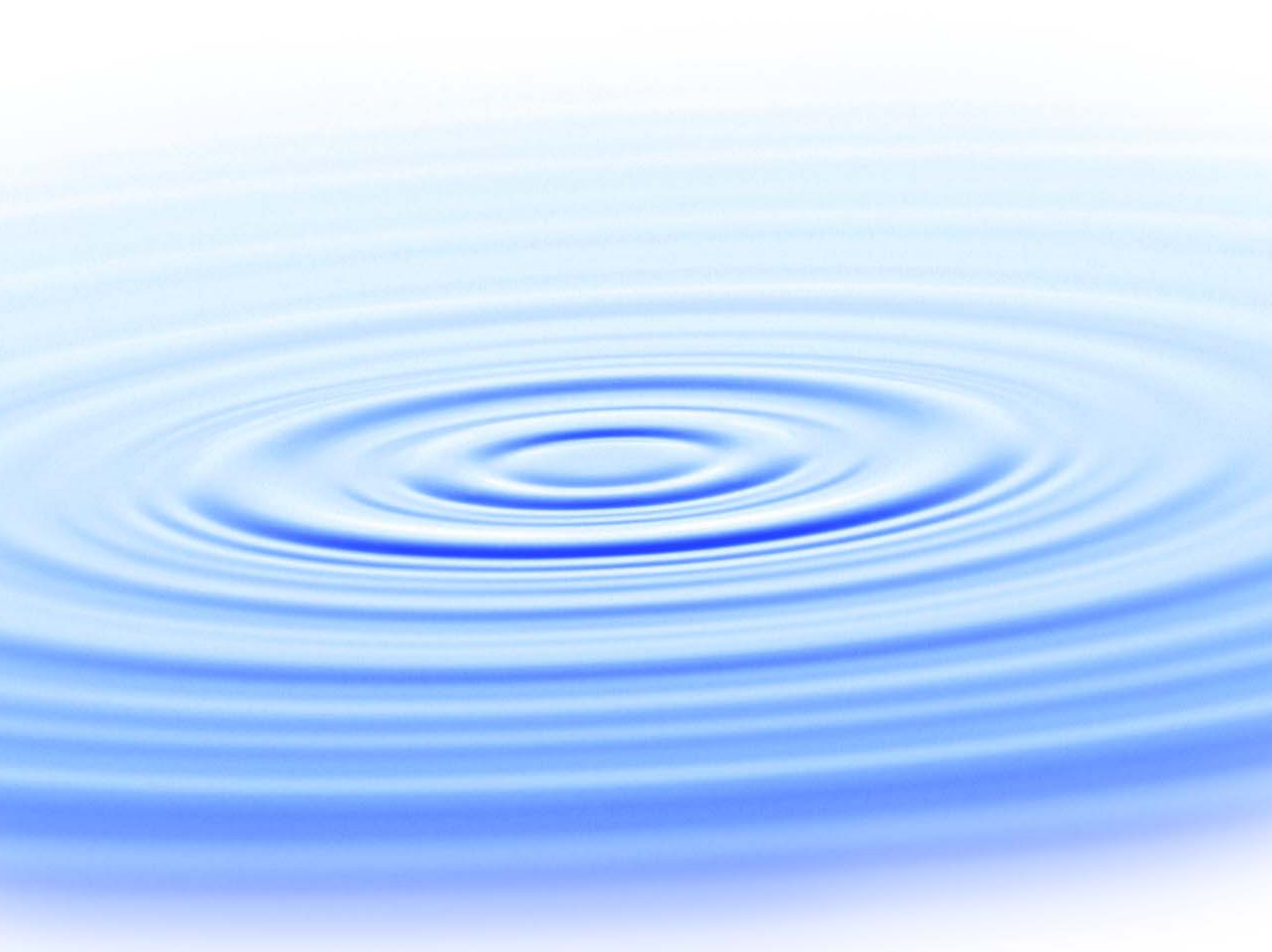
The Opportunities and Economics of Direct Potable Reuse



WateReuse Research Foundation

The Opportunities and Economics of Direct Potable Reuse

About the WateReuse Research Foundation

The mission of the WateReuse Research Foundation is to conduct and promote applied research on the reclamation, recycling, reuse, and desalination of water. The Foundation's research advances the science of water reuse and supports communities across the United States and abroad in their efforts to create new sources of high-quality water through reclamation, recycling, reuse, and desalination while protecting public health and the environment.

The Foundation sponsors research on all aspects of water reuse, including emerging chemical contaminants, microbiological agents, treatment technologies, salinity management and desalination, public perception and acceptance, economics, and marketing. The Foundation's research informs the public of the safety of reclaimed water and provides water professionals with the tools and knowledge to meet their commitment of increasing reliability and quality.

The Foundation's funding partners include the Bureau of Reclamation, the California State Water Resources Control Board, the California Energy Commission, and the California Department of Water Resources. Funding is also provided by the Foundation's Subscribers, water and wastewater agencies, and other interested organizations.

The Opportunities and Economics of Direct Potable Reuse

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Acronyms and Abbreviations

BAC	biologically active carbon
CAT	complete advanced treatment
CDPH	California Department of Public Health (all recycled and nearly all drinking water regulatory responsibilities were transferred from the CDPH to the California State Water Resources Control Board on July 1, 2014)
Cl_2	free chlorine
CO_2	carbon dioxide
CWTRC	California Wastewater Training and Research Center
DDW	Division of Drinking Water (California's State Water Resources Control Board)
DPR	direct potable reuse
ECLSS	Environmental Control and Life Support System
GHG	greenhouse gas
GWRS	Groundwater Replenishment System
H_2O_2	hydrogen peroxide
IPR	indirect potable reuse
ISS	International Space Station
MWD	Metropolitan Water District of Southern California
NASA	National Aeronautics and Space Administration
NPR	nonpotable reuse
O_3	ozone
OCWD	Orange County Water District
O&M	operating and maintenance
SWP	State Water Project
SWRCB	State Water Resources Control Board (California)
TDS	total dissolved solids
U.S. EPA	United States Environmental Protection Agency
UV	ultraviolet
ZLD	zero liquid discharge

Abbreviations for Units of Measure

A	acre; 43,560 ft^2 [(5280 ft/mi^2)/(640 ac/mi^2)]
AF	acre-foot (325,850 gallons)
AF/y	acre-foot per year (also referred to as "AFY")
ft^3/s	cubic foot per second
gal/capita•d	gallons per capita per day
kg CO_2e/AF	kilogram carbon dioxide equivalent per acre-foot

kg CO_2e/kWh	kilogram carbon dioxide equivalent per kilowatt hour
kWh	kilowatt hour
kWh/AF	kilowatt hour per acre-foot
kWh/m^3	kilowatt hour per cubic meter
kWh/10^3 gal	kilowatt hour per thousand gallons
lb/ft^3	pounds per cubic foot
MAF/y	million acre-feet per year
mg/L	milligram per liter
Mgal/d	million gallons per day
MT	metric tonne
MT CO_2e/AF	metric tonne carbon dioxide equivalent per acre-foot
tonne	metric tonne (1000 kg)
µm	micrometer

Foreword

The WateReuse Research Foundation, a nonprofit corporation, sponsors research that advances the science of water reclamation, recycling, reuse, and desalination. The Foundation funds projects that meet the water reuse and desalination research needs of water and wastewater agencies and the public. The goal of the Foundation's research is to ensure that water reuse and desalination projects provide sustainable sources of high-quality water, protect public health, and improve the environment.

An Operating Plan guides the Foundation's research program. Under the plan, a research agenda of high-priority topics is maintained. The agenda is developed in cooperation with the water reuse and desalination communities including water professionals, academics, and Foundation subscribers. The Foundation's research focuses on a broad range of water reuse and desalination research topics including

- Defining and addressing emerging contaminants, including chemicals and pathogens
- Determining effective and efficient treatment technologies to create "fit for purpose" water
- Understanding public perceptions and increasing acceptance of water reuse
- Enhancing management practices related to direct and indirect potable reuse
- Managing concentrate resulting from desalination and potable reuse operations
- Demonstrating the feasibility and safety of direct potable reuse (DPR)

The Operating Plan outlines the role of the Foundation's Research Advisory Committee (RAC), Project Advisory Committees (PACs), and Foundation staff. The RAC sets priorities, recommends projects for funding, and provides advice and recommendations on the Foundation's research agenda and other related efforts. PACs are convened for each project to provide technical review and oversight. The Foundation's RAC and PACs consist of experts in their fields and provide the Foundation with an independent review, which ensures the credibility of the Foundation's research results. The Foundation's Project Managers facilitate the efforts of the RAC and PACs and provide overall management of projects.

Prolonged and severe droughts and other factors have made water supplies increasingly scarce in California, Texas, and many other regions of the United States, as well as elsewhere around the globe. Based on these conditions, there is a clear need to more effectively tap our water resources to provide reliable high-quality potable supplies to our communities. In this context, there is considerable interest in water recycling in general and in potable reuse in particular. This White Paper provides basic information about potable reuse, with a focus on California and the potential value offered by DPR. DPR offers many advantages—including carbon footprint, yields, and costs—compared with the other alternatives available to provide new sources to community water-supply portfolios.

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Executive Summary

Prolonged and severe droughts and other factors have made water supplies increasingly scarce in California, Texas, and many other regions of the United States, as well as elsewhere around the globe. Based on these conditions, there is a clear need to more effectively tap our water resources to provide reliable high-quality potable supplies to our communities. In this context, there is considerable interest in water recycling in general and potable reuse in particular. This White Paper provides basic information about potable reuse, with a focus on California and the potential value offered by direct potable reuse.

S.1 What is Potable Reuse?

Potable reuse may be characterized as either *indirect potable reuse* (IPR) or *direct potable reuse* (DPR). In IPR, wastewater that has been highly purified by complete advanced treatment (CAT) is introduced into an *environmental buffer* for a specified period of time before being withdrawn for potable purposes. The environmental buffer may be a groundwater aquifer or a surface water reservoir. The purpose of the environmental buffer is to provide an additional barrier for the protection of public health. For example, the Division of Drinking Water (DDW) of California's State Water Resources Control Board (SWRCB) allows one-log of virus removal credit for each month the purified water remains in the aquifer.

In DPR, purified wastewater from a CAT facility is introduced into the raw water supply feeding a water treatment plant (or directly into a potable water supply distribution system, "downstream" of a water treatment plant) with or without the use of an *engineered buffer*. The purpose of the engineered buffer is to provide sufficient volumetric capacity to retain purified water for a specified period of time to allow for the measurement and reporting of specific water quality parameters, to be assured that the water provided meets all applicable water quality standards prior to being introduced into the potable water system. In most situations, the storage capacity of the transmission line used to transport the purified recycled water to a water treatment plant will provide sufficient retention time to make any needed interventions.

Both IPR and DPR have been used successfully in many locations. IPR is applied in California and other places, and DPR has been used safely and reliably in Windhoek, Namibia for more than 40 years and is now being implemented in Texas and elsewhere. These existing potable reuse projects are important because the treatment technologies employed have been accepted by various regulatory authorities as being able to reliably produce safe potable drinking water, and the implementation of these projects has been accepted by the public.

S.2 How Much Potable Water Can Reuse Provide?

In California, there is a considerable quantity of highly treated wastewater that is discharged to the ocean or to inland waterways. A significant portion of water discharged to the ocean could be utilized to create potable supplies. It is estimated, using available data and information, that more than 2300 Mgal/d—which amounts to 2.6 MAF/y—may be available in California for new water recycling projects in 2020. This source water, after receiving

CAT, could yield more than 1000 Mgal/d (or more than 1.1 MAF/y) of potable supplies. To place this into context, 1.1 MAF/y is sufficient potable water to supply all municipal needs (including commercial and industrial uses) for more than 8 million Californians, or roughly one-fifth of the state's projected population for 2020.

S.3 Are Proven Technologies Available to Safely and Reliably Provide Potable Reuse?

The individual technologies and their performances in the sequenced combination of a CAT process for potable reuse applications are well established as reliable and safe (e.g., a process flow that combines micro or ultrafiltration, cartridge filtration, reverse osmosis, and advanced oxidation, amongst other treatment components). For example, the Groundwater Replenishment System (GWRS) CAT water purification facility operated by the Orange County Water District (OCWD) has proven to be the standard against which other treatment technologies and process flow diagrams for DPR and/or IPR are compared. In operation since 2008, a number of proven technologies have been integrated in the process (as detailed in Chapter 3). Because the purified water from OCWD's GWRS meets or exceeds all potable drinking water standards and because all unregulated chemicals known or suspected to be of health concern are reduced to non-measurable or *de minimis* levels, the water is considered to be safe for direct human consumption (Burris, 2010).

S.4 What Does Potable Reuse Cost?

The cost of potable reuse depends considerably on many site-specific factors but is expected to be on the order of $820 to $2000/AF (about $2.52/1000 gal at the low end and up to $6.14/1000 gal), which includes about $700/AF for CAT and $120/AF for conveyance at the low end of the cost range. The lower end cost estimate is based on actual experience at the OCWD GWRS, using the CAT processes that typically are expected to be deployed for DPR and IPR projects. The upper end reflects treatment plus a relatively expensive conveyance expense for pipeline construction and operation for an IPR system as well as brine management costs. It is important to note that the cost of CAT for either DPR or IPR will be about the same but that conveyance and brine management costs will be site-specific.

Potable reuse is generally less expensive than—or comparable in cost to—the potential alternative sources of new water supply available to California communities. For example, in San Diego, seawater desalination delivered from the Carlsbad facility is slated to cost $2080 to $2330/AF in 2014 dollars (about $6.38 to $7.15/1000 gal), and the West Basin Municipal Water District estimates that seawater desalination will cost between about $1500 to $2000/AF, depending on facility design, phasing, and sizing options. Treated imported water currently costs residential customers about $1300/AF ($4.00/1000 gal) and also adversely impacts the Bay Delta ecosystem, requires considerable pumping energy, conveys salt loads to the region, provides a far less reliable yield compared with potable reuse (as imported waters are vulnerable to drought, seismic risks, and legal constraints), and continues to experience considerable cost escalations over time.

S.5 How Does Potable Reuse Compare with Other New Water Supply Alternatives?

An overview of how DPR and IPR compare to each other and to other potential sources of new water supplies for California residents is provided in Table S.1. Most of the new water supply alternatives share similar characteristics in terms of treatment technologies used, cost, energy requirements, and related environmental concerns. However, potable reuse (and especially DPR) provides many important advantages compared with these alternatives.

S.6 What Are the Advantages of DPR Relative to IPR?

DPR is a technically feasible option in virtually any location, whereas IPR requires access to a suitable environmental buffer—meaning the availability of either a surface water reservoir or aquifer system in which to store, blend, and extract the water. The need for an environmental buffer renders IPR infeasible for many communities because there are many locations in which a suitable surface water or groundwater buffer system is not available. Further, the relative proximity of treatment to the IPR or DPR application affects conveyance, which can significantly impact costs. DPR may provide the opportunity to reduce conveyance costs in some instances.

S.7 Conclusion

Potable reuse, via IPR or DPR, is a feasible and proven approach for providing safe, reliable yields of drinking water to meet community needs, independent of climate conditions. The treatment technologies associated with CAT are well established, and there is a considerable volume of potable water that can be produced in California through expanded recycling. In addition, potable reuse compares favorably with other new water supply alternatives in terms of cost, energy requirements, environmental considerations, and reliability. Adding DPR to the water supply mix for California will enable many communities to tap into potable reuse where IPR is not feasible (because of the lack of suitable surface reservoir or aquifer storage) and may save many communities on cost and energy requirements as well.

Table S.1. Overview of DPR and Other Available Water Supply Alternatives

SUPPLY OPTION	Cost ($/AF)[a]	Opportunities and Values	Challenges and Constraints
DPR	820–2000	Provides extremely high-quality potable water suitable for all uses. Provides reliable, drought-resistant yields. Relies on proven technologies widely used in the United States and elsewhere. Reduces discharge of effluent to receiving waters. Uses existing water distribution infrastructure, once returned to the water supply system.	Requires additional monitoring and (in some cases) an added treatment barrier (e.g., disinfection) to provide fail-safe quality assurance (compared to IPR). The use of an engineered buffer (e.g., storage) may be required to provide sufficient time for monitoring and quality assurance.
IPR	820–2000		Environmental buffer (suitable reservoir or aquifer) not available in many locations. Risk of contamination or water rights disputes within the environmental buffer. Cost to monitor and manage the buffer. May require more pipe and pumping (and energy use) than DPR.
Seawater Desalination	1500–2330	Provides high-quality potable supply (after blending and/or chemical addition). Offers climate-resistant yields. Source waters (seawater) are virtually unlimited in availability along coastal areas.	Potential environmental impacts associated with intakes, brine discharges, and near-shore facilities. Relatively high energy demands. Accessible only at coastal locations. Vulnerable to red tides and sea level rise. Also, the permitting process is complex.
Brackish Groundwater Desalination	930–1290	Provides high-quality potable supply (after blending and/or chemical addition). Offers climate resistant yields in most locations with access to brackish groundwater.	Available only at locations with access to brackish aquifers. Considerable regulatory challenges associated with concentrate (brine) management (unless a brine line is locally available for coastal discharge).
Imported Water [e.g., State Water Project (SWP)]	850–1300	Existing infrastructure and institutions are in place to govern and deliver water, as available.	Yields are highly uncertain and variable and are subject to several possible disruptions (e.g., drought, seismic event, litigation). Costs are increasing rapidly. Energy intensive pumping. Adverse environmental impacts (e.g., Bay-Delta). Increases salt loadings to import regions.
Nonpotable Reuse (NPR)	310–1960	Helps reduce demands on potable systems. Provides reliable, drought-resistant yields, matching water quality to uses for agriculture, golf courses, and other irrigation and for cooling and industrial customers.	Costs of separate “purple pipe” networks, user on-site retrofits, and pumping. Seasonal demands create stranded assets or a need for storage. Siting pipelines in crowded rights-of-way is both difficult and expensive. Costs of some options may exceed the stated range.
Water Use Efficiency, Conservation, and Use Restrictions	465–980	Helps reduce overall water demands (or helps manage shortages). Reduces energy used to treat and pump water. Additional energy savings where less hot water is used (e.g., high-efficiency clothes washers).	Long-standing water use efficiency and conservation programs have “hardened” demand in most locations, limiting opportunities for additional, cost-effective water savings. Restrictions may adversely impact local businesses, property values, and community amenities and may have negative impacts on wastewater collection systems. Costs shown do not reflect costs borne by customers.

Note: **[a]Basis and citations for cost-range estimates are provided in Chapter 5, reflecting 2014 U.S. dollars, unless otherwise indicated.**

Chapter 1

Introduction

Water shortages, the limitations of current water supplies, the impacts of climate change, and new legal definitions of water and water rights are motivating water agencies to expand and secure their water portfolios. Included in the mix of water supply sources being considered are indirect potable reuse (IPR) and direct potable reuse (DPR). To assist water agencies, the WateReuse Association, the WateReuse Research Foundation, and WateReuse California have provided leadership by sponsoring a combination of research, advocacy, and education and outreach in IPR and DPR. However, a number of questions have arisen that demand answers. For example, how much will DPR cost versus other sources of water? What is the carbon footprint of DPR, and how much new water could be made available through DPR in California? To answer these questions, the WateReuse Research Foundation commissioned the preparation of this "White Paper."

1.1. Scope of White Paper

The scope of this White Paper is as follows:

1. Estimate the capital costs, operation and maintenance costs, and energy requirements of DPR
2. Compare the estimated costs and energy requirements of DPR and of other sources of water
3. Assess the potential cost savings associated with DPR as an alternative water supply source
4. Estimate the total volume of "new water" that could be generated from DPR in California
5. Summarize in a final report the benefits and costs of fully exploiting DPR
6. Prepare a paper for publication in WateReuse's journal and in a peer-reviewed journal

1.2. Organization of White Paper

The white paper is organized into the following chapters:

1. Introduction
2. Potable Reuse: Definitions and Examples
3. DPR Treatment Processes
4. Cost and Energy Usage of DPR
5. Comparison of the Cost of DPR with the Costs of Alternative Water Supplies
6. Relative Carbon Footprint of Potable Reuse and of Its Alternatives
7. Direct and Comparative Benefits of DPR
8. Potential New Water From DPR and IPR in California

Definitions of DPR and IPR are presented and discussed in Chapter 2. The benchmark DPR treatment process to be used in the economic assessment is described in Chapter 3. The cost and energy required for DPR is documented in Chapter 4. Cost comparisons with other water sources are considered in Chapter 5. The energy requirements and carbon footprints of potable reuse and of other water sources are reviewed in Chapter 6. The direct and comparative benefits of DPR are examined in Chapter 7. The amount of new water that could be made available in California is discussed in Chapter 8. References cited in this White Paper are presented following Chapter 8.

Chapter 2

Potable Reuse: Definitions and Examples

The two different forms of potable reuse—direct potable reuse (DPR) and indirect potable reuse (IPR)—are introduced in this chapter along with some examples. Details of the required treatment technologies are presented in Chapter 3. The cost of potable reuse is considered in Chapter 4. Cost comparisons with other sources of water are presented in Chapter 5.

2.1. DPR

In DPR, purified water from a complete advanced treatment (CAT) facility, as illustrated in Figure 2.1, is introduced, with or without the use of an engineered buffer, either into the raw water supply immediately upstream of a water treatment plant or directly into a potable water supply distribution system, downstream of a water treatment plant.

In Figure 2.1a, an engineered storage buffer is included before the purified water is introduced to the water treatment system. The purpose of the engineered storage buffer is to provide a water storage containment facility of sufficient volumetric capacity to retain purified water for a specified period of time to allow for the measurement and reporting of specific constituents, to be assured that the quality of water provided meets all applicable water-quality-related public health standards prior to being introduced into the potable water system.

The engineered storage buffer is not included in Figure 2.1b. In most situations, the storage capacity of the transmission line used to transport the purified water to a water treatment plant will provide sufficient retention time to make any needed interventions. Although the dashed line in Figures 2.1a and 2.1b is used to denote the introduction of purified water directly into the water distribution system, it is not recommended at this time to bypass the potable water treatment facility.

It is anticipated that in the future, as monitoring equipment becomes more sensitive in the measurement of critical constituents of concern, bypassing the potable water treatment facility will be possible, assuming the blending and other public health requirements can be met.

2.2. IPR

In IPR, purified water is introduced into an environmental buffer for a specified period of time before being withdrawn for potable purposes. In Figure 2.2a, the environmental buffer is a groundwater aquifer. In Figure 2.2b, a surface water storage reservoir serves as the environmental buffer. The purpose of the environmental buffer is to provide an additional barrier for the protection of public health. For example, the California SWRCB Division of Drinking Water (DDW) allows one-log of virus removal credit for each month the purified water remains in the aquifer.

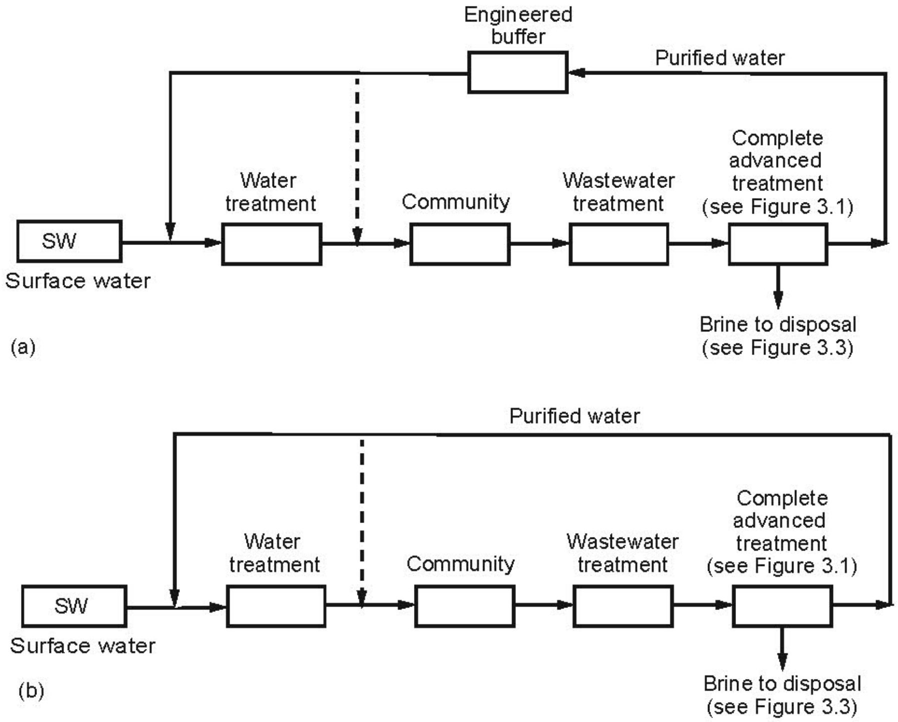

Figure 2.1. Proposed flow diagrams for DPR: (a) with engineered buffer and (b) without engineered buffer.

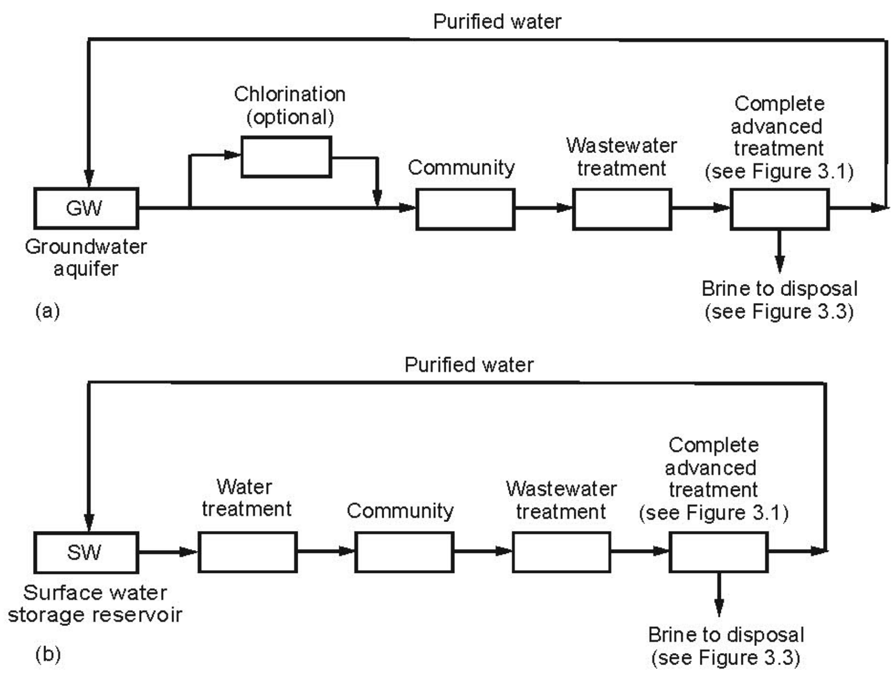

Figure 2.2. Proposed flow diagrams for IPR: (a) with groundwater aquifer as an environmental buffer and (b) with surface water storage reservoir as an environmental buffer.

Where a surface water reservoir is used, the minimum dilution factor required by DDW is likely to be 100 to 1 during some critical period, typically during periods of water turnover within the reservoir. Alternatives to the 100-to-1 dilution requirement have also been proposed, including one option that would require additional treatment in lieu of an increased dilution factor. It must also be recognized that under some operating conditions, all of the water in the reservoir could be purified water from advanced wastewater treatment plants (i.e., virtually no inflow from surface water sources). In the situation of limited alternative inflows, volumetric and specific constituent dilution factors have very different meanings. For example, if the quality of the water in the reservoir is essentially the same as the influent purified water for a specific constituent that is being added, then there is no dilution.

2.3. Examples of Past and Current DPR and IPR Projects

Some examples of potable reuse projects that have been undertaken in the past, are currently in operation, or are under design/construction are reviewed briefly in Table 2.1. These projects are of importance because the treatment process flow diagrams and treatment technologies employed have been accepted by various regulatory authorities as being able to reliably produce safe potable water. Further, the implementation of these projects has been accepted by the public.

In 2012, the National Research Council of the National Academy of Engineering completed a comprehensive evaluation of expanding the nation's water supply through reuse of municipal wastewater (NRC, 2012). Additional details on IPR and DPR can be found in several references (Tchobanoglous and Eliassen, 1969; Asano et al., 2007; Leverenz et al., 2011; Tchobanoglous et al., 2011, 2014; ATSE, 2013; Cotruvo, 2014).

Table 2.1. Examples of DPR and IPR Projects

Entity	Project Type	Description
City of Windhoek, Namibia	DPR	Since 1968, highly treated reclaimed water has been added to the drinking water supply system. The blending of reclaimed water with potable water takes place directly in the pipeline that feeds the potable water distribution network (see dashed line in Figure 2.1b).
Pure Cycle Corporation, Colorado	DPR	The Pure Cycle Corporation developed a complete water recycling system for the production of potable drinking water in the 1970s. A number of these systems were installed in Colorado at individual homes from 1976 through 1982 (see dashed line in Figure 2.1b).
National Aeronautics and Space Administration (NASA) International Space Station (ISS)	DPR	To expand the ISS crew size from three to six members, it was necessary to develop a regenerative Environmental Control and Life Support System (ECLSS). The ECLSS is comprised of the Water Recovery System and the Urine Processor Assembly (Carter, 2009). These two systems are used to produce potable water from a combination of condensate and urine collected on the ISS.
Village of Cloudcroft, New Mexico	DPR	Purified wastewater will be blended with a slightly greater (51%) amount of spring water and/or well water. The blended water will then be placed into a storage reservoir (blending tank) with a detention time of about two weeks. Water from the storage reservoir will be treated in a water treatment plant before being placed into the distribution system (see Figure 2.1a), where the blending water will be added to the engineered storage buffer. Construction of the system is scheduled to be completed in the spring of 2015.
Big Spring, Texas	DPR	Filtered secondary effluent is treated with CAT. The purified water is blended with raw water in a transmission line. The blended water is then treated in a water treatment plant before distribution. The DPR process has been operational since the spring of 2013 (see Figure 2.1b).
OCWD Groundwater Replenishment System (GWRS), California	IPR	Currently, GWRS is the largest water reclamation facility of its kind in the world that employs the latest CAT. Purified water from an advanced treatment process is infiltrated into the groundwater aquifer by means of spreading basins. Blended purified water and groundwater are pumped from the groundwater basin and serve as a water supply source for Orange County (see Figure 2.2a). The IPR process has been in operation since 2008.
San Diego, California	IPR	Pending approvals and funding, a complete advanced water treatment plant and transmission pipeline will be constructed. The city's Advanced Treatment facility will treat tertiary effluent from the North City Water Reclamation Plant, which meets current recycle requirements. The purified water will be transported with a 23 mile pipeline to San Vicente Reservoir, where it will blend with imported untreated water and will be retained for a significant period of time. The blended water from the reservoir will be sent to water treatment plants for additional treatment and distribution as potable water (see Figure 2.2b).

Source: Adapted from Tchobanoglous et al., 2011.

Chapter 3

DPR Treatment Processes

To assess the cost of DPR it will be necessary to select some benchmark treatment process against which comparisons can be made. The purpose of this chapter is to identify the benchmark CAT process that will be used to assess comparative costs. Topics considered include the benchmark advanced treatment process flow diagram, a brief discussion of the development of alternative technologies, the regulatory requirements for a successful DPR project, and brine management.

3.1. Benchmark CAT Process

To date in the United States, the GWRS advanced water purification facility operated by the Orange County Water District (OCWD) has proven to be the standard against which other treatment technologies and process flow diagrams for DPR and/or IPR are compared. Since it began operation in 2008, a number of proven technologies have been integrated in the process flow diagram, as illustrated in Figure 3.1. Because the purified water from OCWD's GWRS meets or exceeds all drinking water standards and because all unregulated chemicals known or suspected to be of health concern are reduced to non-measurable or *de minimis* levels, the water is considered to be safe for direct human consumption (Burris, 2010). For these reasons and because the OCWD treatment process has been approved by the DDW [formally the California Department of Public Health (CDPH)], the GWRS flow diagram will be used as the benchmark for the DPR cost evaluation and comparisons. A brief description of each of the treatment components is presented in Table 3.1. Additional details on these processes may be found in Crittenden et al. (2012) and Tchobanoglous et al. (2014).

3.2. Alternative Technologies

A number of alternative treatment process flow diagrams have been considered and are currently in various stages of development, implementation, and acceptance for the production of purified water. For example, the DPR system currently in use in the City of Windhoek, Namibia (see Figure 3.2 and Table 2.1) does not use reverse osmosis. Further, the development of advanced processes that are able to remove or convert trace constituents without physical separation of constituents from the product water are of special interest, especially in inland locations where management of the residual brines is often cost prohibitive and logistically challenging (see Sections 3.4 and 4.5). Currently, the City of San Diego is evaluating the use of ozone (O_3) and biologically active carbon (BAC) as a pretreatment step before the microfiltration process (see also Figure 3.1). The purpose of the evaluation program is both to assess whether the O_3–BAC process can enhance the breakdown of trace organics and to improve the performance of the microfiltration or ultrafiltration membranes.

Because the thrust of this White Paper is the cost of DPR with proven treatment technologies, alternative treatment processes and systems are not considered here. The equivalency of a variety of alternative treatment trains has been evaluated in detail in a recent WateReuse Research Foundation report (Trussell et al., 2013).

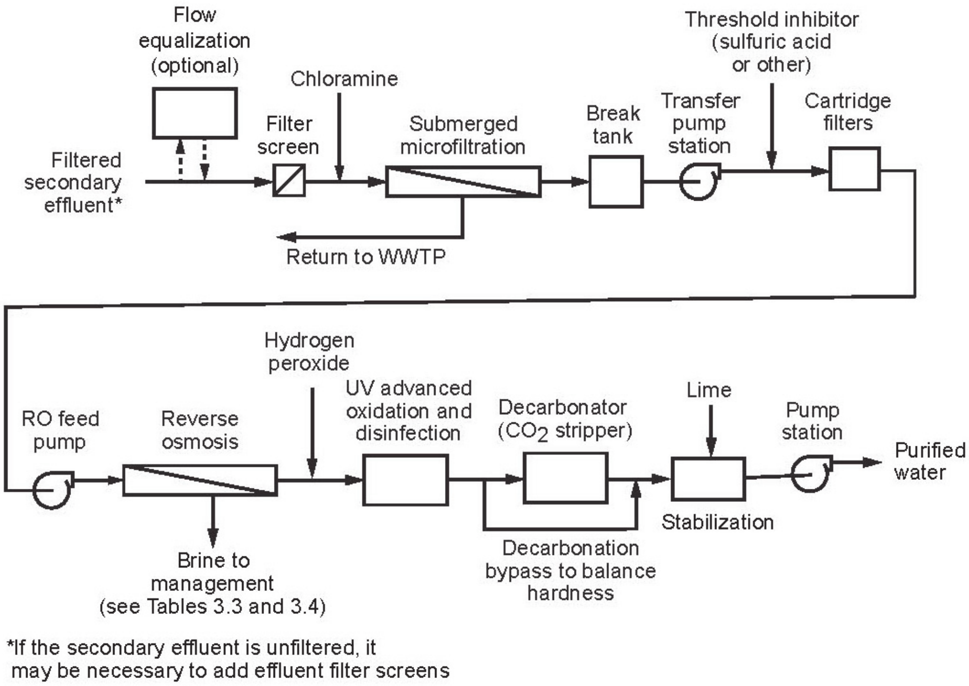

Figure 3.1. Proposed flow diagram for a CAT process.

Notes: The proposed treatment process corresponds to the OCWD water purification treatment process; WWTP = wastewater treatment plant.

Table 3.1. Summary of Treatment Technologies Employed for CAT Water Purification

Treatment Option	Use/Description
Secondary treatment	Conventional activated sludge secondary treatment without effluent filtration.
Secondary treatment with effluent filtration	Used to remove residual suspended solids remaining in secondary effluent following gravity separation (sedimentation).
Secondary treatment with nitrogen removal and effluent filtration	Activated sludge treatment with nitrification/denitrification and effluent filtration. It has been demonstrated that the performance of the microfiltration process is enhanced with tertiary treated effluent. Flow equalization and separate treatment or elimination of return flows will further improve the performance of the advanced treatment process.
Filter screen	Used to remove any large suspended solids in unfiltered secondary effluent. Filter screens are used where effluent filtration is not included in the secondary treatment process.
Flow equalization	Used to eliminate diurnal flow-rate and mass loading variations and to reduce the size of downstream units. Constant flow to the advanced treatment process reduces wear and tear on equipment (e.g., development of stress cracks in equipment because of cycling) and results in improved performance.
Microfiltration	Used to remove residual suspended particles by mechanical sieving. Typical membrane pore size ranges from 0.07 to 2.0 µm.
Cartridge filtration	Used to remove suspended and colloidal impurities from chemicals added to prevent scaling of the reverse osmosis membranes. Typical filter cartridge pore size ranges from 5 to 10 µm.
Ultrafiltration	Used to remove residual suspended particles by mechanical sieving. Typical membrane pore size is in the range from 0.008 to 0.2 µm. Ultrafiltration is often used in place of microfiltration.
Reverse osmosis	Used to remove residual colloidal and dissolved solids by means of size exclusion and solution/diffusion. Typical membrane pore size ranges from 0.0001 to 0.002 µm.
Ultraviolet (UV) oxidation without and with chemical addition	UV photolysis used to destroy or alter trace constituents that cannot be oxidized completely by conventional biological treatment processes. Hydrogen peroxide (H_2O_2) or O_3 is often added to enhance the oxidation process. UV oxidation also serves as an excellent disinfectant.
Decarbonation	Used to remove (strip-out) carbon dioxide (CO_2) from reverse osmosis product water. Removing the CO_2 increases the pH of the product water and reduces the amount of chemical that must be added to stabilize it (see the following).
Stabilization	Chemicals (typically lime) are added to stabilize the decarbonated product water with respect to its corrosive properties. A variety of indexes (e.g., Aggressiveness Index, Langelier Saturation Index) are used to assess the stability of the product water.
Engineered buffer	A purposely defined, natural or constructed storage facility used for flow retention and quality assurance. Examples of such features include storage tanks and pipelines. In DPR applications (see Figure 2.1a), the buffer could involve disinfection with free chlorine (Cl_2) or O_3 prior to blending with other water sources at the entrance to a potable water treatment plant.

Source: Adapted in part from Tchobanoglous et al. (2014).

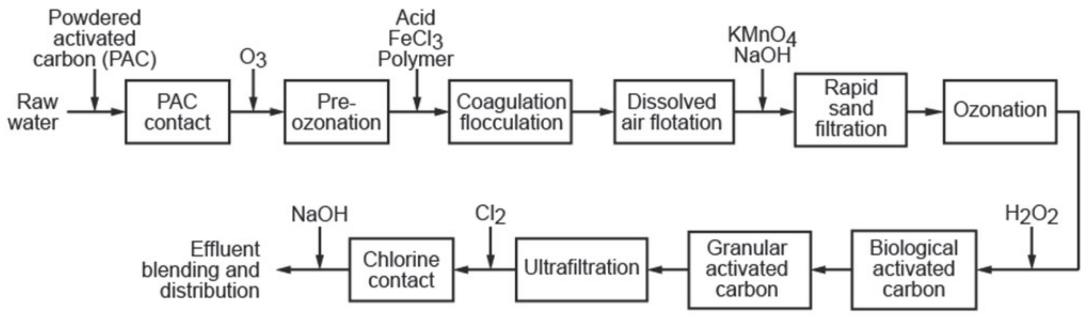

Figure 3.2. Water reclamation process flow diagram at the Goreangab Water Reclamation Plant in Windhoek, Namibia.

Source: Adapted from du Pisani (2005) and Lahnsteiner and Lempert (2005).

3.3. Regulatory Requirements of DPR

The constituents of public health concern in the purified water from an advanced treatment process may include regulated and unregulated inorganic and organic chemical constituents and pathogenic microorganisms. It is important to note, as cited previously, that the treatment process flow diagram identified in Figure 3.1 produces water that meets or exceeds all potable drinking water standards and that all unregulated chemicals known or suspected to be of health concern are reduced to non-measurable or *de minimis* levels. Additional details on the treatment capabilities of the benchmark CAT process may be found in a WateReuse Research Foundation report (Trussell et al., 2013) and in OCWD annual reports.

3.3.1. Pathogenic Microorganisms

Pathogenic organisms, which present acute risks, are of greatest concern in potable reuse applications. For example, the DDW has established overall treatment process log-removal levels for viruses, *Giardia*, and *Cryptosporidium* of 12, 10, and 10, respectively, for IPR projects. It is anticipated that the same values will apply to DPR projects. The pathogen reduction-log credits achieved by the benchmark treatment process components are compared with the DDW-required values for IPR in Table 3.2. It should be noted that Texas uses lower total log-removal values; however, they are applied to the effluent from secondary treatment rather than to untreated wastewater. If log-removal credits for conventional secondary treatment were added to the credits required for treatment processes following secondary treatment, then the Texas overall treatment process log-removal levels for viruses, *Giardia*, and *Cryptosporidium* would be similar to those required by the DDW. Also, some other states question whether the use of log-removal values for individual treatment processes is the appropriate method of regulation for pathogenic microorganisms. As reported in Table 3.2, disinfection with Cl_2 or O_3 can be used following CAT for additional redundancy.

3.3.2. A Third Water Source

In the future, it may be appropriate to designate treated wastewater as a third water source for drinking water along with groundwater and surface water. Further, it is not unreasonable to assume that selected treatment requirements similar to those contained in the current United States Environmental Protection Agency (U.S. EPA) Long-Term 2 Enhanced Surface Water Treatment Rule could be developed and applied to CAT-purified water. If the current surface water rules were applied, CAT-purified water would need minimal additional treatment, if any.

3.3.3. Regulatory Monitoring

OCWD currently has an extensive monitoring program for the CAT process for water quality, water quality assurance, and process performance and control. The monitoring program includes both on-line continuous monitoring and laboratory testing as well as critical control point monitoring and full-scale comparative testing of new technologies. Also, as new and/or improved methods of testing and analysis become available, these methods have been incorporated into the monitoring and testing program. Based on the long-term monitoring results, the extensive nature of the OCWD monitoring program, and the fact that the CAT process operated by OCWD was the first DDW-approved IRP injection project in California, it is anticipated that no significant increase in regulatory monitoring would be required for DPR (with the exception of some additional continuous on-line treatment process monitoring).

Table 3.2. Log-Removal Credits of Various Treatment Processes

	Log Reduction Credit		
Process	**Virus**	***Giardia***	***Cryptosporidium***
Benchmark Treatment Processes			
Secondary treatment	2	2	2
Microfiltration/ultrafiltration	0	4	4
Reverse osmosis	2	2	2
UV/H_2O_2	6	6	6
Water treatment	4	4	4
Total credits	14	18	18
Required credits[a]	12	10	10
Additional Log-Removal Values with Other Treatment Processes			
O_3[b]	4	3	1
Cl_2 (Cl_2 disinfection[c])	4	2	0

Notes: [a]DDW of the California SWRCB requirement.

[b]O_3 could be used before microfiltration or ultrafiltration or following advanced oxidation prior to blending with other water sources at the entrance to a potable water treatment plant.

[c]Disinfection with Cl_2 following advanced oxidation prior to blending with other water sources at the entrance to a potable water treatment plant.

3.4. Brine Management

Because the benchmark CAT system employs reverse osmosis, some form of brine management will be required. In coastal and near-coastal locations, brine typically is discharged to the ocean using an ocean outfall. In inland locations where a brine line to the ocean is not available and in coastal locations where ocean discharge is not allowed or is restricted, other disposal options must be used.

3.4.1. Brine Disposal Options

The principal brine disposal options currently in use are shown pictorially in Figure 3.3 and are described in Table 3.3. For inland locations without access to an ocean brine line, the first five options, arranged in the order of use, comprise 99% of the disposal options currently in use. It is important to note that for inland desalting operations of a scale sufficient to serve as part of a community water system (i.e., serving more than 30 households), deep-well injection is often the only potentially feasible brine management option [i.e., there generally are insufficient freshwater flows to adequately dilute brines discharged to inland surface waters (Archuleta, 2014)]. In some cases, brine from an inland location can be hauled for discharge into a wastewater collection system with sufficient dilution capacity.

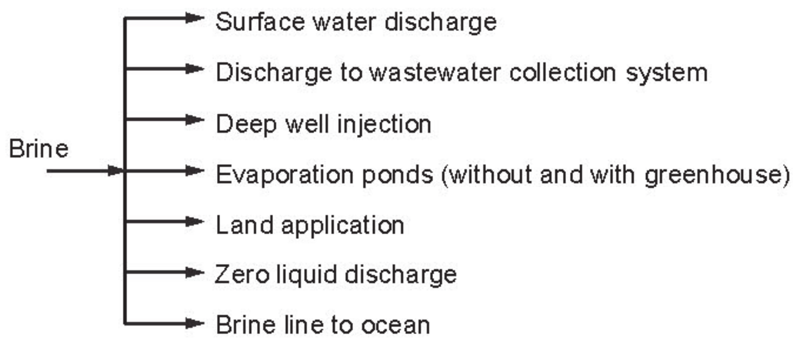

Figure 3.3. Ultimate disposal options for concentrated and unconcentrated brine solutions.

Table 3.3. Summary of Brine Disposal and Management Options

Disposal Option[a]	Use/Description
1. Surface water discharge	Discharge of brines to surface waters where sufficient dilution capacity is available is a common method of disposal for concentrated brine solutions. In some cases, the brine serves to dilute the constituent concentration of the surface water (e.g., Big Spring, Texas).
2. Discharge to wastewater collection system	This option is suitable for relatively small discharges such that the increase in total dissolved solids (TDS) is not significant (e.g., typically less than 20 to 50 mg/L).
3. Deep-well injection	This depends on the availability of a suitable subsurface aquifer and whether the aquifer is brackish water or is otherwise unsuitable for domestic uses.
4. Evaporation ponds (without and with greenhouse)	A large surface area is required in most areas with the exception of some southern and western states. The required surface area can be reduced using greenhouses. The solidified constituents are typically disposed of in a hazardous waste landfill.
5. Land application	Land application has been used for some low-concentration brine solutions. This option is generally not available. Concentrated brine solutions can be disposed of in secure hazardous waste landfills.
6. Zero liquid discharge (ZLD)	ZLD involves the use of brine concentrators (e.g., a vapor compression evaporator) and crystallizers or spray dryers to convert the brine concentrate to water and a solid dry product suitable for landfill disposal. The recovery of useful salts may also be possible.
7. Brine line to ocean	This is the disposal option of choice for facilities located in the coastal regions of the United States. Typically, a brine line, with a deep ocean discharge, is used by a number of dischargers. Combined discharge with power plant cooling water has been used in Florida. For inland locations, trucks, rail hauling, or pipelines are needed for transportation.

Source: Adapted in part from Mickley (2009) and Tchobanoglous et al. (2014)

Note: [a]For inland locations without access to a brine line, the first five options, arranged in the order of use, comprise 99% of the disposal options currently in use; however, of these five options, only deep-well injection appears viable for systems scaled for community supply.

3.4.2. Brine Treatment Options

To reduce the volume of brine that must be managed, a variety of brine treatment processes have been developed. The principal processes used for brine minimization are summarized in Table 3.4. In some applications, the treatment processes have been used in conjunction with other processes for the recovery of specific constituents. The application of the technologies listed in Table 3.4 is usually site-specific and will depend on the volume and constituent concentration of the brine.

Table 3.4. Summary of Brine Processing Options

Treatment Option	Application
Multistage reverse osmosis	Concentrate brine stream
Falling film evaporators	Thicken and concentrate brine stream
Crystallizers	Concentrate brine stream into a crystallized form for processing or disposal
Forward osmosis	Concentrate brine stream with membranes
Membrane distillation	Concentrate brine stream
Solar evaporators	Thicken and concentrate brine stream
Spray dryers	Concentrate brine stream
Vapor compression evaporators	Concentrate brine stream
Evaporation/crystallization	Concentrate and crystallize brine constituents

Source: Adapted in part from Mickley (2009) and Tchobanoglous et al. (2014).

Chapter 4

Cost and Energy Usage of DPR

The cost of DPR is composed of (1) the cost of CAT, (2) the cost of conveyance, and (3) the cost of brine management. Each of these costs, along with energy usage, is considered separately in the following discussion. A comparison of DPR costs with the costs of other new water supply options is considered in Chapter 5.

4.1. Cost of CAT

The cost and energy usage information for CAT is based on the CAT process described in Chapter 3. Because of the regulatory uncertainty, it is challenging to provide cost comparisons for other treatment process flow diagrams.

4.1.1. Sources of Information

The sources of information used to assess the cost of the CAT process are (1) the actual costs and operational expenses of the original OCWD GWRS put into operation in 2008 and (2) the actual bid prices and estimated operational expenses for the expansion of the OCWD GWRS to be put into operation in 2015. In addition, the estimated costs of the CAT facilities of other proposed DPR and/or IPR alternatives were reviewed for consistency.

4.1.2. Treatment Technologies Included in the CAT Process

The treatment technologies that comprise the CAT process for the original OCWD GWRS project and expansion are given in Table 4.1. As reported in Table 4.1, the difference between the original and the expansion projects was the inclusion of flow equalization in the expansion project.

4.1.3. Treatment Costs Based on OCWD CAT Facilities

The estimated cost of the CAT process for potable reuse, as described in Chapter 3 and shown in Table 4.1, is presented in Table 4.2. As shown in Table 4.2, the cost for the original CAT process, based on actual operating data, is about $685/AF. The projected cost for the expansion is $701/AF. Capital costs account for roughly 40% of total annualized costs, with annual operating and maintenance (O&M) costs comprising the majority of the costs. The operating cost for the expansion can be predicted with reasonable accuracy based on the current operating costs of the original facility.

Table 4.1. Summary of Treatment Technologies Employed for Advanced Water Purification

Treatment Technology	OCWD Original	OCWD Expansion
Secondary treatment	✔	✔
Secondary treatment with effluent filtration		
Secondary treatment with nitrogen removal and effluent filtration		
Filter screens	✔	✔
Flow equalization		✔
Microfiltration	✔	✔
Ultrafiltration		
Cartridge filtration	✔	✔
Reverse osmosis	✔	✔
UV oxidation	✔	✔
Decarbonation	✔	✔
Stabilization	✔	✔

Table 4.2. Cost of CAT for IPR and DPR without Conveyance and Brine Management Costs

		Orange County GWRS IPR Project	
Cost/item	Unit	Original	Expansion
Capital expense	$	350,000,000	128,773,322
Annualized capital[a]	$/y	19,267,500	8,376,705
Annual O&M	$/y	28,700,000	13,361,005
Total annual cost	$/y	47,967,500	21,737,710
Yield	AF/y	70,000	31,000
Unit cost	$/AF	685	701

Notes: [a]Capital cost annualized at 5% interest rate over a 30-year period; capital recovery factor equals 0.06505 for the expansion; note that the original OCWD GWRS received more favorable financing.

There are some differences in the components that make up the cost of the expansion as compared with the original facility. The original facility did not include flow equalization, which is included in the expansion. Also, the capital cost of the expansion facility is lower because much of the required yard piping was installed with the original facility. If it is assumed that 30% of the original $70 million spent on yard piping would be needed for a standalone expansion facility, then the unit cost for the expansion would increase by $44/AF. If the capital cost of the flow equalization facilities ($20 million) is excluded, the unit cost drops by about $42/AF. Also, it is estimated that the unit cost of the original facility would have been lower by about $20/AF if the expansion piping had not been installed. Taking all of these factors into account, there is essentially no scaling factor on unit cost between plant capacities of 31,000 versus 71,000 AF/y. For the purpose of comparisons, a value of $700/AF will be used as the low estimate for CAT, excluding flow equalization.

4.1.4. Cost of CAT Facilities at Other Locations

Projected and bid price data were reviewed for San Diego and Santa Clara County, California.

San Diego, California. The treatment process flow diagram proposed for the San Diego IPR project is essentially the same as that used at OCWD. Preliminary cost data for the proposed IPR CAT process for San Diego was reviewed and found to be similar given local constraints. For example, flow equalization will not be used at one of the two proposed facilities because the wastewater treatment plant operates at a constant flow rate.

Santa Clara County, California. Similarly, the cost data for the Santa Clara Valley Water District CAT process, which is also essentially the same as that used at the OCWD facility, was reviewed and found to be similar, again with slight local variations.

4.1.5. Summary

The cost of CAT will vary, as noted previously, with site-specific factors including the characteristics of the influent water and the number of technologies employed as well as varying somewhat with the overall plant capacity, but it is expected to be on the order of $700/AF, excluding conveyance and brine management costs.

4.2. Cost of Conveyance

In addition to the cost of CAT, both DPR and IPR will require conveyance to either the drinking water system or an environmental buffer. For IPR, the conveyance cost for pipe construction and associated pumping may be modest or quite expensive, depending on local circumstances (e.g., distance and terrain between the CAT facility and the environmental buffer and between the buffer and the drinking water system). For example, for OCWD's GWRS, the purified stabilized water is pumped approximately 13 miles to the groundwater infiltration basins. The conveyance cost for OCWD's GWRS amounts to $120/AF. In other settings, the conveyance cost may be substantial. For example, for San Diego, the preliminary estimates of conveyance costs alone for two IPR options under consideration exceed $750/AF per option and may run as high as $1250/AF for one of the options.

For DPR, the conveyance cost may be less expensive, depending on site-specific considerations such as the distance and elevation between the advanced treatment plant and the drinking water treatment facility and the need for engineered storage in cases where the point of water addition to the distribution system is near the CAT facility. In San Diego, for example, one potential treatment facility location may have conveyance capital cost savings of more than $100 million for the DPR configuration as compared with the IPR alternative.

4.3. Cost of Brine Management

As with CAT and conveyance costs, the costs associated with brine management are site-specific and can vary widely depending on the characteristics and volume of the brine that must be managed. Typically, brine will be discharged through an existing wastewater treatment ocean outfall. In some cases, a number of nearby agencies will join forces and construct a separate brine disposal line, which is the situation in Southern California.

Typical brine disposal costs are reported in Table 4.3. For example, in deep-well brine disposal systems, the length of the pipeline from the treatment facility to the location of the injection well can vary from less than one mile to more than 30 miles. Similarly, the cost of the injection well depends on the depth of the receiving aquifer, which can vary from 2000 to 10,000 feet.

4.4. Total Cost of DPR

The total cost of DPR, including CAT, treatment, conveyance, and brine management, may run between \$820/AF (\$700/AF for CAT plus \$120/AF for conveyance) and \$2000/AF. The low-end cost is based on the assumption that brine would be discharged through an existing ocean outfall. The upper-end cost includes CAT plus a relatively expensive conveyance expense for pipeline construction and operation and can include the cost of a separate brine line. In general, the cost of CAT for either DPR or IPR will be about the same, but conveyance and brine management costs will be site-specific and may be quite different. Also, it is important to note that the cost of drinking water treatment (i.e., the cost to re-treat the CAT-generated water at the drinking water system treatment plant) is not included because the same quantity of water is being treated; only the source of supply has changed.

4.5. Energy Usage for DPR

The energy required for DPR is composed of the energy requirements for (1) CAT, (2) conveyance, and (3) brine management. Each of these energy requirements is considered in the following.

4.5.1. Energy Required for CAT

The energy requirements for CAT depend on the flow rate, the characteristics of the incoming secondary or tertiary effluent, and the specific treatment processes employed. Typical energy requirements for individual treatment technologies used in the CAT process (see Figure 3.1 in Chapter 3) are presented in Table 4.4. The energy requirement for the benchmark CAT process, identified in Figure 3.1 and in Table 4.1 (column 5), will vary between 1050 and 1140 kWh/AF, based on actual operating data from OCWD. The total energy requirement for other advanced treatment configurations can be estimated using the values given in Table 4.4.

Table 4.3. Estimated Costs of Selected Brine Disposal Options

	Cost (\$/AF)	
Disposal Option	**Range**	**Typical**
Deep-well injection	60–80	70
Evaporation ponds	140–175	155
Land application, spray	130–160	140
ZLD	600–750	700
Brine line to ocean	110–150	115

Source: Adapted in part from Raucher et al. (2010) and Voutchkov (2013).

Table 4.4. Typical Energy Requirement for Various Treatment Process Technologies Used for Advanced Treatment

Technology	Product Recovery[a] (%)	Energy Consumption		
		kWh/10^3 gal	kWh/m^3	kWh/AF
Wastewater with TDS from 800 to 1200 mg/L				
Secondary treatment[b]	94–96	1–1.6	0.26–0.42	330–520
Tertiary treatment[c]	94–96	1.6–2.2	0.42–0.54	520–670
Media filtration (depth)	96–99	0.1–0.3	0.03–0.08	33–40
Media filtration (surface)	96–99	0.05–0.2	0.001–0.005	15–20
Filter screens	96–99	0.004–0.005	0.001–0.0013	1.25–1.75
Cartridge filtration	96–99	0.04–0.2	0.011–0.05	13–20
Microfiltration (vacuum type)	85–95	0.75–1.1	0.2–0.3	240–360
Microfiltration (pressure type)	85–95	0.75–1.1	0.2–0.3	240–360
Ultrafiltration	85–95	0.75–1.1	0.2–0.3	240–360
Nanofiltration	85–94	1.5–1.9	0.4–0.5	490–620
Reverse osmosis (without energy recovery)	80–85	1.9–2.3	0.50–0.61	620–750
Reverse osmosis (with energy recovery)[d]	80–85	1.7–2.2	0.46–0.58	550–700
Advanced oxidation	na	0.31–0.40	0.053–0.106	100–130
Carbon dioxide stripping	na	0.031–0.046	0.008–0.012	10–15
Lime saturation	na	0.006–0.012	0.0016–0.0032	2–4
CAT[e]	80–85	3.2–3.5	0.84–0.92	1050–1140
Seawater with TDS of about 35,000 mg/L				
Ultrafiltration (pretreatment)	85–95	0.75–1.1	0.2–0.3	240–360
Reverse osmosis (with turbine/pump energy recovery)	30–55	19–26	5–7	5200–8500
Reverse osmosis (with pressure exchange energy recovery)	30–55	9.5–15	~ 2.5–4	3100–4900

Source: Adapted from Tchobanoglous et al. (2014).

Notes: [a]Values based on crossflow mode of operation.
[b]Conventional activated sludge without energy recovery (50 to 5 Mgal/d; see Table 4.5).
[c]Activated sludge with nitrification/denitrification and effluent filtration without energy recover (50 to 5 Mgal/d).
[d]Overall total energy reduction will vary from 6 to 12%, depending on the energy recovery device (ERD) and process configuration.
[e]Based on actual operating data from OCWD for 2012–2013.

Note: kWh/m^3 x 3.785 = kWh/10^3 gal; kWh/10^3 gal x 325.892 = kWh/AF.

For the purpose of comparison, the electrical energy requirements of various secondary treatment processes and of conventional water treatment are presented in Table 4.5, in terms of stepped flow-rate increments. The lowest treatment capacity for which electrical energy requirements are given is 5 Mgal/d. Below 5 Mgal/d, wastewater treatment energy-use values vary widely and are unpredictable. Above 5 Mgal/d, there is a decrease in the energy requirements with plant size to about 20 Mgal/d. Beyond 20 Mgal/d, the energy cost for wastewater treatment does not vary significantly. It is interesting to note that the energy usage for water treatment also does not vary significantly with increasing plant size, in part because many of the processes are modular. Similarly, the energy required for the CAT process at various capacities does not change significantly with plant size because the standard module size is typically about 5 Mgal/d.

4.5.2. Energy Required for Conveyance

The energy requirements for conveyance are also highly site-specific and will depend on the total dynamic head for the conveyance system, the properties of the fluid being pumped, and the efficiency of the pumping equipment. In addition, the energy requirements for the support equipment and facilities must be taken into account. For example, for a flow of 31,000 AF/y (27.7 Mgal/d or 42.8 ft^3/s), which corresponds to the OCWD plant expansion, the energy required for conveyance for every 10 feet of total dynamic head (static head plus dynamic losses) is equal to 64.6 horsepower or 48.2 kW, which corresponds to 13.6 kWh/AF. The computed value is based on the assumption that the specific weight of the purified water at 20°C is 62.3 lb/ft^3 and the pump efficiency is 75%. If the total dynamic head were 250 feet (which is not uncommon), the corresponding value would be 340 kWh/AF. Clearly, the energy required for conveyance can become significant.

Table 4.5. Typical Energy Usage for Water, Wastewater, and CAT Systems

	Energy Required (kWh/AF)				
Capacity (Mgal/d)	**Activated Sludge**	**Activated Sludge with Filtration**	**Activated Sludge with Nutrient Removal and Filtration**	**Conventional Surface Water[a]**	**Complete Advanced Treatment**
5	520	570	670	128	1100
10	450	480	600	124	1090
20	380	435	555	123	1080
40	340	400	530	123	1065
80	330	385	520	122	1060

Source: Adapted in part from Burton (1996), EPRI (1994, 2013), and Howe et al. (2012).

Note: [a]Includes influent pumping (45 kWh/AF) but does not include pumping for distribution.

4.5.3. Energy Required for Brine Management

With the exception of the ZLD process, the corresponding energy requirements of the various brine disposal options described in Table 3.3 and listed in Table 4.5 are also site-specific and are even more difficult to generalize. For ZLD, if it is assumed that the system is composed of an evaporator and a crystallizer, the following values can be used to estimate the energy requirements, excluding the energy required for landfilling (Voutchkov, 2013):

- Evaporator: 60–90 kWh/1000 gal of brine feed water
- Crystallizer: 200–260 kWh/1000 gal of concentrated brine from the evaporator

If it is assumed that the percentage of brine is 15% and that the brine is thickened to 95%, the corresponding values for the evaporator and crystallizer, expressed in terms of kWh/AF of product water, are as follows:

- Evaporator: 2930–4000 kWh/AF gal of product water
- Crystallizer: 490–640 kWh/AF gal of product water

On the basis of these values, the combined energy requirement will vary from 3420 to 5030 kWh/AF, which is about five times the amount of energy required for the CAT process but is similar to the energy requirements for seawater desalination. It is anticipated that these energy requirements will be reduced in the future based on a number of new technologies being tested and others currently under development.

Chapter 5

Comparison of the Cost of DPR with the Costs of Alternative Water Supplies

The costs of DPR, IPR, and other alternative new water supply options will depend largely on several factors, including site-specific conditions, the size and scale of the facility, and regulatory requirements. As noted previously, providing cost comparisons across a wide range of alternatives is challenging because the final DPR regulations are unknown. However, data ranges from a number of different alternative water sources are reviewed in this chapter.

5.1. Limitations of Cost Information

In comparing potable reuse costs to other options, other complications arise. Ideally, a comparison of the costs of water supply alternatives reflects a shared set of conditions, such as the full cost to deliver water to the customers' taps or the full cost to deliver water to the entry of the drinking water treatment plant. However, in many instances the available cost information pertains only to the cost of the applicable treatment facilities (e.g., the cost per AF to generate water at a desalination plant) and may exclude the costs and energy requirements needed to pipe and pump the water from that facility to the drinking water treatment plant or distribution system.

5.2. Comparative Costs of Alternative New Water Supply Options

Alternative options for developing new water supplies are fairly limited; they include desalination (of seawater or, where available, brackish groundwater), increased reliance on already stressed imported water via the State Water Project (SWP) or the Colorado River, nonpotable reuse (NPR; e.g., for irrigation), and water conservation. A summary of the estimated costs of these alternatives, along with their respective caveats, is presented in Table 5.1. In general, potable reuse is likely to have costs comparable to the potentially available alternatives.

Table 5.1. Comparative Costs of Potable Reuse and Alternative New Supply Options

Supply Option	Cost ($/AF)[a]	Comments and Caveats	Basis/Citations
DPR	820–2000	Low-end value includes the cost of CAT and $120/AF for conveyance but does not include brine disposal cost. Conveyance and brine disposal costs are highly site-specific. At the low end, it is assumed that brine is disposed of through an existing wastewater treatment plant outfall.	Low-end value is based on OCWD GWRS actual costs for the DPR-type CAT process. High-end value is based on preliminary San Diego estimates and authors' approximation of potential conveyance costs.
IPR	820–2000	Low-end value includes the cost of CAT and $120/AF for conveyance but does not include brine disposal cost. Conveyance and brine disposal costs are highly site-specific. In some cases, conveyance costs may be significant (e.g., $700 to $1000/AF) and may be considerably higher than for DPR.	Low-end value is based on OCWD GWRS actual IPR costs for treatment and conveyance. High-end value is based on the San Diego preliminary estimate for a modest-scale IPR with San Vincente Reservoir as the buffer. At the low end, it is assumed that brine is disposed of through an existing wastewater treatment plant outfall.
Seawater Desalination	1500–2330	Reported costs of seawater desalination span a very broad range and generally are $2000 or more per AF. Reported costs may not include all components, such as conveyance to the potable water supply system, or permits, which may add considerable upfront capital and O&M expense.	Low-end costs reflect least-cost configurations from West Basin Municipal Water District master plan (Malcolm Pirnie, 2013). Upper end based on water purchase agreement-specified prices for future Carlsbad facility deliveries to San Diego County, updated to 2014 dollars. These contract-specified prices may not reflect full costs. Conveyance costs to potable water supply system can be significant (e.g., $700 to $1000/AF). Higher costs anticipated in some locations.
Brackish Groundwater Desalination (inland)	930–1290	Costs may be considerably higher than indicated if a low-cost concentrate management option (such as a brine line) is not locally available. Regulatory barriers to inland concentrate management are a significant cost factor and an impediment to broader implementation.	Based on actual costs at the Chino desalting facility, including relatively inexpensive concentrate management via the Santa Ana Regional Interceptor brine line. High-end value is based on CDWR (2003) and may be understated.
Imported Water (e.g., SWP)	850–1300 (may be $2000/AF by 2020)	Costs escalating rapidly (9–10% annually over the past five years) and may exceed $2000/AF by 2020. Additional yields generally unavailable; existing yields are unreliable. Salt management and environmental costs are not reflected in prices.	Based on prices borne in Los Angeles and San Diego for water obtained from the Metropolitan Water District of Southern California (MWD) in 2014. Future cost escalation (up to 10% per year: $2000/AF by 2020) reflects observed trends over the past 5 and 10 years.

Table 5.1. Comparative Costs of Potable Reuse and Alternative New Supply Options

Supply Option	Cost ($/AF)[a]	Comments and Caveats	Basis/Citations
NPR	310–1960	Costs vary considerably depending on whether a new treatment facility and/or purple pipe conveyance is required and on the distance and elevation changes between facility and customer. Costs may omit on-site retrofits and other expenses borne by NPR customers. Seasonal storage (or stranded assets) costs are not included and may be significant.	Based on Mitchell (2012), reflecting CA's State Recycled Water Taskforce report (2003) and other estimates. Midpoint of $1140/AF consistent with average cost from a Camp Dresser McKee study in 2005 of 26 Bay Area recycled water projects (per Mitchell, 2012). Some NPR options may cost considerably more than the upper-end estimate reported here.
Water-Use Efficiency, Conservation, and Use Restrictions	465–980	Additional water savings likely to require increasing costs per AF saved. Reflects out-of-pocket expense for the water utility, and omits costs borne by customers to save water (e.g., to purchase and install a high-efficiency washing machine). Also omitted are costs incurred by customers because of reduced water use (e.g., loss and possible replacement of lawn areas, sports fields, shrubs, gardens, business revenues).	Utility-incurred costs only, based on Conservation Master Plans for four California water utilities (per Mitchell, 2012). Average utility-borne costs are about $775/AF.

Note: [a]Dollars are in 2014 values, unless stated otherwise.

Chapter 6

Relative Carbon Footprint of Potable Reuse and of Its Alternatives

A key consideration for new water supply alternatives is the amount of energy—and the associated carbon footprint—required to obtain, treat, and deliver potable quality water. Other than water-use efficiency and conservation (which can reduce energy as well as water use), all of the water supply alternatives considered as viable new supplies rely on a considerable amount of energy for complete advanced treatment (CAT) and/or conveyance. The relative carbon footprints associated with potable reuse, desalination, and imported water are discussed in this chapter.

6.1. Potable Reuse

The energy requirements associated with applicable treatment components of CAT for purifying wastewater were discussed previously in Chapter 4. The overall energy requirements for CAT, brackish water and seawater desalination, and imported water are reported in Table 6.1, along with the corresponding carbon footprint values. For the overall CAT process, the OCWD GWRS's experience with potable reuse provides a useful benchmark of the energy required for the CAT of wastewater for IPR or DPR applications. For the GWRS, the CAT process requires about 1060 kWh/AF of potable water produced, based on actual operating experience from July 2012 through July 2013. (An additional 340 kWh/AF is required for pumping to convey the potable water to the groundwater recharge facilities.) Energy costs for the CAT process amount to $92/AF, which is about 23% of the total O&M expense for treatment at the GWRS.

The carbon footprint values associated with the energy required for the various technologies and water sources are presented in column 4 of Table 6.1. The reported values are obtained by multiplying the energy required in kWh/AF by a conversion factor (0.346 kg CO_2e/kWh), which reflects the CO_2 emission equivalents released in the production of a kilowatt hour of energy. The conversion factor is based on the California Action Registry General Reporting Protocol and represents a mix of energy sources that is specific for California. Thus, the carbon footprint for the CAT process is 367 kg CO_2e/AF or 367 MT/1000 AF.

Beyond treatment, potable reuse and other supply alternatives require additional energy for conveyance of the product water to the drinking water system and for the management of brine. Energy requirements for pumping depend on the distance, elevation gain, terrain, and other site-specific factors and can be substantial in some settings. There also can be a considerable carbon footprint associated with manufacturing and installing the pipeline itself. Similarly, the energy requirements for brine management will depend on whether an existing brine line or ocean outfall can be used or a new brine management system needs to be developed and deployed.

Table 6.1. Comparative Energy Requirements for Alternative Sources of Water

Technology/Water Source	Energy Required (kWh/AF) Range	Typical	Carbon Footprint (kg CO_2e/AF)
Secondary treatment without nitrogen removal[a]	330–520[b]	450[c]	156
Tertiary treatment with nitrogen removal and effluent filtration[a]	520–670[b]	600[d]	208
CAT	1050–1140	1080	373
Brackish water desalination[d]	1500–2000	1900	657
Ocean water desalination[d]	3100–4900	3900	1349
California State Project water[e]	2500–5300	3300	1142
Colorado River water	2000–2100	2000	692
Conventional drinking water treatment[f]	120–130[b]	124[c]	43
Membrane-based water treatment[f]	140–150	145[c]	50

Notes: [a]Energy recovery is not included; for plants that are 10 Mgal/d and larger, the potential energy recovery from biogas is on the order of 115 kWh/AF.

[b]The low and high range limits of the energy required are for an 80 and a 5 Mgal/d treatment plant, respectively (see Table 4.4).

[c]The typical energy required value is for a 10 Mgal/d treatment plant.

[d]The energy required for distribution is not included.

eThis includes the energy required for delivery to point-of-treatment, including energy recovery; the energy required for treatment and distribution is not included; the range of energy-required values reflects the different points of water delivery.

[f]This includes influent pumping (45 kWh/AF) but does not include pumping for distribution.

Source: Adapted in part from Larson et al. (2007), Taffler et al. (2008), and Tchobanoglous et al. (2014).

6.2. Desalination

Desalination is a relatively energy-intensive water supply alternative. Advances in membrane technologies and energy recovery systems have contributed to reducing the net amount of energy required for desalination facilities. Seawater desalination typically requires 3700 kWh/AF of product water. This equates to a carbon footprint of about 1280 MT CO_2e/1000 AF produced.

Brackish water desalination, as may be feasible at some inland locations, tends to be much less energy intensive than seawater desalination because source water TDS levels tend to be much less than 10,000 mg/L (in contrast to seawater, which has TDS levels of about 35,000 mg/L). At the Chino groundwater desalting facilities in the Inland Empire Utilities Agency, energy requirements are 1900 kWh/AF, with an associated carbon footprint of 657 MT CO_2e/1000 AF.

6.3. Imported Water

The broader application of potable reuse, including DPR, will in many locations generate a reduced reliance on imported water. Reducing water imports will in turn avoid the extensive energy requirements associated with transporting water from the Bay Delta or the Colorado River. By offsetting the demand of 1000 AF of imported SWP water (for example), a local potable reuse project will avoid greenhouse gas (GHG) emissions of roughly 1142 MT CO_2e/1000 AF. This value does not include the additional energy and carbon footprint required to treat and distribute the imported water or to address the salt management challenge associated with high TDS loads conveyed by imported waters (see Chapter 7).

On net, a potable reuse project would save about 775 MT of GHG emissions (367 MT versus 1142 MT) for each 1000 AF produced. In turn, this savings would cut CO_2e emissions by about two-thirds when the project is used in lieu of imported waters. In addition, it would yield a higher quality and more reliable supply and would free up import waters for other users and/or environmental flows.

6.4. Summary

Using CAT to generate reclaimed water suitable for potable reuse is less energy intensive than the alternatives available for generating new water for California. Although potable reuse using CAT is more energy intensive than conventional drinking water treatment processes (as shown in Table 6.1), traditional supplies have been fully developed and new alternatives need to be considered. Amongst the viable new sources of water supply, potable reuse is considerably less energy intensive than seawater or brackish groundwater desalination or transporting import waters to Southern California. Potable reuse may reduce energy demands and carbon footprints to one-third or one-half the levels associated with the alternatives.

Chapter 7

Direct and Comparative Benefits of DPR

In California and elsewhere, potable reuse can offer important benefits relative to the other feasible alternatives for ensuring adequate and reliable water supplies into the future. Further, DPR can offer a number of benefits compared with other recycling opportunities, specifically IPR (which requires an environmental buffer) or NPR (which limits types of uses and requires its own distribution infrastructure). Potable reuse also compares favorably with other new water supply alternatives and with imported water on the basis of cost, availability, reliability, energy requirements, and carbon footprint.

7.1. Direct Benefits of Implementing Potable Reuse

The principal benefits of implementing potable reuse can be assessed in terms of (1) public water supply, (2) agriculture, (3) the environment, (4) energy conservation, and (5) cost. The discussion of each of these areas of benefit is derived, in part, from Schroeder et al. (2012).

7.1.1. Public Water Supply Benefits

Alternative solutions to meet urban water supply requirements include the development of local surface and groundwater storage reservoirs, the development and implementation of inter-basin water transfer systems, desalination of brackish water and seawater, conservation, and DPR and/or IPR. In many locations the development of local storage reservoirs is not feasible. Inter-basin water transfers often result in damage to local agriculture and the environment, and transmission systems are at risk from earthquake damage and other natural disasters. Seawater and brackish groundwater desalination is costly and energy intensive, and for inland locations, brine disposal is a serious fiscal and environmental compliance issue. In many communities, the relatively cost-effective demand reductions available through conservation and water-use efficiency measures have already been achieved. In contrast, in many locations sustainable local sources combined with DPR and/or IPR may be adequate. Compared with other alternatives, potable reuse can provide a stable local source of water that is less subject to natural disasters and has relatively modest energy requirements (see Chapter 6). Potable reuse also contributes a more diversified local water supply portfolio, drawing on a locally generated, locally controlled, and climate-independent supplement to a community water supply. It also may free up other local (or imported) waters for other uses.

7.1.2. Agriculture Benefits

Water that is not exported for urban use can be made available for food production and can also help minimize subsidence that is due to overdrafting of aquifers. Given the projected population growth over the next 25 years, protecting agricultural water supplies for irrigation will become of greater importance, especially in times of drought.

7.1.3. Environmental Benefits

A reduction in the amount of water exported to urban areas can have direct environmental benefits by allowing for more effective management of instream flows and aquatic ecosystems. The reduction of aquifer overdrafting can, as noted previously, help to reduce the lowering of groundwater levels and the resulting increase in pumping energy costs, subsidence, and damage to surface infrastructure. Reducing groundwater overdraft will also help maintain base flows for many freshwater rivers and streams, thereby protecting aquatic and riparian habitats.

7.1.4. Energy Conservation Benefits

As noted in Chapter 6, the energy required for the production of purified water through the CAT process will vary from 1050 to 1140 kWh/AF beyond that needed for secondary treatment, depending on the wastewater TDS (i.e., about 500 to 1000 mg/L). By comparison, desalination of seawater, with energy recovery, requires about 3100 to 4900 kWh/AF. Inter-basin transfers of water typically require large expenditures of energy (2500 to 3500 kWh/AF; see Chapter 6 and Table 5.2) to pump water over the mountain ranges that separate and define the basins. In addition, using sources with lower energy demands also reduces the carbon footprint of water supply provision.

7.1.5. Cost Savings

DPR and/or IPR can, as described in Chapter 5, have significant cost-saving benefits. In Southern California, the cost of IPR water produced by the OCWD GWRS, which meets or exceeds all of the drinking water standards, is less than the cost of water from the SWP. In the future, SWP water costs are expected to continue to increase at rates well above general inflation, whereas the costs of CAT will remain relatively the same or may even decrease though continual technological developments.

7.2. Comparative Benefits of Implementing Potable Reuse

The benefits of DPR in a comparative context relative to other alternative available water supply options are considered in the following with respect to (1) imported waters, (2) desalination, (3) conservation and curtailments, (4) NPR, and (5) IPR.

7.2.1. Comparative Benefits of Potable Reuse Relative to Imported Waters

Much of California currently relies extensively on waters imported from the Bay Delta via the SWP or on water drawn from the Colorado River. There are many problems associated with the reliance on imported waters: (1) the yields are subject to many possible natural and institutional disruptions and limitations, resulting in potentially large inter-annual variability; (2) the quality of these imported waters is variable (and they tend to include relatively high salt loads); (3) the energy and associated carbon footprint required to transport these waters is considerable; (4) the extraction of these waters imposes significant adverse environmental consequences; and (5) the cost of imports is high and escalating rapidly. It is vital for California's future that it reduce rather than increase its reliance on imported water.

7.2.1.1. Potable Reuse Provides a More Reliable, Locally Controlled Supply Relative to Imports

In Southern California, the availability of imported water (from both the Colorado River and the SWP) is subject to a number of natural and societal forces, including (1) increased demands from population growth, (2) drought, (3) changes in snowpack, (4) seismic events, (5) earthquakes, and (6) environmental regulations, water rights determinations, and the associated legal challenges and court rulings. Local groundwater extraction is also limited in many areas because of past overdrafting and/or adverse water-quality impacts, highlighting the need for additional reliable sources of water to meet current and future demands under all hydrologic conditions.

In addition, by reducing the need for imported SWP water, wide-scale implementation of potable reuse will augment instream flows in the Sacramento-San Joaquin River Delta (which provides the means by which the SWP delivers water from Northern California to the south) or will offset other diversions that may otherwise reduce instream flows. Reduced demands on Delta supplies also will help reduce the overall salinity of the Delta and improve Delta habitat.

7.2.1.2. Potable Reuse Improves Water Quality by Reducing Import-Related Salt Loading

In the San Diego Recycled Water Study (City of San Diego, 2012), it was noted that when blended with imported water, highly purified water produced using CAT has the potential to reduce salinity in reservoirs by up to 50%. Imported water entering San Vicente Reservoir averages 500 mg/L of TDS, whereas water from Orange County's GWRS—an operating CAT plant—averages 35 to 50 mg/L. The reservoirs that receive the CAT-purified water, and the soil that is irrigated with the water, would all benefit from having water with up to half the current salinity levels. In addition, residents would directly benefit from softer water that extends the lives of household appliances such as water heaters, dishwashers, clothes washers, and faucets.

To estimate the magnitude of potential statewide water-quality improvements that could accrue from potable reuse, the amount of salt import that is avoided by using purified recycled water in lieu of imported water supplies can be used as a metric. For example, if 1 million AFY of potable reuse is generated and offsets about half of MWD's imports into Southern California, then the estimated salt content (50 mg/L) of potable reuse supply results in avoiding 320 million pounds of salt import each year.

7.2.1.3. Reuse Reduces Wastewater Effluent Discharge to the Ocean

Approximately 3.5 million AFY of freshwater is currently discharged to the ocean as wastewater in California (WateReuse California, 2009). Not only could this ocean discharge serve as a source of expanded water reuse opportunities, but an expanded water-recycling program would also reduce wastewater effluent discharge into the marine environment.

For example, in San Diego, the U.S. EPA in 2010 allowed the City of San Diego to continue to operate the Point Loma Wastewater Treatment Plant as a chemically enhanced, primary treatment facility under a modification to its National Pollutant Discharge Elimination System Permit. During the 2008–2010 permit modification process, two environmental organizations entered into a Cooperative Agreement with the city to conduct the *Recycled Water Study,* the purpose of which was to identify alternatives to large-scale wastewater system upgrades, including the alternative of a water reuse program. Reductions in ocean discharges could have a substantial impact on coastal ecosystems directly adjacent to ocean outfalls (City of San Diego, 2012).

7.2.2. Comparative Benefits of Potable Reuse Relative to Desalination

In coastal locations, seawater desalination may be a technically feasible option that can provide a high-quality potable supply (after blending and/or chemical addition) that adds to the portfolio of water sources in a region. Seawater desalination also offers climate resistant yields, and its source water (seawater) is virtually unlimited in availability along coastal areas.

Seawater desalination also has some important drawbacks, including potential environmental impacts associated with feed water intakes, brine discharges, and the construction of facilities at sensitive shoreline or near-shore locations. Seawater desalination also has relatively high energy demands and carbon footprints compared with potable reuse. Feed water quality for desalination is vulnerable to red tides and other ocean water quality challenges, and coastal facilities may be vulnerable to sea level rise and storm surge. Seawater desalination facilities are subject to considerable permitting and regulatory requirements and have proven to be very difficult, costly, and time-consuming to receive authorization for and to build. These collective factors can make seawater desalination a more expensive option than potable reuse.

Brackish water desalination may be a viable option in some inland and coastal locations. It provides a high-quality potable supply and offers reliable, climate-resistant yields in most locations with access to brackish groundwater. It also tends to be less energy intensive and less expensive than seawater desalination.

A disadvantage of inland brackish water desalination, relative to potable reuse, is that desalination is available only at locations with access to brackish aquifers. Inland desalting also appears to be somewhat more energy intensive than CAT for potable reuse, depending on the TDS of the brackish water source. Perhaps most importantly, there are considerable regulatory challenges and costs associated with concentrate (brine) management at inland desalination facilities (unless a brine line is locally available for coastal discharge).

7.2.3. Comparative Benefits of Potable Reuse Relative to Conservation and Curtailments

Improvements in water-use efficiency and conservation are very desirable and are an essential component of prudent water resource management. As a result of concerted efforts throughout the past few decades to educate water users and to incentivize water savings through rebates and other mechanisms, significant per capita water-use reductions have been realized in residential, commercial, and industrial settings. This has not only conserved water but also saved the energy required to pump, treat, and heat the water. At this point in time, however, the "low hanging fruit" of water-use reductions have been harvested, and there is now more limited potential for major additional advances in urban water savings to free up existing supplies. Long-standing water-use efficiency and conservation programs have "hardened" demand in most locations, limiting opportunities for additional, cost-effective water savings. Additional water conservation is likely to come at a relatively high cost per AF of water saved.

It also is important to note that the costs estimated for conservation efforts are typically only those expenses borne by the water utility. Costs borne directly and indirectly by customers investing in water-saving appliances or foregoing lawns and gardens are not factored into the estimates. These omitted customer and community costs include the expense of acquiring and installing water-saving appliances and the losses incurred by foregoing residential and public green spaces. In addition, reduced revenues from lower water sales create a sizable challenge to water utilities, which typically face high fixed costs. Rate increases are often necessary to enable utilities to meet fiscal obligations associated with large capital investment needs for infrastructure renewal and regulatory compliance.

7.2.4. Comparative Benefits of Potable Reuse Relative to NPR

NPR has been widely implemented throughout California and elsewhere, generating important benefits for a wide array of water users, communities, and the environment. NPR provides a dependable and generally cost-effective water supply to agricultural irrigators, reducing the uncertainties and periodic drought-related adverse economic impacts associated with crop production in many communities with important agricultural sectors. It likewise has provided a reliable and cost-effective water supply for many industrial users, energy producers, large-scale cooling operations, and other businesses critically reliant on a dependable supply as a vital input in their production processes.

NPR has also served to relieve demand-side pressures on potable supplies, providing “fit for use” water that offsets potable demands otherwise needed for irrigating golf courses, athletic fields, school yards, public parks, community landscapes, and residential gardens. As such, NPR has enabled potable supplies to stretch further while concurrently enhancing property values, community aesthetics, recreational opportunities, and overall quality of life. NPR also has been used to restore and create important environmental resources, such as wetlands and other ecosystems that provide important natural functions, including the provision of critical habitat for flora and fauna.

NPR does have its limitations, however. Many NPR demands are seasonal, meaning either that water recycling assets are underutilized part of each year or that a form of storage needs to be created to match year-round production with part-year demands. Further, NPR requires its own separate distribution system, requiring not only a significant investment in pipes and pumps but also the considerable disruption often associated with large-scale pipeline projects.

In contrast, potable reuse relies predominantly on existing water supply distribution systems, provides the highest quality water to meet the highest value uses, and serves a basic human need that does not fluctuate with the seasons or over time. Ultimately, potable reuse has higher value than NPR and also is likely to be less expensive in many instances (especially as the most cost-effective opportunities for NPR become tapped).

7.2.5. Comparative Benefits of DPR Relative to IPR

The comparative advantage of DPR relative to IPR is due to a number of factors, including (1) avoiding water rights issues that may arise when water is placed into an environmental buffer, (2) the lack of suitable surface or groundwater environmental buffers in proximity to some locations where reclaimed water is produced (meaning that IPR is not feasible in such locations), (3) the potential for contamination of the reclaimed water when it is released into the environmental buffer, and (4) the costs associated with maintenance, operation, and monitoring of environmental buffers (NRC, 2012).

In some instances, DPR will typically avoid or minimize the need for expensive pipelines, pump stations, and other infrastructure that is generally required to transport recycled water to IPR environmental buffer locations (e.g., reservoirs, aquifer recharge sites) or to nonpotable customers using purple pipe networks. This will also typically reduce the energy use and GHG emissions associated with conveying the recycled water to the buffer site or to customer locations.

The benefits of being able to implement potable reuse without an environmental buffer may be illustrated by one of the alternatives under preliminary consideration by the City of San

Diego. Because of increasing concerns over the reliability of imported water in Southern California, San Diego has developed extensive plans for expanding potable reuse within its service area. Currently, the city is evaluating the potential for an IPR program that might ultimately recycle up to nearly 100,000 AF/y of wastewater using CAT. Following treatment, this water could be pumped to the San Vicente Reservoir (which effectively serves as the environmental buffer), blended with water from other sources, and ultimately treated again at the potable water treatment plant. For one location being considered for IPR in San Diego, the pipeline from the city's Advanced Treatment Facility to the San Vicente Reservoir would be 23 miles long.

Although IPR through reservoir augmentation (i.e., using the San Vicente Reservoir as an environmental buffer) would provide important benefits to the city, potable reuse without the use of an environmental buffer has the potential to save the city significant amounts of money (a preliminary estimate is more than $100 million in construction costs for the pipeline development alone). With one DPR option, recycled water would also be developed at the city's Advanced Treatment Facility but would be delivered directly to San Diego County Water Authority's regional raw aqueduct system (which serves the City of San Diego and other local communities). Similar to IPR, this water would be treated again at a potable water treatment plant. The pipeline from the city's Advanced Treatment Facility to the raw aqueduct system would be 10 miles long. The cost savings arise from the reduction in the conveyance pipeline of 13 miles.

It is likely that in most applications, DPR will require less piping and pumping to deliver the recycled water supplies to the potable water treatment and distribution facilities as compared with the pipe and pumping distances typically associated with delivering recycled water to an environmental buffer. Thus, it is likely that DPR approaches will typically have lower construction costs, lower energy needs, and lower related O&M costs for water transport compared with IPR. This will vary by location, depending on site-specific circumstances.

In addition, where pipeline construction is reduced via a DPR approach, there will also be a considerably reduced carbon footprint as well as considerably reduced environmental disruption associated with the construction (and operation) of the conveyance system. For the San Diego illustration, the avoidance of 13 miles of pipeline with the DPR alternative would save more than 50,000 MT of CO_2e emissions, most of which is embedded in the manufacturing of the pipe itself.

7.2.6. Summary

Implementation of DPR in areas having limited surface and groundwater sources can result in a sustainable and reliable system for supplying high-quality water to urban communities. Because the water requirements of cities are greater than wastewater discharges, DPR will not be a standalone water supply, but it can serve as a highly valuable water supply asset within a broader integrated regional water management portfolio.

Chapter 8

Potential New Water from DPR and IPR in California

An important question that must be assessed is how much water could be made available in California through DPR. For the purpose of this analysis, the year 2020 was selected to serve as the basis for analysis, taking into account the projected increase in population and the impact of additional water conservation measures. Estimates beyond 2020 are too highly speculative. The amount of water that could be made available through DPR is addressed by first estimating the amount of treated wastewater that will be discharged to surface waters or the ocean in the year 2020 and then estimating the amount of that water that could potentially be available for recycling, including DPR and IPR.

8.1. Water Quantities Discharged to Surface Waters or to the Ocean in 2020

To estimate the amount of water that will be discharged to surface water or to the ocean in California in 2020, it was necessary to (1) consider the current and future population projections by California State Water Resources Control Board (SWRCB) Region; (2) estimate the number of people served by on-site and centralized collection systems in each State Board Region; (3) estimate the amount of wastewater that will be discharged to centralized collections systems; (4) subtract the expected amount of water to be recycled in 2020 from the total amount of water discharged; and (5) finally, estimate the potential amount of water that could be available for recycling, including DPR and IPR. The various steps involved are delineated in what follows. Detailed computation tables are presented in Appendix A. The reason for aggregating the flow-rate data by SWRCB Region is that data are available by SWRCB Region on the number of people served by on-site systems and on the amount of water now recycled.

8.1.1. Current and Future Population Projections by State Board Region

The current and projected future population data by county used in the analysis were developed by California Department of Finance (2013). The estimated 2010 population data and the projected total population data in five year increments until 2030 are presented in Table 8.1. The population data for each of the counties were then distributed by SWRCB Region. The resulting populations by SWRCB Region for 2020 are presented in Table 8.2 in column 2. The detailed computation tables used to derive the data in column 2 are presented in Appendix A.

Table 8.1. Estimated and Projected Population of California

Year	Population	
	Estimated	Projected
2010	37,309,382	
2015		38,801,062
2020		40,643,643
2025		42,451,760
2030		44,279,354

Source: From California Department of Finance (2013).

Table 8.2. Estimated Summary Demographic Information for 2020 for California by SWRCB Region

SWRCB Region	Total Population[a]	Population Served by On-site Systems[b]	Population Served with Centralized Collection Systems[c]
1. North Coast	723,503	263,953	459,550
2. San Francisco Bay	5,516,277	176,705	5,339,572
3. Central Coast	2,395,293	327,258	2,068,035
4. Los Angeles	10,200,553	162,516	10,038,037
5. Central Valley	8,502,994	1,778,752	6,724,250
6. Lahontan	2,592,811	480,248	2,112,565
7. Colorado River	2,682,984	827,522	1,855,462
8. Santa Ana	4,917,468	395,332	4,522,136
9. San Diego	3,111,760	197,066	2,914,694
Total	40,643,643	4,609,352	36,034,301

Source: [a]From California Department of Finance (2013).

Notes: [b]Scaled according to population growth based on information from CWTRC and U.S. EPA (2003).

[c]Difference between total population and population served by on-site systems.

8.1.2. Number of People Served by On-site and Centralized Collection Systems in Each State Board Region

The number of people in 2020 served by on-site systems (e.g., septic tanks) was estimated by scaling the values available by SWRCB Region in a report prepared by the California Wastewater Training and Research Center and U.S. EPA (CWTRC and U.S. EPA, 2003). The estimated population served by on-site systems in 2020 is given in column 3 in Table 8.2. The population served by centralized collection systems (sewers), the difference between the values in columns 2 and 3, is reported in column 4 in Table 8.2.

8.1.3. Amount of Wastewater Discharged to Centralized Collection Systems in Each State Board Region

The amount of wastewater discharged to centralized collection systems was estimated using the per capita wastewater flow rate given in Table 8.3 for the year 2020 and the population served by centralized collection systems from Table 8.2 (column 4). The estimated wastewater flow rates in 2020 are given in Table 8.4 for three different per capita flow rates. The value of 90 gal/capita•d used to estimate the total wastewater given in column 3 was derived from information given in Table 8.3 by assuming the amount of water from indoor use, commercial use, and municipal use that will become wastewater is 50, 30, and 10 gal/capita•d, respectively. Lower per capita values were used to compute the wastewater flow rate in columns 4 and 5 to represent less-optimistic estimates of the amount of wastewater that will be available.

Table 8.3. Current and Projected Municipal Water Use Quantities in the United States

	Flow (gal/capita•d)					
	2013		2020		2030	
Use	**Range**	**Typical**	**Range**	**Typical**	**Range**	**Typical**
Domestic						
Indoor use	40–80	60[a]	35–65	55	30–60	45
Outdoor use	16–50	35[b]	16–50	35	16–50	35
Commercial	10–75	40	10–70	35	10–65	30
Public	15–25	20	15–25	18	15–25	15
Loss and waste	15–25	20	15–25	18	15–25	15
Total	96–255	175	91–235	161	86–225	140

Sources: Adapted from Tchobanoglous et al. (2014), with input from DeOreo (2013) and Mayer (2014).

Notes: [a]2014 Water Research Foundation Residential End Uses of Water Update (rounded up from 58.5 gal/capita•d).

[b]In some parts of the country, outdoor water use is significantly higher than indoor use, depending on location and season of the year.

Table 8.4. Estimated Amount of Water Discharged to Wastewater Collection Systems in 2020 by SWRCB Region

SWRCB Region	Population Served with Sewers in 2020[a]	Estimated Amount of Wastewater Collected in 2020 Based on Different Per Capita Wastewater Flow Rates (Mgal/d)[a,b]		
		90 gal/capita•d	80 gal/capita•d	70 gal/capita•d
1. North Coast	459,550	41.4[c]	36.8	32.2
2. San Francisco Bay	5,339,572	480.6	427.2	373.8
3. Central Coast	2,068,035	186.1	165.4	144.8
4. Los Angeles	10,038,037	903.4	803.0	702.7
5. Central Valley	6,724,242	605.2	537.9	470.7
6. Lahontan	2,112,563	190.1	169.0	147.9
7. Colorado River	1,855,462	167.0	148.4	129.9
8. Santa Ana	4,522,136	407.0	361.8	316.5
9. San Diego	2,914,694	262.3	233.2	204.0
Total	36,034,291	3243.1	2882.7	2522.5

Sources: [a]Population data from Table 8.2 and Appendix A; [b]per capita flow-rate data from Table 8.3.
Note: [c]For example, 41.4 Mgal/d = (459,550 capita)(90 gal/capita•d).

8.1.4. Potential Amount of Water Available for Reuse Applications Including DPR and IPR

The estimated amount of treated wastewater available in 2020 for recycling, including DPR and IPR, is presented in Table 8.5. The values presented in Table 8.5 were derived as follows. The values in column 2 are from Table 8.4 (column 3). The values in column 3 represent the amounts of water recycled in 2011, based on data from California Water Boards' *Annual Performance Report Fiscal Year 2010–2011, Plan and Assess: Water Recycling*. The values in columns 4 and 5 are the estimated amounts of wastewater recycled in 2020 expressed in different units and were derived by scaling up the 2011 values (column 3) by 15% to reflect growth in recycling by 2020. Finally, the value in column 6 is the estimated amount of treated effluent that will be discharged to surface waters or the ocean, taking into account water lost to sludge processing (estimated to be 10%). The water discharged to surface waters or the ocean represents the amount of water that could be available for recycling, including DPR and IPR. If the actual amount of wastewater discharged to the collection system were 70 gal/capita•d, the total amount of water available would be on the order of 1789 Mgal/d. The estimated amount of water that could be realistically recycled by means of DPR or IPR is considered in the following section.

Table 8.5. Estimated Amount of Treated Wastewater Potentially Available in 2020 for Reuse by SWRCB Region

Water Resources Control Board Region	Estimated Amount of Wastewater Collected in 2020 Based on 90 gal/capita•d[a] (Mgal/d)	Estimated Amount of Water Recycled in Various Applications in 2011[b] (AF/y)	Estimated Amount of Water Recycled in Various Applications in 2020[c]		Estimated Amount of Water Discharged to Surface Water or Ocean[d] (Mgal/d)
			Mgal/d	AF/y	
1. North Coast	41.4	25,772	26.5	29,638	13.4
2. San Francisco Bay	480.6	41,019	42.1	47,172	394.7
3. Central Coast	186.1	23,275	23.9	26,766	146.0
4. Los Angeles	903.4	169,641	174.2	195,087	652.6
5. Central Valley	605.2	177,885	182.6	204,568	380.3
6. Lahontan	190.1	9810	10.1	11,282	169.9
7. Colorado River	167.0	14,090	14.5	16,204	101.0
8. Santa Ana	407.0	155,743	159.9	179,104	222.4
9. San Diego	262.3	51,952	53.3	59,745	224.4
Total	3243.1	669,187	687.1	769,566	2304.7

Sources: [a]Flow-rate data from Table 8.4; [b]based on data from California Water Boards' *Annual Performance Report Fiscal Year 2010–2011, Plan and Assess: Water Recycling;* [c]data from 2011 scaled up to 2020 by a factor or 15%.

Notes: [d]Difference between amount of wastewater collected and amount recycled times a factor of 0.9 to account for other water losses (e.g., sludge processing); the actual amount of water available will vary by region, depending on the types of reuse projects that may be implemented.

Mgal/d x 1120.15 = AF/y.

8.2. Potential Amount of Water Available for Potable Use

The total amount of water available for recycling in 2020—including water that could be used for DPR and IPR—corresponds to the estimated amount of water discharged to surface waters and the ocean in 2020, as reported in column 6 in Table 8.5. The amount of water that could be recycled by DPR and/or IPR will be some percentage of the total for each of the Regional Boards; recycling by DPR and/or IPR would most likely occur in coastal areas of the state where ocean outfalls are available for the discharge of residual brine.

The estimated amount of water that could be used for DPR and/or IPR by Regional Board is reported in columns 5 and 6 in Table 8.6 in terms of Mgal/d and AF/y. The estimated percentage of the available amount of water that could potentially be used for DPR and IPR is shown in column 4. As shown in column 4, zero percent was assumed for some of the inland counties with sparse population. Thirty percent was allocated for the Central Valley where larger communities are located, including (from north to south) Sacramento, Stockton, Merced, Fresno, and Bakersfield. As shown in Table 8.6, about 50% of the estimated 2300 Mgal/d of water discharged to surface waters and the ocean in 2020 could potentially be recycled by DPR and/or IPR. This amounts to a possible potable supply in California of more than 1000 Mgal/d, or more than 1.1 million AF per year. This quantity would be a sufficient potable water supply to meet all residential, commercial, and industrial water needs for communities totaling eight million people, or more than 20% of California's projected 2020 population.

Table 8.6. Estimated Amount of Treated Wastewater Potentially Available in 2020 for Reuse by DPR and/or IPR by SWRCB Region

Water Resources Control Board Region	Estimated Amount of Wastewater Collected in 2020, Based on 90 gal/capita•d (Mgal/d)[a]	Estimated Amount of Water Discharged to Surface Water or Ocean in 2020[b] (Mgal/d)	Estimated Percentage of Available Water that Could Potentially Be Used for DPR and IPR	Estimated Amount of Water that Could Be Recycled by DPR and/or IPR in 2020: Mgal/d	Estimated Amount of Water that Could Be Recycled by DPR and/or IPR in 2020: AF/y
1. North Coast	41.4	13.4	0		
2. San Francisco Bay	480.6	394.7	40	157.9	176,871
3. Central Coast	186.1	146.0	50	73.0	81,771
4. Los Angeles	903.4	652.6	60	391.6	438,650
5. Central Valley	605.2	380.3	30	114.1	127,809
6. Lahontan	190.1	169.9	0		
7. Colorado River	167.0	101.0	0		
8. Santa Ana	407.0	222.4	60	133.4	149,428
9. San Diego	262.3	224.4	60	134.6	150,772
Total	3243.1	2304.7		1004.6	1,125,301

Sources: [a]Flow-rate data from Table 8; [b]flow-rate data from Table 8.5.

Note: Mgal/d x 1120.15 = AF/y.

It should be noted that the percentage values of discharged waters potentially available for potable reuse (column 4 of Table 8.6) are current best estimates of what could happen in the future. By way of comparison, a recent paper (Pacific Institute, 2014) estimated that 0.9 to 1.1 million AF/y could be reused in coastal regions in California. If the DPR allocation for the Central Valley is excluded from the data presented in Table 8.6, then the estimated amount of water that could be produced via potable reuse in California's coastal regions is about 1 million AF/y, which is consistent with the Pacific Institute (2014) estimate.

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Appendix A

Population Served by Centralized Collection and On-site Systems by SWRCB Region

The population by California SWRCB Region was determined by taking the California Department of Finance (2013) county population data and allocating it according to State Board Region for each of the nine State Board Regions. The required computations are presented in Tables A.1 through A.9. A summary population table by SWRCB Region is given in Table A.10.

The development of the population data for each SWRCB Region is illustrated by considering SWRCB Region 1, which is presented in Table A.1. The counties included in Region 1 are listed in the first column. The estimated 2020 population for each county is listed in column 2. Because some counties are in two or more regional boards, the population had to be distributed between regional boards. The estimated percentage of the county population that is in the region is given in column 3. The total estimated population in State Board Region 1 is given in column 4. The estimated population served by on-site systems is given in column 5. The population data in column 5 were based on information from CWTRC and U.S. EPA (2003).

Table A.1. Estimated Demographic Information for SWRCB Region 1

County or Portion of County in SWRCB Region 1	2020 Total Population in County[a]	Percentage of County Population in Region 1	2020 Total Population in Region 1	2020 On-site Population in Region 1
Del Norte	29,635	100	29,635	14,331
Glen	30,780	10	3078	1508
Humboldt	139,132	100	139,132	44,837
Lake	71,228	20	14,245	8396
Marin	251,361	10	25,136	3884
Mendocino	91,498	100	91,498	55,730
Modoc	9965	50	4983	3871
Siskiyou	46,369	100	46,369	24,027
Sonoma	507,250	70	355,075	92,628
Trinity	14,352	100	14,352	14,741
Total			723,503	263,953

Source: [a]From California Department of Finance (2013).

Table A.2. Estimated Demographic Information for SWRCB Region 2

County or Portion of County in SWRCB Region 2	2020 Total Population in County[a]	Percentage of County Population in Region 2	2020 Total Population in Region 2	2020 On-site Population in Region 2
Alameda	1,608,204	100	1,608,204	13,900
Contra Costa	1,147,399	50	573,700	20,072
Marin	251,361	90	226,225	20,000
Napa	145,660	50	72,830	15,210
San Francisco	852,788	100	852,788	0
Santa Clara (north of Morgan Hill)	1,889,898	60	1,133,939	37,380
San Mateo	747,563	90	672,807	20,000
Solano	447,217	50	223,609	10,445
Sonoma	507,250	30	152,175	39,698
Total			5,516,277	176,705

Source: [a]From California Department of Finance (2013).

Table A.3. Estimated Demographic Information for SWRCB Region 3

County or Portion of County in SWRCB Region 3	2020 Total Population in County[a]	Percentage of County Population in Region 3	2020 Total Population in Region 3	2020 On-site Population in Region 3
Kern (small portion)	1,057,440	100	0	0
Monterey	436,107	100	436,107	74,293
Santa Barbara	449,505	95	427,030	36,000
San Benito	60,278	85	51,239	19,000
Santa Clara (south of Morgan Hill)	1,889,898	40	755,959	24,920
San Mateo (southern portion)	747,563	10	74,756	355
Santa Cruz	275,704	100	275,704	80,374
San Luis Obispo	287,744	100	287,744	86,410
Ventura (northern portions)	867,535	10	86,754	5906
Total			2,395,293	327,258

Source: [a]From California Department of Finance (2013).

Table A.4. Estimated Demographic Information for SWRCB Region 4

County or Portion of County in SWRCB Region 4	2020 Total Population in County[a]	Percentage of County Population in Region 4	2020 Total Population in Region 4	2020 On-site Population in Region 4
Los Angeles	10,441,441	90	9,397297	108,164
Ventura	867,535	90	780,781	53,622
Kern (small portions)	1,057,440	0	0	0
Santa Barbara (small portions)	449,505	5	22,475	730
Total			10,200,553	162,516

Source: [a]From California Department of Finance (2013).

Table A.5. Estimated Demographic Information for SWRCB Region 5

County or Portion of County in SWRCB Region 5	2020 Total Population in County[a]	Percentage of County Population in Region 5	2020 Total Population in Region 5	2020 On-site Population in Region 5
Amador	39,352	100	39,352	27,250
Butte	241,521	100	241,521	132,249
Calaveras	48,312	100	48,312	48,947
Colusa	24,886	100	24,886	9686
Contra Costa (east)	1,147,399	50	573,700	20,073
El Dorado	203,095	85	172,630	102,917
Fresno	1,071,728	100	1,071,728	181,135
Glen	30,780	90	27,702	13,567
Kern	1,057,440	55	581,592	122,384
Kings	176,647	100	176,647	26,319
Lake	71,228	80	56,982	33,586
Lassen	35,934	30	10,780	5006
Madera	185,056	100	185,056	83,042
Mariposa	20,463	100	20,463	18,639
Merced	301,376	100	301,376	72,537
Modoc	9965	25	2491	1935
Napa (northeast)	145,660	50	72,830	15,210
Nevada	104,343	90	93,909	7515
Placer	391,682	85	332,930	90,293
Plumas	20,731	100	20,731	20,336
Sacramento	1,543,522	100	1,543,522	66,039
San Benito	60,278	15	9042	708
San Joaquin	810,845	100	810,845	119,568
San Luis Obispo	287,744	100	0	0
Shasta	199,814	100	199,814	88,224
Sierra	3034	75	2276	2397
Siskiyou	46,369	100	0	0
Solano (west)	447,217	50	223,609	10,445
Stanislaus	589,156	100	589,156	112,918
Sutter	108,939	100	108,939	47,616
Tehama	69,340	100	69,340	43,133
Tulare	526,718	100	526,718	166,354

Table A.5. Estimated Demographic Information for SWRCB Region 5

County or Portion of County in SWRCB Region 5	2020 Total Population in County[a]	Percentage of County Population in Region 5	2020 Total Population in Region 5	2020 On-site Population in Region 5
Tuolumne	55,938	100	55,938	41,733
Yolo	223,657	100	223,657	20,848
Yuba	84,520	100	84,520	26,143
Total			8,502,994	1,778,752

Source: [a]From California Department of Finance (2013).

Table A.6. Estimated Demographic Information for SWRCB Region 6

County or Portion of County in SWRCB Region 6	2020 Total Population in County[a]	Percentage of County Population in Region 6	2020 Total Population in Region 6	2020 On-site Population in Region 6
Alpine	1172	100	1172	1293
El Dorado	203,095	15	30,464	17,159
Inyo,	19,350	100	19,350	5449
Kern (east)	1,057,440	45	475,848	100,132
Lassen (east side)	35,934	70	25,154	11,680
Los Angeles (northeast corner)	10,441,441	10	1,044,144	200,875
Modoc (east)	9,965	25	2491	1936
Mono	15,037	100	15,037	7933
Nevada	104,343	10	10,433	60,000
Placer	391,682	15	58,752	15,935
San Bernardino	2,273,017	40	909,207	57,057
Sierra	3034	25	759	799
Total			2,592,811	480,248

Source: [a]From California Department of Finance (2013).

Table A.7. Estimated Demographic Information for SWRCB Region 7

County or Portion of County in SWRCB Region 7	2020 Total Population in County[a]	Percentage of County Population in Region 7	2020 Total Population in Region 7	2020 On-site Population in Region 7
Imperial	222,920	100	222,920	31,860
Riverside	2,593,211	30	777,963	355,883
San Bernardino	2,273,017	30	681,905	256,758
San Diego	3,333,995	30	1,000,196	183,021
Total			2,682,984	827,522

Source: [a]From California Department of Finance (2013).

Table A.8. Estimated Demographic Information for SWRCB Region 8

County or Portion of County in SWRCB Region 8	2020 Total Population in County[a]	Percentage of County Population in Region 8	2020 Total Population in Region 8	2020 On-site Population in Region 8
Orange	3,198,279	100	3,198,279	19,946
Riverside	2,593,211	40	1,037,284	118,628
San Bernardino	2,273,017	30	681,905	256,758
Total			4,917,468	395,332

Source: [a]From California Department of Finance (2013).

Table A.9. Estimated Demographic Information for SWRCB Region 9

County or Portion of County in SWRCB Region 9	2020 Total Population in County[a]	Percentage of County Population in Region 9	2020 Total Population in Region 9	2020 On-site Population in Region 9
Riverside	2,593,211	30	777,963	118,628
San Diego	3,333,995	70	2,333,797	78,438
Total			3,111,760	197,066

Source: [a]From California Department of Finance (2013).

Table A.10. Estimated Summary Demographic Information for 2020 for California by SWRCB Region

SWRCB Region	Total Population[a]	Population Served by On-site Systems[b]	Population Served with Sewers[c]
1. North Coast	723,503	263,953	459,550
2. San Francisco Bay	5,516,277	176,705	5,339,572
3. Central Coast	2,395,293	327,258	2,068,035
4. Los Angeles	10,200,553	162,516	10,038,037
5. Central Valley	8,503,002	1,778,752	6,724,250
6. Lahontan	2,592,813	480,248	2,112,565
7. Colorado River	2,682,984	827,522	1,855,462
8. Santa Ana	4,917,468	395,332	4,522,136
9. San Diego	3,111,760	197,066	2,914,694
Total	40,643,653	4,609,352	36,034,301

Sources: [a]From California Department of Finance (2013).

[b]Scaled according to population growth based on information from CWTRC and U.S. EPA (2003).

Note: [c]Difference between total population and population served by on-site systems.

Practical Solutions for Water Scarcity




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