The Cost of Alternative Water Supply and Efficiency Options in California

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EXECUTIVE SUMMARY

Water is one of our most precious and valuable resources. California communities, farms, businesses, and natural ecosystems depend upon adequate and reliable supplies of clean water. Pressures from continued economic and population growth and climate change, as well as the need to restore degraded ecosystems, have led to concerns over our ability to meet future water demands. California is reaching, and in many cases has exceeded, the physical, economic, ecological, and social limits of traditional supply options. Rivers are over-allocated, and options for new surface reservoirs are expensive, politically controversial, and offer only modest improvements in water supply. Likewise, groundwater is so severely overdrafted in parts of the state that there are growing tensions among neighbors and damage to public roads, structures, and, ironically, water delivery canals from the land subsiding over depleted aquifers.

In response, we must expand the way we think about both "supply" and "demand." There is no "silver bullet" solution to our water problems, as all rational observers acknowledge. Instead, we need a diverse portfolio of sustainable solutions. But the need to do many things does not mean we must, or can afford, to do everything. We must do the most effective things first.

Economic feasibility is a key consideration in determining how to prioritize investments among the available water supply and demand management options. Yet, only limited and often confusing data are available on the relative costs of these options. To fill this gap, we offer here the first comprehensive analysis of the cost of several urban water management strategies to augment local supplies and reduce demand. These include stormwater capture, recycled water, brackish and seawater desalination, and a set of water conservation and efficiency measures. This study focuses on centralized water-supply options and does not include distributed water supply options, such as rain barrels or onsite reuse, due to the lack of data on the cost and yield of these options. Additional research is also needed on the cost of water supply and demand management options for the agricultural sector.

Our analysis uses methods developed in the field of energy economics to estimate the levelized cost of water in California. This approach accounts for the full capital and operating costs of a project or measure over its useful life and allows alternative projects with different scales of operations, investment and operating periods, or both, to be compared with one another. For each alternative, a ratio of net costs (costs minus benefits) to the output achieved in physical terms is determined.

To the extent possible, we integrate co-benefits associated with these projects, such as reductions in wastewater and/or energy bills; however, the economic value of environmental costs and benefits are not well documented and are thus not included in this analysis.[1] Throughout this report, the cost of water is defined as the annual cost per unit of water produced or saved and is expressed in units of dollars per acre-foot of water.[2] All costs have been adjusted for inflation and are reported in year 2015 dollars.

It is important to note that the cost and availability of these options may vary according to local conditions and should be based on site-specific analyses. Seawater desalination, for example, is not available in inland areas. Where seawater desalination is an option, its cost would be affected by several factors, such as the design and technologies employed and the infrastructure needed to bring the water produced to the existing distribution system. Thus, the costs presented in this report can be used as a general guide for communities and decision makers on the most cost-effective options available and how to maximize the value of their investments.

The results indicate that the cost of new supplies in California is highly varied (Figure ES1). Large stormwater capture projects are among the least expensive of the options to expand water supplies examined in this study, with a median cost of $590 per acre-foot. By contrast, seawater desalination, with a median cost of $2,100 for large projects and $2,800 for small projects, is among the most expensive water supply options. Brackish water desalination is much less expensive due to lower energy and treatment costs. Generally, the cost of municipal recycled water projects is in between that of stormwater capture and seawater desalination. Non-potable reuse is typically less expensive than potable reuse due to the lower treatment requirements; however, the cost of building or expanding a separate "purple pipe" distribution system to deliver non-potable water may be such that indirect potable reuse would be more cost effective.

Further, the results indicate that urban water conservation and efficiency measures are less expensive than most new water-supply options and are thus the most cost-effective ways to meet current and future water needs. Indeed, many residential and non-residential measures have a "negative cost," which means that they save the customer more money over their lifetime than they cost to implement. Nearly all devices that save hot water (and thus energy) exhibit a highly negative cost, while even some devices that save cold water, such as pre-1994 era toilets, may have a negative cost due to lower wastewater bills.

Non-residential water use accounts for about one-third of urban water demand, and the total potential water savings, while significant, are less than for the residential sector.[3] Yet, the potential water savings *for each device* are typically much larger for the non-residential sector than for the residential sector. For example, an efficient ice machine has a negative cost and saves an estimated 13,000 gallons of water per year – nearly ten times as much water as would be saved by installing an efficient showerhead in a home. Likewise, an efficient medical steam sterilizer has a negative cost

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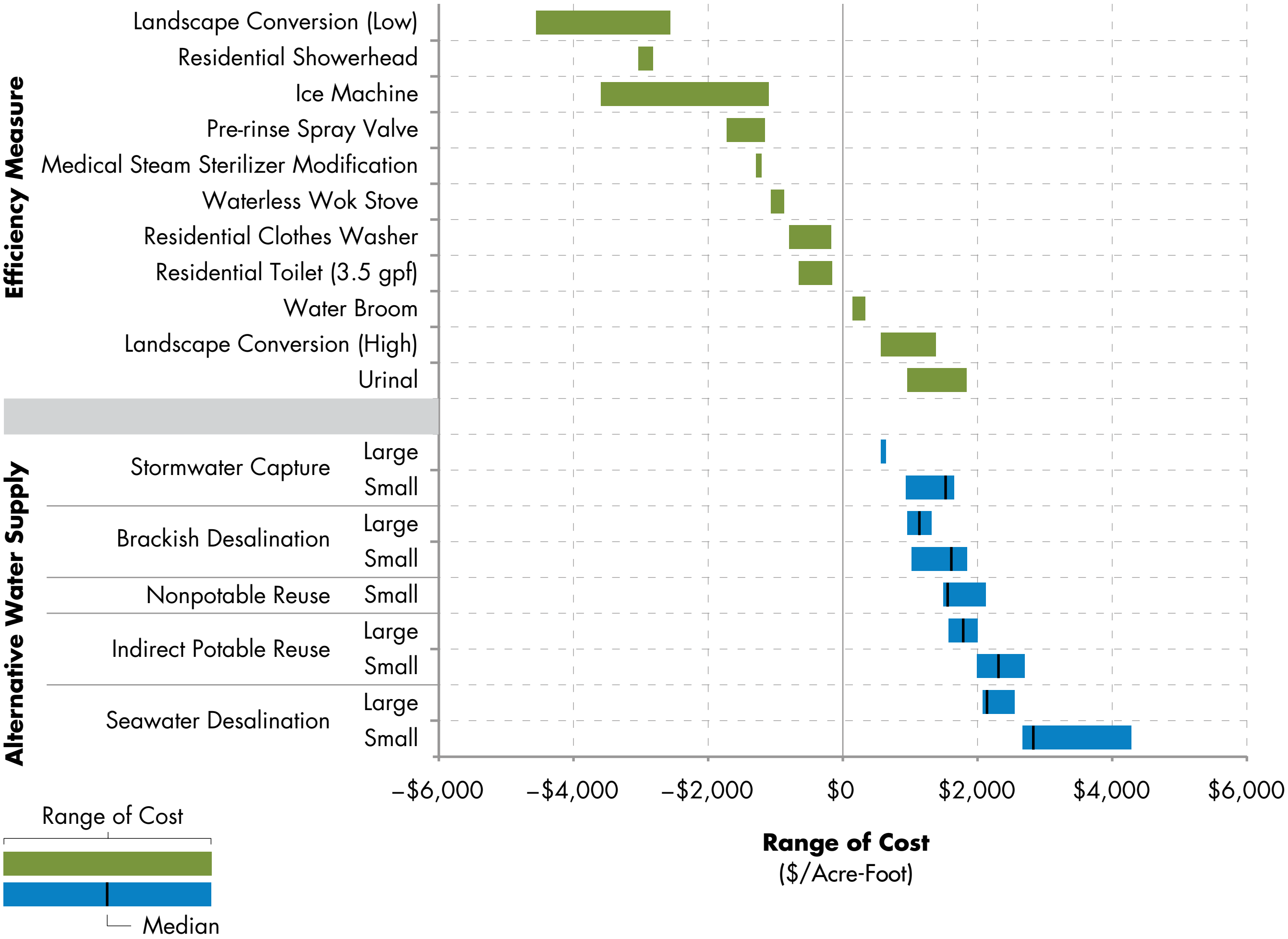
[1] While difficult to quantify, they are economically relevant, and further research is needed to develop better environmental benefit and cost estimates.

[2] California, and much of the western U.S., uses "acre-feet" as a standard water unit, and we adopt that convention here. An acre-foot of water is 325,851 gallons, or 1,233 cubic meters.

[3] Heberger, M., H. Cooley, and P. Gleick (2014). Urban Water Conservation and Efficiency Potential in California. Oakland, Calif.: Pacific Institute.

Figure ES1.

Levelized Cost of Alternative Water Supplies and Water Conservation and Efficiency Measures, in 2015 dollars per acre-foot



Notes: All values are rounded to two significant figures. Costs for water supplies are based on full-system cost, which includes the cost to integrate the supply into a water distribution system. Ranges for water supplies are based on 25th and 75th percentile of project costs, except for large stormwater projects, which include the full cost range of the two projects. Conservation and efficiency measures shown in this figure represent only a subset of the measures examined in this study due to space limitations. Cost ranges for water conservation and efficiency measures are based on varying assumptions about the incremental cost and/or water savings associated with a measure.

and saves up to 650,000 gallons per year, at least 30 times more than would be saved by retrofitting an entire home with efficient appliances and fixtures.

Landscape conversions in residential and non-residential settings can also be highly cost effective. We characterize water savings in five California cities – Fresno, Oakland, Sacramento, San Diego, and Ventura – and estimate that annual water savings from landscape conversions in these cities range from 19 to 25 gallons per square foot. Based on interviews with experts, we estimate that the cost of landscape conversions ranges from $3 to $5 per square foot. If the consumer is in the market for a new landscape, as may occur after a lawn dies or when buying a new home, then the incremental cost of installing the low water-use landscape would be as low as $2 per square foot.[4] In this case, the cost of conserved water ranges from -$4,500 to -$2,600 per acre-foot (i.e., negative costs) because the reduction in maintenance costs outweighs the investment cost of the conversion. At $5 per square foot, the higher end of the landscape conversion cost, the cost of conserved water would be $580 to $1,400 per acre-foot, which is still less expensive than many new water-supply options in California.

Finally, water system leak detection is also highly cost-effective. Throughout California, high-quality treated water is lost from the system of underground pipes that distributes water to homes, businesses, and institutions. By helping to identify leaks earlier than would have occurred otherwise, leak detection surveys can reduce annual water losses by 260,000 gallons per mile surveyed at an estimated cost of $400 per acre-foot.[5] By comparison, water purchased from the Metropolitan Water District of Southern California, which provides water to 23 million Californians, exceeds $900 per acre-foot. This indicates that leak detection is highly cost effective when compared to existing water supplies and most potential new water supply options.

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[4] Here, the incremental cost is the difference between a new lawn, at $1 per square foot, and a new low water-use landscape, at $3 per square foot.

[5] This estimate does not include the cost to repair the leak, as the utility would have fixed the leak regardless of when it was discovered. The surveys help to reduce water losses by more quickly allowing for the identification and repair of the leak.

INTRODUCTION

Water is one of our most precious and valuable resources. California communities, farms, businesses, and natural ecosystems depend upon adequate and reliable supplies of clean water. Pressures from continued economic and population growth and climate change, as well as the need to restore degraded ecosystems, have raised concerns over our ability to meet future water demand. As we approach the economic and ecological limits of traditional water supplies, more effort is being made to reduce water demand through conservation and efficiency improvements and develop alternative water supplies.

A key factor in the adoption of these strategies is their economic feasibility; yet, only limited and often confusing data are available on the relative costs of these options. To fill this gap, this study examines the cost of (1) stormwater capture; (2) recycled water; (3) brackish and seawater desalination; and (4) a range of urban water conservation and efficiency measures. We provide estimates for the cost of these options, expressed in dollars per acre-foot.

Notably, some of these options provide important co-benefits, such as reducing energy bills or reducing polluted runoff in coastal waterways. We integrate these benefits into the cost estimates to the extent possible; however, the economic value of most environmental costs and benefits is not well documented and is thus not included in this analysis. There is a growing recognition that, while difficult to quantify, they are economically relevant, and we strongly encourage further research and analysis to develop estimates of environmental costs and benefits.

METHODS AND APPROACH

Our analysis uses methods developed in the field of energy economics to estimate the levelized cost of water in California. This method accounts for the full capital and operating costs of a project or device over its useful life and allows for a comparison of alternative projects with different scales of operations, investment and operating periods, or both (Short et al. 1995). For each alternative, a ratio of net costs (costs minus benefits) to the output achieved in physical terms is determined.[1] For the purposes of this study, the output is a unit of water in the case of a new supply, or a unit of water savings in the case of an efficiency measure. In this analysis, the levelized cost of water is expressed as 2015 dollars per acre-

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[1] We adopt a 6% discount rate, which is recommended by the Department of Water Resources for economic and financial analyses involving proposed water projects (DWR 2008).

foot of water.[2] Summaries of the methodology for water supply and efficiency options are below, and additional details are provided in Appendices A and B.

WATER SUPPLY PROJECTS

For water supply projects, this analysis takes into account the investment required to build a new facility and the associated operation and maintenance costs over the lifetime of the facility. Key components of the analysis include capital costs, operation and maintenance (O&M) and replacement costs, discount rate, expected useful life, water production capacity, and water yield. Capital costs are fixed, one-time expenses needed to bring the project into operation and include structures, land, equipment, labor, and allowances for unexpected costs or contingencies.[3] These costs are annualized over the life of the project and divided by the water production capacity. O&M costs are incurred during operation of the device or facility and typically vary with output levels. For projects that are currently in operation, we use average annual O&M costs whenever possible; otherwise, we use values from the most recent year available. The O&M costs are annualized over the life of the project and divided by the annual water yield. The annualized capital and variable costs are then added together, resulting in an estimate of the cost of water expressed in 2015 dollars per acre-foot of water. Because a number of project- and site-specific factors affect the cost of a particular project, we include the 25th and 75th percentiles of the cost range for each water supply option, which are represented in this report as the low and high values, respectively.

WATER EFFICIENCY MEASURES

A water efficiency measure reduces the amount of water required to produce a particular good or service. An efficiency measure is a direct alternative to a new or expanded physical water supply and can also be evaluated using a levelized-cost approach. In this paper, we use the term "conserved water" to refer to the water savings associated with an efficiency measure. We calculate the cost of conserved water from efficiency savings based on the incremental cost of purchasing and installing a new, water-efficient device and any changes in operation and maintenance costs resulting from the investment (excluding water bill payments). This cost is annualized over the life of the device and divided by the average annual volume of water conserved, resulting in an estimate of the cost of conserved water expressed in 2015 dollars per acre-foot of water.

For most efficiency measures, we assume that the customer is in the market for a new device because the old device has reached the end of its useful life. This is typically referred to as natural replacement. To estimate water savings and incremental cost under natural replacement, we develop two scenarios: a baseline and an efficient scenario. For the baseline scenario, we assume that the customer replaces the old device with a new device that uses the same amount of water. For our efficient scenario, we assume that the customer replaces the old device with a new, efficient model. Annual water savings are then calculated as the difference in water use between the two models, multiplied by the estimated average frequency of use. The incremental cost is the cost difference between a new efficient and a new inefficient device and is based on price surveys of available models.

Assigning an incremental cost to replacement fixtures that meet mandated water-efficiency standards presents a unique problem. For 3.5 gallon

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[2] California, along with much of the western U.S., uses "acre-feet" as a standard water unit, and we adopt that convention here. An acre-foot of water is 325,851 gallons, or 1,233 cubic meters.

[3] Contingencies are generally assumed to be 20% to 30% of the project construction cost.

per flush (gpf) toilets and commercial clothes washers, a new inefficient device uses less water than the old models currently in use because all replacement fixtures must meet mandated water-efficiency standards. For discontinued models, such as 3.5 gpf toilets, limited data are available on the cost of a device in the absence of a standard. In the absence of these data, we assume that the baseline inefficient model is 10% more expensive than it would have been in the absence of the standard.[4] We then add this 10% cost premium to the cost difference of a new efficient and a new inefficient device to obtain the full incremental cost of the efficient device in the absence of a standard.

As noted above, natural replacement is assumed for most measures. For some measures (i.e., faucet aerators, water brooms, some landscape conversions, and medical steam sterilizer modifications), we assume that the customer would not have made the investment otherwise. In these cases, the cost analysis is based on the full cost of the efficiency measure.

In this analysis, efficiency measures are evaluated from the perspective of the customer. We do not, however, evaluate water bill savings as a benefit to customers. Instead, we calculate the cost of conserved water based on the investment required by the customer and any changes in operation and maintenance costs the customer would experience from the investment (excluding water bill payments).

Some efficiency measures have a “negative” cost. This is because for these measures, the non-water benefits that accrue over the lifetime of the device exceed the cost of the water efficiency investment. This is especially true for efficiency measures that save customers energy, but other “co-benefits” may include savings in labor, fertilizer or pesticide use, and reductions in wastewater treatment costs. For example, a high-efficiency clothes washer costs more than a less-efficient model; however, it uses less energy and produces less wastewater than a less-efficient model, thereby reducing household energy and wastewater bills.[5] Over the estimated 14-year life of the device, the reductions in energy and wastewater bills are more than sufficient to offset the cost of the more efficient model, resulting in a negative cost of conserved water.

DATA SOURCES AND LIMITATIONS

We rely on the best-available public information on the cost and yield of water supply projects and conservation and efficiency measures. Data sources for efficiency measures include end-use and field studies, expert knowledge, market price search, and other online resources. Data for water supply projects are drawn from analyses by state agencies and local water utilities. We have carefully examined these numbers to check that project costs and assumptions are generally consistent with one another. To the extent possible, we rely on actual project costs. However, due to data limitations, we also rely on data from proposed projects, which may not represent actual costs as a result of design errors, construction delays, regulatory and price changes, or other factors. As noted previously, capital costs are annualized over the life of the project and divided by the

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[4] This is a conservative estimate based on Gleick et al. (2003), which compared the cost of more- (3.5 gpf) and less-efficient (1.6 gpf) toilets in Canada and found that the cost ratio for these devices was 1.064, meaning that 1.6 gpf toilets were 6.4% more expensive than 3.5 gpf toilets.

[5] While some pay a flat charge for wastewater services, others pay a rate based on an estimate of the volume of wastewater generated. Based on a survey of wastewater utilities serving 10.3 million Californians, we estimate that the population-weighted average cost for wastewater service is $3.49 per thousand gallons for residential customers and $4.24 per thousand gallons for non-residential customers.

water production capacity. Operational decisions to produce less water would increase the levelized cost of a project.

The water supply and efficiency options included in this analysis may provide additional costs and/or benefits that are not well quantified and thus could not be included. For example, a stormwater capture project may reduce polluted runoff into waterways, reducing downstream water treatment costs and providing environmental benefits. A recycled water project could produce environmental benefits by reducing the discharge of treated wastewater into an estuary or the ocean. Integrating these benefits into the economic analysis would reduce the cost of water. However, recycling water in the upper watershed could reduce water available for important downstream uses, such as for fish habitat or recreation, and integrating these costs may increase the cost of water. Additional research is needed to quantify these costs and benefits. In the following sections, we provide a summary of the results of our analysis.

STORMWATER CAPTURE

For more than a century, stormwater has been viewed as a liability, and most urbanized areas were designed to remove this water as quickly as possible. Urban runoff washes pesticides, metals, and other pollutants into inland and coastal waterways and can worsen erosion. Both the U.S. Environment Protection Agency and the State Water Resources Control Board (State Water Board) have determined that "stormwater and urban runoff are significant sources of water pollution that can threaten aquatic life and public health" (State Water Board 2014). Improving stormwater management through stormwater capture can improve water quality, while also reducing flood damage and boosting local water supplies. Moreover, it provides a number of non-water benefits, including enhancing wildlife habitat, reducing the urban heat island effect, improving community cohesion, and reducing greenhouse gas emissions (CNT 2010).

Increasingly, stormwater is being viewed as an asset in water-scarce regions. In 2009, the State Water Board set a goal to increase the annual use of stormwater over 2007 levels by at least 500,000 acre-feet by 2020, and one million acre-feet by 2030 (State Water Board 2013). They also developed, and are now implementing, a Storm Water Strategy to better manage this resource and optimize its use within the next ten years (State Water Board 2016). In addition, the Rainwater Capture Act (AB 275), passed in 2012, authorizes residential users and public and private utilities to install and operate rainwater capture systems that meet specified requirements for landscape use. Further, regulatory agencies, such as the Los Angeles Regional Water Board, are beginning to incentivize additional stormwater capture by basing Clean Water Act compliance on the volume of storm water captured.

Local efforts to capture stormwater are also expanding. For example, the Fresno-Clovis metropolitan area captures and recharges about 17,000 acre-feet a year (DWR 2014b), while the Los Angeles Department of Water and Power and its partners actively capture about 29,000 acre-feet of stormwater annually and plan to recharge an additional 68,000 to 114,000 acre-feet per year by 2035 (Geosyntec Consultants 2015). An analysis by Garrison et al. (2014) suggests that there is still significant potential for stormwater capture in urbanized Southern California and the San Francisco Bay areas, which could contribute 420,000 to 630,000 acre-feet per year to local water supplies.

Table 1.

Stormwater Capture and Reuse Cost

	Sample Size	Stormwater Capture and Recharge Facility ($/AF)			Groundwater Pumping and Treatment ($/AF)	Total Cost ($/AF)		
		Low	Median	High		Low	Median	High
Small Project (≤1,500 AF)	8	$590	$1,200	$1,300	$340	$930	$1,500	$1,600
Large Project (>6,500 AF)	2	$230	$250	$260		$570	$590	$600

Note: All values are rounded to two significant figures and are shown in year 2015 dollars. Low and high costs represent the 25th and 75th percentile, respectively, of the estimated cost range. However, we report the full cost range for large stormwater capture projects as only two projects are included in this analysis. Groundwater pumping and treatment are based on a median cost of $100 per acre-foot and $240 per acre-foot, respectively.

COST OF STORMWATER CAPTURE

Measures to capture stormwater were initially designed to improve water quality and provide flood relief. Increasingly, projects are also being designed to boost local water supplies. For example, rain barrels or cisterns can be used at a household or building scale to capture and store water onsite. Bioswales and spreading basins can capture stormwater on a larger scale. The potential to capture and reuse stormwater varies by soil properties, geologic properties, aquifer water quality, topography, and precipitation levels. Variability in the type of project and local conditions results in a wide range of costs for stormwater capture projects.

Stormwater detention basins have been used for decades for flood control and/or groundwater recharge. To reflect current costs, our analysis relies on 10 proposed stormwater projects included in the State Water Board FAAST database for Proposition 84 Storm Water Grant Program, the Department of Water Resources Proposition 84 Implementation Grant Program and Proposition 1E Stormwater Flood Management, and the Los Angeles Department of Water and Power Stormwater Capture Master Plan. Five of these projects were selected to receive funding under grant programs.

Table 1 shows the cost estimates for centralized stormwater capture projects, such as spreading basins. We grouped projects by size, defining small projects as those with an annual yield of 280 to 1,500 acre-feet and large projects as those with an annual yield of 6,500 to 8,000 acre-feet.[6] We do not include estimates for distributed stormwater capture systems, such as rain barrels or cisterns that may be installed at a household- or building-scale, due to data limitations. The cost of small, centralized projects ranges from $590 to $1,300 per acre-feet, with a median cost of $1,200 per acre-foot. Projects at the higher end of the cost range reflect those requiring additional infrastructure to convey stormwater to recharge areas. Large, centralized projects exhibit significant economies of scale, with a much lower cost of $230 to $260 per acre-foot, and a median cost of $250 per acre-foot.

In addition to the cost to capture and store stormwater, there is a cost to extract that water from the aquifer and treat it to drinking water standards. These costs will vary based on groundwater quality, well depth, and other factors. We estimate that groundwater pumping would cost $100 per acre-foot, and treatment would cost $240 per acre-

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[6] Data for projects with expected annual yields between 1,500 and 6,500 acre-feet were not available and thus are not included in this analysis.

foot.[7] Thus, the total cost of small projects ranges from $930 to $1,600 per acre-foot, with a median cost of $1,500 per acre-foot. The total cost of large projects ranges from $570 to $600 per acre-foot, with a median cost of $590 per acre-foot.

Notably, these costs do not include some of the potential co-benefits of stormwater capture projects, such as reducing pollution in nearby waterways, avoiding the cost of Clean Water Act compliance, providing habitat, minimizing flooding, beautifying neighborhoods, and providing recreational opportunities, among others. Integrating these benefits into the economic analysis would reduce the cost of water. Additional research is needed to quantify these benefits.

RECYCLED WATER

A variety of terms are used to describe water reuse. For the purposes of this report, the terms "water reuse" and "water recycling" are used interchangeably to refer to wastewater that is intentionally captured, treated, and beneficially reused. Municipal recycled water refers to municipal wastewater that is collected from homes and businesses and conveyed to a nearby reclamation facility, where it undergoes treatment to meet the water quality standards needed for reuse. We note that some forms of wastewater can also be reused onsite with little or no treatment. For example, a home may have a graywater system that collects wastewater from a clothes washer and uses it to irrigate a garden, or an office building may be equipped with a wastewater treatment system to reuse a portion of the wastewater for flushing toilets and other non-potable applications. For this analysis, we focus solely on municipal recycled water because only limited data are available on the cost of onsite reuse systems.

Californians have been using recycled water for more than a century. The earliest uses of recycled water were for agriculture (Newton et al. 2012). Today, there is a broader set of recycled water applications, including for geothermal energy production, groundwater recharge, landscape and agricultural irrigation, and industrial use, and usage is growing. Between 1970 and 2009, the beneficial use of recycled water increased almost fourfold, due in part to changes in state law and policy to support water recycling infrastructure, production, and use. According to a 2009 statewide survey (Newton et al. 2012), the most recent survey available, California beneficially reuses about 0.7 million acre-feet of recycled water per year, or an estimated 13% of the wastewater generated. Tremendous opportunities exist to expand water reuse. An analysis by Cooley et al. (2014) estimated that the technical potential for water reuse in California was at least an additional 1.2 million to 1.8 million acre-feet per year.

COST OF WATER RECYCLING AND REUSE

Data on the cost of water recycling projects are drawn from three sources: direct correspondence with water agencies; published documents on agency websites; and water recycling project grant proposals. While recycled water projects have been in operation for decades, we are unable to obtain complete cost information for older projects. As a result, we evaluate the cost of proposed projects as well as project upgrades designed to augment water supplies. A total of 13 projects are evaluated; of these, seven are non-potable reuse projects

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[7] Groundwater pumping cost was calculated based on OCWD (2015), Upper Kings Basin IRWM Authority (2013), LACFCD (2013), City of Pasadena (2011), LADWP (2010), and MWDSC (2007). Treatment costs were based on MWDSC (2007). Basic groundwater treatment involves an addition of chlorine and polyphosphates if contaminants in the water do not exceed the Maximum Contaminant Levels (MCLs) under the Safe Drinking Water Act. For high-quality groundwater, treatment cost would be minimal.

and six are indirect potable reuse projects. The source water for most projects in this analysis is secondary effluent from a nearby wastewater treatment plant.[8]

Non-potable reuse requires lower levels of treatment than other types of reuse and is distributed to customers in a separate water distribution system, which can be identified by its unique purple color. Its main applications include landscape and agricultural irrigation, habitat restoration, and certain industrial processes, such as for concrete production and cooling water.[9] With indirect potable reuse, high-quality wastewater is put into an environmental system, such as an aquifer or reservoir, before it is treated again to drinking water standards and placed in the drinking water distribution system. Indirect potable reuse has been practiced in California since the early 1960s, and a growing number of projects are using this approach (Crook 2010).

Table 2 shows cost estimates for non-potable and indirect potable water reuse projects. Water recycling for non-potable reuse is typically less expensive than indirect potable reuse because it has lower treatment requirements. However, non-potable reuse projects that cannot take advantage of an existing "purple pipe" distribution system may cost more than indirect potable reuse project because of the need to build or expand such a system. The cost of small, non-potable reuse facilities, defined as those with a capacity of 10,000 acre-feet or less, ranges from $550 to $1,200 per acre-foot, with a median cost of $590 per acre-foot. Expanding non-potable reuse may require the installation or extension of a separate, purple-pipe water distribution system, which would result in an additional cost of $950 per acre-foot.[10] In this case, the total cost for a small, non-potable reuse project would range from $1,500 to $2,100 per acre-foot, with a median cost of $1,500 per acre-foot.[11] Project costs for large projects are not available; however, we would expect them to be less expensive due to economies of scale.

We estimate that the cost of small indirect potable reuse facilities ranges from $1,500 to $2,200 per acre-foot, with a median cost of $1,900 per acre-foot. The cost of larger projects ranges from $1,100 to $1,600 per acre-foot, with a median cost of $1,300 per acre-foot. Energy is often the single largest O&M expense, accounting for 30% to 55% of the O&M costs. Prior to use, treated water is sent to an environmental buffer, such as a groundwater recharge basin or reservoir. If the water is used to recharge groundwater, we estimate that there would be an additional cost of $460 per acre-foot to convey the water to a groundwater recharge basin, extract it from the aquifer, and treat it to drinking water standards.[12] Thus, the total cost for small indirect potable reuse projects ranges from $2,000 to $2,700, with a median cost of $2,300 per acre-foot. The total cost for large indirect potable reuse projects ranges from $1,600 to $2,000 per acre-foot, with a median cost of $1,800 per acre-foot.

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[8] The source water for one project is a mix of secondary- and tertiary-treated effluent, while another uses tertiary-treated effluent as source water.

[9] Habitat restoration projects include, for example, the Napa Sonoma Salt Marsh Restoration Pipeline, South County Agriculture and Habitat Lands Recycled Water Program, and the Emily Renzel Wetlands Restoration Project.

[10] Costs are based on three projects in our non-potable reuse project sample and seven other purple pipe projects from Proposition 84 Round 1 and 2 implementation grant proposals. Low-end value reflects costs from our sample of non-potable reuse projects. We note that the cost of a distribution system is typically driven by the length of that system rather than the volume of water delivered; however, in the absence of better data, we normalized the cost by volume of water delivered.

[11] Lower and median costs may appear the same, due to rounding to two significant figures.

[12] This additional cost is based on the median costs of conveying water to an environmental buffer ($120 per acre-foot) as well as extracting and treating the groundwater ($340 per acre-foot).

Table 2.

Water Recycling and Reuse Cost

	Sample Size	Non-Potable Reuse Facility ($/AF)			Distribution ($/AF)	Total Cost of Non-Potable Reuse ($/AF)		
		Low	Median	High		Low	Median	High
Small Project (≤ 10,000 AFY)	7	$550	$590	$1,200	$950	$1,500	$1,500	$2,100

	Sample Size	Indirect Potable Reuse Facility ($/AF)			Conveyance, Groundwater Pumping and Treatment ($/AF)	Total Cost of Indirect Potable Reuse ($/AF)		
		Low	Median	High		Low	Median	High
Small Project (≤ 10,000 AFY)	3	$1,500	$1,900	$2,200	$460	$2,000	$2,300	$2,700
Large Project (> 10,000 AFY)	3	$1,100	$1,300	$1,600		$1,600	$1,800	$2,000

Note: All values are rounded to two significant figures and are shown in year 2015 dollars. Low and high costs represent the 25th and 75th percentile, respectively, of the estimated cost range. Distribution for non-potable reuse refers to the median cost of a purple-pipe distribution system. Additional costs for distribution, pumping, and treatment for indirect potable reuse refers to the median cost of operating and maintaining finished water pumps and pipelines to transport water to an environmental buffer (e.g., a groundwater recharge basin or reservoir), plus the cost to extract and treat the groundwater. The low and median costs for small non-potable reuse projects are the same due to rounding.

These estimates do not include all of the potential costs and/or benefits of water reuse projects. In coastal areas, for example, recycling treated wastewater reduces pollution discharge into the ocean. Likewise, recharging groundwater aquifers with highly-treated wastewater may improve groundwater quality. Integrating these benefits into the economic analysis would effectively reduce the cost of water. However, recycling water in the upper watershed could reduce water available for important downstream uses, such as for fish habitat or recreation, and integrating these costs may increase the cost of water. Additional research is needed to quantify these costs and benefits.

Finally, we note that there is a growing discussion about the potential for direct potable reuse of wastewater. Because wastewater can be treated to highly purified levels, it is technically feasible to directly return that water to the drinking water system. The most significant barrier to this is public opinion and the absence of a regulatory framework, rather than any technical or water-quality obstacle. If direct potable reuse becomes feasible, the costs discussed here would likely be lower because of the potential to eliminate, or greatly reduce, the need for additional distribution and treatment costs associated with indirect potable reuse systems.

DESALINATION

Desalination refers to a wide range of processes designed to remove salts from water of different salinity levels (Table 3). Most modern plants and all of the proposed plants in California use reverse osmosis membranes. Reverse osmosis desalination typically requires pre-treatment to prevent fouling of the membranes and post-treatment to add minerals that improve taste and reduce corrosion to the water distribution system.

Interest in desalination in California began in the late 1950s. The state's first commercial desalination plant treated brackish groundwater for residents of Coalinga in Fresno County (Crittenden et al. 2012). By 2013, there were 23 brackish groundwater desalination plants, with a combined annual capacity of 140,000 acre-feet (DWR 2014a). Seawater desalination has had only limited application in California, but interest remains high, with the Carlsbad desalination plant operating since December 2015 and an additional nine plants proposed along the coast (Pacific Institute 2015).

Table 3.

Relative Salinity of Water

Type of Water	Relative Salinity (mg/L TDS)
Freshwater	Less than 1,000
Brackish water	1,000 – 30,000
Seawater	30,000 – 50,000
Brine	> 50,000

COST OF DESALINATION

The cost of seawater desalination is based on engineering estimates because there are a limited number of facilities in operation along the California coast.[13] Data on brackish water desalination facilities are more readily available because water districts have been treating brackish groundwater for several decades. However, the capital cost for facilities that have been in operation for more than ten years is difficult to obtain and may not be relevant for estimating current costs. For these projects, we include the cost of expansion, although note that these values likely reflect the lower bound of new project costs.

We estimate that the cost of small seawater desalination facilities, defined as those with a capacity of 10,000 acre-feet or less, ranges from $2,500 to $4,100 per acre-foot, with a median cost of $2,600 per acre-foot. The cost of large seawater desalination plants, defined as those with a capacity of more than 10,000 acre-feet, ranges from $1,900 to $2,300 per acre-foot, with a median cost of $1,900 per acre-foot (Table 4). A seawater desalination plant must also be integrated into the drinking water system, which we estimate costs an additional $200 per acre-foot. Thus, the total cost for small seawater desalination projects ranges from $2,700 to $4,300 per acre-foot, with a median cost of $2,800 per acre-foot. The total cost for large seawater desalination projects ranges from $2,100 to $2,500 per acre-foot, with a median cost of $2,100 per acre-foot.

Brackish water has lower salt and total dissolved solids (TDS) levels than seawater, and as a result, brackish water desalination requires less treatment to bring the water to drinking water standards. We estimate that the cost of a large project with a capacity of more than 10,000 acre-feet ranges from $840 to $1,200 per acre-foot, with a median cost of $1,000 per acre-foot. Smaller projects have a higher unit cost, ranging from $900 to $1,700 per acre-foot, with a median cost of $1,500 per acre-foot. We estimate that the cost to integrate water from a brackish water desalination facility into the drinking water distribution system is about $110 per acre-foot. This is less than for seawater desalination, likely because brackish plants are typically located closer to an existing water distribution system. Thus, the total cost for a small brackish desalination project ranges from $1,000 to $1,800 per acre-foot, with a median cost of $1,600 per acre-foot. The total cost for a large brackish desalination project ranges from $950 to $1,300 per acre-foot, with a median cost of $1,100 per acre-foot.

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[13] Although the Carlsbad desalination facility is in operation, data are not available on the actual costs to build and operate that system. With the absence of these data, we include the engineering estimates for the Carlsbad desalination facility in this analysis.

Table 4.

Seawater and Brackish Water Desalination Cost

	Sample Size	Brackish Water Desalination Facility ($/AF)			Integration ($/AF)	Total Cost of Brackish Water Desalination Project ($/AF)		
		Low	Median	High		Low	Median	High
Small Project (≤ 10,000 AFY)	11	$900	$1,500	$1,700	$110	$1,000	$1,600	$1,800
Large Project (> 10,000 AFY)	5	$840	$1,000	$1,200		$950	$1,100	$1,300

	Sample Size	Seawater Desalination Facility ($/AF)			Integration ($/AF)	Total Cost of Seawater Desalination Project ($/AF)		
		Low	Median	High		Low	Median	High
Small Project (≤ 10,000 AFY)	3	$2,500	$2,600	$4,100	$200	$2,700	$2,800	$4,300
Large Project (> 10,000 AFY)	5	$1,900	$1,900	$2,300		$2,100	$2,100	$2,500

Note: All values are rounded to two significant figures and are shown in year 2015 dollars. Low and high costs represent the 25th and 75th percentile, respectively, of the estimated cost range. Integration cost is based on the median cost to integrate the desalinated water into the drinking water distribution system. For large-scale desalination projects, the low and median costs appear to be the same because the values are rounded to two significant figures.

URBAN WATER EFFICIENCY

Water conservation and efficiency are essential for meeting existing and future water needs in urban areas. California has made considerable progress in implementing water conservation and efficiency improvements, as seen from the decline in residential water use from 163 gallons per person per day (gpcd) in 2000 to 131 gpcd in 2010.[14] Without these past efforts, our current challenges would be more severe, demands on limited water supply would be higher, and ecosystem damage would be worse. Despite this progress, there are still additional opportunities to reduce demand for water in urban areas without affecting the services and benefits that water provides.

There are many ways to reduce water waste and improve water-use efficiency in homes and businesses. Between 2001 and 2010, urban water use averaged 9.1 million acre-feet per year (DWR 2014). A study by Heberger et al. (2014) found that the statewide technical potential to reduce urban water use ranged from 2.9 to 5.2 million acre-feet per year. An estimated 70% to 75% of the potential savings, or 2.2 million to 3.6 million acre-feet per year, are in the residential sector. As shown in Figure 1, water savings are possible for every end use within the home. An additional 0.74 million to 1.6 million acre-feet of water savings are possible from efficiency improvements among non-residential users, i.e., the commercial, industrial, and institutional sectors. Finally, repairing leaks in water distribution systems reduced water losses, although insufficient data are currently available to quantify the potential water savings.

COST OF URBAN WATER EFFICIENCY MEASURES

We examine the cost of conserved water for reducing water distribution system losses and for implementing various end-use efficiency measures in the residential and non-residential sectors. Data

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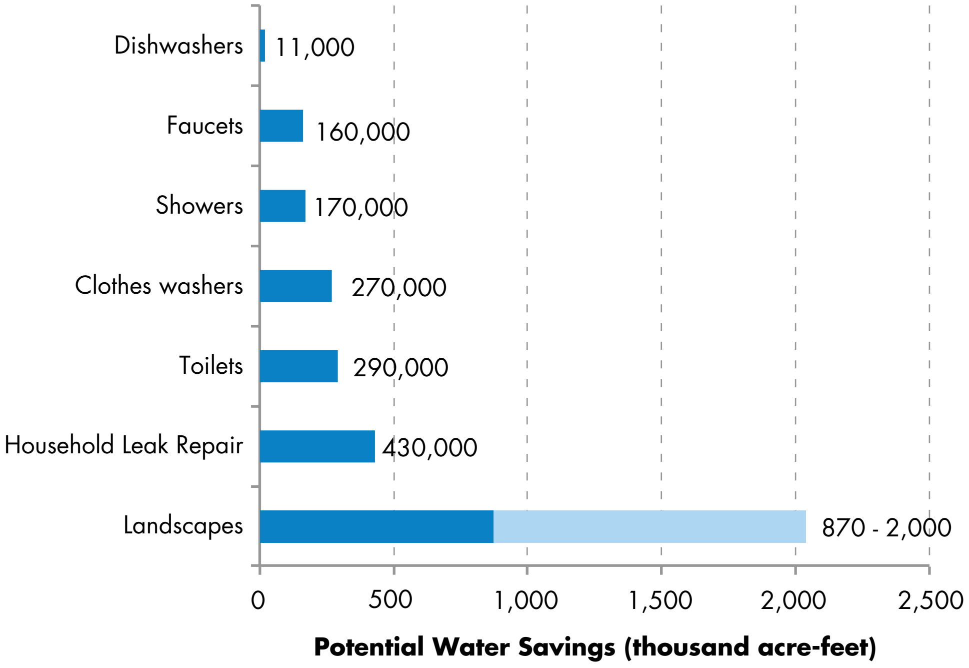
[14] Authors' calculations based on the DWR's water balances data (see DWR 2014c). Residential water usage rates were even lower in 2015, although it is difficult to estimate usage once drought restrictions are removed.

Figure 1.

Potential Residential Water Savings by End Use

Notes: Figure shows household water savings and does not include potential water savings from the non-residential sector or from reducing losses in water distribution systems. Potential water savings for landscape efficiency improvements are shown as a range based on assumptions about the extent of landscape conversions.

Source: Based on data in Heberger et al. (2014)



on water savings are based on available literature, industry estimates, operational experience, and expert advice. The cost of the efficiency measures is based on a review of online retailers. Additional detail on the methodology and data sources can be found in Appendix B. We note that data on the water savings and related benefits of urban water efficiency measures are limited. Accurate, transparent, and consistent assessments of water-efficiency measures are needed to demonstrate the performance, and ultimately the value, of these investments.

A wide variety of measures are available to reduce residential and non-residential water use. For the residential sector, we examine high-efficiency toilets, showerheads, clothes washers, dishwashers, and landscape conversions. For the non-residential sector, we examine a set of efficiency measures for end uses found in a wide range of businesses (e.g., toilets, faucet aerators, and showerheads), as well as devices for specific commercial, industrial, or institutional end uses (e.g., commercial dishwashers, food service pre-rinse spray valves, waterless wok stoves, and modifications for medical steam sterilizers). We note that there are additional measures, such as cooling tower retrofits, with high water- and energy-saving potential that are not included in this study due to data limitations.

Residential Efficiency Measures

Table 5 shows the cost of conserved water for residential water conservation and efficiency measures. Notably, several efficiency measures have a "negative cost," which means that they save more money over their lifetime than they cost to implement. All indoor efficiency measures reduce wastewater flows, and some, such as showerheads and clothes washers, also reduce hot water usage. The resulting reductions in household energy and/or wastewater bills are greater than the incremental cost of the efficiency measure. Similarly, in some cases, reductions in fertilizer, pesticide, and maintenance costs are sufficient to offset the installation cost of a low water-use landscape.

We find that the cost of efficient showerheads is highly negative, making it among the most cost-effective efficiency measure available. Replacing an older showerhead using 2.5 gallons per minute (gpm) with a model that uses 2.0 gpm would save an estimated 1,400 gallons of water per year. Heberger et al. (2014) estimates that statewide savings total 170,000 acre-feet annually. These devices are relatively inexpensive and provide large financial savings over their estimated 10-year life due to reductions in energy and wastewater costs. Replacing older showerheads that use more than 2.5 gpm and/or installing showerheads that use less than 2.0 gpm, which are widely available, would provide even greater water and financial savings.

High-efficiency clothes washers also have a negative cost and are highly cost effective. A front-loading clothes washer saves an estimated 7,100 gallons of water per year. Statewide savings are estimated at 270,000 acre-feet annually (Heberger et al. 2014). While a new front-loading clothes washer is considerably more expensive ($340 to $460) than a standard model, lower wastewater and energy bills over the life of the machine more than offset the higher upfront cost. As a result, the cost of conserved water ranges from -$760 to -$190 per acre-foot.

High-efficiency toilets (defined as those using 1.28 gpf or less) also provide significant statewide water savings, estimated at 290,000 acre-feet per year (Heberger et al. 2014). Replacing older toilets that use 3.5 gpf or more is highly cost effective, with the cost of conserved water ranging from -$630 to -$190 per acre-foot. However, replacing newer (post-1994 era) toilets that use 1.6 gpf with high-efficiency models is considerably less cost effective due to lower water savings, with a cost of conserved water ranging from $1,200 to $4,600 per acre-foot. This suggests that targeting water-efficiency programs at those fixtures manufactured before 1994 would provide the greatest water savings at the lowest cost.

Dishwasher replacement is the least cost-effective option of the water efficiency measures we analyzed. Switching from an older model using 6.7 gallons per load to a high-efficiency model using 3.5 gallons per load would save only 410 gallons of water and 52 kilowatt-hours (kWh) of electricity annually. While a more efficient dishwasher would reduce household wastewater and energy bills, they are not sufficient to offset the incremental cost of replacement, resulting in a cost of conserved water of $12,000 to $19,000 per acre-foot.

Table 5 also shows the cost of reducing outdoor water use by converting lawns to low water-use landscapes. We characterize water savings in five California cities – Fresno, Oakland, Sacramento, San Diego, and Ventura – and estimate that annual water savings from landscape conversions in these cities range from 19 to 25 gallons per square foot. Statewide, such landscape conversions have the potential to reduce annual water use in California homes by 0.87 million to 2.0 million acre-feet (Heberger et al. 2014). We estimate that the cost of installing a new low water-use landscape ranges from $3 to $5 per square foot, while the cost of installing a new lawn is $1 per square foot.[15] If the consumer is in the market for a new landscape, as may occur after a lawn dies or when buying a new home, then the incremental cost would be as low as $2 per square foot, i.e., the difference between a new lawn and a new low water-use landscape. If the customer converts an existing, healthy lawn, then the cost would be $5 per square foot. At $2 per square foot, the cost of conserved water is -$4,500 to -$2,600 per acre-foot. The cost is negative due to substantial reductions in fertilizer and maintenance costs, i.e., the avoided costs from reduced fertilizer use and maintenance outweigh

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[15] Cost estimates for landscape conversion are based on interviews with experts, while those for turf installation are based on regionally-adjusted data from promatch.com.

Table 5.

Residential Water Efficiency Measures

Efficiency Measure	Potential Statewide Water Savings (acre-feet per year)	Device Water Savings (gallons per device per year)	Cost of Conserved Water ($ per acre-foot)		Notes
			Low	High	
Toilet	290,000	4,700	-$630	-$190	3.5 gpf to 1.28 gpf
		680	$1,200	$4,600	1.6 gpf to 1.28 gpf
Showerhead	170,000	1,400	-$3,000	-$2,800	2.5 to 2.0 gpm
Clothes washer	270,000	7,100	-$760	-$190	
Dishwasher	11,000	410	$12,000	$19,000	
Landscape conversion	870,000 – 2,000,000	19 – 25	-$4,500	-$2,600	$2 per square foot
			$580	$1,400	$5 per square foot

Note: All values are rounded to two significant figures. Potential statewide water savings based on Heberger et al. (2014). Device water savings for landscape conversions are based on converting a square foot of lawn to a low water-use landscape. Because outdoor water savings are influenced by climate, we use a simplified landscape irrigation model to characterize water savings in five cities: Fresno, Oakland, Sacramento, San Diego, and Ventura.

the cost of the landscape conversion. At $5 per square foot, the cost of conserved water is $580 to $1,400 per acre-foot.

Non-Residential Efficiency Measures

California's commercial, industrial, and institutional sectors (also referred to as non-residential sectors) use approximately 2.5 million acre-feet of water annually, accounting for about 30% of all urban water use. Heberger et al. (2014) found that efficiency measures could reduce non-residential water use by 30% to 60%, saving an estimated 0.74 million to 1.6 million acre-feet per year. The estimated statewide water savings for the non-residential sector is less than for the residential sector, which was estimated at 2.2 million to 3.6 million acre-feet per year; however, the water savings for each efficiency measure tends to be much larger for the non-residential sector than for the residential sector. For example, an efficient ice machine saves an estimated 13,000 gallons of water per year – nearly ten times as much water as would be saved by installing an efficient showerhead in a home. Likewise, an efficient medical steam sterilizer saves up to 650,000 gallons per year, at least 30 times more than could be saved by retrofitting an entire home with efficient appliances and fixtures.

Table 6 shows the cost of conserved water for non-residential water conservation and efficiency measures. We find that many non-residential measures also have a negative cost and are highly cost effective. A number of efficiency measures for restaurants, such as food steamers, waterless wok stoves, and ice machines, offer significant financial savings over their lifetime. For example, an efficient connectionless food steamer, which operates as a closed system that captures and reuses steam, would save about 53,000 gallons of water and 14,000 kWh of electricity per year (FSTC n.d.), resulting in a cost of conserved water of -$14,000 per acre-foot. Conversely, toilet and urinal replacements are less cost effective than other measures. However, as with the residential sector, targeting high-use customers and devices would increase the cost effectiveness of these measures.

Table 6.

Non-residential Water Conservation and Efficiency Measures

Efficiency Measure	Device Water Savings (gallons per device per year)	Cost of Conserved Water ($ per acre-foot)		Notes
		Low	High	
Toilet	5,200	-$680	-$70	3.5 to 1.28 gpf
	750	$1,800	$6,500	1.6 to 1.28 gpf
Urinal	2,700	$970	$1,800	0.71 to 0.125 gpf
Showerhead	4,300	-$3,000	-$2,800	2.5 to 2.0 gpm
Faucet aerators	1,600	-$1,200	-$700	2.2 to 1.0 gpm
Pre-rinse spray valve	7,000	-$1,700	-$1,200	2.2 to 1.42 gpm
Medical steam sterilizer modification	450,000 – 650,000	-$1,300	-$1,200	
Food steamer	53,000	-$14,000	-$13,000	Boiler-based to connectionless
Ice machine	13,000	-$3,600	-$1,100	
Waterless wok	170,000	-$1,000	-$880	
Clothes washer	36,000	-$1,600	-$1,100	Top-loader to front-loader
Landscape conversion	19 – 25	-$4,500	-$2,600	Assumes $2 per square foot
		$580	$1,400	Assumes $5 per square foot
Rotary nozzle	2,100 – 4,000	$190	$1,000	
Water broom	50,000	$160	$340	

Note: All values are rounded to two significant figures. Device water savings for landscape conversions are based on converting a square foot of lawn to a low water-use landscape. Because outdoor water savings are influenced by climate, we use a simplified landscape irrigation model to characterize water savings in five cities: Fresno, Oakland, Sacramento, San Diego, and Ventura.

Water Loss Control

Throughout California, high-quality water is lost from underground pipes that distribute water to homes, businesses, and institutions. A survey of 85 California utilities found that real water losses averaged 44 gallons per service connection per day (Sturm 2013).[16] Water loss rates vary based on a number of factors, such as the age of the system, the materials used, and maintenance levels. Studies suggest that leak detection surveys could reduce annual water losses by 260,000 gallons per mile surveyed, at a cost of $300 per mile (Reinhard Sturm, personal communication, 2015).[17] Assuming that leak detection and repair are an ongoing process, we estimate that the cost for this measure is about $400 per acre-foot.[18] In addition to providing a new source of supply and deferring or eliminating expenditures on new supply and treatment infrastructure, reducing water losses can also protect public health and reduce flood damage liabilities. While not included in this analysis, these co-benefits would further reduce the cost of conserved water from a distribution system leak detection program.

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[16] Real losses are physical losses of water resulting from leaks, breaks, and overflows in the pressurized system and the utility's storage tanks. Apparent losses, by contrast, refer to water that is used but is not properly measured, accounted for, or paid for.

[17] Based on work with 13 California utilities.

[18] This estimate does not include the cost to repair the leak, as the utility would have fixed the leak regardless of when it was discovered.

SUMMARY AND CONCLUSIONS

Alternative water supplies and efficiency measures are being implemented across California and there is significant opportunity to expand the implementation of these options to meet the state's current and future water needs. Economic feasibility is an important consideration to more widespread adoption, and we offer a comprehensive analysis of the cost of stormwater capture, recycled water, seawater and brackish water desalination, and urban water conservation and efficiency. We provide our best estimates for the cost of these options, expressed in dollars per acre-foot. To the extent possible, we integrate co-benefits associated with these projects; however, the economic value of environmental costs and benefits are not well documented and are thus not included in this analysis. While difficult to quantify, they are economically relevant, and further research is needed to develop better environmental benefit and cost estimates.

Figure 2 compares the cost of alternative water supplies and efficiency measures. We find that the cost of alternative water supplies is highly varied. Large stormwater capture projects are among the least expensive of the water supplies examined in this study, with a median cost of $590 per acre-foot. Seawater desalination projects, by contrast, are the most expensive water supply option examined, with a median cost of $2,100 per acre-foot for large projects and $2,800 per acre-foot for small projects. Brackish water desalination is typically much less expensive than seawater desalination due to lower energy and treatment costs. Generally, the cost of municipal water recycled water projects are in between those of stormwater capture and seawater desalination. Non-potable reuse is typically less expensive than indirect potable reuse due to the lower treatment requirements; however, the distribution costs for a non-potable reuse system could increase the cost of that water.

We find that urban water conservation and efficiency measures offer significant water savings and are the most cost-effective ways to meet current and future water needs. Indeed, many residential and non-residential measures have a negative cost, which means that the financial savings over the lifetime of the device that result from lower wastewater and/or energy costs exceed the incremental cost of the more efficient device. Financial savings from high-efficiency showerheads and clothes washers are especially high. Landscape conversions in residential and non-residential settings can also have a negative cost, depending on the cost of the conversion and reductions in maintenance costs. Yet, even when landscape conversions cost $5 per square foot, we find that the cost of conserved water is less expensive than many new water-supply options.

Leak detection in the water distribution system is also highly cost-effective. Throughout California, high-quality, treated water is lost from the system of underground pipes that distributes water to homes, businesses, and institutions. By identifying leaks earlier than would have occurred otherwise, leak detection surveys can reduce annual water losses by 260,000 gallons per mile surveyed, at an estimated cost of $400 per acre-foot.[19] By comparison, water purchased from the Metropolitan Water District of Southern California, which provides varying amounts of water to 23 million Californians, exceeds $900 per acre-foot (MWDSC 2016). Thus, leak detection can be highly cost effective, even when compared

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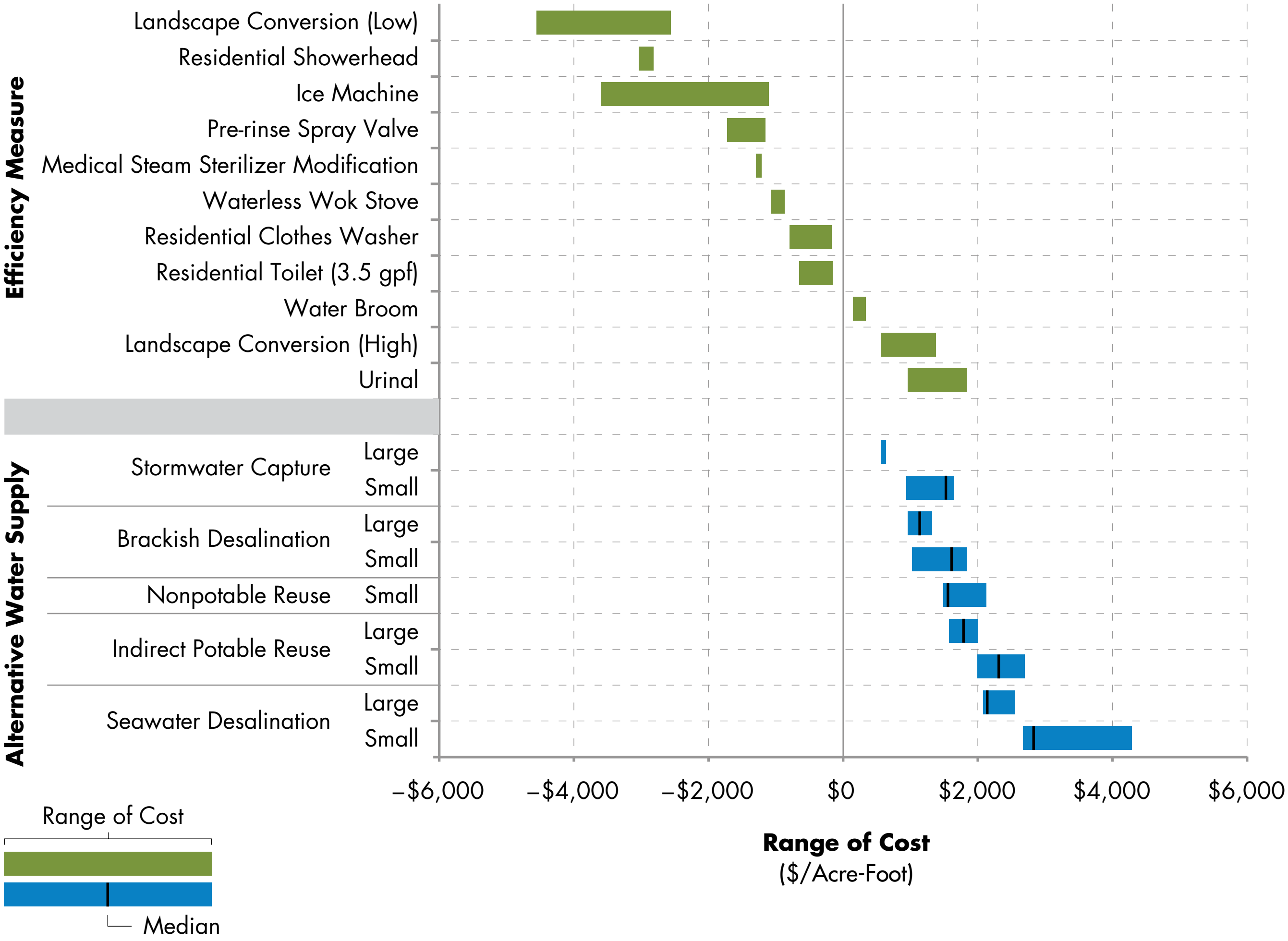
[19] This estimate does not include the cost to repair the leak, as the utility would have fixed the leak regardless of when it was discovered. The surveys help to reduce water losses by more quickly allowing for the identification and repair of the leak.

Figure 2.

Levelized Cost of Alternative Water Supply and Water Conservation and Efficiency Measures, in 2015 dollars per acre-foot



Notes: All values are rounded to two significant figures. Costs for water supplies are based on full-system cost, which includes the cost to integrate the supply into a water distribution system. Ranges for water supplies are based on 25th and 75th percentile of project costs, except for large stormwater projects, which include the full cost range of the two projects. Conservation and efficiency measures shown in this figure represent only a subset of the measures examined in this study due to space limitations. Cost ranges for water conservation and efficiency measures are based on varying assumptions about the incremental cost and/or water savings associated with a measure.

to existing water supplies, let alone some of the newly proposed water-supply options examined in this study.

California is reaching, and in many cases has exceeded, the physical, economic, ecological, and social limits of traditional supply options. We must expand the way we think about both "supply" and "demand" – away from costly old approaches and toward more sustainable options for expanding supply, including improving water use efficiency, water reuse, and stormwater capture. There is no "silver bullet" solution to our water problems, as all rational observers acknowledge. Instead, we need a diverse portfolio of sustainable solutions. But the need to do many things does not mean we must, or can afford, to do everything. We must do the most effective things first.

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