

# Grey Water: Agricultural Use of Reclaimed Water in California

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**Abstract:** Potential for use of recycled water<sup>1</sup> is great, especially for agricultural irrigation, which comprises by far the highest percentage of water taken from developed sources in the arid and semi-arid regions of the world. In California, 80% of developed water is used for agriculture, and the same pattern prevails throughout the western United States. The potential for recycled water use in agriculture remains under-realized because of numerous impediments. Understanding how the incentives and impediments to agricultural reuse vary based on local context is critical to understanding the tradeoffs and technology requirements for different end uses of recycled water. Public perceptions about the safety of reclaimed water (from human waste) were a major impediment to water recycling until recent years. Several pioneers of water recycling have demonstrated—as specialists in the field of social psychology have hypothesized—that these attitudes are ephemeral and can be changed with proper outreach, demonstration, and education. Another impediment is the regulatory structure in some states. Water rights issues are another impediment specific to some western states in the United States. Cost differences for delivered water from traditional sources versus recycled water can be another challenge potentially requiring financial incentives in the interest of the greater good. One other impediment to the use of recycled water for agricultural irrigation is competition with other demands for the same water—landscape, golf course, industrial, and potable reuse. Potential for increased use of recycled water is great if impediments are removed and incentives are provided at the local, state, and/or federal levels to close the gaps (geographic and otherwise) between the utilities and the farmers.

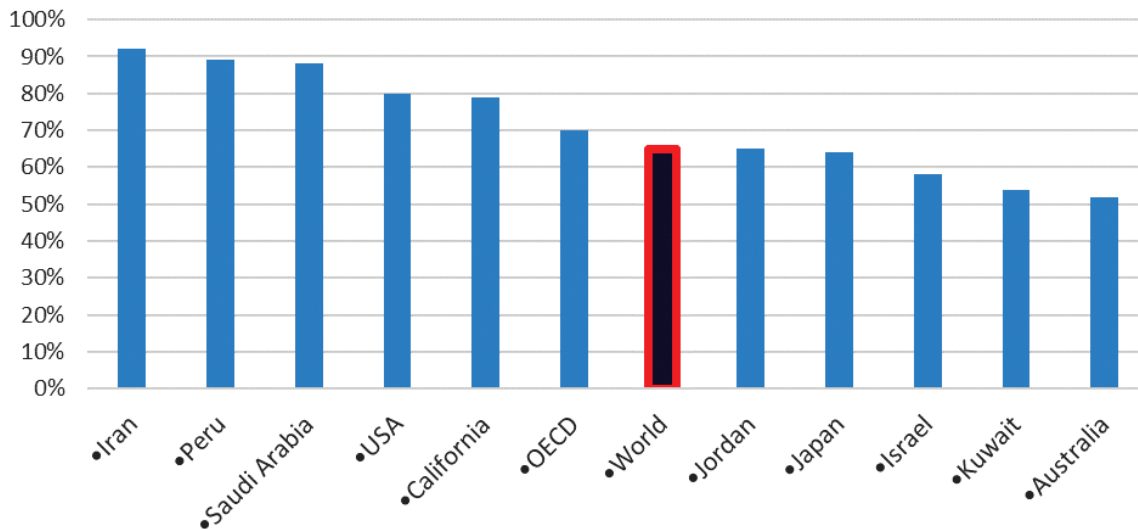
**Keywords:** *agricultural reuse, recycled water, reclaimed water, water reuse, California agriculture*

<sup>1</sup> As used in this paper, “recycled water” and “reclaimed water” are synonymous and interchangeable. In California and some other states, “recycled water” is consistently employed, while in Florida and some other states “reclaimed water” is the term of art.

This paper is a high-level overview of the use of recycled water (treated municipal wastewater) for agricultural irrigation for crop production. The majority of the world’s food supply comes from agriculture which is dependent on water, whether from rain, irrigation, or a combination. In the arid and semi-arid regions of the world irrigation is essential for nearly all crop production. In these regions, the vast majority of developed water is dedicated to agriculture. As shown in Figure 1, the world-wide percentage of

water used for agriculture is more than 60%, with the USA (and California) percentages hovering around 80%.

This work is based in part on the results of research supported by the Water Environment and Reuse Foundation (WE&RF) (Sheikh et al. 2018). The WE&RF research project is titled “State of Irrigated Agricultural Water Reuse — Impediments and Incentives.” This paper presents highlights from a comprehensive literature review, interviews with farmers and utilities, and case



**Figure 1.** Proportion of developed water used for agricultural irrigation in various world regions. Sources: United Nations Food and Agriculture Organization (UN FAO 2010); California Department of Water Resources (Pezzetti and Balgobin 2016); Organization for Economic Co-operation and Development (OECD 2018); Snapshot of Australian Agriculture (ABARES 2018).

studies of specific projects. A team of scientists from the United States, Australia, Japan, Spain, and the Middle East contributed to the project. Another source of data is the recently completed 2015 survey of recycled water use in California, conducted by the California State Water Resources Control Board in collaboration with the California Department of Water Resources (DWR) (Pezzetti and Balgobin 2016).

### From Wastewater Use to Water Recycling

Agricultural water reuse practices vary significantly around the world, ranging from the use of untreated wastewater in regions where wastewater treatment is limited, through the use of highly treated recycled water in the more developed regions. In either case, both food and non-food crops are commonly irrigated. Across all contexts, water scarcity is the common motivation for agricultural reuse.

### Methods

While “Grey Water” in this special journal issue refers to recycled water, graywater per se is defined as untreated wastewater that excludes wastewater from toilets and, in most states that have graywater regulations, wastewater from

kitchen sinks and dishwashers. While this type of graywater can be a significant source of irrigation water for landscaping under certain circumstances for individual residences and businesses, it is estimated to comprise a very small fraction (by volume) of the total water recycling in California. For these reasons, the discussion that follows is confined to reclamation of municipal wastewater and recycling the reclaimed water for agricultural irrigation. In the context of this special issue, “Grey Water” encompasses non-conventional sources of water derived predominantly from domestic wastewater, including the following:

**Recycled Water**, also called “**reclaimed water**” is a regulated, treated water suitable for specifically allowed classes of uses. **Graywater** is untreated wastewater from domestic sources (except toilet/urinal wastes, kitchen sink, and dishwasher) and allowed to be used with specific regulatory restrictions.

In order to provide a general overview of the subject, the authors drew upon summaries of literature reviews, results of recent research, outcome of recent surveys, and professional knowledge of the field collected over several decades of work in the field of water reuse in the United States and abroad, with some emphasis on California conditions.

## Results

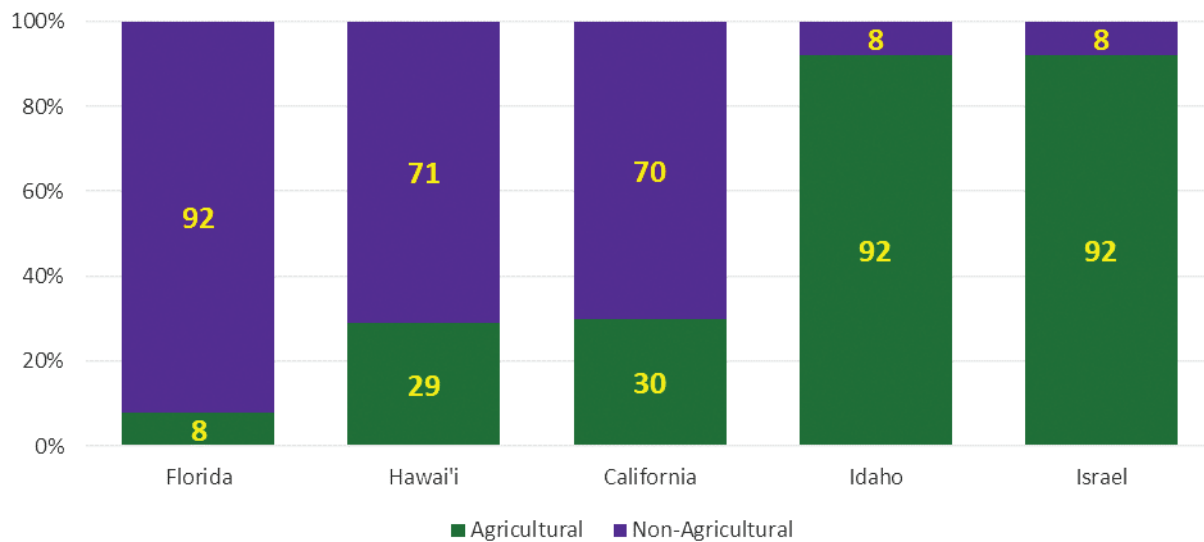
### Use of Water in Agriculture

The predominance of water utilization for agriculture emphasizes the importance of the nexus between water and food production, essential for human life and the economic health of nations. In addition to food, agriculture provides many other products necessary for economic development in the built environment, including construction materials, textiles, and medicines.

Agricultural use of water resources accounts for the largest demand on water by far, while use of recycled water in agriculture, in most regions, accounts for a much smaller proportion of the overall recycled water use. Agricultural percentage of use of recycled water in California is illustrated in Figure 2, and contrasted with corresponding percentages in Florida, Hawai'i, Idaho, and Israel. While the percentages in Idaho and Israel reflect the general pattern of water use in agriculture (shown in Figure 1), California's lower percentage of recycled water use shows a sharply different picture, possibly due to the more aggressive urban uses of recycled water, where non-agricultural customers are at closer proximity to the sources of water.

The contrast between California, Florida, and Hawai'i on the one hand, and Idaho and Israel on

the other, is striking. This contrast may well be an illustration of the effect of impediments to the use of recycled water for agriculture in some regions in contrast to the relative lack of impediments in Idaho and strong incentives in Israel. While impediments play a large part in the differences noted in Figure 2, there is also simply more urban demand for recycled water in California and Florida for such applications as landscape irrigation, industrial uses, and increasingly, for potable reuse. The coastal urban utilities in California are generally better resourced than their interior counterparts and thus are better able to provide funding for urban recycled water projects. Increased urban uses of recycled water may have contributed to the declining proportion of recycled water used in agriculture in California since the previous survey in 2009 (the volume of recycled water used in agriculture stayed about the same while overall recycled water use increased). Likewise, in Florida, the use of recycled water for urban and industrial uses is actively incentivized via larger potable water offset credits (Florida DEP 2016). In some regions, such as in southern California, urban reuse can make more economic sense due to long distances to agricultural lands, pumping costs, vulnerability, and increasing costs of imported water supplies.



**Figure 2.** Proportion of recycled water used for agriculture in various regions. Sources: Hawaii 2013; Florida DEP 2016; Pezzetti and Balgobin 2016; Nichols 2017 (personal communication on March 7, 2017 with the Idaho State regulator for uses of recycled water); Sheikh et al. 2018.

### Use of Recycled Water in Agriculture

The state of Florida ranks first among U.S. states in total annual water reuse, followed closely by California. The aggregated total water reuse by all the other states is much less than that in either Florida or California. Table 1 illustrates these standings in total water reuse.

Of the totals presented in Table 1, a fraction is used for agriculture, as illustrated in Figure 2. In California, that fraction is currently 30%, as estimated in a 2015 survey of water reuse throughout California by the California DWR (Pezzetti and Balgobin 2016). A historical depiction of trends in use of recycled water in the various hydrologic regions of California, based on the 1970-2015 survey results, is presented in Figure 3.

The rate of increase of water reuse in California declined since the most recent (2009) survey. The reasons for this decline are attributed in part to the recession of 2008, which caused lower water sales and limited capital investments in water reuse infrastructure. The recession was followed closely by a prolonged drought from 2011 to the end of

2015, causing water rate hikes, potable water supply issues, mandatory conservation, and less wastewater generation (resulting in some projects recycling less water) with higher salt content. However, the drought appears to have motivated planning for numerous water reuse projects into the coming years, incentivized by state and federal grants and loans.

The DWR 2015 survey (Pezzetti and Balgobin 2016) revealed the following breakdown of recycled water among various categories of applications, shown in Figure 4.

An interesting water quality aspect of use of recycled water in agriculture is that for most crops it is not necessary to use a highly treated recycled water. As shown in Figure 5, undisinfected secondary recycled water accounts for the largest volume of water reuse in agriculture with disinfected tertiary treated recycled water (the highest non-potable grade) in second place.

In California, disinfected tertiary recycled water is allowed for unrestricted irrigation of all food crops, including root crops. Use of undisinfected secondary effluent is allowed for surface irrigation

**Table 1.** Water reuse flow rates for nine states reporting data in 2015.

State	Population	Reported Water Reuse, MGD*	Reported Water Reuse, m3/d**
Florida	18,019,093	663.0	2,500,000
California	36,121,296	580.0	2,200,000
Texas	23,367,534	31.4	120,000
Virginia	7,628,347	11.2	42,000
Arizona	6,178,251	8.2	31,000
Colorado	4,751,474	5.2	20,000
Nevada	2,484,196	2.6	10,000
Idaho	1,461,183	0.7	3,000
Washington	6,360,529	0.1	400

\* MGD = million gallons per day

\*\* m3/d = cubic meters per day (rounded to two significant digits)

Source: Adapted from Florida 2015 Reuse Inventory, with credit to WaterReuse Foundation National Database of Water Reuse Facilities and California State Water Resources Control Board, from its previous survey results (Florida DEP 2016).

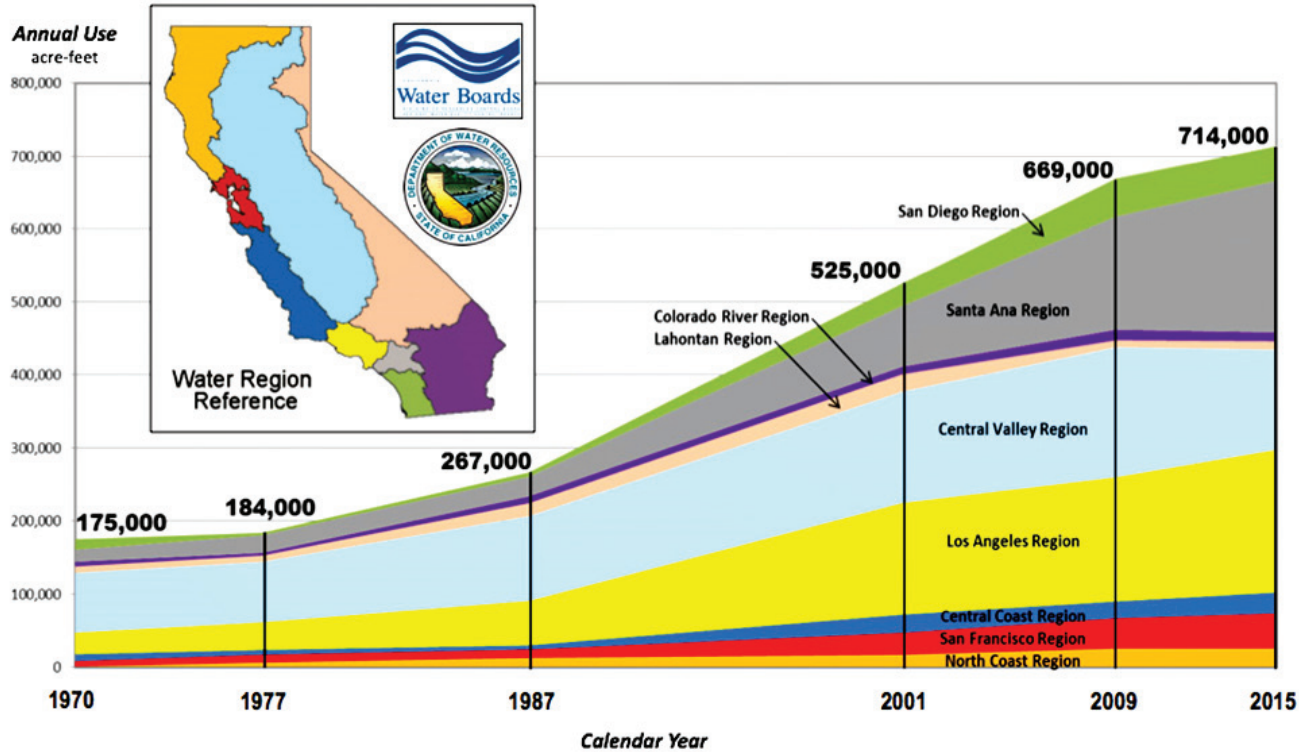


Figure 3. Historical growth of water recycling in California, from 1970 to 2015. Source: Pezzetti and Balgobin 2016.

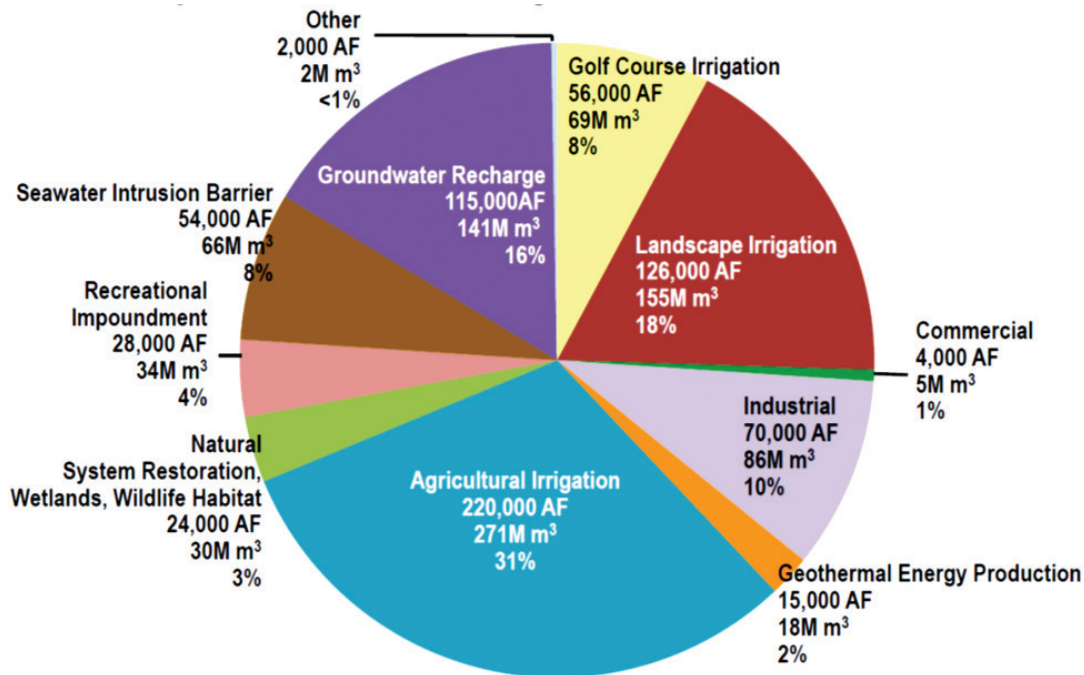
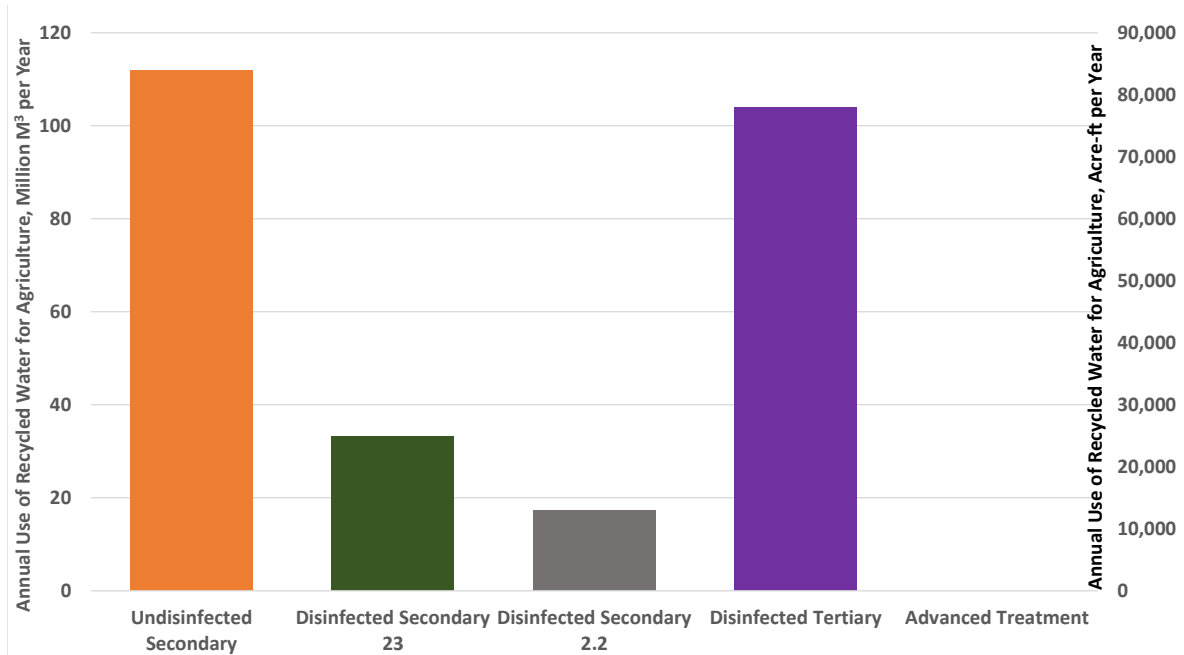


Figure 4. Distribution of California water reuse among application categories – from the 2015 DWR Survey. Source: Pezzetti and Balgobin 2016.



**Figure 5.** Level of treatment for agricultural uses of recycled water in California. Source: Pezzetti and Balgobin 2016 (DWR 2015 Water Resuse Survey); re-plotted for greater clarity.

of orchards and vineyards where the edible portion is produced above ground and not contacted by the recycled water. In addition, secondary effluent is allowed for irrigation of non-food bearing trees including Christmas trees, fodder and fiber crops, pasture for non-milk animals, seed crops, food crops undergoing commercial pathogen-destroying processes, ornamental nursery stock, and sod farms. For a complete list of allowed uses of recycled water in California, under four different treatment levels, refer to Title 22, Division 4, Section 60304 (Use of Recycled Water for Irrigation) of the California Code of Regulations. The allowed uses of recycled water in California are summarized at <https://www.sdcwa.org/sites/default/files/files/water-management/recycled/uses-of-recycled-water-new.pdf>.

### Drivers for Use of Recycled Water for Agriculture

A broad variety of drivers motivate for switching from conventional water sources to recycled water for irrigation. Kunz et al. (2016) conducted a detailed literature review of drivers for and against water recycling. They generally classified these drivers into social, policy, technical, natural, and

economic categories and noted the importance of scale in driver applicability. A condensed summary of their findings is presented in Appendix A.

In California, nearly all of these drivers were observed to be at work, depending on locality, state of drought, and the persistence of a visionary champion capable of removing impediments and bringing together stakeholders that individually would not have had the motivation to spearhead a water recycling project. This has been most evident in southern California where water agencies and wastewater utilities have collaborated to implement some of the largest water recycling projects, usually led by a tenacious champion unwilling to accept “no” for an answer. In the central coastal region of California, agricultural use of recycled water has been successfully implemented in Monterey and Watsonville over the past 20 years. The long-running success of these projects is credited with motivating other agricultural reuse projects in other parts of the world.

### Impediments to Use of Recycled Water in Agriculture

**Water Quality Impediments.** Water quality-related impediments to agricultural use of recycled water

may include salt concentrations, pathogenic microorganisms, chemical contaminants, and water quality variability. Water quality can influence both the process of agricultural production and the end-product's quality. Salinity, sodium, and boron in higher concentration can impact the productivity of irrigated fields. The more water conservation is practiced in prior uses, the higher the salt concentration of wastewater will be. The type of irrigation (sprinkler, drip emitters, subsurface drip) and local soil characteristics influences the degree of salt impact.

#### ***Risk Evaluation and Management.***

Microorganisms are found in nearly all waters and are prevalent in urban wastewaters. Risks can be associated with both agricultural products and production processes. Multiple opportunities exist to reduce microbial risk along the food production supply chain. The first begins at the wastewater treatment plant during advanced treatment stages. Proper operation can reduce the microbial load of recycled waters to below ambient surface water levels. Then, on the farm, recycled water can be used for non-edible agricultural products and irrigation methods that avoid contact between irrigation water and edible portions can be used. It should be noted, however, that the most stringent category of recycled water regulated for agricultural irrigation reduces risk to acceptable levels even when spray irrigation of edible crops is practiced. At the processing stage, edible portions can be rinsed or outer leaves removed. At the retail, institutional use, and consumption stages, edible portions can be further rinsed before consumption; however, this stage should not be relied upon and edible produce must arrive at the consumption stage free of pathogens.

Risk identification, characterization, tracking, avoidance, and mitigation are part of a sound food safety strategy. The Hazard Analysis and Critical Control Point (HACCP) process has well-established procedures for risk management in the food industry. HACCP provides useful principles for thinking about one aspect of the use of recycled water for agricultural irrigation: product contamination risk.

Also, based on plant physiology, root systems and xylem cells serve as filters making it very unlikely that pathogens will enter edible portions of

crops from root uptake. The more likely pathway of contamination for edible plants (food products) is through spray irrigation of edible portions depositing pathogens on the surface of the plant.

***Perceived Risks As Impediments.*** With respect to perceived risk, in the highly competitive global markets for agricultural products, fear of food contamination can influence a buying decision even if the fear is not consistent with results of a hazard analysis. In the early years of irrigation with recycled water this was a concern of growers who were either considering or using recycled water. Growers were concerned about both wholesale buyer reaction and end-user reaction, and even were concerned that rivals growing the same crop without recycled water would raise the issue to influence market outcomes. As the years of incident-free irrigation with recycled water grow, farmer and market concerns have reduced.

***Public and Farmer Acceptance Impediments.*** Use of recycled water has not emerged as a product perception issue in the agricultural irrigation sphere, and market participants rarely know or care about the origins of their food's irrigation water. Non-food agricultural markets have shown even less concern. Public attitudes about use of recycled water have improved in California over the last several decades, especially for non-potable water reuse. Several longitudinal surveys have shown these positive trends for different communities in the United States and Australia (Sheikh and Crook 2014). In Israel, the public has completely accepted the practice of water recycling for agriculture. In the United States, potential customers, farmers, utilities, and some regulators with little or no knowledge of (or experience with) water recycling exhibit a skeptical or negative initial reaction.

***Technological Impediments.*** The technology of water treatment is well established. An impediment for growers involved in high-end production that demands exact growing conditions is the variability of recycled water's chemistry. Recycled water treatment facilities focus on carrying out required treatment processes and meeting public and environmental health goals for recycled water quality. The targets in terms of concentrations of constituents in the water are regulatory, not market driven. In some instances, such as Watsonville,

California, the treatment facility intermittently blends its advanced recycled water with well water to meet non-regulatory salinity goals required by farmers.

Two areas of impediments potentially exist. One is availability of recycled water storage so near-constant flows of urban water can be applied when farmers actually irrigate. Wastewater flows regularly out of cities 24 hours per day. Farmers primarily irrigate during or close to daylight hours. Without sufficient storage, reclaimed water resulting from nighttime wastewater flows would not be available to farmers.

The next technological impediment involves the extent to which farmers know what quality water they are receiving. Recycled water meets minimum health standards but varies in salinity, nutrient levels, and other measures. Treatment plants already monitor nearly every quality measure of concern to farmers. Therefore, it is necessary to communicate water quality mitigation measures to farmers in time for farmer to take the necessary on-farm management decisions to optimize their irrigation practices.

***Regulatory Impediments and Institutional Settings.*** In the early stages of agricultural use of recycled water, stakeholders felt that the lack of regulatory roadmaps to permitting and operation of facilities was a significant barrier to new projects. Colorado and six other states specifically prohibit use of any recycled water for irrigation of edible crops including fruits and nuts. Regulations are evolving across the U.S. that increasingly allow for agricultural use of recycled water, although they differ in their thrust and details, ranging from prohibitive to permissive. The challenge to regulators and legislators is to base regulations on science and on the success story of ongoing agricultural enterprises using recycled water, while also recognizing that recycled water is an underutilized beneficial resource.

***Economic and Financial Impediments.*** In stakeholder interviews, economic risks were raised as the most important impediment to recycling projects for agricultural use. Cost impediments were especially emphasized in the case of smaller municipal utilities. Economically, the least-cost approach to water supply is to take water that is

naturally stored in aquifers or winter snowpack and delivered by rivers. In most parts of the world, the low-cost, low-hanging fruit of water supply has been claimed. The unique characteristics of recycled water start with its non-seasonality. Cities, even those dependent on rainfall-supplied surface waters, generate a fairly constant flow of wastewater regardless of season, hence a consistent supply of recycled water. Agricultural regions rarely enjoy an equivalent engineered storage system and therefore experience the risk of extended drought periods. The flow reliability of recycled water is a recognized benefit to farmers.

***Supply/Demand Imbalance Impediments.*** The consistent diurnal and year-round flows from urban recycled water that serve farming regions may require additional storage to meet two imbalances related to agricultural irrigation. The first challenge is due to the general lack of agricultural irrigation in the middle of the night. The second is related to the lack of demand for irrigation water during the rainy season. Additional storage can help address these problems but require significant capital expenditures. Of the two challenges, the more serious imbalance relates to lack of farmer demand for recycled water during the rainy season. Storage is a potential solution to this problem, but the scale of required seasonal storage is much larger than the diurnal need for storage. Groundwater aquifers can serve as storage reservoirs, where geological formations are suitable for the purpose. During non-irrigation periods, the reclaimed water could be used for other beneficial purposes or discharged to surface waters in compliance with state/federal regulations.

***Coordination Impediments.*** In California, as in many other states, different utilities are charged with the responsibility to manage different parts of the water cycle (raw water, bulk water, potable water, stormwater, floodwater, agricultural water, urban wastewater, retail sale of water to the end user, etc). Implementation of a newly conceived recycled water project usually involves coordination among two or more of these utilities—sometimes a formidable challenge. The earliest and most successful water reuse projects, especially for agriculture, were those involving one agency handling both potable water and wastewater management responsibilities.



## Case Studies

In Table 2, several case studies are summarized, illustrating the specific drivers, impediments, incentives, and other details about each case in which impediments were successfully overcome and the project was ultimately implemented successfully. The Monterey case is described in more detail below.

### Monterey County, California

The federal Clean Water Act of 1972 provided substantial subsidies to utilities across the United States to upgrade wastewater treatment in their

regions so as to eliminate discharges of pollutants to the nation's receiving waters. Supported by the Clean Water Act subsidies, a basin planning program for the central coastal region of California recommended a regional wastewater collection and treatment system for northern Monterey County. The U.S. Environmental Protection Agency agreed to provide funding for this regional plant on the condition that the effluent from the treatment plant would be reclaimed and reused for agriculture, in part to relieve demand on the over-drafted aquifers and the consequent seawater intrusion. Farmers were highly skeptical about using recycled water and demanded proof-of-concept with a

**Table 2.** Summary of drivers, impediments, and incentives for selected case studies.

Case Study	Drivers	Impediments	Incentives	Treatment, Reuse	Crops Irrigated
Monterey, CA	<ul style="list-style-type: none"> <li>Overdrafted groundwater</li> <li>Seawater intrusion</li> <li>Saline groundwater</li> </ul>	<ul style="list-style-type: none"> <li>Safety concerns,</li> <li>Soils impact from salt</li> <li>Sales impact from customer acceptance issues</li> </ul>	<ul style="list-style-type: none"> <li>11-year pilot project</li> <li>Clean Water Act grants and loans</li> </ul>	Disinfected tertiary, pressure-pipe distribution	Cauliflower, broccoli, lettuce, celery, artichokes, strawberries, etc.
Modesto, CA	Nitrogen discharge limit to river	Farmers' senior water rights	State grant, loan	MBR*, UV*, Delta-Mendota conveyance	Nuts, stone fruit, citrus
Hayden, ID	<ul style="list-style-type: none"> <li>Discharge limits to Spokane River</li> <li>Nitrate pollution of groundwater</li> </ul>	Separate permits for reuse	Farmer pays \$55/acre	Oxidation ditch, BNR, ultrafiltration, chlorination, irrigation on city-owned farmland	Alfalfa, poplar trees
Oxnard, CA	Reduce dependence on imported water	Farmer resistance	Lower salinity recycled water	MF*, RO*, AOP*, irrigation and groundwater recharge	Lettuce, broccoli, strawberries
Escondido, CA	<ul style="list-style-type: none"> <li>\$0.5 billion cost of outfall</li> <li>Water scarcity</li> </ul>	Recycled water salt content and avocado salt sensitivity	\$0.25 billion cost savings	Reverse osmosis	Avocados
Virginia Pipeline, AU	<ul style="list-style-type: none"> <li>Algae blooms in Gulf St Vincent</li> <li>Groundwater overdraft</li> <li>Seawater intrusion</li> </ul>	<ul style="list-style-type: none"> <li>Private company risk aversion</li> <li>Cost to upgrade and distribute recycled water</li> </ul>	<ul style="list-style-type: none"> <li>\$1.0 billion government subsidy</li> <li>Monterey case as pioneer</li> </ul>	Disinfected tertiary + sidestream reverse osmosis	High-value raw-eaten vegetables

\* MBR = membrane bio-reactor; MF = microfiltration; UV = ultraviolet disinfection; BNR = biological nitrogen removal; RO = reverse osmosis; AOP = advanced oxidation processes.

pilot research and demonstration program. As a result, an eleven-year research effort, including a five-year field trial was undertaken (Sheikh et al. 1990). Locally produced vegetable crops (lettuce, broccoli, celery, cauliflower, and artichokes) were grown in 96 randomly selected plots each receiving one of three types of water (disinfected tertiary with coagulation and settling, disinfected tertiary with in-line coagulation, and locally available well water from a depth of about 200 m (600 ft)). Four fertilization regimes and four replications were also incorporated to account for the impact of nutrients in recycled water and to minimize the impacts of natural variations in the field.

Thousands of samples were collected from the edible tissues of crops at harvest and from the soils. Samples also were collected from the irrigation water, from the tailwater, and from the groundwater. Harvests were weighed and inspected for shelf-life appearance and other subjective qualities. Samples were subjected to microbiological and chemical analysis and the results were analyzed using Analysis of Variance (ANOVA) to evaluate for statistically significant differences between variables. (ANOVA is a powerful statistical tool for distinguishing real differences from random, natural variations.) The results of the pilot research and demonstration study are summarized below.

Both types of reclaimed water had higher levels of most chemicals, including metals, than the native local groundwater. Measurable levels of viruses were detected in 80% of secondary effluent. No naturally occurring viruses were detected in disinfected tertiary effluent from either pilot treatment train throughout the study, and no viruses were detected in any of the crop or soil samples. Indicator (coliform) organisms were occasionally found in all three types of irrigation water. None of the samples taken from the three water sources or the soil indicated the presence of *Salmonella*, *Shigella*, *Ascaris lumbricoides*, *Entamoeba histolytica*, or other pathogens. Pathogens were detected in plant tissues during the first year of the study, but there were no differences between the levels in reclaimed and well water. There was no significant difference in any of the nine heavy metals studied (cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, and zinc) among plots irrigated with the different water types. Heavy metal input from

commercial fertilizer impurities was far greater than from irrigation waters and accounted for the differences observed in soil samples throughout the five-year study period. Analyses of edible plant tissues indicated no consistent significant differences in heavy metal concentrations.

Crop yield for most of the vegetables grown during the study was slightly higher for crops irrigated with either of the two reclaimed waters than with well water. Field crop quality assessments, shelf life measurements, and visual inspection did not reveal any difference between produce irrigated with reclaimed water and produce irrigated with well water. A marketing firm was commissioned to identify the key issues associated with marketability of crops irrigated with reclaimed water. Interviews were conducted with individuals involved with produce distribution, such as wholesale-retail buyers, brokers, and store managers. Responses indicated that produce grown in reclaimed water would be accepted, and labeling would not be necessary.

Based on the results of the pilot study, in 1998 farmers finally agreed to switch from well water to recycled water for irrigation of their crops. Since then, nearly 5,000 hectares (12,000 acres) of raw-eaten vegetables and fruits (including strawberries) are irrigated with recycled water without any adverse incidents.

A recent study examined growers' attitudes toward water reuse practices in the Monterey region (Reed 2017). It identified growers' perceived need for water supply, how recycled water differs from existing alternatives in quality and reliability, how information is provided to farmers, and the level of trust or confidence growers have in the provider of reclaimed water as key determinants in the decision to use recycled water for crop irrigation. The level of trust is a most important criterion for farmer acceptance of recycled water, achieved in the Monterey region by involvement of farmer representatives in water supply decisions affecting their enterprise.

## Conclusions

### Water Quality and Quantity

In the arid regions of the world, such as western United States, shortages of surface or groundwater

are the most common reasons for inability to irrigate with surface and groundwater, possibly indicating that there is potential for recycled water to replace those water sources. Particularly in water-scarce regions, recycled water can help utilities and irrigation districts reduce their reliance on imported water or diminishing local resources.

### **Costs and Benefits**

The availability of funding to design, construct, and operate recycled water facilities is one of the most important incentives for initiating these projects. Water quality drivers for agricultural reuse are motivated by economics. In several instances, agricultural reuse helps facilities reduce their discharge of nutrients or high-temperature waters to sensitive receiving waters and, in so doing, helps them avert expensive facility upgrades. There is a large potential for agricultural reuse to help utilities facing more stringent nutrient discharge requirements avoid the installation of expensive and energy-intensive nutrient removal processes. Financial constraints are the most frequently cited impediments to initiating agricultural water reuse projects. Particularly in California, where significant funding for recycled water projects is included in state bond measures, timing and utility preparation play a major role in overcoming this impediment.

### **Emulating Successful Water Reuse Projects**

The successful implementation of agricultural reuse projects by peer utilities is frequently cited as an impetus for the initiation of new projects. The long-term, safe operation of older projects combined with previous work evaluating the health risks of agricultural reuse are cited as major factors in ameliorating any health-related concerns that arise during the planning process of recent projects.

### **Water Reuse Regulations and Treatment Technologies**

State regulations are the primary driver motivating the selection of treatment technologies for the production of recycled water. The main driver for what treatment technologies are used for producing recycled water for agricultural irrigation is compliance with state regulations. In most cases specific treatment technologies are mandated, although processes exist to demonstrate

equivalency of alternative technologies.

Some utilities adopt a higher level of treatment to better manage two common impediments of particular relevance to agricultural reuse—seasonal variation in irrigation demand and total dissolved solids (TDS) concentration in recycled water. In most of the world, demand for irrigation water is seasonal. However, utilizing a higher level of treatment can help utilities manage recycled water in conjunction with other local resources. More specifically, installing treatment technologies that produce water of adequate quality for indirect potable reuse can allow utilities to supply recycled water to agriculture during the irrigation season and recharge groundwater during the non-irrigation season. The second impediment, high TDS concentration in some recycled waters compared to surface and groundwater, is a major concern for many growers, but it can be ameliorated with higher levels of treatment and/or strategic blending with other water sources.

### **Potential to Increase Agricultural Reuse**

There are both compelling reasons and extensive potential for increasing agricultural reuse in many regions of the United States. Of all the treated effluent that is produced each day in the United States, only a small fraction is put to beneficial use. A substantial portion of the remainder is lost to ocean outfalls, surface evaporation, or other unproductive uses (e.g., over-spray on forests and pastureland.) This portion could be put to beneficial reuse in agriculture or other applications.

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## Appendix A

### Summary of Drivers For and Against Water Recycling (adapted from Kunz et al. 2016).

	For Water Recycling	Against Water Recycling
<b>Social Drivers</b>	Population pressures	Public opposition
	Community enthusiasm	Negative perceptions
	Changes in attitude	User rejection
	Community engagement	Preconceptions
	Psychological factors	Lack of public involvement
	Demonstration projects	Lack of cooperation among stakeholders
	Success of ongoing projects	Lack of cooperation among water utilities
	Influential stakeholders	Lack of trust and confidence in public institutions
	Organizational support for water reuse	
<b>Technical Drivers</b>	Ageing infrastructure	Water quality requirements (salinity issues)
	Technological advancements	Uncertainties around water quality
	Research and technology development	Availability of recovery technologies
		Technological challenges

**Appendix A Continued.**

	<b>For Water Recycling</b>	<b>Against Water Recycling</b>
<b>Policy Drivers</b>	Reforms for improvement of receiving waters	Prohibitive or restrictive regulations
	Wastewater discharge regulation	Protective legislation for water utilities' service territories
	Environmental protection laws	Lack of adequate guidelines
	Discharge regulations with tightened rules	Convolutd project approval paths
	Water recycling goals	Lack of standardization
	Subsidies with a reuse requirement	Lack of definition of responsibilities
	State government support	Uncertainties over future legislation
	Planning mechanisms with reuse agendas	Fragmented water institutions (silos)
	Advocacy by environmental groups	Too many utilities vs. "one water"
	Water recycling guidelines	
	Water reuse as a condition of project approvals	
	Integrated water management planning	
<b>Economic Drivers</b>	Price security for users of recycled water	Higher cost of recycled water
	Federal government grants and loans	Low (subsidized) cost of conventional water
	State government subsidies	Economic/financial disincentives
	Economic/financial subsidies	High up-front infrastructure costs
	Recognition of value of recycled water	Economies of scale—decentralized reuse
	Restrictions on potable water supply	Relatively low cost for wastewater disposal
	Corporate sustainability focus	Farmers' core business focus
	Lower cost of (subsidized) recycled water	Distance from source to farm
	Higher cost (full-value) of potable water	Financial stability of water reuse projects
<b>Natural Drivers</b>	Drought and water scarcity	Water quality impacts
	Need for water supply security	Environmental concerns
	Ecological goals/requirements	Human health and safety concerns
	Limits on natural sources of water	Seasonality of demand for irrigation
	Environmental abatement	Lack of appreciation of the hydrologic cycle
	One-water approach to water management	
	Climate change	
	Geographic isolation	
	Awareness of environmental impacts of over-use of water drawn from natural systems	

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