supply.*"

In addition to specific regulatory requirements, state recycled water policy goals or mandates were selected as a driver by nearly a third (31%) of 2010 Survey respondents and as one of the three most important drivers by 14% of respondents. Additionally, 25% of respondents selected basin plan water quality objectives as one of the three most important drivers of implementation. Such objectives may relate to discharge volume requirements: one respondent who described Basin Plan Water Quality Objectives as the single most important driver of their program's implementation stated, "*Reducing our volume discharged to surface water helps us to meet increasingly more stringent effluent discharge loading requirements.*" Notably, "Ecological protection or enhancement goals" were drivers for the implementation of many

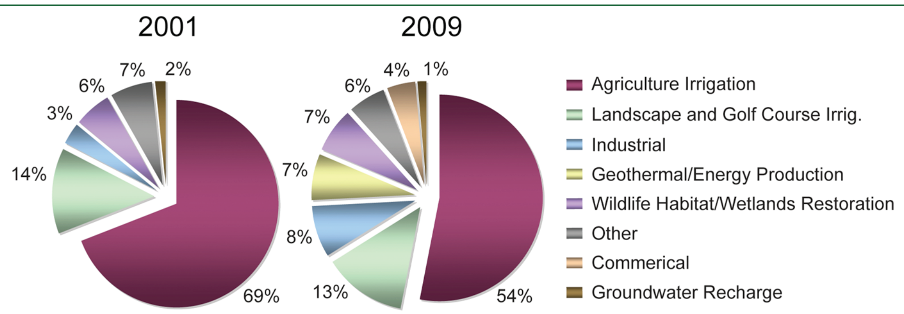

Figure 3. Beneficial uses of recycled water in Northern California in 2001 and 2009. 2001 Survey data shown include private agencies, which were excluded in the 2009 Survey; see the Supporting Information for a description of categories. In recent years, agricultural reuse volumes have remained relatively stable, becoming a smaller fraction of total reuse as new industrial and commercial uses are developed.

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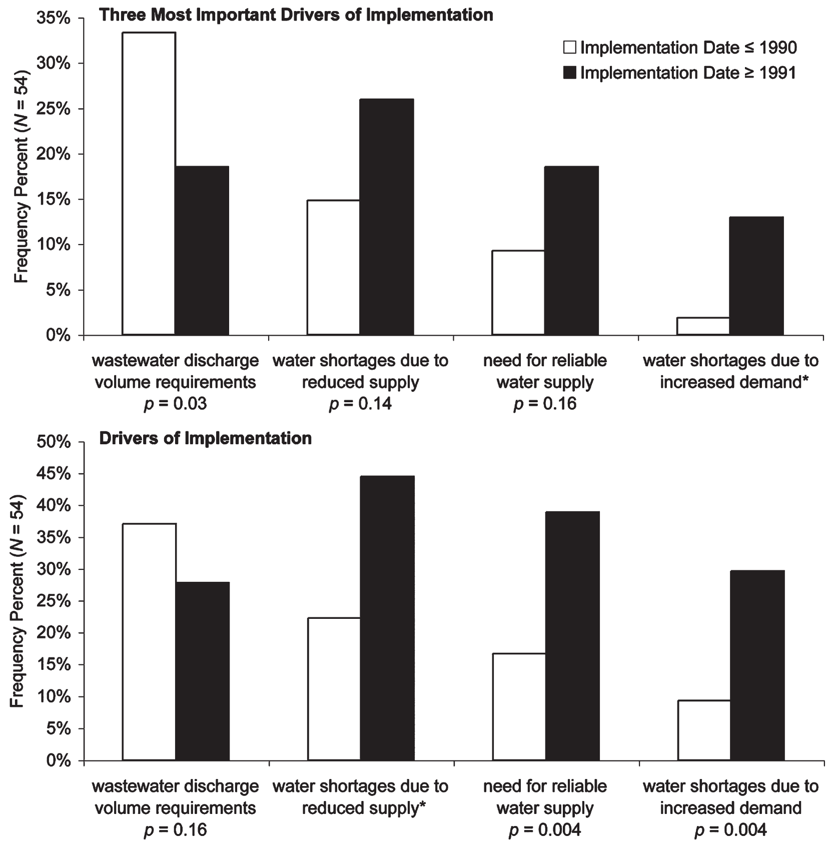

Figure 4. Results of χ^2 analysis by implementation date for specific factors indicated as one of the *Three Most Important Drivers* (top) or more generally a *Driver* of implementation (bottom) with *p*-values indicated (*estimated $p < 0.05$, see the Supporting Information).

programs (49%) but were rarely the most important drivers for these programs (12%). Recognition of ecological benefits from recycled water implementation exemplifies how issues may generate common ground between stakeholders, even if they are not of high priority to any one group. However, in 2001 and 2009, only 6−7% of reuse was for direct natural system/wildlife enhancement (Figure 3), indicating a missed opportunity for recycled water usage.

Controlling Wastewater Discharge and the Role of Regulation

"We needed a method [to] dispose of treated effluent. The only viable alternative was recycling."

Results demonstrate that regulatory requirements, such as those limiting discharge of wastewater, have historically played an important role in driving the implementation of water reuse in Northern California. The California Department of Public Health establishes state public health criteria for wastewater reclamation via Title 22 for bacterial quality, treatment types and levels, and facility reliability. Individual Regional Water Quality Control Boards (RWQCBs) and local water and health agencies may also develop more stringent policies and programs related to recycled water use.[10] In free-form responses, respondents who cited regulatory requirements as a very important category of drivers ($n = 28$) noted a range of specific regulatory pressures that drove the implementation of their program (see the Supporting Information for details). Various agencies were mandated or recommended to reduce percolation and increased reuse, cap discharge flows despite population growth, and eliminate point source discharges or meet dilution requirements in receiving waters during a particular time period (e.g., summer months).

Transitioning from Wastewater Discharge Control to Recycled Water As a Resource

"The original driver is not the current driver. Currently water supply and reliability is the most important driver."

Water shortages are commonly experienced throughout California, with several severe droughts throughout the period of implementation represented by survey responses (Figure 1). Recognizing such challenges, the California State Legislature enacted, for example, the Water Recycling Act of 1991 following a 5-year period of drought, setting new recycling goals from those established in 1977.[26,27] California's elaborate system of dams, canals, aqueducts, groundwater basins, and levees mediates the dichotomy between the state's water sources and demand centers, where 75% of the state's precipitation falls north of Sacramento and 75% of demand occurs in the population and farming centers to the south.[28] Because of the interconnectedness of water infrastructure in the state and the dependence of the largest urban centers on imported water, Northern California is not immune to challenges associated with limited water supplies. The growing awareness and response to water supply challenges are reflected in agency experiences. Programs implemented after 1990 were more likely to cite water supply needs including water shortages due to increased demand as drivers than older programs ($p < 0.01$, Figure 4 and Table S3). Conversely, wastewater discharge volume requirements were more frequently indicated as one of the three most important drivers of implementation by agencies with reported implementation dates before 1991 ($p < 0.05$, Figure 4), suggesting that early implementation of water reuse in the region was driven more frequently by such regulatory requirements. Newer recycled water programs were also more likely to cite the need for reliable water supply as an important driver of implementation ($p < 0.01$).

Only 5% of respondents in the present survey indicated climate change adaptation plans as a driver of recycled water program implementation. However, guidance by the California Natural Resources Agency[29] and Department of Water Resources[30] incorporate recycled water as a drought-proof and sometimes energy efficient water management strategy to complement climate change adaptation measures. As these goals filter from state planning to local practices, state policies for climate change adaptation may become more influential in recycled water implementation.

Although water shortages were not directly an issue during project implementation for some older projects, anticipated water shortages and need for long-term reliable sources are now critical issues, especially following the 2007−2009 drought in California. Projects that were implemented initially due to wastewater requirements may expand or find new benefits of reuse due to water supply challenges. One respondent illustrated this changing paradigm, stating the following:

> *"Fifteen years ago when we started our program, public acceptance was an issue. People did not understand recycled water, and we spent a lot of time educating potential customers and marketing recycled water. There was some 'fear factor' slowing the expansion. However, things have changed completely with the worsening drought, delta water problems, climate change awareness, and the public's desire to be 'green' and recycle everything now. We currently cannot get the water out to customers fast enough."*

Increasing reliability of potable water supplies (e.g., by sustaining groundwater supplies for drinking), supplementing water supply needs, or freeing up freshwater entitlements for use elsewhere were described as other drivers of implementation.

CHALLENGES FOR WATER REUSE IMPLEMENTATION IN NORTHERN CA

Challenges for water reuse projects include the following: a need for public information, education, and outreach; lack of available funding; recovery of capital costs for dual distribution systems; political support; a need for additional research for innovative technologies; flawed or unevenly applied regulations and standards; and concerns and liability over the unknown long-term health effects of chemical contaminants.[10,25] When asked to select factors that hindered program implementation at the respondent's site from a list of 20 specific options, 87% of respondents cited financial or economic challenges as one of the three most important hindrances to water reuse implementation (Table 2). One respondent commenting on the single most important hindrance to implementation simply stated, "*These projects are big ticket items outside the range of a rate base.*". Specific hindrances from the category of financial or economic disincentives shown in Table 2 dominated the selection of the most important challenges relative to other categories consistently through time. Despite various sources of policy and financial support for water reuse in California, lack of sufficient funding may be the main factor preventing recycling goals from being achieved.[20] Challenges in the next most-cited category, public perception and social attitudes, were indicated as an important hindrance by only 26% of respondents. In addition to those in Table 2, other factors hindering program implementation identified by individual respondents included soil salinity, lack of seasonal storage, and overcoming opposition from influential stakeholders.

Economic Constraints and Financial Implications of Challenges

> *"Generally in the industry and specifically for us, the cost of pipelines is really the only reason we haven't been recycling more."*

Several examples of recycled water programs in Northern California provide context for the expected costs of recent treatment facilities and distribution systems. For 16 projects seeking regional federal funding as part of the San Francisco Bay Area Recycled Water Coalition, the total costs ranged from \$220/AF to \$3400/AF, with a \$1200/AF median value, assuming a 20-year period for recycled water generated at the initial project yield (Table S11).[31] Recycled water deliveries expected for these projects range from 115 AFY (0.0045 m^3/s) initially to up to 28,000 AFY (1.1 m^3/s) in the future. A City of Palo Alto analysis indicated an annualized cost of \$2700/AF (over 30 years, in March 2008 dollars) expected for expansion of distribution facilities. This compared with a projected cost of \$1,600/AF by 2015 for wholesale purchase of potable water from the San Francisco Public Utilities Commission (SFPUC).[32] An earlier phase of the Palo Alto project completed in 2009 came to approximately \$3.4 million/mile of pipeline for construction base contract of approximately 5 miles of pipeline along US Highway 101 to the neighboring City of Mountain View.[33] A project under analysis by the SFPUC estimates \$9.4 million (including a 30% contingency) for approximately 6.5 miles of pipeline construction costs as part of a \$153 million recycled water treatment and distribution system.[34,35] To assist and encourage user connection to the recycled water system, agencies may provide financial incentives for recycled water use via a recycled water rate structure discounted from potable water rates (e.g., by 20% to 80%) or by offering services for establishing connections, retrofits, training, permit review, and testing.[36] However, in describing an important strategy to overcome cost recovery challenges (Q15, Table S12), one respondent described, "*Recycled water must be treated as a commodity and a utility rate charged to completely recover costs.*" Additional strategies adopted by agencies to address funding challenges are described in the Supporting Information. System cost recovery is often supplemented by grants and loans, including Title XVI through the US Bureau of Reclamation as well as Proposition 50 Grant and the State Revolving Fund loan Program for the State of California.[26,36]

2010 Survey respondents were asked to characterize, as quantitatively as possible, the impact of cited hindrances to implementation in terms of program cost, scope, and timing. Respondents indicated that hindrances led to a change in program cost ($n = 9$), reduced program scope ($n = 5$), delay of implementation ($n = 14$), project cancellation ($n = 7$), or other ($n = 1$). For a subset of these responses, estimated costs associated with impacts ($n = 21$) ranged from \$50,000 to almost \$100 million per agency. Estimates by respondents for changes in program cost represented construction cost increases over time, costs for additional studies, increased staff time, additional testing "*beyond reasonable needs*", "*huge*" impacts from years of delay, costs to upgrade to tertiary treatment, costs for new processes, and a combination of changes in program scope, changes in design, addition of professional consultants or a combination of conveyance pipes, distribution piping, tanks, and pressure stations.

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Issues related to institutional coordination were also noted for increasing project costs. Nearly a third of respondents indicated institutional coordination as a hindrance to implementation. One respondent described the following:

"While water agencies need recycled water to help them with long term supply issues, they cannot justify the increased costs and thus tend to be unsupportive. Water agencies are also concerned about loss of revenue with recycled water projects. If the water agency is not the same as the recycled water agency (as in our area), implementation of recycled water projects means a loss of revenue for the water district as customers are shifted to the recycled water agency. This means that the potable water agency must raise rates for the remaining customer base, which is very difficult in today's economic climate."

Limited Role of Negative Perceptions

"In 1984, the biggest hindrance was the negative perception by landowners next to the farms scheduled to receive recycled water today. Today the biggest hindrance is cost."

Since the 1970s, a significant amount of research has investigated reasons for public resistance to recycled water.[37,38] Although public perceptions of risks are identified as key impediments in the adoption of indirect potable water reuse,[39−41] nonpotable water reuse programs generally receive public support.[14] Thus, opposition surrounding high-profile indirect potable reuse is likely unrepresentative of the landscape of challenges faced by managers of non-potable reuse programs. A notable contrary case developed when homeowners actively opposed the use of recycled water for landscape irrigation in Redwood City, CA.[1] Analyses emphasize the importance of public engagement early during project conception and continuously throughout planning, design, and construction.[10,14] While utilities and consultants have developed more appropriate modes of communicating with the public, some remain skeptical about the safety of the practice, especially as projects are proposed in their community and the likelihood of human contact increases.[42−44] Nearly two-thirds of 2010 Survey respondents (61%) cited perceptions or social attitudes as hindrances to program implementation, though these factors were less frequently considered among the most important challenges to overcome. Forms of public communication (e.g., signage, symbols, and terminology) can influence consumer intentions to use, and willingness to pay for, recycled water,[45,46] and the media may play a role in constructing positive or negative perceptions of recycled water.[17,47]

The primary drivers of water reuse programs may also influence public opposition or acceptance. An early public opinion study in California indicated that those who believed water supply augmentation was necessary in California were somewhat less likely to be opposed to reclaimed water for drinking than those who did not believe that water was scarce.[38] Consequently, public education efforts to effectively communicate the need for water reuse are important. In the present study, respondents who cited wastewater discharge volume requirements as a driver of implementation were somewhat more likely to also cite a specific factor within the category of public perceptions and social attitudes as a hindrance ($0.1 < p < 0.2$). As freshwater supply and distribution agencies experience increased demands and pressures on existing resources, greater public awareness of augmentation needs may reduce challenges associated with public perceptions. Conversely, in communities where the drivers of recycled water are discharge-based, rather than supply driven, public perception problems may arise more readily. Organizational trust correlates with intended behavior toward using recycled water and may be an area of further focus for institutional practices to increase public acceptance.[48]

"Perceived human or environmental health risks due to constituents of emerging concern" was cited as a hindrance to implementation by almost half of respondents. Yet this factor was not correlated to program implementation date, reminding us that unknown or unregulated contaminants change in specific definition with time but have challenged managers for decades. Concern for residuals in recycled water has been expressed in various forms. In the 1970s and 1980s, issues of public perception were difficult to overcome, as recycled water was relatively unfamiliar and long-term safety of reuse for high-contact uses was unproven. Today, chemicals of emerging concern (CECs) are a topic for technological research and a source of concern for recycled water managers.[22] Noting this issue as an additional challenge to cost hindrances, one respondent commented, "*opponents are also trying to use the issue of emerging constituents as a way to portray the project in a negative light.*" Public perception of recycled water continues to be an important nontechnical challenge for water reuse implementation, especially with regards to CECs. However, the present study finds that economic issues, rather than public perception, stand as the largest hindrance to nonpotable reuse implementation for Northern California programs.

Responses to Recycled Water Policy. In 2009, the SWRCB adopted a California Recycled Water Policy "to increase the use of recycled water from municipal wastewater sources". The policy "strongly supports recycled water as a safe alternative to potable water for such approved uses". Despite the policy's stated objectives, whether the water reuse policy will actually accelerate efforts to develop and maintain new recycled water projects remains unclear. The legislation itself takes on a hopeful tone by striving for, among other items, increased use of recycled water "over 2002 levels by at least one million acre-feet per year (AFY) by 2020 and by at least two million AFY by 2030".[12]

Recycled water managers were questioned about their expectations concerning how the California Recycled Water Policy of 2009 will facilitate or hinder the implementation of new recycled water programs. Survey responses reveal both support and trepidation toward the policy, with a greater number of respondents voicing concern that the policy will hinder project implementation. According to respondents, a perceived beneficial impact of the policy stems from standardized and consistent guidance for recycled water projects. For example, the water reuse policy established a Blue Ribbon Panel for evaluating CECs that will apply to all projects across California and also contains language endorsing water reuse under the California Environmental Quality Act (CEQA). Second, many respondents viewed the policy favorably due to its singular management structure. The establishment of an overarching permitting process, and of salt and nutrient management requirements, in particular, drew positive reviews. As one manager put it, "*The standardization of salinity and nutrient management provisions among the various regional boards should facilitate reuse and make it easier for some projects to get permitted.*". Thus, for water reuse project managers, the provision of administrative, legal, and scientific continuity across state, regional, and local agencies was perceived as the most beneficial aspect of the policy.

Much of the skepticism expressed for the 2009 policy may be traced to funding issues. A majority of respondents (19 of 30 question responses) felt the policy would obstruct new projects through onerous regulatory and cost requirements. According to a number of managers, while statewide project streamlining and standardization is important, ultimately the fate of projects will depend on adequate funding support. A common refrain among respondents was a concern over added administrative layers that will arise with new oversight and reporting requirements. In sum, the perceived presence of additional financial costs and administrative requirements have led nearly 2 of every 3 survey respondents to suggest the 2009 water reuse policy will in some way hinder new project implementation. From a management perspective, results suggest that the 2009 policy has done little to alter the perceived drivers and hindrances of water reuse project implementation for managers in Northern California.

■ SIGNIFICANCE

A diverse body of responses from the 2010 Survey illuminates a number of influential drivers of water reuse implementation, including the protection of ecosystems, meeting wastewater discharge requirements, and needs for water supply and reliability. Throughout the analysis, we detect manifestations of the intrinsic links between water supply and quality: threats of long-term diminished water quality (e.g., seawater intrusion) necessitates new water conservation and reuse measures, while new water supplies of altered quality may galvanize community opposition. Although water supply agencies increasingly face challenges associated with population growth and drought, wastewater agencies have traditionally approached recycled water as an issue of disposal. This push/pull duality that either push implementation forward (via regulatory requirements for wastewater discharge) or pull agencies into recycled water programs (by increased demand for water) is apparent. Results provide evidence of changing perspectives toward recycled water management, from a waste disposal issue toward a water supply resource opportunity.

Specifically, our study reveals the following: 1) In Northern California, water reuse programs are widely distributed across 48 counties and, though more numerous than programs in the 10 Southern California counties, are often smaller in annual reclaimed water delivery volumes. This finding highlights how management experience across both urban and rural regions of Northern California differ from the predominance of highly urbanized centers in the south. 2) Regulatory requirements that limit discharge played an important role in motivating many water reuse programs in Northern California. However, a trend away from reuse as a wastewater disposal issue is documented, as water supply and reliability become more prevalent drivers of water reuse. 3) Although ecosystem enhancement or protection goals are frequently cited as drivers of water reuse, such goals are rarely the most important drivers for reuse programs. Few water reuse programs in California have been implemented for the purpose of ecosystem enhancement. 4) Negative perceptions of water reuse were not frequently major hindrances to implementation of water reuse programs in Northern California. Public perception of water reuse may be positively influenced by a shift in view of recycled water toward that of a valuable resource and as public knowledge of water supply challenges increases. 5) Economic issues stand as the largest hindrance to successful project implementation from a management perspective. In particular, smaller water reuse programs are less frequently incentivized by federal or state grants and loans, while larger programs have somewhat greater challenges associated with distribution system costs.

Failure to meet statewide reuse goals results largely from lack of sufficient funding for water recycling, as the cheapest recycled water opportunities have already been exploited.[10] Following three years of drought and recent passage of the Safe, Clean, and Reliable Drinking Water Supply Act of 2010 by the State of California that included \$1.25 billion general obligation bond proposal for Water Recycling and Water Conservation, the physical and political climates may be ripe for aggressive implementation of new water reuse programs, where financially viable, socially accepted, and technically sound. Yet the legislature's 2010 decision to postpone the water bond initiative for at least two years[28] is testament to the realities of financial limitations for new water infrastructure in California.

■ ASSOCIATED CONTENT

S Supporting Information. (1) Methodological details, (2) a brief description of recycled water policy and regulation in California, and (3) additional analysis and summary tables. This material is available free of charge via the Internet at http://pubs.acs.org.

■ AUTHOR INFORMATION

Corresponding Author

*Phone: 650.721.2615. Fax: 650.725.8662. E-mail: luthy@stanford.edu.

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■ REFERENCES

(1) Ingram, P. C.; Young, V. J.; Millan, M.; Chang, C.; Tabucchi, T. From controversy to consensus: The Redwood City recycled water experience. *Desalination* **2006**, *187*, 179–190.

(2) Rosenblum, E. Selection and implementation of nonpotable water recycling in "Silicon Valley" (San Jose area) California. *Water Sci. Technol.* **1999**, *40* (4–5), 51–57.

(3) Hermanowicz, S. W.; Diaz, E. S.; Coe, J. Prospects, problems and pitfalls of urban water reuse: A case study. *Water Sci. Technol.* **2001**, *43* (10), 9–16.

(4) Sheikh, B.; Cort, R. P.; Kirkpatrick, W. R.; Jaques, R. S.; Asano, T. Monterey waste-water reclamation study for agriculture. *Res. J. Water Pollut. Conrol Fed.* **1990**, *62* (3), 216–226.

(5) Nakamoto, M., Watsonville recycled water project story: Preserving agriculture in the Pajaro Valley. In *WateReuse California Annual Conference*, San Diego, CA, 2010.

(6) Gearheart, R. A. Use of constructed wetlands to treat domestic waste-water, City of Arcata, California. *Water Sci. Technol.* **1992**, *26* (7–8), 1625–1637.

(7) Levine, B.; Reich, K.; Sheilds, P.; Suffet, I. H.; Lazarova, V. Water quality assessment for indirect potable reuse: A new methodology for controlling trace organic compounds at the West Basin Water Recycling Plant (California, USA). *Water Sci. Technol.* **2001**, *43* (10), 249–257.

(8) Everest, W. R.; Watson, I. C.; MacLain, D. Groundwater reclamation by innovative desalting in Orange County, California. *Desalination* **1998**, *117* (1−3), 197–202.
(9) Asano, T.; Cotruvo, J. A. Groundwater recharge with reclaimed municipal wastewater: Health and regulatory considerations. *Water Res.* **2004**, *38* (8), 1941–1951.
(10) *Water Recycling 2030: Recommendations of California's Recycled Water Task Force*; Department of Water Resources: Sacramento, CA, 2003.
(11) *California Statewide Recycled Water Survey in 2001*; California State Water Resources Control Board Sacramento, CA, 2002.
(12) *Recycled Water Policy*; State Water Resources Control Board: Sacramento, CA, 2009. http://www.swrcb.ca.gov/water_issues/programs/water_recycling_policy/docs/recycledwaterpolicy_approved.pdf (accessed November 22, 2009).
(13) *Strategic Plan Update 2008−2012*; California State Water Resources Control Board: Sacramento, September 2, 2008.
(14) Mantovani, P.; Abu-Orf, M.; O'Connor, T. In *Nonpotable water reuse management practices*, Bridging the Gap: Meeting the World's Water and Environmental Resources Challenges, Proceedings of World Water and Environmental Resources Congress, Orlando, Florida, 2001; Phelps, D., Sehlke, G., Eds.; ASCE: Orlando, FL, 2001.
(15) Mills, R. A.; Asano, T. A retrospective assessment of water reclamation projects. *Water Sci. Technol.* **1996**, *33* (10−11), 59–70.
(16) Mills, R. A.; Karajeh, F.; Hultquist, R. H. California's Task Force evaluation of issues confronting water reuse. *Water Sci. Technol.* **2004**, *50* (2), 301–308.
(17) Ching, L.; Yu, D. J. H. Turning the tide: informal institutional change in water reuse. *Water Policy* **2010**, *12*, 121–134.
(18) Stenekes, N.; Colebatch, H. K.; Waite, T. D.; Ashbolt, N. J. Risk and governance in water recycling public acceptance revisited. *Sci. Technol. Hum. Values* **2006**, *31* (2), 107–134.
(19) National Database of Water Reuse Facilities. In WateReuse Foundation: 2008.
(20) *California State Municipal Wastewater Recycling Survey in 2009*; California State Water Resources Control Board: Sacramento, CA, April, 2011.
(21) *California Municipal Wastewater Reclamation in 1987*; California State Water Resources Control Board: Sacramento, CA, June, 1990.
(22) Drewes, J. E.; Anderson, P.; Denslow, N.; Olivieri, A.; Schlenk, D.; Snyder, S. *Monitoring strategies for chemicals of emerging concern (CECs) in recycled water: Recommendations of a Science Advisory Panel*; California State Water Resources Control Board: Sacramento, CA, April 15, 2010.
(23) *California Water Plan Update 2009*; Bulletin 160-09; 2009.
(24) Higgins, J.; Warnken, J.; Sherman, P. P.; Teasdale, P. R. Survey of users and providers of recycled water: Quality concerns and directions for applied research. *Water Res.* **2002**, *36* (20), 5045–5056.
(25) Miller, G. W. Integrated concepts in water reuse: Managing global water needs. *Desalination* **2006**, *187* (1−3), 65–75.
(26) *Water Recycling Funding Program Division of Financial Assistance Strategic Plan*; California State Water Resources Control Board: Sacramento, 2007.
(27) Seiver, O. H. *Inventory of major California environmental legislation and accomplishments since 1970*; California State University: Northridge, 1995.
(28) Hanak, E.; Lund, J.; Dinar, A.; Gray, B.; Howitt, R.; Mount, J.; Moyle, P.; Thompson, B. B. *Managing California's water: From conflict to reconciliation*; Public Policy Institute of California: San Francisco, CA, 2011.
(29) *2009 California Climate Adaptation Strategy: A report to the Governor of the State of California in Response to Executive Order S-13-2008*; California Natural Resources Agency: Sacramento, CA, 2009.
(30) *Managing an uncertain future: Climate change adaptation strategies for California's water*; California Department of Water Resources: Sacramento, CA, 2008.
(31) *San Francisco Bay Area Recycled Water Coalition Project Summary*; San Francisco Bay Area Recycled Water Coalition: Antioch, CA, March 3, 2011. http://www.barwc.org/ (accessed August 1, 2011).
(32) *Recycled Water Facility Plan*; City of Palo Alto: Palo Alto, CA, December, 2008.
(33) *MV/Moffet area recycled water pipeline project: Project completion report*; BACWA: City of Palo Alto, October, 2009.
(34) *San Francisco Westside Recycled Water Project Alternatives Workshop Series: Evaluation of Alternatives*; San Francisco Public Utilities Commission: San Francisco, CA, 2011.
(35) Munoz, C. San Francisco Public Utilities Commission, San Francisco, CA. Personal communication, 2011.
(36) RMC *City of Palo Alto - Recycled Water Market Survey Report (Final Report)*; Palo Alto, CA, July, 2006.
(37) Po, M.; Kaercher, J. D.; Nancarrow, B. E. N. *Literature review of factors influencing public perceptions of water reuse*; CSIRO Land and Water: 2003.
(38) Bruvold, W. H.; Ward, P. C. Using reclaimed wastewater: Public opinion. *J. - Water Pollut. Control Fed.* **1972**, *44* (9), 1690–1696.
(39) *Communication principles and practice, public Perception and message effectiveness*; WateReuse Foundation: Alexandria, VA, 2008.
(40) Hurlimann, A.; Dolnicar, S. When public opposition defeats alternative water projects - The case of Toowoomba Australia. *Water Res.* **2010**, *44* (1), 287–297.
(41) Marks, J. S. Taking the public seriously: The case of potable and non potable reuse. *Desalination* **2006**, *187* (1−3), 137–147.
(42) Hartley, T. W. Public perception and participation in water reuse. *Desalination* **2006**, *187* (1−3), 115–126.
(43) Dolnicar, S.; Hurlimann, A.; Grun, B. What affects public acceptance of recycled and desalinated water? *Water Res* **2011**, *45* (2), 933–943.
(44) Bruvold, W. H. Public-opinion on water reuse options. *J. - Water Pollut. Control Fed.* **1988**, *60* (1), 45–49.
(45) Menegaki, A. N.; Mellon, R. C.; Vrentzou, A.; Koumakis, G.; Tsagarakis, K. P. What's in a name: Framing treated wastewater as recycled water increases willingness to use and willingness to pay. *J. Econ. Psychol.* **2009**, *30* (3), 285–292.
(46) Tsagarakis, K. P.; Mellon, R. C.; Stamataki, E.; Kounalaki, E. Identification of recycled water with an empirically derived symbol increases its probability of use. *Environ. Sci. Technol.* **2007**, *41* (20), 6901–6908.
(47) Ching, L. Eliminating 'yuck': A simple exposition of media and social change in water reuse policies. *Int. J. Water Resour. Dev.* **2010**, *26* (1), 111–124.
(48) Nancarrow, B. E.; Leviston, Z.; Po, M.; Porter, N. B.; Tucker, D. I. What drives communities' decisions and behaviours in the reuse of wastewater. *Water Sci. Technol.* **2008**, *57* (4), 485–491.