PROJECT NO.
4962

Identifying the Amount of Wastewater That Is Available and Feasible to Recycle in California

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Abstract and Benefits

Abstract:

The purpose of project 4962 was to identify the amount of treated municipal wastewater that is available for recycled water production in California now and projected into the future considering factors such as the required minimum instream flows, water quality, proximity to potential water reuse sites, and cost.

Despite continuing development and increased recognition of the importance of recycled water in water resources management, the volume of recycled water recorded in California has been well under the recycled water goal of 1.5 million ac-ft set in 1980s. This study was conducted to understand the amount of recycled water potentially available for beneficial uses and inform the development of realistic recycled water goals. The current state of water reuse in California, including impediments and apparent opportunities, are highlighted in the introduction. Methodologies adopted in the study are explained to clarify the intent and limitations of the analysis, including: the boundary conditions of the analysis; adjustments for future water volumes available for reuse; development of a database with potential sites for water reuse; model development to determine the least cost pipelines from effluent source to reuse site; an economic model to estimate cost to upgrade water quality for a range of water reuse applications; and development of high-level cost curves for implementing water reuse.

Projection of the potential volume of treated wastewater that could be directed to recycled water is presented with considerations for the seasonality of wastewater flow and recycled water demand, declining wastewater flows due to water conservation, and limitations on the use of treated water for beneficial purposes. A geographic Information system (GIS)-based modeling approach is presented to identify potential water reuse opportunities for each wastewater treatment facility evaluated and transmission requirements using the Least Cost Path (LCP) analysis for a range of beneficial uses.

High-level treatment cost analyses for non-potable reuse, indirect potable reuse, and direct potable reuse are provided. Combining the findings of potentially available volume, water reuse opportunities and treatment cost analysis, the total cost for various water reuse projects is presented, which illustrates the potential volume of recycled water against the cost effectiveness of various water reuse projects.

The study findings highlight the fact that traditional non-potable water reuse applications will likely provide lower cost reuse opportunities for limited total volumes, while indirect and direct potable water reuse options will be essential water reuse strategies to approach the technically feasible total volumetric water reuse rate of 2.53 Mac-ft/y, consisting of 0.7 Mac-ft/y of existing reuse and 1.83 Mac-ft/y of potential new water reuse capacity. This report provides a high-level view of opportunities and limitations, from which audiences will learn factors that may affect the feasibility of achieving high recycled water goals.

Benefits:

- Estimated volumes of recycled water that is available for water reuse projects.

- High-level perspective on minimum project costs for different types of water reuse projects.
- Statewide distribution of costs for recycled water projects, considering both treatment upgrades and distribution systems.
- Review of potential constraints that may be relevant for potential recycled water projects.
- Impacts of indoor water conservation rates and population changes on the availability and quality of recycled water.

Keywords:
Water reuse goals, recycled water planning, cost estimation, project constraints

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Acronyms and Abbreviations

1211	California Water Code Section 1211
$	United states dollar (2019)
$/ac-ft	Dollar per acre foot
ac-ft	Acre-foot (1 ac-ft ~ 326,000 gal)
ac-ft/y	Acre-foot per year
Ag	Agricultural irrigation
AOP	Advance oxidation process
ATW	Advanced treatment water
AVR	Annual volumetric report (referred to as VAR in this report)
AWT	Advanced water treatment
BAC	Biological activated carbon
CCR	California Code of Regulations
CEC	California Energy Commission
CEQA	California Environmental Quality Act
CIWQS	California Integrated Water Quality System
CRF	Capital recovery factor
CT	Product of concentration and time
CV-SALTS	Central Valley Salinity Alternatives for Long-Term Sustainability
DOE	United State Department of Energy
DPR	Direct potable reuse
DWR	California Department of Water Resources
EAC	Equivalent annual cost
EC	Electrical conductivity (of water)
ft	Foot
ft/y	Foot per year
gal	Gallon
gal/cap-d	Gallon per capita day
GRRP	Groundwater replenishment reuse projects
I	Interest rate for capital
I&I	Inflow and infiltration
IEUA	Inland Empire Utilities Agency
in.	Inch
IPR	Indirect potable reuse
IW	Injection well
JWPCP	Joint Water Pollution Control Plant
LCP	Least cost path
log	logarithm

M	Million
Mac-ft	Million acre-foot
Mac-ft/y	Million acre-foot per year
MBR	Membrane bioreactor
MF	Microfiltration
Mgal	Million gallon
MJ	Millijoule
MPN	Most probably number
Ms/cm	Millisiemen per centimeter
MWD	Metropolitan Water Districts of Southern California
MWh	MegaWatt hour
n	Lifespan in years
NEAC	Normalized equivalent annual cost
NPDES	National pollution discharge elimination system
NPV	Net present value
NRCS	United States Natural Resource Conservation Service
NTU	Nephelometric turbidity units
OCSD	Orange County Sanitation District
OCWD	Orange County Water District
O&M	Operation and maintenance
PFAS	Per- and Polyfluoroalkyl Substances
PP	Power plant cooling tower
PWS	Public water supply
Q	Volumetric flow rate
RA	Reservoir augmentation
RB	Recharge basin
RC	Recharge capacity
RO	Reverse osmosis
RWP	Recycled water producer
RWQCB	Regional Water Quality Control Board
SAGBI	Soil agricultural groundwater banking index
SDWIS	Safe Drinking Water Information System
SGMA	Sustainable Groundwater Management Act
SR	Search radius
SSURGO	NRCS Soil Survey Geographic Database
SWRCB	California State Water Resources Control Board
SWSAP	Surface Water Source Augmentation Projects
TBD	To be determined
TBL	Triple bottom line

TDS	Total dissolved solids
TIGER	Topologically integrated geographic encoding and referencing
Title 22	California Code of Regulations Title 22 , Div. 4, Chap. 3 Water Recycling Criteria
TOC	Total organic carbon
TNC	The Nature Conservancy
UC	University of California
UF	Ultrafiltration
USGS	United State Geological Society
UV	Ultraviolet
VAR	Volumetric annual report
WBR	Water board region (refers to RWQCBs)
WBMWD	West Basin Municipal Water District
WRF	Water reclamation facility (used interchangeably with WWTF in this report)
WSO	Water supply options
WWTF	Wastewater treatment facility (used interchangeably with WRF in this report)
WWTF/RW	Wastewater treatment facility that produces recycled water (as used in VAR)

Executive Summary

As California has entered a period of extended drought, it is essential to evaluate the viability of potential alternative water supply sources to meet both human and environmental needs. The primary purpose of this report was to develop an understanding of the spatial distribution of effluent flows and the potential feasibility of corresponding water reuse projects. A summary of the project and key findings from this study are summarized below.

ES.1 Background and Objectives

The contemporary targets for water recycling in California were based on the 2003 Recycled Water Task Force report (DWR, 2003), which projected that the effluent flow available for reuse in 2030 would be 6.5 Mac-ft/y. According to the California State Water Resources Control Board (SWRCB), the 2019 influent flow of municipal wastewater to treatment facilities in California totaled about 3.6 million ac-ft/y (Mac-ft/y). The success of water conservation and efficiency measures in California have resulted in an available effluent flow for reuse that is about half of what was predicted only two decades ago. The reduced flows highlight the dramatic change in water use that has taken place. The principal objectives of this study are:

(1) Identify the amount of treated municipal wastewater available to produce recycled water in California now and projected into the future.

(2) Determine how much of the treated municipal wastewater is feasible to be reused—considering the required minimum instream flows, water quality, proximity to potential recycle water users, and cost.

The tasks outlined in the scope of work and completed in this study are as follows:

- Task 1: Estimate the total municipal wastewater available in California for recycled water production (Chapter 2)
- Task 2: Estimate the total municipal wastewater volume that could be used if treated for beneficial reuse (Chapter 3)
- Task 3: Identify potential uses of recycled water at a planning level estimate (Chapters 4 and 5)
- Task 4: Analyze the cost of treating available municipal wastewater to the following recycled water standards: un-disinfected secondary, disinfected secondary-23, disinfected secondary-2.2, disinfected tertiary, and full advanced treatment (Chapter 6)
- Task 5: Summarize how much of the available treated municipal wastewater is feasible to reclaim and reuse, along with the associated costs (Chapter 7)

ES.2 Key Findings

- Task 1: The total volumetric flow to wastewater treatment facilities (WWTFs) in California hypothetically available for reuse in 2019 was 3.58 Mac-ft. It is projected that influent dry-weather wastewater flows in California will remain relatively constant, notwithstanding worsening drought or greater than expected population declines, increasing from 3.1 in 2019 to an estimated 3.3 Mac-ft/y in the year 2030.

- Task 2: In 2019, the total volume of planned water reuse was approximately 0.7 Mac-ft/y, representing 22% of the total effluent flow. Further, an additional 1.83 Mac-ft/y of effluent flow is technically feasible for planned reuse projects in 2030, resulting in a total potential reuse volume of 2.53 Mac-ft/y or 77% of the total effluent flow
- Task 3: The potential uses of recycled water were assessed by Water Board Region (WBR)—see Table ES-1—using a spatial model to locate sites of interest for water reuse planning, including areas of agricultural land use, reservoir locations, potable water connections, recharge areas, and power generation facilities. The potential volumetric demand and supply of recycled water was analyzed for each WWTF and reuse site(s) identified. As shown on Figure ES-1, WBRs 2 and 4 have the greatest potential for supplemental effluent reuse, followed by WBRs 9, 5S, 8, and 5F.

Table ES-1. Summary of estimated 2030 population served by onsite and municipal sewers organized by water board region (WBR).

Data Sources: Raucher and Tchobanoglous (2014) and California Department of Finance (2022)

	Estimated 2030 population		
WBR	Total in WBR	Served by onsite systems	Served by sewers
1. North Coast	707,917	253,148	454,768
2. San Francisco Bay	6,026,500	206,373	5,820,126
3. Central Coast	2,549,966	343,558	2,206,408
4. Los Angeles	10,109,659	166,744	9,942,915
5F. Central Valley – Fresno	2,839,970	660,790	2,179,181
5R. Central Valley – Redding	520,928	278,552	242,376
5S. Central Valley – Sacramento	5,406,275	838,858	4,567,417
6T. Lahontan – Tahoe	137,228	109,584	27,644
6V. Lahontan – Victorville	2,453,005	361,198	2,091,807
7. Colorado River	2,773,872	861,430	1,912,441
8. Santa Ana	5,093,491	412,814	4,680,677
9. San Diego	3,241,739	206,244	3,035,495
Total	41,860,549	4,699,293	37,161,256

- Task 4: The baseline cost of water reuse projects is driven primarily by the cost associated with upgrading existing WWTFs, the cost associated with advanced water treatment, and the cost to transport the water to reuse sites. The relative proximity of potential reuse sites to the WWTF location varied by WBR and application, resulting in a wide range of costs. In many cases, coastal communities had longer transport distances to reach potential agricultural and recharge basin sites. A summary of median cost to produce and deliver recycled water in WBRs with the highest potential are shown on Figure ES-1. It was noted that the estimated cost for water reuse projects was highly variable and may not account for site-specific factors that can increase costs by a significant factor.

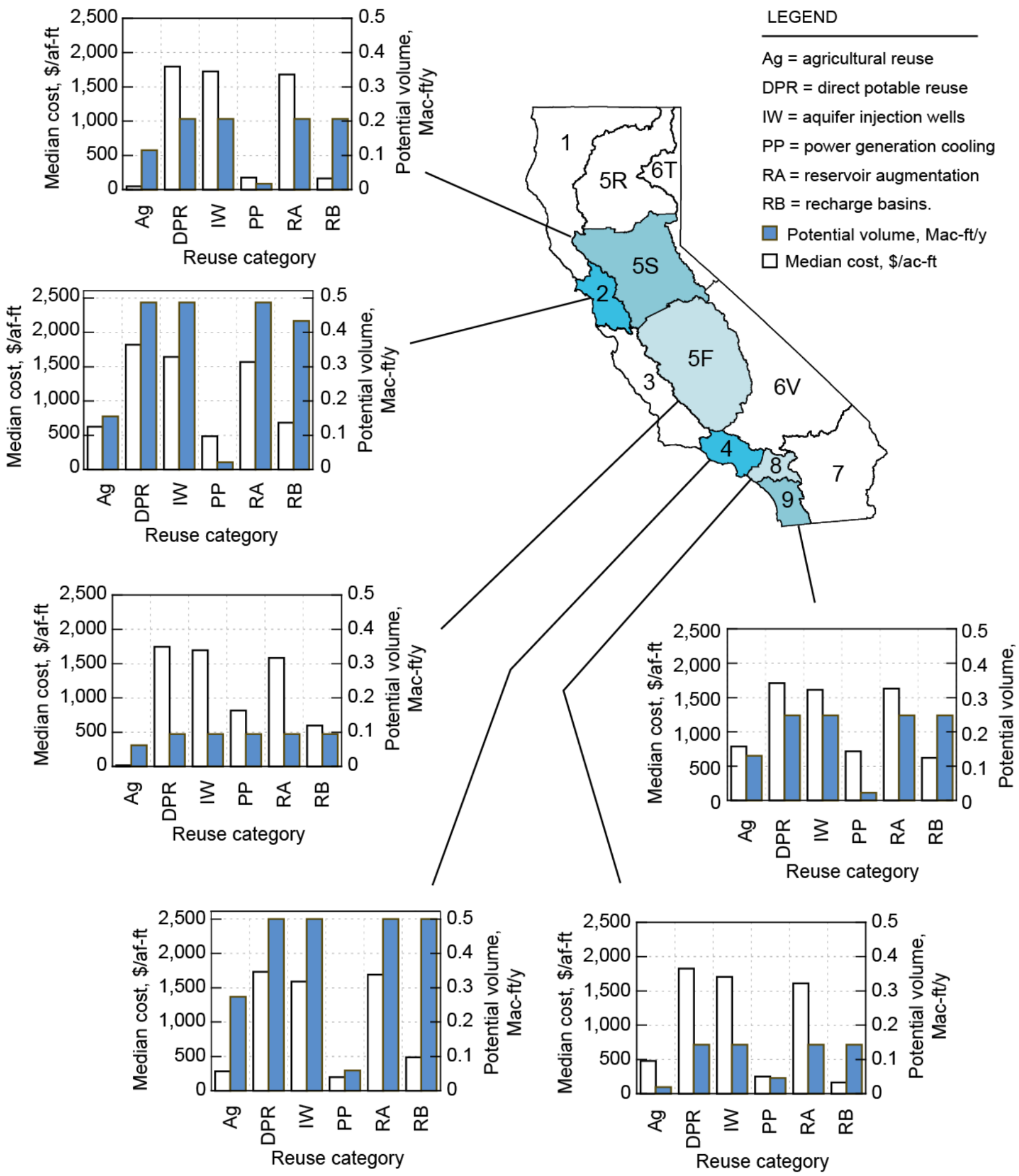


Figure ES-1. Map showing WBRs with more than 100,000 ac-ft/y of effluent potentially available for water reuse.

The highlighted WBRs represent the areas with the greatest technically feasible potential water reuse (WBRs shaded to differentiate between regions).

- Task 5: Approximately 0.52 Mac-ft/y of the water volume discharged to inland surface waters is technically feasible to divert to planned reuse projects. However, the opportunities and challenges associated with diversion of effluent flows from freshwater systems will need to be considered on a case-by-case basis. In contrast, an estimated 1.32 Mac-ft/y of effluent flow is technically feasible to divert from coastal disposal, thereby augmenting or offsetting potable water use.

ES.3 Project Approach

Using 2019 Volumetric Annual Report data from the SWRCB along with projections of population and water use rates, a wastewater flow balance was developed to estimate dry weather flow and the fraction of that flow that could be treated to California recycled water standards. To model the total cost of increased volumetric water reuse, the estimated 2030 potential reuse volume from 86 WWTFs with effluent flowrates greater than 4000 ac-ft/y was matched with hypothetical sites for water reuse. An ArcGIS modeling approach was used to identify the route and calculate the least cost recycled water transmission pipeline. In addition to pipeline cost (capital and operating), the cost to upgrade and operate the WWTF for the required water quality was estimated for each of the 86 facilities.

The total estimated cost to produce, deliver, and use recycled water was determined for six different water reuse applications: (1) secondary or tertiary recycled water to agricultural irrigation, (2) tertiary recycled water for power plant cooling towers, (3) tertiary recycled water for groundwater recharge basins, (4) advanced treatment recycled water for groundwater injection wells, (5) advanced treatment recycled water for reservoir augmentation, and (6) enhanced advanced treatment recycled water for direct potable reuse. Due to the highly site-specific nature of urban dual plumbed systems, retrofit of urban areas for recycled water use was not considered in this study.

ES.4 Results

In 2019, the total volume of planned water reuse was approximately 0.7 Mac-ft/y, representing 22% of the total effluent flow. The technical volume of water available for reuse in 2030 was estimated using adjustment factors to scale current WWTF effluent base flows greater than 4000 ac-ft/y to predicted future effluent base flows at these facilities. The adjustment factors were used to model considerations such as water losses during wastewater management, predicted regional changes in water usage and population, variations in recycled water utilization, and required stream discharges. Using the adjustment factors, it is projected that an additional 1.83 Mac-ft/y of effluent flow is technically feasible for planned reuse projects in 2030, resulting in a total potential reuse volume of 2.53 Mac-ft/y or 77% of the total effluent flow. The technical water reuse potential in each WBR was found to vary due to logistical constraints associated with different reuse applications. Projected total reuse volumes in WBRs with significant water reuse potential are summarized in Figure ES-1.

The baseline cost of water reuse projects is primarily driven by expenses associated with upgrading and operating advanced recycled water treatment processes and the cost to transport the water to reuse sites. The relative proximity of potential reuse sites to the WWTF location was highly variable and resulted in a distribution of costs. In many cases, coastal communities had longer transport distances to reach potential agricultural and recharge basin sites. As shown in Table ES-2, agricultural irrigation has the lowest relative median cost and direct potable reuse has the highest median cost. In general, each community will need to evaluate the tradeoffs of alternative water supply options to determine the most feasible approach to securing future water supply.

Table ES-2. Summary of estimated cost range for alternative recycled water projects at 86 WWTFs with effluent flows exceeding 4000 ac-ft/y.

Water reuse application	Facility matches	Estimated baseline project cost, $/ac-ft			
		Minimum	Maximum	Mean	Median
Agricultural irrigation	51	5	1661	344	130
Power plant cooling towers	25	15	854	389	281
Recharge basins	74	102	1574	500	593
Reservoir augmentation	86	1234	2089	1647	1648
Injection wells	86	955	1929	1638	1693
Direct potable reuse	86	1168	2202	1775	1808

The total estimated cost of water reuse in WBRs with greater than 0.1 Mac-ft/y of total additional reuse potential is summarized in Figure ES-1. As shown in Figure ES-1, WBRs 2 and 4 have the greatest potential for effluent reuse; however, it was found that the median cost of agricultural irrigation and groundwater recharge basins are relatively higher in coastal WBRs. The cost of agricultural reuse was found to be lowest in WBR 5 due to the closer proximity of WWTFs with potential reuse sites. As a high-level study, site-specific factors that increase the cost of an actual project as compared with the estimates presented in Figure ES-1 could not be taken into account. For example, the cost calculations did not include any site-specific considerations including regulatory compliance, implementation of flow/load equalization, upgrades or repairs to existing wastewater collection and treatment systems, the availability of land to construct new facilities, unknown construction obstacles, water rights issues, the construction of large reservoirs for seasonal flow storage, potential in-stream flow requirements, or local political issues. Further, and perhaps most significantly, the cost of concentrate (brine) management from reverse osmosis (RO) treatment was not included but is expected to add 80 to $750/ac-ft to the overall cost, depending on the management options available.

ES.5 Benefits

Given the severity of the ongoing drought in California, it is expedient to consider if the available water resources are being used as effectively as possible to support both human and natural systems. A substantial volume of water currently being discharged to the ocean is technically feasible to recycle. There is also a significant volume of effluent being discharged to freshwater systems, but this water is a lower priority to divert to reuse because of the importance of maintaining stream flow and dependent habitat. From this research, utilities can get a high-level perspective on minimum project costs, the statewide distribution of costs, and potential constraints that may be relevant for potential recycled water projects. However, it was also found that the indoor water conservation rates that have been achieved in California will have an overall negative impact on the availability and quality of recycled water, as well as impacts on existing infrastructure that all utilities will need to take into consideration for long term planning.

ES.6 Related WRF Research

- Impact of Wastewater Treatment Performance on Advanced Water Treatment Processes and Finished Water Quality (4833)
- Long Term Water Demand Forecasting Practices for Water Resources and Infrastructure Planning (4667)

CHAPTER 1

Introduction

The use of municipal recycled water, referred to as ‘water reuse’ in this report, has become an important element of the water supply for many communities in California. Most communities in California also continue to discharge effluent from a local wastewater treatment facility (WWTF) to the ocean, saline bays, rivers, land, or other local sites and many do not have a recycled water program. Clearly, a diversity of factors can impact the potential for water reuse for any given community, including regulatory, jurisdictional, and cost constraints. In a recent effort to estimate the potential for potable water reuse in California, Raucher and Tchobanoglous (2014) projected that implementation of potable reuse on a large scale could achieve an overall planned water reuse rate of 55% of the total wastewater influent to municipal treatment facilities. Yet, current permitted recycled water use is estimated to be only 22% of the total municipal dry weather wastewater influent flowrate in 2019 (SWRCB, 2019). Given that there is a large potential volume of effluent (~78%) not being used in permitted projects and that many WWTFs are being or have already been upgraded to produce improved effluent quality, there could be increased opportunities for water reuse. Along with improved treatment technology, there have been advances in data acquisition, digital data availability, and analytical tools. Until recently, the data needed to assess the potential for water reuse, namely the monthly influent, effluent, and recycled water use, have not been widely available for all WWTFs. The Recycled Water Policy requires wastewater and recycled water facilities to annually report monthly volumes of influent, wastewater produced, and effluent, including treatment level and discharge type and recycled water use by volume and category of reuse as applicable. Data collected from this requirement are compiled in the California volumetric annual report of wastewater and recycled water (VAR). The California State Water Resources Control Board (SWRCB) implemented the VAR starting in the year 2019. Further, with California subject to the current extended drought conditions in a future with increasingly constrained water supplies, it is important to investigate the factors involved in expanded water reuse.

1.1 Project Objectives

This study had two primary objectives:

(1) Identify the amount of treated municipal wastewater that is available for recycled water production now in California and projected into the future.
(2) Determine how much of the treated municipal wastewater is feasible to produce and use, considering the required minimum instream flows, water quality, proximity to potential recycle water users, and cost.

The tasks outlined in the original scope of work and completed in this study are as follows:

- Task 1: Estimate the total municipal wastewater that is available for recycled water production in California (Chapter 2).
- Task 2: Municipal wastewater volumes which could be used if treated for beneficial reuse (Chapter 3).

- Task 3: Identify potential uses of recycled water at a planning level estimate (Chapters 4 and 5).
- Task 4: Analyze the cost of treating the available municipal wastewater to the following recycled water standards: un-disinfected secondary, disinfected secondary-23, disinfected secondary-2.2, disinfected tertiary, and full advanced treatment (Chapter 6).
- Task 5: Summarize how much of the available treated municipal wastewater is feasible to produce and use, along with the associated costs (Chapter 7).

1.2 Report Overview

Following this introduction, a background on water reuse in California is presented in Chapter 2. In Chapter 3, the wastewater flow balance is developed based on estimated dry weather flow and the fraction of that flow that could be treated to current CA recycled water standards. Potential reuse sites are discussed and identified in spatial databases in Chapter 4. Cost was evaluated as the primary factor controlling the implementation of recycled water projects. The modeling for identification of potential pathways for recycled water transmission pipelines, known at the least cost path analysis (LCP) is presented in Chapter 5. In Chapter 6, the cost curves to upgrade facilities with relatively large available effluent flows to incrementally higher water quality levels are developed. The estimated cost to treat and deliver recycled water from significant municipal wastewater flows to alternative reuse sites as a function of treatment level is presented in Chapter 7. Findings and implications developed from the model results are summarized in Chapter 8. A summary of the technical approach is shown in Figure 1-1.

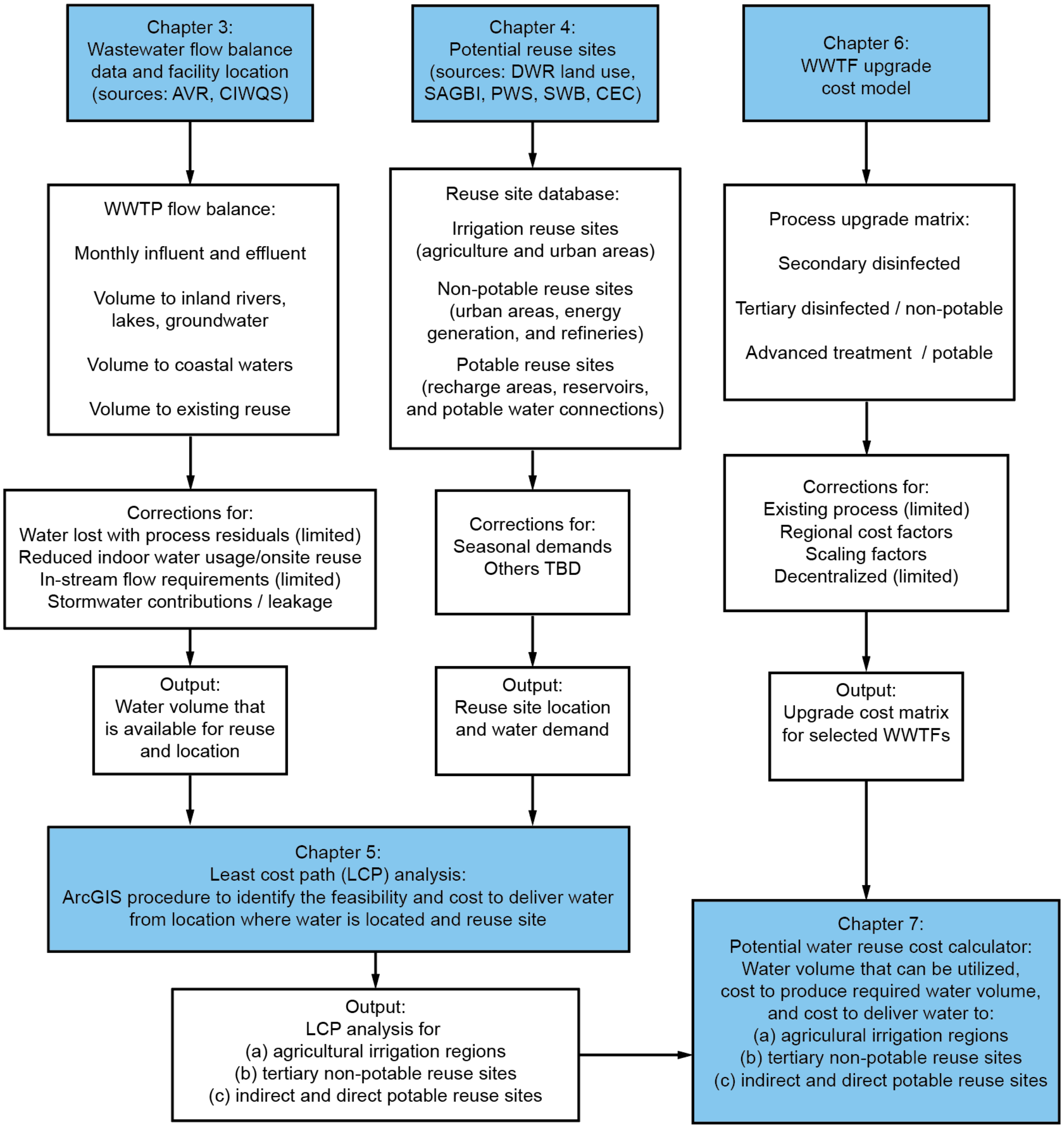


Figure 1-1. Summary of methodology used to estimate potential for water reuse and corresponding cost.

CHAPTER 2

Background on Water Reuse in California

Because the practice of water reuse varies across different regions and from site to site, it is important to review the different elements that need to be considered when evaluating the potential for water reuse. In this section, planned and unplanned water reuse are first defined, followed by a review of water reuse applications, recycled water producers, centralized and decentralized systems. Factors that will impact the potential for water reuse that are important in assessing site-specific constraints, but are outside of the scope of this study, are identified.

2.1 Historical Water Reuse Estimates and Goals

The current treatment requirements to produce recycled water and the allowable water reuse applications in California are specified in the California Code of Regulations Title 22, Division 4, Chapter 3 Water Recycling Criteria – referred to as Title 22 (CCR 2018). The full implementation of planned Title 22 water reuse projects in California has been complicated by a variety of expected and unexpected barriers. In 1987, a special task force of the California State Water Resources Control Board (SWRCB) projected that California would reach an ultimate water reuse potential of 827,000 ac-ft/y by the year 2000 (Asano et al., 1992). Two decades later, the State had not reached the expected water reuse potential, instead achieving an estimated 686,000 and 728,000 ac-ft of Title 22 permitted water reuse reported by 2019 and 2020, respectively (SWRCB, 2020; 2021). The water reuse goals for California, shown on Figure 2-1, were developed during a time of increasing population and increasing indoor water use. Subsequent reductions in indoor water use have reduced the total volume of potential influent and recycled water available. As discussed in the following section, it is also apparent that a significant amount of water reuse takes place that is not accounted for under Title 22.

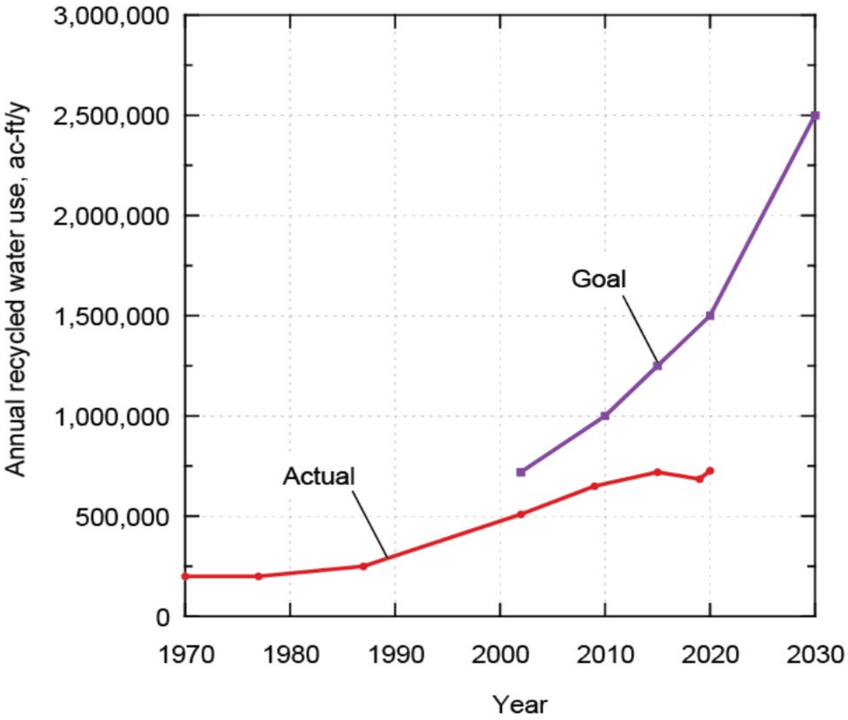


Figure 2-1. Summary of water reuse goal and Title 22 water reuse in California
Data Source: SWRCB 2020

In a recent study to estimate the potential for potable water reuse in California, Raucher and Tchobanoglous (2014) estimated an additional 1,125,000 ac-ft/y could be reused beneficially through the implementation of advanced water treatment (AWT) in regions including San Francisco Bay, Central Coast, Los Angeles, Central Valley, Santa Ana, and San Diego. It is noted that given the region-specific differences with regard to demand, water pricing, etc., the investment in AWT may not be feasible in some areas. The year 2020 reuse volume of 728,000 ac-ft and the additional 1,125,000 ac-ft/y of potential potable reuse equates to an estimated maximum water reuse rate in the range of 1.85 Mac-ft/y, or about mid-way between the historical State goals of 1,500,000 and 2,500,000 ac-ft/y by 2020 and 2030, respectively, as shown on Figure 2-1 (SWRCB, 2019, 2020). However, as reported in the 2003 Recycled Water Task Force report (DWR, 2003) these historic recycled water goals were based on an available 2030 effluent flow of 6.5 Mac-ft/y; due to water efficiency measures, the 2030 effluent flow now expected to be available for reuse is about half of what was predicted only two decades ago. Because the previous estimates for water reuse were based on legacy wastewater generation data, the historical goals are no longer relevant.

2.2 Planned and Unplanned Water Reuse

Several factors impacting water reuse may not have been considered adequately in the previous projections of water reuse goals. These factors include increased rates of water conservation and regulatory obstacles, as well as the growing complexity of modern water reuse projects. However, it must also be acknowledged that there has been and continues to be a significant amount of unplanned reuse that occurs within inland water systems. Unplanned reuse applications may provide environmental and habitat benefits, often not accounted for, as well as serving as downstream potable and non-potable water supply sources (see Figure 2-2).

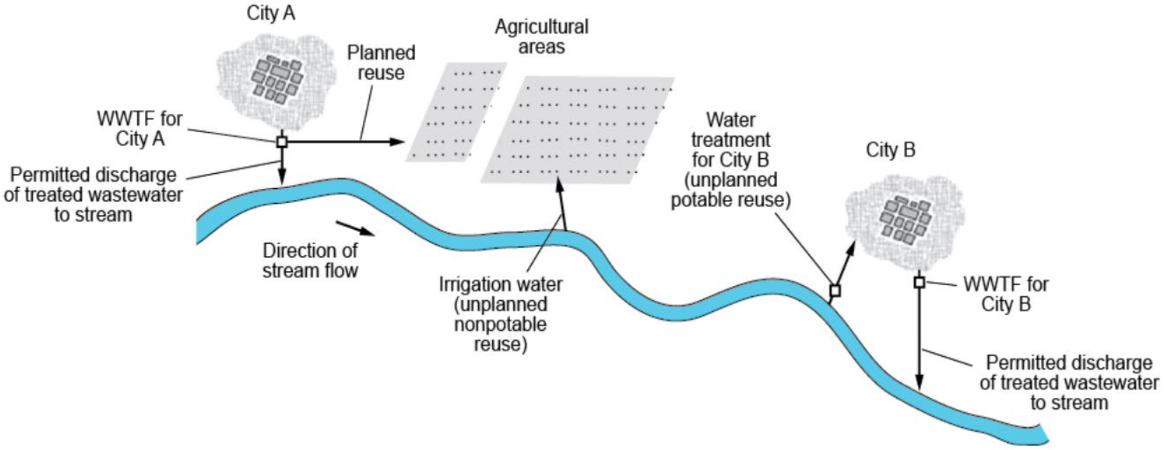
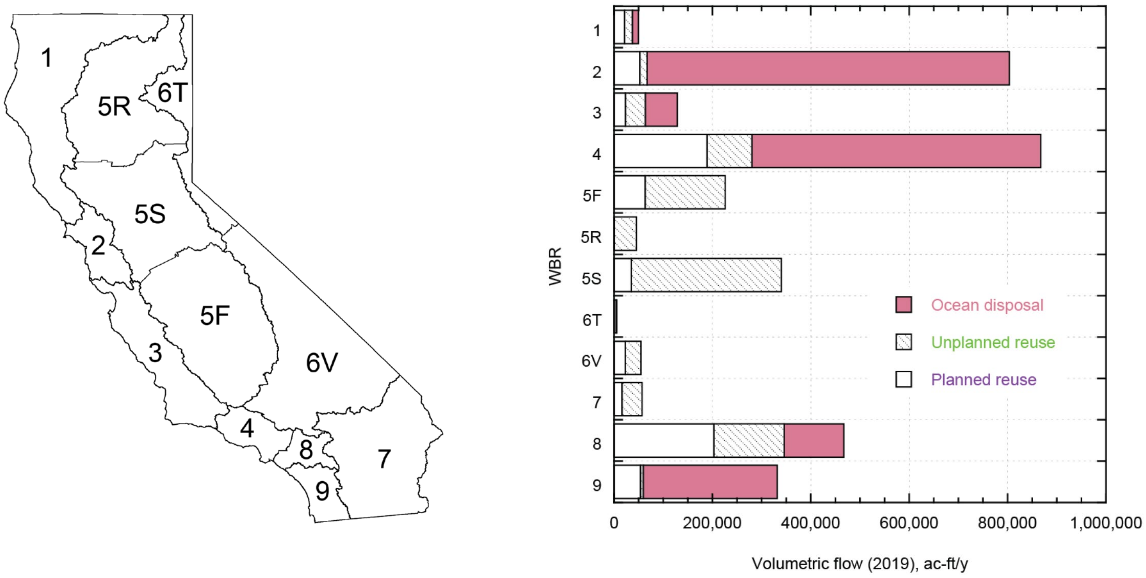


Figure 2-2. Views of planned and unplanned water reuse

There are some WWTF effluent flows, discharged under an NPDES permit which are harvested downstream for reuse. As an example, in the Santa Ana Watershed, the WWTF discharges to the river in the upper watershed are captured downstream for groundwater recharge, but the upstream discharges do not have permits as planned reuse projects. Further, due to water rights judgements, the effluent from the upstream WWTF is not available for local reuse projects and instead must be discharged to maintain flows to downstream water rights holders. Where treated effluent is land-applied, the water may reach aquifers used for potable and non-potable purposes. The Sustainable Groundwater Management Act (SGMA) considers impacts of land-applied treated effluent on groundwater quality. However, the quantity of water contributing to the groundwater resource from land application is not fully acknowledged.

The SWRCB implemented the first volumetric annual report (VAR) in 2019 to collect data on treatment level and water flows through approximately 750 WWTFs. The analysis presented in this report is based on the data published in the 2019 VAR (SWRCB, 2019). Effluent flow data from the 2019 VAR are summarized in Table 2-1 and illustrated on Figure 2-2. It should be noted that the flow data presented in Table 2-1 includes some non-wastewater sources. For example, during wet weather events, some stormwater runoff can flow into wastewater collection systems. It should be noted that in combined collection systems, stormwater and wastewater flows are collected together; the City of San Francisco and the City of Sacramento operate the only combined collection systems in California. The entrained stormwater flow to all WWTFs in California is estimated to be about 6 percent of the total influent. These wet weather flows are not used for planning water reuse projects because they are not predictable.



(a) (b)

Figure 2-3. Summary of effluent flow in California.

(a) overview map of Water Board Regions (WBRs) including: North Coast (Region 1), San Francisco Bay (Region 2), Central Coast (Region 3), Los Angeles (Region 4), Central Valley/Fresno (Region 5F), Central Valley/Redding (Region 5R), Central Valley/Sacramento (Region 5S), Lahontan/Tahoe (Region 6T), Lahontan/Victorville (Region 6V), Colorado River Basin (Region 7), Santa Ana (Region 8), and San Diego (Region 9); and (b) 2019 volumetric effluent flows for water reuse, unplanned/non-Title 22 reuse, and disposal by WBR.

As shown in Table 2-1, the total flow dispersed within freshwater systems (unplanned reuse, not regulated under Title 22) is estimated to be 898,000 ac-ft/y. Combining the unplanned reuse (898,000 ac-ft/y) and planned water reuse (879,000 ac-ft/y) volumetric flows in 2019, it is estimated that approximately 50% of the total municipal effluent generated in California is currently used for beneficial purposes. The balance of the effluent flow is discharged into coastal waters and therefore no longer can be used readily as a fresh water source without desalination (note that a small amount of effluent is also disposed of by deep well injection). As illustrated on Figure 2-3, the largest discharge is to coastal waters from Water Board Regions (WBRs) 2, 4, and 9, while the discharge from WBRs 5F and 5S are dominated by unplanned reuse.

Table 2-1. Summary of all reported volumetric flows for each Water Board Region (WBR) from WWTFs

Data Source: (SWRCB, 2019)

	Effluent flows to various applications from 2019 Volumetric Annual Report, ac-ft/y							
	Dispersal to fresh waters and land (unplanned reuse)			Planned water reuse (Title 22)		Disposal		
WBR	Inland surface waters	Land	Natural systems	Recycled water producer	Recycled water use	Deep well injection	Coastal waters	Total
1	9042	7035	322	437	21,393	1134	11,513	50,876
2	7129	540	7255	121,041	46,809		736,004	918,778
3	7668	26,713	6582	10,383	13,325	34	64,416	129,120
4	66,833	4225	20,287	44,570	158,128	10	586,925	880,977
5F	9959	150,753	1518	390	63,358	248		226,226
5R	33,324	11,248			689			45,262
5S	268,856	33,097	2583	1064	34,894	5		340,499
6T		1121	4		4388	5733		11,246
6V	5557	22,439	3938		22,825			54,760
7	21,797	18,588		4062	11,809			56,255
8	129,353	13,200	504	166,299	96,686		120,913	526,955
9	4372	2003		3468	51,589		271,430	332,861
Total	563,890	290,966	42,993	351,713	527,004	7164	1,793,293	3,577,023

Note: Recycled water producer (RWP) flows to reuse sites reported to be 159,307 ac-ft in 2019 (see Table 2-4), the difference is attributed to return flows and other inefficiencies.

2.3 Recycled Water Application

While there are many potential uses for recycled water, each reuse application has general and site specific implications which must be considered. Some of the key considerations for water reuse projects are summarized in this section. A description of contemporary non-potable and potable water reuse applications, organized by the required treatment level, are summarized in Table 2-2. The specific water quality requirements for a given water reuse scenario can vary significantly depending on the expected level of public exposure to constituents present in recycled water. As highlighted in Table 2-2, each water reuse application has specific considerations that impact the feasibility and impact on the municipal water balance.

2.3.1 Secondary Treatment

The treatment requirements for agricultural irrigation water are generally a function of the relative exposure to recycled water, however, secondary effluent is used commonly for irrigation of non-food crops. The use of recycled water for irrigation of commercial agriculture is permitted under Title 22, and in some cases where there is restricted access, irrigation is acceptable without disinfection. Because agricultural irrigation does not typically have the same quality requirements as urban water supply, for example, water quality is not expected to limit most irrigation projects, with the possible exception of salinity and specific constituents. Along with the lower quality of secondary treated recycled water for agricultural reuse is the relatively low cost of production, which has increased the consideration of irrigation as a low cost water reuse option. However, irrigation projects are typically seasonal in nature, which reduces the total amount of recycled water that can be used. In the few remaining regions where WWTFs are located near agricultural areas, irrigation may be in direct competition with other non-potable reuse options such as power generation cooling towers and habitat flows for water during peak demand.

Recycled water is applied to crops at agronomic rates based on nutrient and hydraulic loading to limit groundwater impacts. In general, using recycled water for commercial crop irrigation is not expected to offset or augment urban water supply unless water rights belonging to agricultural uses are explicitly exchanged with recycled water and offset water explicitly allocated to other uses. However, these transactions are considered to be relatively insignificant because the estimated amount of recycled water used for planned irrigation projects is about 1% of the estimated irrigation flow of 28 million acre feet (Mac-ft/y) originating primarily from the Sacramento-San Joaquin Delta, the Colorado River, and groundwater sources (SWRCB, 2014). Therefore, recycled water is not currently a significant source of agricultural irrigation water statewide.

2.3.2 Tertiary Treatment

The application of tertiary treatment, typically consisting of the addition of filtration following secondary treatment and prior to disinfection, allows for the use of recycled water for various urban applications. There are many examples where the use of tertiary treated effluent can be used for specific applications that offset the use of potable water supply. For example, urban landscape irrigation, as well as industrial and commercial uses, such as toilet flushing and car washing, can be accomplished with tertiary treatment levels. These urban reuse systems are commonly referred to as purple-pipe systems because of the purple-colored pipe used to distribute recycled water. In some urban areas, the cost to install the purple pipe distribution system and retrofit of urban water uses for recycled water can be prohibitively expensive. In general, water supply augmentation is expected to be more cost effective (in terms of $/ac-ft) with higher recycling potential compared with purple-pipe systems, which can be costly to retrofit in urban areas. However, in areas that have already been developed with purple pipe distribution and dual plumbing systems, such as those implemented by IRWD and EID, it may not be cost effective to shift to water supply augmentation. In addition, there are many small inland communities with limited rate bases where purple pipe systems and tertiary treatment will be the most cost-effective alternative. In regions with suitable land area that can be used for aquifer recharge it may be feasible to use tertiary effluent to augment water supply by surface spreading to achieve both soil aquifer treatment and percolation to groundwater. Among the earliest examples in California is the 1962 Montebello Forebay Groundwater Recharge Project, which will be celebrating its 60th anniversary this year (2022).

Table 2-2. Water reuse applications: examples, constraints, and concerns

Data Source: Tchobanoglous, 2018

Application	Typical examples	Considerations	Water supply impacts
Secondary treatment			
Agricultural irrigation	Crop irrigation; commercial nurseries; orchards	Limited area for agricultural irrigation within metropolitan regions; seasonal demand; effects of salts on soils and crops; lower quality water acceptable in most cases	Unknown offset to potable water use
Non-potable urban uses	Street sweeping, sewer flushing, dust control, and construction activities (concrete mixing, soil compaction)	Intermittent use; limited demand;	Likely to offset potable water use
Tertiary treatment			
Landscape irrigation	Parks; freeway medians, golf courses, athletic fields, green roofs	Point of use often far away from the point of water reclamation; dual distribution system required; variable demand	Likely to offset potable water use
Industrial recycling and reuse	Cooling water, boiler feed water, process water, concrete, high-quality water for electronics manufacture	Constant demand; site-specific water quality requirements	Likely to offset potable water use
Recreational and environmental uses	Lakes and ponds, streamflow augmentation, snow production for skiing, and snow melting in cities	Site specific; often seasonal	Augments water supply
Non-potable urban uses	Fire protection, car washing, toilet flushing, cooling water, and landscape irrigation in large building complexes	Intermittent use; limited demand; dual piping required for toilet flushing; dual piping most feasible in new construction; costly to retrofit buildings	Likely to offset potable water use
Surface spreading	Introduction of tertiary effluent into surface recharge areas	Availability of suitable recharge area;	Augments water supply
IPR advanced treatment + natural buffer			
Control of seawater intrusion	Introduction of ATW in groundwater aquifer to control sea water intrusion	Limited to coastal areas; treatment and infrastructure costs	Augments water supply
Groundwater augmentation	Introduction of ATW into a groundwater aquifer for groundwater replenishment	Availability of suitable groundwater aquifer; infrastructure and pumping costs	Augments water supply
Surface water augmentation	Introduction of ATW into a surface water	Availability of suitable surface water storage facilities; infrastructure and pumping costs	Augments water supply
DPR advanced treatment			

Application	Typical examples	Considerations	Water supply impacts
Raw water augmentation	Blending of ATW with other water sources upstream of a water treatment facility	No existing regulations (expected 2024), variable available dilution	Offsets use of other raw water sources
Drinking water augmentation	Introduction of ATW directly into water distribution system	No existing regulations (expected 2024); public health concerns; social acceptance	Offsets use of other raw water sources

Note: ATW: Advanced treatment water

2.3.3 Advanced Water Treatment (AWT)

While unplanned potable reuse has been the de facto mode of operation for most inland water systems, the development of permitted potable reuse projects utilizing advanced treatment (i.e., reverse osmosis and advanced oxidation) is a more recent development in California. When the ultimate reuse potential estimates were made in the 1990s, the technology to produce potable water reliably from wastewater effluent at full scale was not available (Asano et al., 2007). Compared with non-potable reuse, potable reuse projects, where feasible, have the advantage of replenishing urban water supply and utilizing the existing drinking water distribution system, minimizing the challenges in developing a separate and expansive recycled water distribution system. Advancements in technology to monitor water quality in real time, constituent source control, development of advanced treatment processes, and public acceptance have made potable reuse one of the most sustainable options for water supply in some areas (Leverenz et al., 2011). The Groundwater Replenishment System in Orange County, started in 2008, continues to be among the most prominent indirect potable reuse projects utilizing AWT in North America. There have also been a number of advances in the regulatory framework needed to facilitate expanded water reuse, including groundwater recharge (2015-16), surface water augmentation (2018), and raw water and drinking water augmentation (in development, expected in 2024).

2.3.4 Current Reuse Rates

Reported Title 22 water reuse activity from the 2019 VAR is summarized in Table 2-3. The data shown in Table 2-3 are the estimated volumetric flows to permitted water reuse projects and it is noted that the values deviate from the values shown previously in Table 2-1 under planned water reuse. The reason for the deviation is that a large amount of the flow volume sent to recycled water producers (RWPs, described in the following section) is returned to the originating WWTF for discharge to inland or coastal waters. It is also important to note that Title 22 prescribes requirements to ensure the protection of human health only. However, as described in Section 2.2, disposal of effluent to streams and natural systems equates to over 1 Mac-ft/y of flow that was used to augment freshwater systems in 2019.

As shown in Table 2-3, water reuse applications vary across WBRs. Agricultural irrigation is prominent in the southern region of the Central Valley, while large groundwater recharge projects and urban distribution systems for non-potable reuse have been developed in southern California. It is clear that there is more permitted water reuse activity associated with water-short areas that also have large urban populations, where the population is both the source of potential recycled water and the demand for municipal water supply. It should be noted that there are already a number of very large water reuse projects in the planning, design, funding and construction stages. According to WateReuse California (2019), an estimated 0.53 Mac-ft/y of permitted potable reuse was in the planning stages.

Table 2-3. Summary of water reuse by water board region (WBR) and reuse application

Data Source: SWRCB, 2019

	Title 22 flows from 2019 Volumetric Annual Report, ac-ft/y, to indicated water reuse application									
WBR	**Agricultural irrigation**	**Landscape irrigation**	**Golf course irrigation**	**Commercial application**	**Geothermal energy production**	**Industrial application**	**Other non-potable uses**	**Groundwater recharge**	**Seawater intrusion barrier**	**Total**
1	5820	753	882	214	13,688	7	28			21,393
2	3857	13,873	5267	235		26,429	2702			52,363
3	15,340	2629	3267	7		660	1118		0	23,022
4	4703	25,987	7584	239		63,298	26,483	46,509	14,210	189,012
5F	55,711	1129	306				4807	1405		63,358
5R	339	46	87					218		689
5S	19,675	5426	3105	1231	3983	1479	360	0		35,261
6T	4388									4388
6V	18,303	399	1170	0		693	2260			22825
7	2672	417	13,109							16,198
8	10,687	35,644	4986	363		5609	31,310	87,944	26,442	202,985
9	672	29,353	4644	274	45	2540	16,177			53,705
Total	142,942	115,723	44,662	2563	17,716	100,732	85,246	136,075	40,652	686,311

2.4 Recycled Water Producers (RWPs)

While raw wastewater must be processed using wastewater treatment processes designed for the task, the effluent from a WWTF can also be further treated at a separate facility known as a recycled water producer (RWP). The RWP designation is used to identify facilities which upgrade treated wastewater to tertiary or advanced recycled water, but do not receive untreated wastewater directly. The Orange County Water District (OCWD) Groundwater Replenishment System and the West Basin Municipal Water District's (WBMWD) Edward C. Little Water Recycling Facility are examples of RWPs. The OCWD receives secondary effluent from the Orange County Sanitation District (OCSD) and further treats the secondary effluent to potable water quality for groundwater recharge. The WBMWD receives secondary effluent from the City of Los Angeles' Hyperion Wastewater Treatment Plant and treats the secondary effluent with a variety of processes to produce several different qualities of recycled water for applications such as seawater intrusion barrier injection, cooling towers, boiler feed, and urban landscape irrigation. Therefore, RWP facilities are not considered specifically as a potential separate source of influent wastewater. To avoid double counting of potential influent, in this analysis RWP facilities are considered to be equivalent to a reuse demand for a given WWTF, i.e., the originating WWTF is the only source of influent considered. Volumetric flows to RWP facilities identified in the 2019 VAR are listed in Table 2-4.

As shown in Table 2-4, water reuse from RWPs in 2019 accounted for 23 percent of the total water reuse activity, with Region 8 having the largest volumetric flow delivered to RWP facilities. The RWP type of facility is effectively an extension of the WWTF, and in most cases the RWP will return reject flows to a WWTF. Using RWPs to support regional recycled water projects may reduce the economic barriers associated with full advanced treatment at small WWTFs. Additionally, given the cost to install new distribution infrastructure in urban areas, it is likely to be more economically feasible in some areas to develop RWPs upstream in the sewershed near the point of reuse.

Table 2-4. Summary of Title 22 permitted water reuse from WWTF/RW and RWP facilities

Data Source: SWRCB, 2019

Region	2019 WWTF/RW volume, ac-ft/y	2019 RWP volume, ac-ft/y	Total apparent reuse, ac-ft/y
1	21,393	-	21,393
2	46,809	5554	52,363
3	13,325	9697	23,022
4	158,128	30,884	189,012
5F	63,358	-	63,358
5R	689	-	689
5S	34,894	367	35,261
6T	4388	-	4388
6V	22,825	-	22,825
7	11,809	4390	16,198
8	96,686	106,299	202,985
9	51,589	2117	53,705
Total	527,004	159,307	686,311

2.5 Centralized and Decentralized Wastewater Systems

The conventional infrastructure model used for urban sanitation is referred to as centralized wastewater management. Centralized wastewater systems utilize extensive underground wastewater collection systems as well as pumping stations to convey municipal wastewater to the wastewater treatment location. In places that cannot be served effectively using a recycled water supply from a centralized WWTF, decentralized reuse makes it possible to achieve water reuse at various locations within the sewershed (see Figure 2-4). Decentralized water reuse systems can range in size from small projects at individual homes to municipal projects with satellite wastewater facilities. For example, onsite non-potable water reuse systems have been installed in several multi-family residential, mixed-use, and commercial buildings in San Francisco. These systems make use of onsite wastewater and / or other non-potable water sources for toilet flushing, irrigation, water features, and cooling systems. Examples of satellite wastewater treatment facilities are found in the City of Los Angeles and in the Los Angeles County Sanitation Districts system. These satellite water reclamation plants (WRPs) intercept and treat urban wastewater flows for local reuse. In both the individual building reuse systems and the municipal satellite systems, solids are not processed on site and are instead discharged into the wastewater collection system for treatment in downstream facilities.

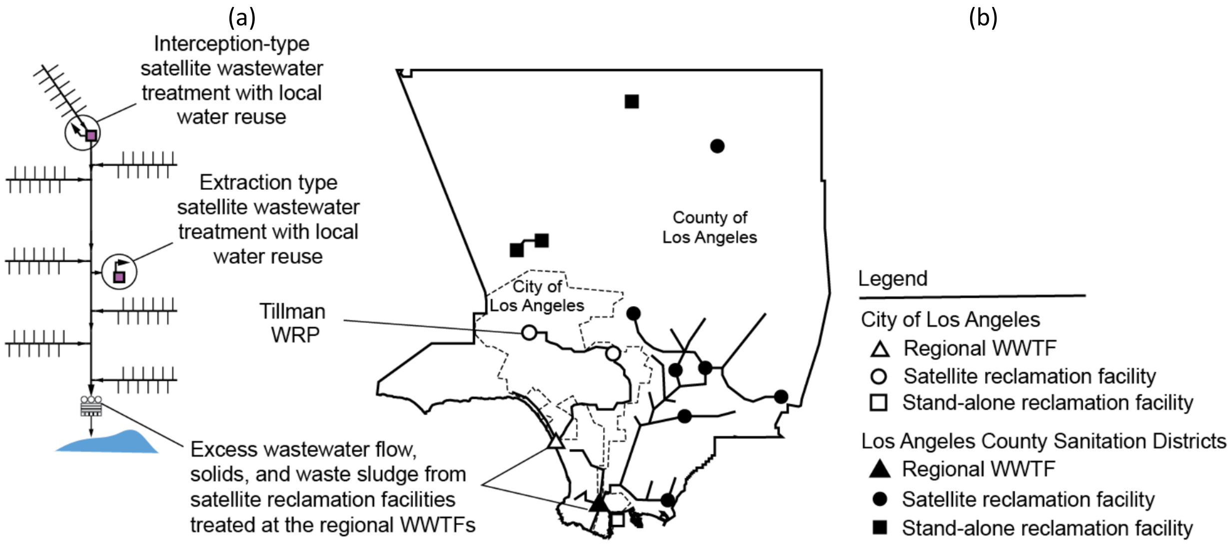


Figure 2-4. Integrated wastewater management system employing extraction type satellite constant flow WWTFs.

(a) definition sketch and (b) diagram of the satellite treatment systems employed by the City of Los Angeles and the Sanitation Districts of Los Angeles County
Adapted from Tchobanoglous et al., 2014

From an urban water balance perspective, in-building decentralized reuse is similar to indoor water conservation because both approaches result in reduced potable water demand and reduced wastewater discharge rates to wastewater collection systems. There is some potential that high levels of decentralized water reuse, similar to high levels of indoor water conservation, can have adverse impacts on wastewater management systems, such as increased sulfide generation, increased chemical precipitation, and increased influent concentrations. For example, it has been found that transporting concentrated solids discharged from satellite WRPs in wastewater collection systems can increase sulfide generation leading to increased odor and corrosion. Therefore, the implementation of private water conservation efforts, including onsite water reuse, and larger scale satellite reuse systems, should be implemented with consideration of potential impacts on downstream municipal wastewater collection and treatment systems. The regulations for onsite water reuse in California are still under development and the implementation and feasibility of these systems will depend, in large part, on the regulatory requirements.

2.6 Feasibility Considerations for Water Reuse

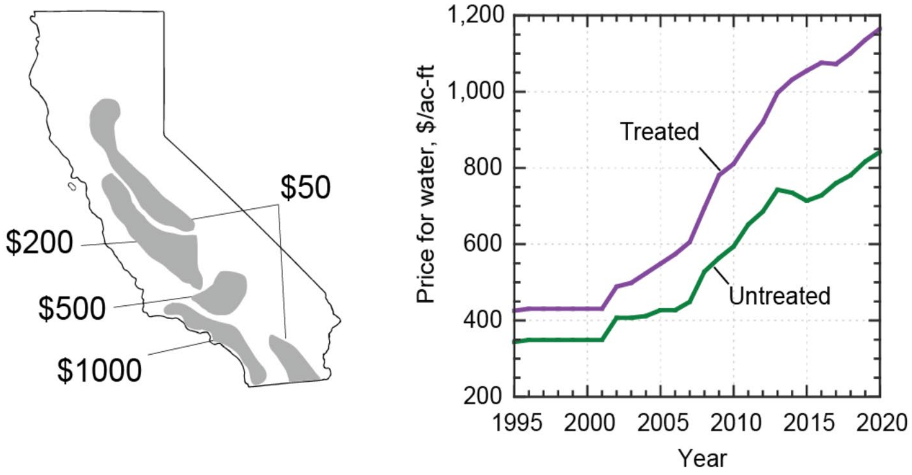
While there are many potential applications for water reuse, the feasibility of using recycled water cannot be determined based solely on the availability of potential reuse sites. Matching recycled water to a recycled water demand in California is relatively complex, requiring approved treatment facilities, available transmission lines, suitable facilities at the reuse sites, user/public acceptance, and regulatory approvals/constraints. Because of the complexity of developing and implementing recycled water projects, it is not possible to know all of the factors that could impact project feasibility without conducting detailed studies. In this study, estimated annual cost was used to compare recycled water alternatives in lieu of site specific data. Some of the key factors and constraints that may be considered for recycled water projects, but were not considered specifically in this study, are summarized below. Additional discussion of the implication of WWTF size and the capacity of small agencies to implement recycled water programs is presented in Section 3.1.

2.6.1 Comparison of Water Supply Options

A variety of factors must be taken into consideration when estimating the potential for recycled water as an alternative potable or non-potable water supply option (WSO). Key factors were explored in detail in a report by Stanford et al., 2018, with each WSO requiring detailed implementation data. Another approach put forth by Paulson et al. (2018) includes a framework with five modules to evaluate alternative WSOs. The framework includes (1) development of scope and goals, (2) definition of risk and uncertainties, (3) performance metrics, (4) evaluation approach, and (5) modeling.

The WSO evaluation methods developed by Stanford et al. (2018) and Paulson et al. (2018) use a holistic approach to consider the project triple bottom line (TBL): reliability, resiliency, and sustainability, respectively. Using these methods, water reuse projects can be evaluated as an element of an interconnected municipal water and wastewater infrastructure. It is common for water reuse projects to have one or more ancillary benefits that can make the difference between a project and no project. For example, diversion of effluent to a reuse application can obviate upgrading and expanding alternative effluent management systems, such as outfall structures. Similarly, the development of reuse projects may result in avoided costs of upgrading other treatment facilities. For example, implementation of the Monterey One Water project allowed for the removal of agricultural return flows from the Salinas River, eliminating the need for other costly river mitigations. In addition to the cost of water, the relative reliability of recycled water sources may be a consideration. If water from traditional sources is unavailable due to drought or curtailments, there are some areas where recycled water could be the preferred option for agriculture, in particular where there are tree crops.

For many communities, decisions on municipal services including water supply have been driven primarily by economic considerations, including total cost and availability of financing. If the cost to produce recycled water far exceeds the cost of other suitable water supply options, it will be difficult to justify the investment to develop the recycled water project. The price of raw water is generally low for agencies that have senior water rights. As drought conditions persist and the potential need to develop new, more distant, and costlier water sources arises, the cost of potable water increases in response to the reduced supply and the feasibility of recycled water projects improves. Examples of the cost of water in California are shown in Figure 2-5.



(a) (b)

Figure 2-5. Typical water rates in California 2019-20.

(a) variability of water rates by region, $/ac-ft and (b) untreated and treated water rates for Metropolitan Water District of Southern California (MWD). The water rates reflect the cost of water and do not include distribution costs

Data Source: MWD, 2022

The cost model developed for this project was used to determine the technical feasibility of reuse projects, assuming the availability of funding/financing. It should be noted that the cost model used for this project does not take the place of a project-specific feasibility analysis. Because cost data on the price of raw water changes over time, no effort has been made to compare the price of producing recycled water with the local cost of alternative supplies. A potential refinement to future modeling efforts will be to predict feasibility of water reuse based on projecting the date when the cost of the current water supply will exceed the cost to produce non-potable and potable recycled water.

2.6.2 Regulatory Requirements

The development of recycled water projects includes compliance with the California Code of Regulations, Title 22 (CCR 2018) and the Recycled Water Policy. Every recycled water project requires an engineering report on the recycled water system along with the permit application. The engineering report is used to describe how the recycled water will be produced, transported, and reused in compliance with CCR, Title 22. To demonstrate compliance, specified monitoring of water quality along with daily measurement of pathogen surrogates is required, for example. Well-funded and large agencies are more likely to have sufficient resources needed for design and project development, as well as resources to operate and administer the recycled water program successfully; however, smaller communities will encounter significant economic obstacles in implementing water reuse systems. Given that the Title 22 regulations for non-potable reuse applications are more than 20 years old and treatment and monitoring technology has advanced significantly, there is a need to reevaluate the applicable regulations and how they can be a barrier to water reuse and improve the feasibility of local water reuse projects. For example, the requirement for daily coliform testing is based on legacy analytical techniques, is not representative of all pathogens of concern, and does not provide real-time information. Any project could be subject to obstacles associated with the California Environmental Quality Act (CEQA) compliance, for example. Further, for systems that discharge to inland water systems, compliance with CA Water Code 1211 may be required, and is discussed in Section 2.6.5.

2.6.3 Declining Indoor Water Use

Improvements in the water use efficiency of indoor appliances and fixtures has resulted in a continuous decrease in the indoor per capita water use rate over time, as shown in Table 2-5. Most WWTFs in California were designed with an average influent flow rate equivalent at or above 100 gal/cap-d. Due to reductions in indoor water use, in some communities the average dry weather flow rate to the WWTF has declined to 35 gal/cap-d. AB 1668 requires the SWRCB to adopt indoor residential water use standards in coordination with the California State Department of Water resources (DWR). Indoor water use targets recommended by DWR are in the range of 42 gal/cap-d by 2030.

Table 2-5. Typical distribution of sources comprising municipal wastewater influent

Data Source: Raucher and Tchobanoglous (2014).

	Influent flow rate normalized to population, gal/cap-d					
	2013		**2020**		**2030 (projected)**	
Use	**Range**	**Typical**	**Range**	**Typical**	**Range**	**Typical**
Domestic						
Indoor	40 – 80	60	35 – 65	50	30 – 60	35 – 45
Outdoor	16 – 50	35	16 – 50	35	16 – 80	35
Commercial	10 – 75	40	10 – 70	35	10 – 65	30
Public	15 – 25	20	15 – 25	18	15 – 25	15
Inflow / other	15 – 25	20	15 – 25	18	15 – 25	15
Total	96 – 255	175		156		130 – 140

Declining flows can impact existing water reuse projects, for example, where there may not be adequate flow to meet summer peak demand for irrigation and cooling tower projects. Operation of water reuse systems at flow rates that are less than the design generally results in inefficiencies and lost revenue. Another issue with declining flows is in the planning for new water reuse projects. For example, where influent flows may decrease significantly, there are challenges with process and conveyance system sizing, changes in water quality, and grants/loans where terms are dependent on meeting flow targets. While it is apparent that declining flow rates will have a direct impact on the amount of water available for reuse, the declining flows also translate to a proportional increase in the concentration of wastewater constituents. As wastewater concentrations increase, agencies will experience greater challenges in meeting regulated effluent quality objectives. Additionally, the increased concentration of wastewater constituents results in increased salt concentration, oil/grease accumulation, and sulfide generation within the wastewater collection system. The increased salt and sulfide concentrations increase the rate of corrosion in collection systems, lift stations, and headworks at treatment facilities, and high salinity may make the recycled water less suitable for some uses (e.g., irrigation of some types of plants). Another important concern is the increasing concentration of oil / grease and the detrimental impacts on wastewater collection and treatment (Tchobanoglous and Leverenz, 2019). Managing the various impacts associated with the reduction in indoor water use can significantly increase the capital and operational costs of wastewater treatment, and result in diverting resources from potential water reuse projects.

2.6.4 Logistical Constraints

The cost to install new water distribution systems is expensive and especially so in developed areas. The locations to which water can be feasibly delivered to depend in part on the cost to install and operate the distribution system, as well as other political and economic factors. Obstacles that can impede the ability to deliver recycled water include various types of physical and abstract barriers. Natural obstacles can include rivers, canyons, elevation, and distance. The diurnal and seasonal demands for recycled water can also pose a significant problem. For example, irrigation typically takes place at night or in the early morning, when the supply of effluent to recycle is typically at a minimum. During the wet season there may be little or no demand for irrigation water. If there is no way to store the recycled water from the wet months until it is needed, the recycled water program and operations will need to be adapted to the variable demand. Therefore, to improve the volumetric efficiency for some types of water reuse, there may be a need to store and transfer large volumes of water. Without the addition of storage facilities, which can be costly, and / or other flow equalization measures, in some areas it may not be possible to meet the full water reuse potential. Consideration of seasonality of water reuse is discussed further in Section 3.6.

As discussed in Section 2-5, the design of current wastewater infrastructure itself can create a barrier to water reuse. The development and implementation of the centralized wastewater infrastructure now in use in most cities preceded or did not consider the goal of achieving high levels of water reuse. In fact, the common practice of locating WWTFs at the point of lowest elevation, to take advantage of wastewater collection by gravity flow, and to be near surface water to serve as a discharge location, complicates the potential for water reuse. It is apparent that many of the potential locations for water reuse are not located near the WWTF discharge location, and in most cases the water must be pumped to a higher elevation. For recycled water distribution systems supplying urban reuse customers, recycled water also needs to be pumped to provide enough operating pressure for the various irrigation systems, regardless of whether they are upgradient or downgradient. Further, the pipelines to deliver recycled water to urban areas or other reuse locations will need to be constructed, as existing potable water distribution lines in most cases cannot be used. Because of the complexity of above and below ground infrastructure, the cost to retrofit urban areas with recycled water distribution piping is highly site specific and could be prohibitively expensive. Retrofit of urban areas for recycled water use was not considered in this study.

2.6.5 In-stream Flow Requirements

Due to the impacts of the current sustained California drought, aquatic ecosystems are in significant peril and at risk of permanent damage. In dry years, some streams lack adequate flows to support the species that are present. In some cases, treated effluent flows have been essential to keeping species alive through the dry season and there have been efforts to establish instream flow requirements for effluent in these areas. As climate and hydrologic conditions change, the need for treated effluent flows will also change.

The in-stream flow requirements for treated effluent identified in the VAR (SWRCB, 2019) have a total volume of around 70,000 ac-ft/y (see Table 2-5). However, there are cases where there is no existing requirement to provide treated wastewater flows to a particular inland surface water but there is a practice of having done so, and where removing the flows may not be deemed beneficial/permissible by the SWRCB Division of Water Rights or the Department of Fish and Wildlife (or federal resource agencies) . Therefore, it is apparent that some portion of discharges to surface water may be considered beneficial reuse but are not reflected in the VAR. It is presumed that Water Code Section 1211 (1211), which states that 'prior to making any change in the point of discharge, place of use, or purpose of use of treated wastewater, the owner of any wastewater treatment plant shall obtain approval of the board for that change', would apply to most of these cases. However, it is not feasible at this time to determine the status of these cases until 1211 petitions are filed. It is noted that water rights to returned effluent in a river only extends to that effluent that originated from that river as the source of local potable water. Potable water tributary to the WWTF/WRP that was derived from imported water is not subject to these water rights and can be diverted to water reuse without impacting downstream water rights. Because any discharge into a freshwater system could potentially be determined to be beneficial in maintaining wildlife habitat, or affect downstream water rights, each treated effluent discharge to inland surface water must be evaluated on a case-by-case basis. . In summary, if stream flows continue to decline, it may be overly challenging and potentially infeasible or undesirable to divert potential recycled water from surface water to a reuse project because of the challenges in balancing the priority of water reuse with waters designated for habitat maintenance.

2.6.6 Water Rights

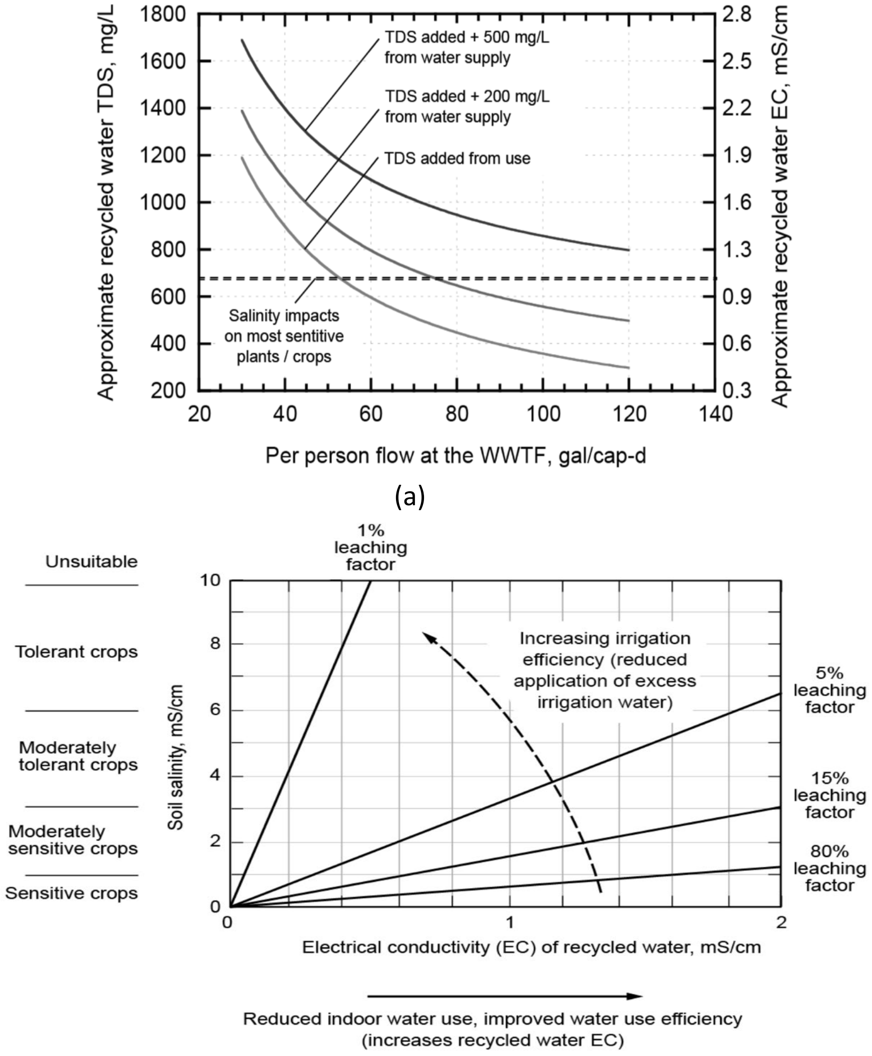
California's water rights allow a senior water right holder to use available surface water when there is not enough water for all water right holders. The seniority of water rights may affect the local water supply agencies' incentive to explore alternative water supplies including recycled water. For example, if a water district has a senior water right for a large reservoir, there may be less incentive for this district to explore other sources of water compared with junior water rights holders of the same water source. The districts holding more recent water rights would be cut off earlier from access to water in case of drought and therefore this district may be more likely to seek out alternative water sources. Framed another way, as discussed in Section 2.6.1, some water providers have an adequate and reliable water supply without developing recycled water, and the decision to use recycled water will be based on other factors, such as relative cost and availability of other options.

The in-stream flow requirements discussed in Section 2.6.5 are a combination of maintaining flow for habitat protection and maintaining flow for the downstream water right holders. For the latter, water rights can affect the feasibility of implementing water reuse where an agency with water rights downstream of a WWTF discharge point claims the right to use the flow of discharged effluent. The guaranteed access to the blended discharge can obviate developing recycled water projects.

2.6.7 Water Quality Requirements

The decline in indoor water use, as described above, has resulted in an increase in wastewater constituent concentrations. While the increasing concentration of organics and nutrients can make it more challenging to meet wastewater treatment objectives, the increasing concentration of dissolved solids and specific constituents in both municipal water supply and wastewater is a concern due to the higher cost for wastewater treatment and increased challenges associated with use of this recycled water. For example, some sensitive crops, such as strawberries, can be impacted by irrigation water total dissolved solids (TDS) in the range of 650 mg/L, a value that is commonly exceeded for recycled water in areas with water conservation as well as in areas using imported water from the Colorado River. An increase in the TDS of potable water supply, widespread use of residential self-regenerating water softeners to address hardness issues, and seawater intrusion in some coastal areas are all factors that can further drive up wastewater TDS to challenging levels. Similarly, plants can be sensitive to certain constituents in irrigation water, such as boron and sodium, as well as impacts on soil structure depending on the relative concentration of cations and the makeup of the soil itself.

The effects of salinity and specific constituents on landscape plants is exacerbated by low rainfall and restricted irrigation because excess water is required to flush constituents that may be harmful to the plants from the root zone. An example of the interrelationship between per person flow at the WWTF, the quality of the resulting recycled water, and the potential impact of the water on plant irrigation is illustrated on Figure 2-6. As shown on Figure 2-6(a), for a WWTF with a historical flow rate of 100 gal/cap-d and water supply TDS of 200 mg/L, the wastewater TDS is expected to be around 500 mg/L and there are no expected issues for irrigation with this water. As the influent flowrate is reduced to 50 gal/cap-d over time (current statewide average indoor water use), the TDS of the recycled water is expected be around 1000 mg/L (electrical conductivity or EC ~ 1.5 Ms/cm) and the water may not be suitable for some sensitive plants. Further, as shown on Figure 2-5(b), as the EC of recycled water increases, more irrigation water is required to achieve a higher leaching fraction for soil salinity control. The leaching fraction is the amount of additional water that must be used to flush salts from the root zone. For a leaching fraction of 80%, the plant uptake is only 20% of the irrigation water. Therefore, irrigation water must be applied at a rate of 5 times the plant water demand. At a leaching factor of 5%, only salt-tolerant crops are suitable.



(a)

(b)

Figure 2-6. Summary of flows, leaching factors, and crop sensitivity.

(a) per person water use and recycled water TDS and (b) recycled water TDS and the leaching factor and crop sensitivity

Adapted from Asano et al., 2007

In another example, the use of cooling towers can result in the evaporation of around 90% of the cooling water flow. Where recycled water is used for cooling towers, the blowdown flow that is returned to the WWTF contains a much higher concentration of wastewater constituents than were present originally in the recycled water. When the return flow is added back to the WWTF, the resulting blended water has an elevated TDS content and / or specific constituent concentrations that can preclude irrigation without blending. Ironically, the summer peak power demand (and evaporative cooling load) to provide electricity for indoor air conditioning occurs at the same time as the peak in high quality irrigation water demand.

Yet another consideration with recycled water is the presence of known and unknown trace organic chemicals in secondary and tertiary effluent, such as per-and polyfluoroalkyl substances (PFAS), that may drive the need for additional treatment technology to be implemented for both wastewater treatment and water reuse to remove these constituents. The technological upgrades needed to remove these chemicals would themselves result in higher capital and operating costs. Along with removing the chemicals from treated effluent, RO removes and concentrates salts. The concentrated chemical and salt brine, known as concentrate, must be managed as a waste stream generated as a by-product of treatment. Managing the concentrate flow is a non-trivial matter because the reject flow from RO can range from about 10 to 20% of the feed flow to the process. Therefore, a 10 Mgal/d process flow could produce 1 to 2 Mgal/d of concentrate that may require special handling, depending on site specific considerations. For example, the Santa Ana Region has 2 brine outlets, the SARI line to Orange County Sanitation District (OCSD) and a high-strength wastewater line from Inland Empire Utilities Agency (IEUA) to the Joint Water Pollution Control Plant (JWPCP) in Carson. In the Central Valley, the CV-SALTS program was established in 2006 to provide long-term salinity planning support. In some areas, lack of salinity management options, or the cost of achieving zero liquid discharge, is likely to preclude some recycled water options.

2.6.8 Climate Change

While specific impacts of climatic changes in the future are not known for certain, in California it is generally assumed that conditions will become drier and the incidence of drought longer and more frequent. Based on past experience, drought conditions result in enhanced indoor water conservation with lasting impacts. Therefore, it is not unreasonable to expect that future droughts will, over time, result in lower indoor water usage rates as compared to current values in regions that have not already achieved minimum indoor water use rates. Similarly, a drier climate is expected to increase the TDS content of the water supplies, and along with conservation this will result in higher TDS recycled water. As the TDS of recycled water increases beyond about 1000 mg/L, there is expected to be an increase in RO usage to condition recycled water where it is used for landscape irrigation. The RO concentrate flows from irrigation water treatment further increases the recycled water TDS and the corrosivity of the influent flow to the WWTFs. In some coastal regions, sea level rise is increasing the TDS of recycled water due to infiltration of saline water into low lying areas of the collection system. In some areas the high TDS and sulfate associated with sea water intrusion into the wastewater collection system increases the rate of corrosion and makes the effluent unsuitable for irrigation and certain other non-potable reuse applications.

Drought, along with enhanced water conservation, will make sizing wastewater treatment and reuse facilities more challenging and expensive to design and operate. In some locations, inter-basin transfers of untreated wastewater will be necessary to meet existing design capacity requirements for satellite treatment facilities, for example Tillman WRP in Los Angeles. New technologies and approaches, some already under development or commercially available, will be necessary to adapt wastewater infrastructure to the knowns and unknowns of the future.

2.7 Summary

From a review of the available volumetric flow data, a total of 3.58 Mac-ft/y of water was being dispersed from WWTFs in California in 2019 that could hypothetically be available for recycled water projects. However, a portion of this influent flow is composed of intercepted stormwater that cannot be used reliably for planning purposes. Additionally, some fraction of this influent must be returned to freshwater systems to support habitat or as required by regulations or water rights considerations. An estimated 1.80 Mac-ft/y (50%) of the total volumetric flow was discharged into the ocean and approximately 0.69 Mac-ft/y (19%) of this total influent volume was already being used in planned recycled water projects in 2019. The volume of municipal wastewater that could be used if treated for beneficial reuse is estimated in the following chapter.

CHAPTER 3

Potential Volume for Water Reuse

The purpose of the analysis presented below is to estimate the volume of municipal wastewater that is available for reuse. In this analysis, the 2019 VAR data were used to extrapolate volumetric flows to the year 2030. The data from the 2019 VAR were adjusted using several correction factors for supply and demand to estimate more accurately the amount of water that will be available for reuse in 2030. It should also be noted that while the 2019 VAR data was used in this study, subsequent and future drought and enhanced water conservation could drive the flows presented in this section lower and that the estimate developed in this study is likely to be the upper range of what might be expected. The procedure and factors used to estimate the future available recycled water are summarized below and described in the following discussion.

- Identify influent sources
- Estimate dry weather / summer season flow rate (base flow).
- Estimate reduction in influent base flow lost due to evaporation and activities associated with the management of residual solids from wastewater treatment.
- Estimate the change in influent base flow for the 2030 timeframe.
- Make corrections based on demand variation for irrigation, urban, and potable uses.
- Make adjustments for in-stream flow requirements.
- Make corrections based on current water reuse practice.
- Estimate future volume adjusted for current reuse and demand variation.

3.1 Identification of Influent Sources

A summary of the WWTFs included in this analysis, organized by influent flowrate and WBR, is presented in Table 3-1. The WWTF sources reporting consistent influent flows of raw wastewater totaled 661 facilities. It is noted that non-operational and seasonal facilities were not considered in this study. It is notable that about 83% of these WWTFs have an influent flowrate of less than 4 Mgal/d, and in total account for about 11% of the influent under consideration. Water reuse projects are challenging to implement at any scale, but large facilities have access to more technical and financial resources to develop and operate water reuse systems. While water reuse at small facilities is possible, water reuse at facilities less than about 4 Mgal/d is additionally constrained by technical and economy of scale considerations. Challenges with operating tertiary and advanced treatment trains at small WWTFs include lack of resources for monitoring and permit compliance, limited capacity and staffing issues, operational costs higher by a factor of 2.5 to 6 compared with large WWTFs, and limited options for concentrate disposal (Scruggs et al., 2020). Due to these technical and financial barriers in addition to the overall negligible impacts the smaller treatment facility can make on the state-level water balance, facilities with influent flows less than 4 Mgal/d were not considered for planned potable reuse applications in this study. It should be noted, however, planned potable reuse at some of these smaller facilities may become feasible and desirable depending on the site-specific circumstances in obtaining alternative water sources.

In general, the influent flow to existing WWTFs can be treated and discharged to the environment, distributed to one or more reuse sites, or sent to a recycled water producer (RWP) for additional treatment and reuse. In the following analysis, RWP facilities are not considered specifically as a potential source of influent wastewater. To avoid double counting of potential influent flow, RWP facilities are considered to be equivalent to a reuse demand for a given WWTF. The RWP type of facility is effectively an extension of the WWTF, and, in most cases, the RWP will return reject flows to a WWTF. Using RWPs to support regional recycled water projects may reduce the economic barriers associated with the production of recycled water at small WWTFs.

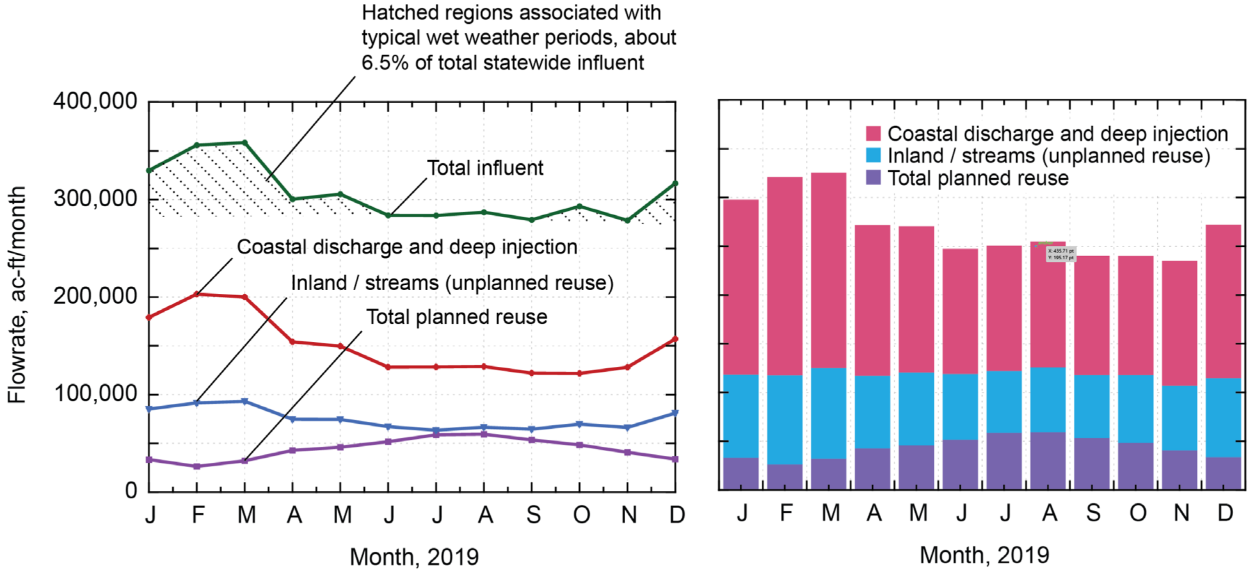
Table 3-1. Summary of facility count according to dry weather wastewater flow ranges.

	Count of facilities based on dry weather flow range, Mgal/d						
Region	< 1	1 – 4	4 – 20	20 – 50	50 – 100	> 100	Total
1	47	5	1				53
2	14	14	19	2	2	1	52
3	47	13	8				68
4	27	5	13	1	1	2	49
5F	99	19	11		1		130
5R	21	4	2				27
5S	89	18	11	1		1	120
6T	8	1	1				10
6V	39	7	3				49
7	17	7	5				29
8	12	6	8	5	1	1	33
9	19	11	8	2		1	41
Total	439	110	90	11	5	6	661

3.2 Estimated Dry Weather Flow (Base Flow)

The total influent flow to WWTFs includes wastewater from residential, commercial, industrial, and institutional sources. The flows from these sources are assumed to originate from indoor water use and subsequent discharge to the wastewater collection system and be relatively consistent on a seasonal basis. It is further assumed that the amount of raw wastewater leakage to the environment during transport in the collection system, including uptake by tree roots and evaporative losses, is negligible. However, wastewater collection systems are also subject to non-wastewater inflows from stormwater and groundwater sources, either directly or through cracks and joint defects (inflow and infiltration, I&I). The non-wastewater inflows are not considered to be reliable water sources for planning recycled water projects, given the seasonal nature and the lower demand for irrigation water during the wet season (see Figure 3-1).

Monthly influent flow data, from dry season periods, were used to estimate the baseline wastewater generation rate for each WWTF. Average dry weather flows were based on the months of July, August, and September. The average of the three summer months was then multiplied by 12 to estimate the annual baseline wastewater flow. Estimated dry weather flows by WBR are presented in Table 3-2.



(a) **(b)**

Figure 3-1. Summary of 2019 VAR data.
total influent, discharge into coastal and inland areas, and total permitted recycled water use and (b) cumulative effluent volume discharged to coastal and deep injection, inland and stream flow unplanned reuse, and total permitted reuse.

3.3 Estimate of Water Losses During Wastewater Treatment

Typically, a small proportion of the influent flow to a WWTF does not leave as effluent, mostly due to evaporative losses and water associated with solids processing. For purposes of this analysis, water loss due to evaporation and solids processing were estimated as follows. The relative potential for evaporative loss was estimated by considering typical pan evaporation rates of 0.2 and 0.5 in./d based on the annual average and peak summer rates, respectively. Using these evaporation rates and assumed influent flowrate of 5 Mgal/d and free water surface area of 1 acre, the water lost with surface evaporation was calculated to range from 0.1 to 0.27% percent of the influent flow. While it is expected that the evaporative loss rate from different WWTFs would be variable, in general the amount of water lost to evaporation is likely to be less than 1%. To estimate typical solids processing related water losses, a flow balance was conducted using a wastewater process model. Typical wastewater process configurations were evaluated to determine the volumetric flow of water contained in dewatered solids. In general, when wastewater solids are dewatered to 22 percent, the amount of water associated with solids is less than 0.06 percent of the total influent flow. Similarly, solids thickened to 6 percent would contain 0.6 percent of the influent flow, while a blend of primary and secondary solids from the clarifier directly would account for about 5 to 10 percent of the influent volume. Therefore, satellite type WWTFs that send solids downstream for treatment will tend to have less potential volume remaining for reuse.

Table 3-2. Summary of volumetric influent flows in WBRs grouped by dry weather flow ranges estimated from 2019 VAR database

Data Source: SWRCB, 2019

	Sum of dry weather influent, ac-ft/yr, grouped by flow range, Mgal/d						
WBR	**<1**	**1 – 4**	**4 – 20**	**20 – 50**	**50 – 100**	**> 100**	**Total**
1	10,346	10,375	17,548				38,269
2	4,214	30,214	197,211	64,895	115,760	114,301	526,594
3	10,101	27,932	83,903				121,935
4	2,571	12,369	156,802	46,364	73,809	587,618	879,533
5F	23,979	37,065	109,227		64,880		235,151
5R	5,786	8,518	13,879				28,183
5S	20,970	36,659	103,635	31,316		159,495	352,074
6T	1,310	4,057	5,203				10,570
6V	7,950	14,481	38,827				61,258
7	3,438	18,000	36,171				57,609
8	4,490	16,646	76,263	166,586	79,120	131,128	474,232
9	5,546	30,388	87,679	53,793		150,148	327,554
Total	100,699	246,703	926,348	362,953	333,569	1,142,690	3,112,962

The water lost with solids was also evaluated by using a water balance based on reported monthly influent and effluent flowrates in the 2019 VAR database. The effluent flow subtracted from the influent flow and divided by the influent flow resulted in values ranging from about +10 to -5%. The average difference, based on the VAR data, was approximately 0.5%. The distribution of percent change values, shown on Figure 3-2 was consistent across months as there is no apparent seasonal effect. Therefore, it is assumed that for facilities that include solids dewatering about 0.5% of the influent flow may be lost with solids and incidental evaporation. Facilities that send solids downstream for offsite management will have a greater fraction of the influent flow unavailable for reuse. In some facilities with a large water surface area or retention ponds, there could also be greater evaporative losses. Intercepted rainwater in treatment facilities was not considered.

The water losses estimated to take place, based on reported data and the modeling approach, are in general agreement. Based on the findings from the flow balance modeling, operation of a WWTF with solids dewatering will result in less than 0.1 percent of the influent flow being removed with the solids. For purposes of this analysis, the evaporated water and water entrained in the solids is considered to be negligible.

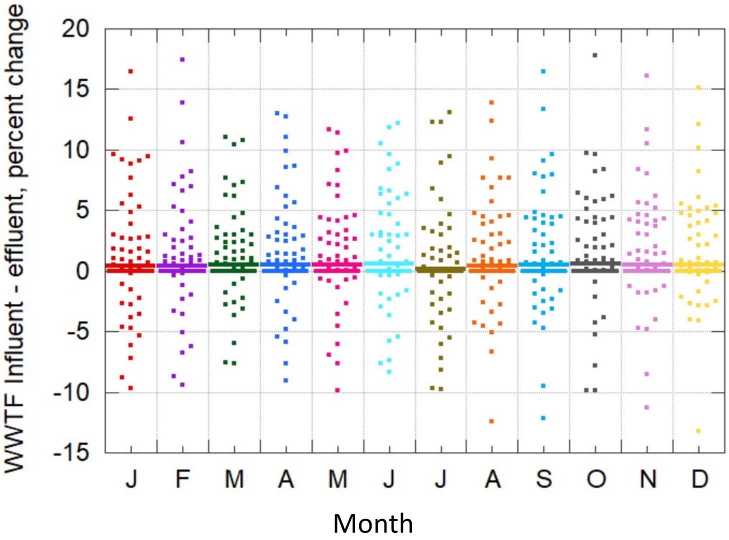


Figure 3-2. Summary of percent change in influent and effluent flow for each month as reported in 2019 VAR data

3.4 Regional Corrections to 2030 Influent Flowrate

The influent flowrate to WWTFs is impacted directly by reductions in indoor water use. In 2030, the average amount of water used per person for indoor residential purposes is expected to be less than it is currently, due principally to replacement of older appliances and fixtures with low flow alternatives. The current statewide average for indoor water use is around 50 gal/person-d. Future indoor water usage rates, as projected by DWR, range from 42 to 35 gal/person-d (DWR, 2021). However, many facilities are serving communities where indoor water conservation has already reached these low values. Therefore, assuming an across-the-board reduction in influent flow may not be a reliable method to predict future flow.

To estimate the influent flow volume that could be available in 2030, the 2019 VAR baseline (dry weather) influent flows were adjusted using projected regional shifts in indoor water use and population changes. These adjustment factors were obtained from a recent study (OWP, 2022) to evaluate the effects of urban water use efficiency standards associated with the implementation of AB 1668 and SB 606 on urban retail water suppliers, wastewater management agencies, and urban landscapes (trees and urban parklands). The adjustment factors used for the volumetric estimates in this study were developed for the scenario in which there is normal rainfall and not severe drought. The adjustment factors represent the predicted composite change in regional influent flowrates from the combined impacts of changes in residential population and changes in indoor water usage rates. It should be noted that the influent flow adjustment factors were applied in each WBR according to WWTF design capacity classification. The adjustment factors used to predict 2030 influent flows are summarized in Table 3-3. While most regions are project to see a small increase or decrease (e.g., 3 to 4%) by 2030, notable increases are anticipated in Regions 1, 2, 3 and 9. Regions 1 and 2 have the highest adjustment factors primarily due to expected population growth in these areas.
For purposes of this analysis, the actual 2030 flows are expected to change in response to projected population and water use rate changes as presented in Table 3-3. The adjustment

factors in Table 3-3 translate directly into wastewater production projections, e.g., for a WWTF with current influent flow of 100 Mgal/d and adjustment factor of 1.18, the expected flowrate is 118 Mgal/d in 2030. Using the factors shown in Table 3-3, the expected influent flows in each region can be estimated. A summary of the estimated 2030 influent volume is presented in Table 3-4. Based on a non-prolonged drought scenario, it is expected that the dry weather influent flow will increase from the 2019 value of 3.11 Mac-ft/y to 3.32 Mac-ft/y in 2030. Under the conditions of a severe and / or prolonged drought, the influent volume will be lower than the predicted value due to voluntary and required reductions in indoor water use. Similarly, changes in population that are different than the assumed value could also impact urban wastewater flows. The factor of 1.76 applied for effluent flows in WBR 2 WWTFs with design capacity greater than 100 Mgal/d results in a significant effluent flow increase and may overestimate the actual future value. For example. If there is only a moderate increase in WBR 2 effluent flows of 1.2, the estimated 2030 regional flow estimate for WBR 2 would be off by 10%. In an extreme case of severe drought and declining populations the 2030 flows could be equal to or less than the effluent flows presented in Table 3-2.

Table 3-3. Summary of influent wastewater adjustment factors applied for 2030 under non-drought scenario.

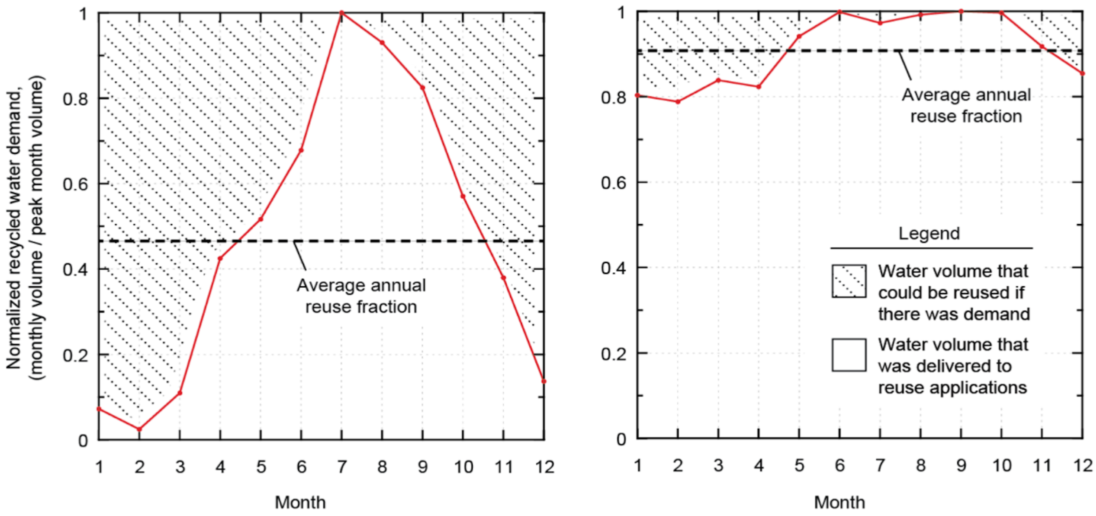
	Design capacity, Mgal/d				
WBR	**<4**	**4-20**	**20-50**	**50-100**	**>100**
1	1.25	1.51	0.85		
2	1.19	1.14	1.20	1.09	1.76
3	1.18	1.30	1.07		
4	0.99	0.97	1.04	1.01	1.00
5F	0.93	1.00		0.97	
5R	0.90	0.97			
5S	1.04	0.98		1.01	0.98
6T	0.97	0.98			
6V	0.97	0.94			
7	0.97	0.98			
8	0.97	1.00	1.00	1.02	0.98
9	1.32	1.09	1.05		1.28
Average	1.06	1.07	1.04	1.02	1.20

3.5 Demand Adjustment Factors

Water reuse applications have specific volumetric flow and water quality requirements. For example, in many areas the need for irrigation water is seasonal due to winter rain events or crop cycles. Therefore, when estimating how much water could be used for various applications, an adjustment or correction factor is needed to estimate how much water could be used over a twelve-month period. Because of the spatial differences across the state, the 2019 VAR data were used to estimate demand adjustment factors. The factors were developed through an analysis of the 2019 VAR monthly flows to water reuse projects. Within each WBR, selected WWTFs providing recycled water to irrigation, urban, or potable reuse projects greater than 0.5 Mgal/d were used to establish normalized demand curves, such that the peak month was set to 1 and other months were divided by the peak month, resulting in a value of less than 1 to reflect reduced usage in off-peak months. Examples of typical normalized water reuse demand plots for an agricultural reuse site and industrial reuse site are shown on Figure 3-3.

Table 3-4. Calculated 2030 influent wastewater flow values in each region.

	Volumetric sum of dry weather influent flows, ac-ft/yr, at given WWTF, Mgal/d						
WBR	**<1**	**1 – 4**	**4 – 20**	**20 – 50**	**50 – 100**	**> 100**	**Total**
1	12,933	12,969	26,497	0	0	0	52,399
2	5,015	35,955	224,821	77,874	126,178	201,170	671,012
3	11,919	32,960	109,074	0	0	0	153,953
4	2,545	12,245	152,098	48,219	74,547	587,618	877,272
5F	22,300	34,470	109,227	0	62,934	0	228,932
5R	5,207	7,666	13,463	0	0	0	26,336
5S	21,809	38,125	101,562	0	0	156,305	317,802
6T	1,271	3,935	5,099	0	0	0	10,305
6V	7,712	14,047	36,497	0	0	0	58,255
7	3,335	17,460	35,448	0	0	0	56,242
8	4,355	16,147	76,263	166,586	80,702	128,505	472,559
9	7,321	40,112	95,570	56,483	0	192,189	391,675
Total	105,721	266,091	985,619	349,161	344,361	1,265,788	3,316,742



(a) **(b)**

Figure 3-3. Example of unit water reuse demand curves for typical (a) agricultural irrigation project and (b) industrial reuse project.

The area under the curves shown on Figure 3-3 represents the fraction of the normalized influent that was delivered to the water reuse application, and the hatched area represents the fraction of the normalized influent that was not used due to lack of demand for recycled water. The volumetric adjustment factors were determined by computing the average annual water reuse fraction, shown as a dashed line on Figure 3-3. The average adjustment factors for each region were divided into the following categories (a) irrigation applications, (b) urban, commercial, and industrial uses, and (c) indirect and direct potable reuse applications. The adjustment factors are summarized in Table 3-5. Application of the adjustment factors is described further in Section 3.9.

Table 3-5. Summary of volumetric adjustment factors for each WBR based on 2019 VAR data.

	Reuse application type		
WBR	**Irrigation**	**Urban**	**Potable**
1	0.42		
2	0.42	0.80	
3	0.58	0.59	
4	0.59	0.90	0.82
5F	0.65		0.89
5R	0.32		
5S	0.56	0.66	
6T	0.81		
6V	0.50	0.79	
7	0.62		
8	0.53	0.76	
9	0.63	0.88	0.73

3.5.1 Irrigation Seasonal Demand Corrections

Reuse for irrigation includes all forms of irrigated agriculture, urban irrigations (parks, schools, public and commercial buildings, landscaping, medians), and golf courses. Although irrigation projects do not necessarily require the same water quality needed for urban and potable uses, high TDS or specific constituents may limit irrigation use. However, the need for irrigation water is driven by local weather conditions and crop needs. An example of seasonal demand for an irrigation project, where there is high demand in the summer and limited demand in the winter season, is shown on Figure 3-3(a). As shown in Table 3-4, typical seasonal irrigation water demand ranges from 40 to 60% across regions. Therefore, most irrigation projects are expected to have peak water demand in the summer season when influent flows are at a minimum and lower demand in the winter season, resulting in a total annual demand factor around 50%. In this analysis, the region specific correction factors from Table 3-4 are used for estimating irrigation demands. As an example, consider a WWTF located in Region 1 with an assumed annual potential volume of recycled water of 10,000 ac-ft. For this WWTF, it would be estimated that about 42% of the potential volume (4200 ac-ft) could be reused for irrigation. It should be noted that seasonal storage of recycled water for crop irrigation is not considered.

3.5.2 Urban Reuse Correction Factor

Urban non-potable water uses that require tertiary treatment include car washes, dual plumbed buildings, laundries, cooling towers, and other commercial and industrial applications. Similar to irrigation uses, each of these urban applications has site specific requirements that control the demand for recycled water. An example of demand variation for an industrial reuse was shown on Figure 3-3(b). While seasonality can impact the demand for various urban uses, some reuse applications are limited by the buildup of dissolved solids during usage. For example, where recycled water is used for evaporative cooling in cooling towers, salts and other dissolved constituents become concentrated. To control the salt concentration, some of the cooling tower water ("blowdown") is discharged to the wastewater collection system and make-up recycled water is added to replace the blowdown flow. The blowdown flow is typically concentrated by a factor of 2 to 5 (depending on the source wastewater) and can possibly be returned to the originating WWTF. Additionally, some cooling tower applications will also have seasonal demand, such as power generation facilities that experience peak cooling water demand during the peak power demand period to meet summer air conditioning loads. In addition to the reduced demand for recycled water in the winter season, it is estimated that 7 to 10% of the recycled water supply will be discharged back to the WWTF as elevated TDS blowdown flow (Asano et al., 2007). It is noted that as the TDS of wastewater increases due to indoor water conservation and elevated TDS in the water supply, the blowdown flow requirements will be increased. Other urban uses, such as laundries and car washes, are also subject to seasonal demands. To account for the water use efficiency in various urban non-potable reuse schemes, a demand correction factor of 15% is used to estimate recycled water flows in 2030. For example, a WWTF with an annual volume of 10,000 ac-ft would be projected to deliver up to 85% of the total volume to an urban reuse project, resulting in 8500 ac-ft of potential recycled water.

3.5.3 Potable Reuse Correction Factor

In general, potable reuse requires that dissolved constituents are separated from wastewater. Where RO is used to desalinate recycled water, there is some fraction of the influent that becomes concentrated to a point that it must be removed from the process as concentrate or reject flow. Based on a water balance for some of the existing recycled water projects and input from industry professionals, for 2030 planning an assumed recovery rate of 85% of the influent flow was used. The actual recovery rate observed will depend on the characteristics of the particular wastewater, the type of membranes used, and other site-specific factors. New technology is also available to recover additional water from the reject flow through evaporation and condensation cycles, but with increased cost and energy demand. For purposes of this study, it is assumed that when reverse osmosis is used for potable reuse, 15% of the influent flow may not be recoverable economically and is not included in the recycled water flow. Where recharge basins are used to replenish aquifers, while there is negligible water loss during treatment, there are evaporative and recovery losses. For purposes of this study, the overall water recovery efficiency of recharge basins is also assumed to be 85%.

3.6 Required Stream Discharges

In several WBRs, WWTFs are required to discharge some portion of their effluent flow to streams which have minimum flow requirements. WBRs with low flow streams requiring flow augmentation are identified in the 2019 VAR (see Table 3-6). It is expected that there are more cases where effluent dispersal into freshwater systems would be found to be necessary if the effluent were proposed to be diverted from the stream (e.g., new reuse projects). As climate conditions shift, the impacts on California streams and potential need for flow augmentation will also change. Unfortunately, at this time, there is no known list of flow impaired streams that can be used to assess the status of any particular discharge location. However, geospatial tools being developed by The Nature Conservancy and UC Davis could be adapted in the future to assess stream conditions (TNC natural flows database rivers.codefornature.org and California Environmental Flows Framework ceff.ucdavis.edu). Currently, the known in-stream flows are relatively small compared to the volume of effluent being considered across the state. Further, as these flows are considered to be essential for habitat, they cannot be considered for planned water recycling and potentially be categorized as a type of environmental reuse.

Table 3-6. Reported in-stream flow required discharge from 2019 VAR.

WBR	Required discharge, ac-ft/yr
3	2693
5S	18,532
7	465
8	51,514
Total	73,204

3.7 Future Effluent Volume Corrected for Reuse

The expected future effluent volumes available for reuse after current reuse project flows are removed are shown in Table 3-7. As discussed above, where measures are taken to process and dewater solids at WWTFs, the total volume of water exported with solids is estimated to be less than 0.1% of the influent flow. The water lost with solids is ignored in the following calculation; therefore, after the current planned reuse flows are removed from the projected 2030 influent, the remaining influent flow is approximately equal to the volume remaining to be considered for potential future reuse.

Table 3-7. Potential effluent available for reuse in 2030 after removing 2019 Title 22 recycled water volume.

	Volumetric sum of dry weather influent flows, ac-ft/yr, at given WWTF, Mgal/d						
WBR	**<1**	**1 – 4**	**4 – 20**	**20 – 50**	**50 – 100**	**> 100**	**Total**
1	10,654	11,565	8,350	0	0	0	30,569
2	4,357	33,414	199,537	72,799	120,457	189,286	619,849
3	10,464	29,592	91,653	0	0	0	131,709
4	1,357	7,609	111,984	19,236	26,135	508,252	674,573
5F	17,181	24,142	64,437	0	58,647	0	164,408
5R	4,618	7,566	13,463	0	0	0	25,647
5S	15,659	32,527	77,353	0	0	156,305	281,845
6T	1,271	0	5,099	0	0	0	6,370
6V	5,644	10,364	19,423	0	0	0	35,430
7	2,958	13,129	24,286	0	0	0	40,372
8	2,632	10,325	41,277	87,943	80,702	0	222,879
9	4,005	26,035	60,194	53,859	0	192,189	336,282
Total	80,799	206,268	717,056	233,836	285,941	1,046,032	2,569,933

3.8 Estimated 2030 Influent Volume Potentially Available for Reuse

The potential volume available for reuse, as reported in Table 3-7, includes some portion of flow that is not considered to be practical for reuse due to availability or demand constraints. The correction factors for agricultural, urban, and potable reuse applications presented in Section 3.5 were applied to the values from Table 3-7 according to dry weather flow grouping range. Facilities in the influent flow range of less than 4 Mgal/d range were assigned the correction factors for irrigation type reuse projects from Table 3-4. Facilities with dry weather flows greater than 4 Mgal/d were assumed to be able to achieve a maximum of 85% reuse (all regions) and considered urban and potable reuse projects. It is important to note that in cases where RO volumetric recovery is less than 85% or where concentrate must be diluted prior to disposal, the fraction available for reuse would be proportionally reduced. The computed values, which represent the estimated volume of influent that could be reused, are summarized in Table 3-8. As summarized in Table 3-8, an influent volume of approximately 2.1 Mac-ft/y, not including water that is already being used in planned recycled water projects, is expected to be available in 2030. However, it is important to note that this influent volume given in Table 3-8 does not represent that volume that is technically available for reuse as additional considerations are needed for concentrate management and geographic limitations, as described in subsequent chapters.

The minimum instream flows that have been identified in the VAR have not been considered in this analysis because the currently reported instream flows are insignificant volumes. As described in Sec. 3.6, the potential instream flows could be greater but will need to be evaluated on a case-by-case basis by the SWRCB. Flows to freshwater systems are separated out for consideration in Section 3-9.

Table 3-8. Summary of potential 2030 wastewater volume that is not currently being recycled and is available for water reuse projects.

	Influent flow range, Mgal/d, and corresponding cumulative volume, ac-ft/y						
WBR	**<1**	**1 – 4**	**4-20**	**20-50**	**50-100**	**> 100**	**Total**
1	4,474	4,857	7,098	0	0	0	16,430
2	1,830	14,034	169,606	61,879	102,389	160,893	510,630
3	6, 069	17,163	77,905	0	0	0	101,137
4	801	4,489	95,186	16,350	22,215	432,014	571,056
5F	11,168	15,693	54,771	0	49,850	0	131,482
5R	1,478	2,421	11,443	0	0	0	15,342
5S	8,769	18,215	65,750	0	0	132,859	225,594
6T	1,029	0	4,334	0	0	0	5,363
6V	2,822	5,182	16,510	0	0	0	24,513
7	1,834	8,140	20,643	0	0	0	30,617
8	1,395	5,472	35,085	74,752	68,597	0	185,301
9	2,523	16,402	51,165	45,780	0	163,361	279,231
Total	44,192	112,069	609,497	198,761	243,050	889,127	2,096,697

3.9 Inland and Coastal Diversions

After considering the total potential influent volume that could be processed for planned reuse projects, it is also of interest to determine what fraction of the total effluent volume would be diverted from inland surface waters and as compared with diversions from coastal waters. Of these two categories, diversion from disposal in coastal waters is considered to be the highest priority as this water is lost from the freshwater systems. It is noted that a minor amount of water is also injected into deep wells and therefore not contributing to any planned or unplanned beneficial reuse. For the purposes of this study, it was assumed that the 86 WWTFs with effluent flowrates, not including flow that is already being used in planned reuse projects, greater than 4 Mgal/d are in communities that can obtain the resources to implement tertiary or advanced treatment systems. The comparison of effluent flows to inland and coastal waters are summarized by region in Table 3-9. Considering only the 86 largest WWTFs with more than 4 Mgal/d of effluent available, a total of 1.83 Mac-ft/y of potential reuse projected in 2030 could directly offset other potable water supplies.

It is estimated that 0.52 Mac-ft/y of potential reuse volume is associated with WWTFs dispersing effluent to inland waters/land and, therefore, contributes to unplanned environmental and habitat benefits. At least 0.073 Mac-ft/y of this flow to inland surface waters is mandated by instream flow requirements. It is expected that some portion of the remaining flow to inland surface waters will be determined to be necessary to support habitat or other benefits. With the impacts of prolonged drought on streams it is expected that treated effluent flows could become an important source of environmental water flows in a growing number of locations. Because the 0.52 Mac-ft/y currently discharged into freshwater systems needs to be evaluated further for potential beneficial uses (current and future), the suitability of diverting this effluent flow needs to be evaluated on a case by case basis subject to environmental/habitat/water rights reviews.

As shown in Table 3-9, 72% of the potential diversions are from coastal disposal. Further, the effluent volume of 1.32 Mac-ft/y diverted from coastal discharge, together with the current 0.69 Mac-ft/y of existing reuse (2019), represents an overall total planned reuse rate of 60 percent, projected to 2030.

3.10 Site Specific Factors Not Considered

With regard to the feasibility of implementing a particular recycled water project, site-specific factors and constraints could not be considered in this study. These considerations include regulatory and legal constraints, climate related considerations (such as sea level rise), intensive energy demands, required instream flows for habitat preservation, emerging water quality and quantity issues, conveyance issues, jurisdictional and purveyorship conflicts, and dual-plumbing systems. The feasibility of any particular project cannot be known until actual constraints and limitations are evaluated. Therefore, the results presented in this report represent the potential reuse volume without consideration of site specific constraints. An expanded discussion of factors that could not be considered in this high-level analysis was presented in Section 2.5, in Chapter 2.

Table 3-9. Summary of effluent diversions from inland and coastal waters under 2030 potential reuse scenario for 86 largest WWTFs with potential wastewater influent volumes greater than 4000 ac-ft/y.

WBR	Source of effluent diversion under reuse scenario, ac-ft/y		Total
	Inland surface waters, land, wetlands (unplanned reuse)[a]	Coastal waters (ocean disposal)	
1	4376		4376
2		487,570	487,570
3	13,970	58,406	72,376
4	81,097	449,249	530,346
5F	94,695		94,695
5R	11,443		11,443
5S	206,193		206,193
6T		4334	4334
6V	13,896		13,896
7	17,715		17,715
8	74,431	68,597	143,028
9		247,670	247,670
Total	517,816[a]	1,315,826	1,833,642

[a] Potentially subject to in-stream discharge requirements

3.11 Summary

The volumetric flow data were processed further to determine what portion of municipal wastewater effluent could be used if it were treated for beneficial reuse. After correcting for seasonal stormwater inflows, known in-stream flow requirements, fluctuation in future influent flows, existing planned reuse projects, and identification of WWTFs with potential capacity to implement advanced recycled water projects, it was estimated that 1.83 Mac-ft of effluent flow could be diverted to new planned recycled water projects in 2030. However, it is noted that a future severe drought condition would be expected to reduce the effluent flow volume available for water reuse projects. Of the total volume available for new recycled water projects in 2030, it was further estimated that 1.32 and 0.52 Mac-ft could be potentially diverted from coastal and freshwater systems, respectively. In cases where RO recovery is less than 85% or where concentrate must be diluted prior to disposal, the fraction available for reuse would be proportionally reduced. Potential uses of recycled water at a planning level estimate is discussed in the following two chapters.

CHAPTER 4

Identification of Potential Sites for Water Reuse

As discussed briefly in Chapter 2, there are many constraints that limit feasibility of specific water reuse projects, including but not limited to the availability of recycled water, availability of recycled water application sites and demand, relative distance between the site of recycled water production and recycled water demand, availability and/or constructability of recycled water distribution systems, financing construction of recycled water infrastructure, costs for producing recycled water and means to recover these costs, and user acceptance. These constraints are highly site-specific and it is difficult to generalize the magnitude of these potential impacts and their relative importance as impediments to water reuse projects. Nonetheless, an understanding of potentially available volume of water and potential end uses of recycled water provides an order-of-magnitude projection of water reuse potential in California. The availability of wastewater influent and treated effluent was discussed previously in Chapter 3. In this chapter, potential water reuse application sites and their potential demand are identified. The potential reuse sites identified for this analysis include agricultural crop irrigation, power plants, permeable groundwater recharge areas, reservoir augmentation, and direct potable reuse sites. The data utilized for this analysis are also summarized in this chapter.

4.1 Secondary Treatment

In earlier stages of recycled water projects in California, agricultural irrigation was the most prevalent recycled water application. Irrigation represented 67% of total water reuse by volume as of the early 2000s (Asano et al., 2007). Title 22 regulations allow recycled water to be used for irrigation of all types of food crops. The level of treatment required depends on the type of crops and the exposure risk reduction measures taken. Typically, non-food crops such as fodder can be irrigated in a restricted access area with disinfected secondary recycled water. Food crops that could be consumed raw, such as spinach and strawberries, can only be irrigated with disinfected tertiary recycled water. In 2015, farmers used roughly 219,000 ac-ft of recycled water for agriculture irrigation, but out of the 27 Mac-ft/y used for California agriculture purposes, recycled water makes up less than 1 percent of the agricultural water supply in California (SWRCB 2014). Sources of water used for agriculture in California are presented in Table 4-1.

There are different water quality requirements for irrigation of each type of crop (i.e., raw crops and processed crops). The main concern associated with the use of recycled water for irrigation is the potential transmission of pathogens via ingestion, contact and inhalation. Heavy metals taken up by food crops also present potential health risks. Recycled water quality information and impact on agricultural irrigation is listed in Table 4-2. In this study, all water quality requirements were not considered for purposes of site selection; therefore, there may be some additional considerations in matching effluent water quality with crop needs.

Table 4-1. Water supply for California agriculture

Data Source: SWRCB, 2014

Source	Flow, ac-ft/y	Percent of total
Sacramento – San Joaquin Delta	14,090,000	50.8
Colorado River	3,716,000	13.4
Groundwater wells	9,660,000	34.9
Municipal recycled water	245,000	0.9
Total	27,711,000	100

Table 4-2. Recycled water quality information and impact on agricultural irrigation

Data Source: Asano et al., 2007

Information	Impact on irrigation management
Microbial quality	Selection of crop types and irrigation methods. The need for additional treatment.
Total salt concentration and/or electrical conductivity of the effluent.	Selection of crops, irrigation method, leaching, and other management requirements.
Concentrations of cations, such as Ca2+, Mg2+, and Na+.	Assessment of sodium hazard and need to take appropriate mitigating measures.
Concentration of toxic ions, such as heavy metals, Boron, and Cl–.	Assessment of toxicities that are likely to be caused by recycled water irrigation and need for appropriate measures.
Concentration of trace elements (particularly those which are suspected of being phytotoxic).	Assessment of toxicities that are likely to be caused by recycled water irrigation and need for appropriate mitigating measures.
Concentration of nutrients, particularly nitrate-N.	Fertilization requirements and crop selection. The need for nutrient removal at the treatment plant.
Suspended solids.	Irrigation system selection and measures to prevent clogging. The need for additional treatment for solids removal.

Agricultural reuse sites were identified using DWR land use data, as shown on Figure 4-1. The land use data are publicly accessible and this analysis used statewide crop mapping data for the year 2016. DWR land use sites include citrus and subtropical, deciduous fruits and nuts, field crop, grain and hay crops, pasture, rice, truck nursery and berry crop, vineyard, young perennial and urban areas.

Agricultural reuse sites are classified as areas that could potentially use existing secondary or tertiary effluent for commercial crop irrigation. The estimated hydraulic loading rate for irrigation of the agriculture reuse sites is based on the evapotranspiration rate during peak summer demand.

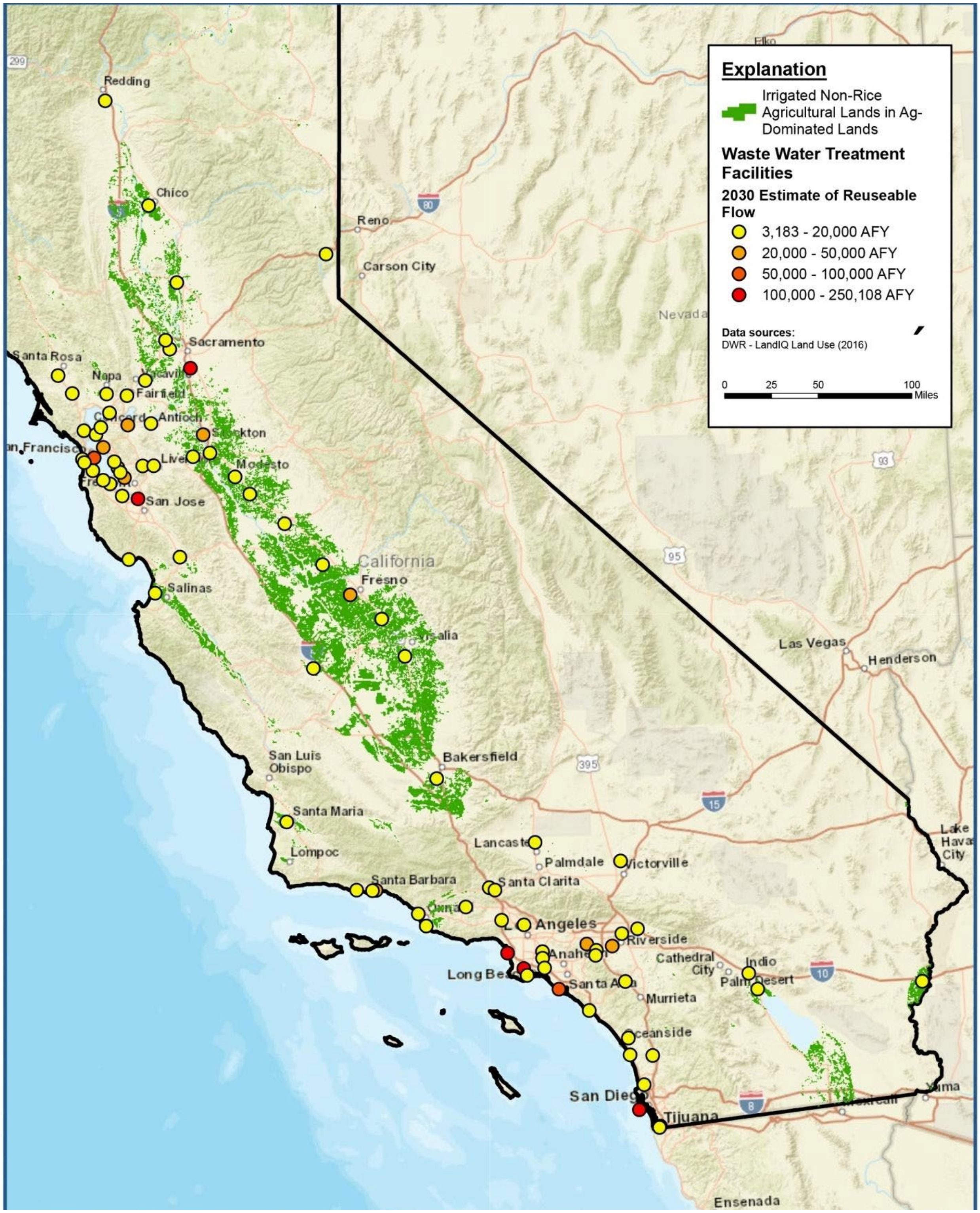


Figure 4-1. DWR land use data for agricultural reuse sites.

4.2 Tertiary Treatment

When secondary effluent is upgraded to tertiary quality, e.g., using media or membrane filtration, there is potential to use the water for various urban uses, as well as groundwater recharge through surface spreading. Examples of urban water reuse applications include landscape irrigation, fire protection, toilet/urinal flushing, commercial car washing, commercial laundries, water features, dust control, and street cleaning. These uses typically require a purple-pipe recycled water distribution system operating in parallel to the potable water distribution system. As these urban reuse applications are generally limited in volumetric capacity and expensive to install, and low cost alternatives are likely to have already been developed, they were not considered in the modeling for this study. However, it should be noted that this type of local tertiary reuse has been a prevalent type of use for recycled water over the past 30+ years in California, constituting about half of the total 2019 Title 22 recycled water use. The vast majority of purple-pipe tertiary reuse has been applied to landscape and golf course irrigation, which are assigned a lower priority for SRF funding. In this section, reuse applications that were considered for tertiary effluent, including water reuse for industrial cooling and groundwater recharge basins, are discussed.

4.2.1 Power Generation Cooling Towers

Recycled water used by the power industry for cooling purposes has the potential to be expanded, offsetting current water usage and / or allowing existing plants to expand capacity. The power industry can also use recycled water for air pollution control equipment like scrubbers, which is expected to become more important as more legislation is passed to restrict air pollution. One key logistical challenge with using recycled water for power plant cooling towers is that the summer peak power demand for building air conditioning also results in peak demands for cooling water, which also overlaps with peak seasonal irrigation demands and peak habitat demands. Using recycled water for cooling concentrates the returned wastewater constituents, increasing potential toxicity and concentration concerns (e.g., salinity). The water intensity estimates for common power generation cooling systems are summarized in Table 4-3.

Table 4-3. Water intensity estimates for power generation cooling systems

Data Source: DOE, 2006

		Water intensity, gal/MWh	
Plant type	**Cooling water use**	**Withdrawal**	**Consumption**
Biomass/waste	Once-through	20,000–50,000	300
	Cooling tower	300–600	300–480
	Cooling pond	500–600	480
Nuclear	Once-through	25,000–60,000	400
	Cooling tower	500–1,100	400–720
	Cooling pond	800–1,100	720
Geothermal steam	Cooling tower	2,000	1,400
Natural gas	Once-through	7,500–20,000	100
	Cooling tower	230	180
Coal	Cooling tower	250	200

The type of water cooling system is the primary determinant for the amount of water consumed. Two types of cooling systems are used: once-through and recirculation. Once-through cooling refers to cooling systems where water is withdrawn and circulated through heat exchangers, then returned to a surface-water body. Recirculation cooling refers to cooling systems where water is withdrawn and circulated through heat exchangers, then cooled using ponds or towers prior to recirculation. Once-through cooling systems, which are being eliminated in California, require a large amount of water withdrawal, but consumption and TDS buildup are relatively low. Recirculation systems require a smaller amount of water uptake because the water is used to replace water lost due to evaporation, blowdown, drift, and leakage. However, the consumptive use for the recirculation system is a larger percentage of the amount withdrawn.

Overall, the power industry withdraws and consumes vast quantities of water each day for cooling. The U.S. Geological Survey (USGS) estimated that in 2000 the U.S. power industry withdrew 136 Bgal/d of freshwater for cooling, a similar amount to the daily volume of freshwater withdrawn for agricultural irrigation (Hutson et al., 2004).

The California Energy Commission (CEC) database of refineries and power generation facilities was used to identify commercial and industrial non-potable reuse sites that are near WWTFs. Hundreds of power generation facilities have been located in the state, including 19 coal power plants, 616 gas power plants, 51 geothermal power plants, and 2 nuclear power plants (soon to be one). Significant power generation facilities that were used as potential consumers of recycled water are summarized in Figure 4-2.

4.2.2 Recharge Basins

Surface spreading is a common method for artificial recharge and is considered to be a form of indirect potable reuse. In surface spreading, the recycled water percolates from spreading basins through the unsaturated soil and ground zone (Asano et al., 2007). It is notable that this is the only form of indirect potable reuse that allows tertiary effluent to be used as it is assumed that percolation through the unsaturated zone of the soil provides the equivalent of advanced treatment. In surface spreading, the recycled water percolates from spreading basins through the unsaturated soil and ground zone (Asano et al., 2007). Groundwater recharge by surface spreading allows for groundwater supplies to be replenished in the vicinity of areas impacted by severe drought. The advantages and disadvantages of surface spreading are presented in Table 4-4.

Groundwater recharge by surface infiltration sites were identified using the Soil Agricultural Groundwater Banking Index (SAGBI). The SAGBI index represents a suitability index for groundwater recharge on agricultural land and for potential groundwater recharge areas. The database is based on deep percolation, root zone residence time, topography, chemical limitations, and soil surface condition. The SAGBI sites used for identification of potential recharge basins are shown on Figure 4-3.

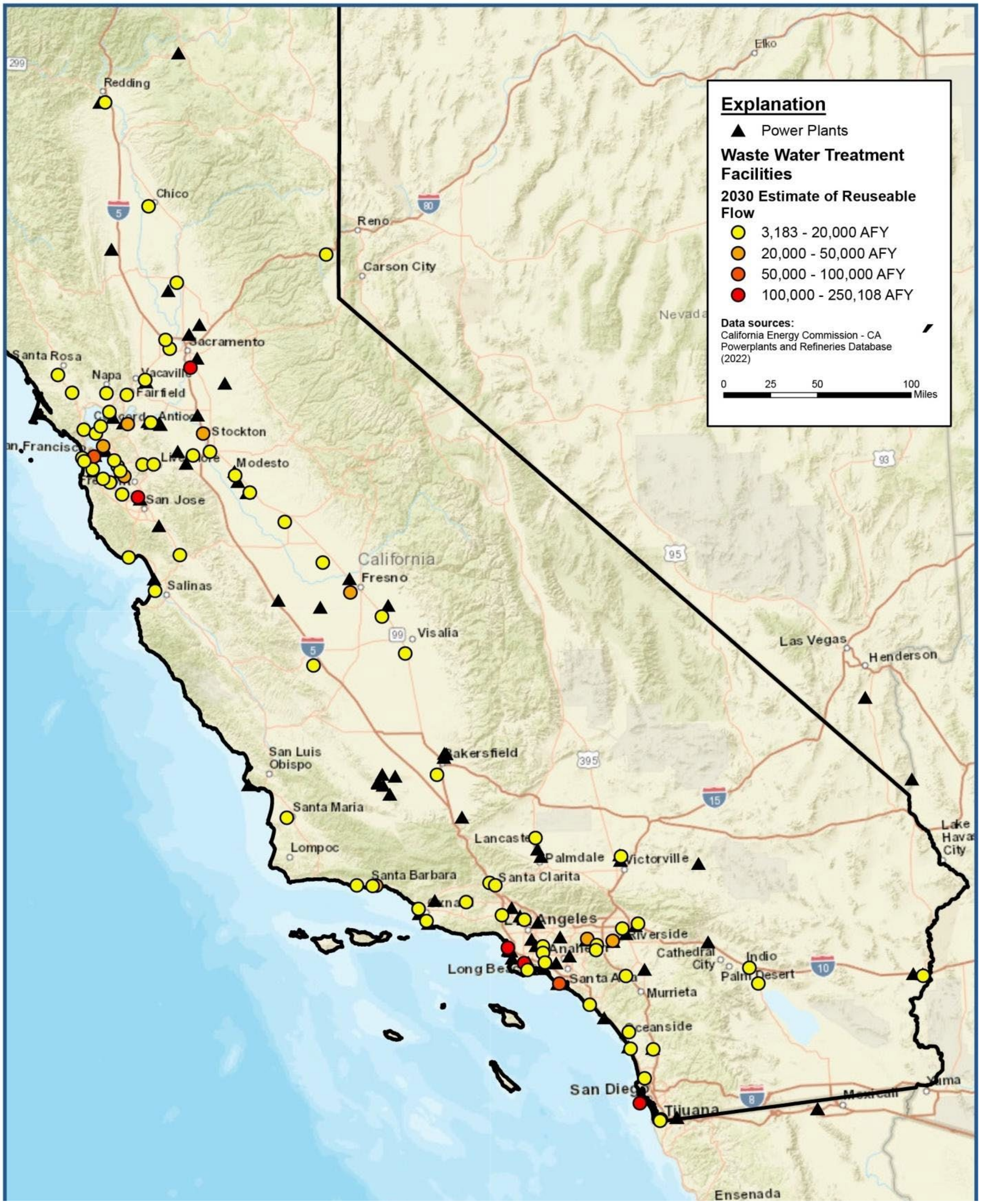


Figure 4-2. Power generation facility sites.

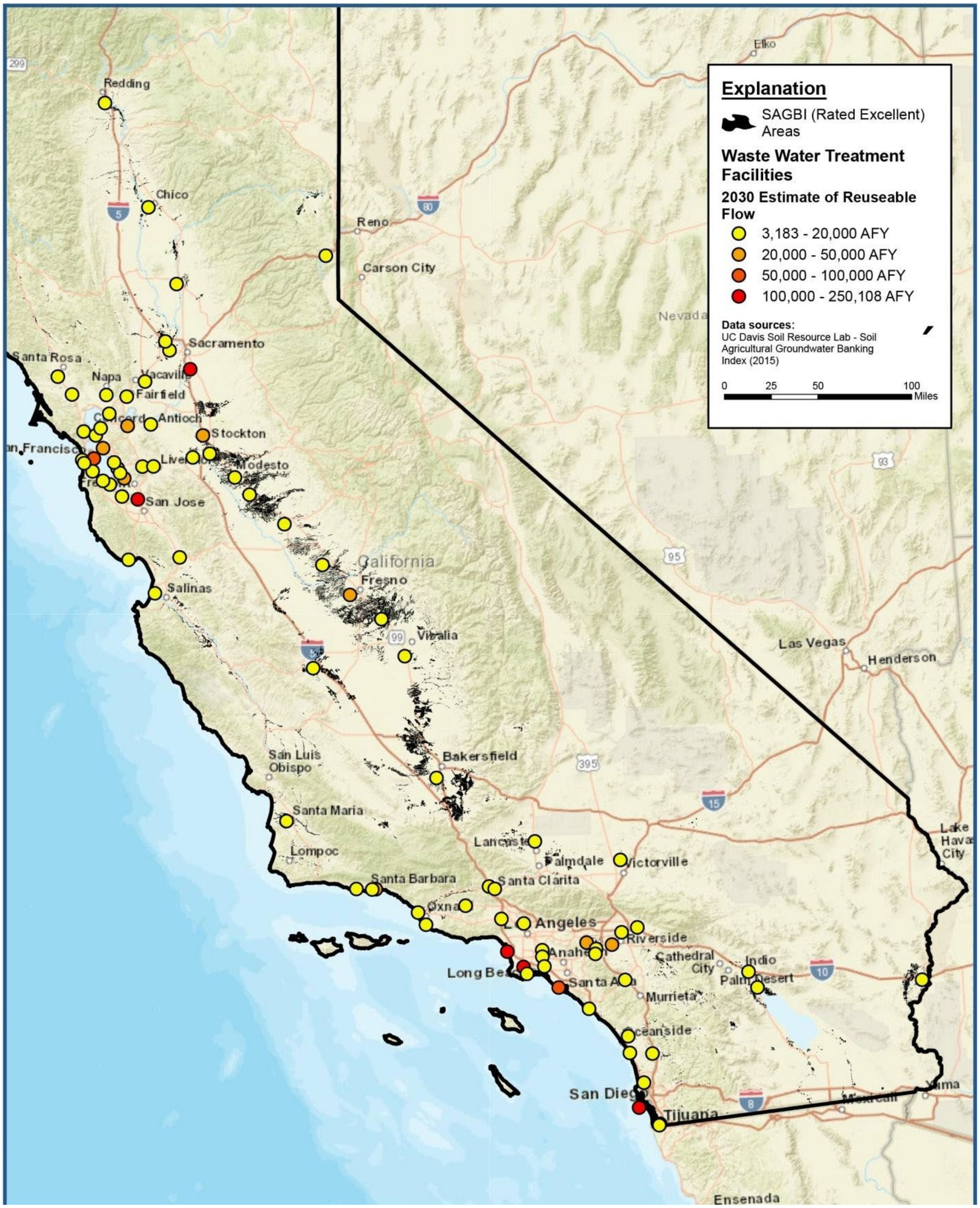


Figure 4-3. SAGBI Index for groundwater recharge by surface infiltration sites.

Table 4-4. Advantages and disadvantages of surface spreading

Data Source: Asano et al., 2007

Advantages	Disadvantages
• Relatively easy to construct and operate • In California, the only permitted IPR that can utilize tertiary treatment. • No concentrate flow generated • Among the lowest cost methods to recharge groundwater. • No injection equipment required.	• Large land area required • Limited availability of suitable sites; soil characteristics are important in site selection • Wetting and drying cycles required to maintain infiltration rates as well as vector control • Periodic bed maintenance required • Some evaporation losses from open water • Algae growth may affect clogging • Potential water rights issues. • While recycled water is highly treated, some trace constituents, e.g., PFAS, are not removed during surface spreading.

In this study WWTFs producing tertiary effluent were connected to potential groundwater recharge sites. It is a key assumption that the percolation of tertiary treated effluent through the soil results in the equivalent of advanced treatment, at much lower cost. However, it may be found that there are dissolved or colloidal constituents present in tertiary effluent that must be removed or reduced by blending with another water source prior to groundwater recharge, which will increase the total cost of the project. Tertiary effluent is known to contain various trace constituents that are challenging to remove or manage through source control, including pharmaceuticals, hormones, and PFAS. In addition, the generation of a concentrate stream, as with other potable reuse applications, is another potential concern related to increased treatment requirements due to reduced water recovery and increased total cost.

4.3 Advanced Treatment

Where advanced treatment is applied, water can be used to augment surface water reservoirs or groundwater aquifers using injection wells. As with every potential water reuse project, each of these methods requires significant exploration to evaluate feasibility and cost. Indirect potable reuse by surface spreading was discussed previously in Section 4.2 as this can be achieved using tertiary effluent.

4.3.1 Groundwater Injection Wells

Groundwater recharge by direct injection involves pumping highly treated recycled water directly into the groundwater zone. Direct injection is practiced in areas where the groundwater is deep, soils are impermeable, or when surface spreading is impractical due to land constraints. In coastal areas, direct injection can be effective in creating freshwater barriers to prevent saltwater intrusion. Advantages and disadvantages of direct injection are considered in Table 4-5.

In this study WWTFs producing tertiary effluent were connected to potential groundwater recharge sites. It is a key assumption that the percolation of tertiary treated effluent through the soil results in the equivalent of advanced treatment, at much lower cost. However, it may be found that there are dissolved or colloidal constituents present in tertiary effluent that must be removed or reduced by blending with another water source prior to groundwater recharge, which will increase the total cost of the project. Tertiary effluent is known to contain various trace constituents that are challenging to remove or manage through source control, including pharmaceuticals, hormones, and PFAS. In addition, the generation of a concentrate stream, as

with other potable reuse applications, is another potential concern related to increased treatment requirements due to reduced water recovery and increased total cost.

Table 4-5. Advantages and disadvantages of direct groundwater injection wells

Data Source: Asano et al., 2007

Advantages	Disadvantages
• Relatively small site required • May be used for both injection and extraction of recycled water • High rate of recycled water injection • Flow in well can be reversed for maintenance and redevelopment of well • Can be designed to recharge multiple aquifers	• Relatively expensive to construct • Energy intensive; high pressure pumping required for recycled water injection • Design and construction requires greater expertise than surface spreading basins • Extensive pretreatment of wastewater is necessary to prevent clogging with solids and development of microbial growth; may require a higher level of treatment than vadose zone injection wells. Note: advanced treated effluent assumed in this study. • Potential water rights issues. • Potential degradation of advanced treated water by contaminants in aquifer.

4.3.2 Reservoir Augmentation

Potential water supply reservoir sites were evaluated using National Hydrography Data, as shown on Figure 4-4. Compared with groundwater injection, surface water reservoirs may have a lower cost because they do not require the development and operation of the injection wells. However, surface storage reservoirs are often located at a higher elevation than WWTFs, which requires additional pumping to reach. Additionally, evaporative losses from the water surface could be significant, whereas evaporation is assumed to be negligible for groundwater injection. Advantages and disadvantages of reservoir augmentation are summarized in Table 4-6.

For this study, it was assumed that the reservoir needed to be located within 20 miles of the WWTF; however, the distance could be extended for larger flows or if no local sites were found. The reservoir size in acres was also considered in assigning potential volumetric flow. A reservoir loading of 100 ft/y was assumed to allow adequate dilution and blending capacity.

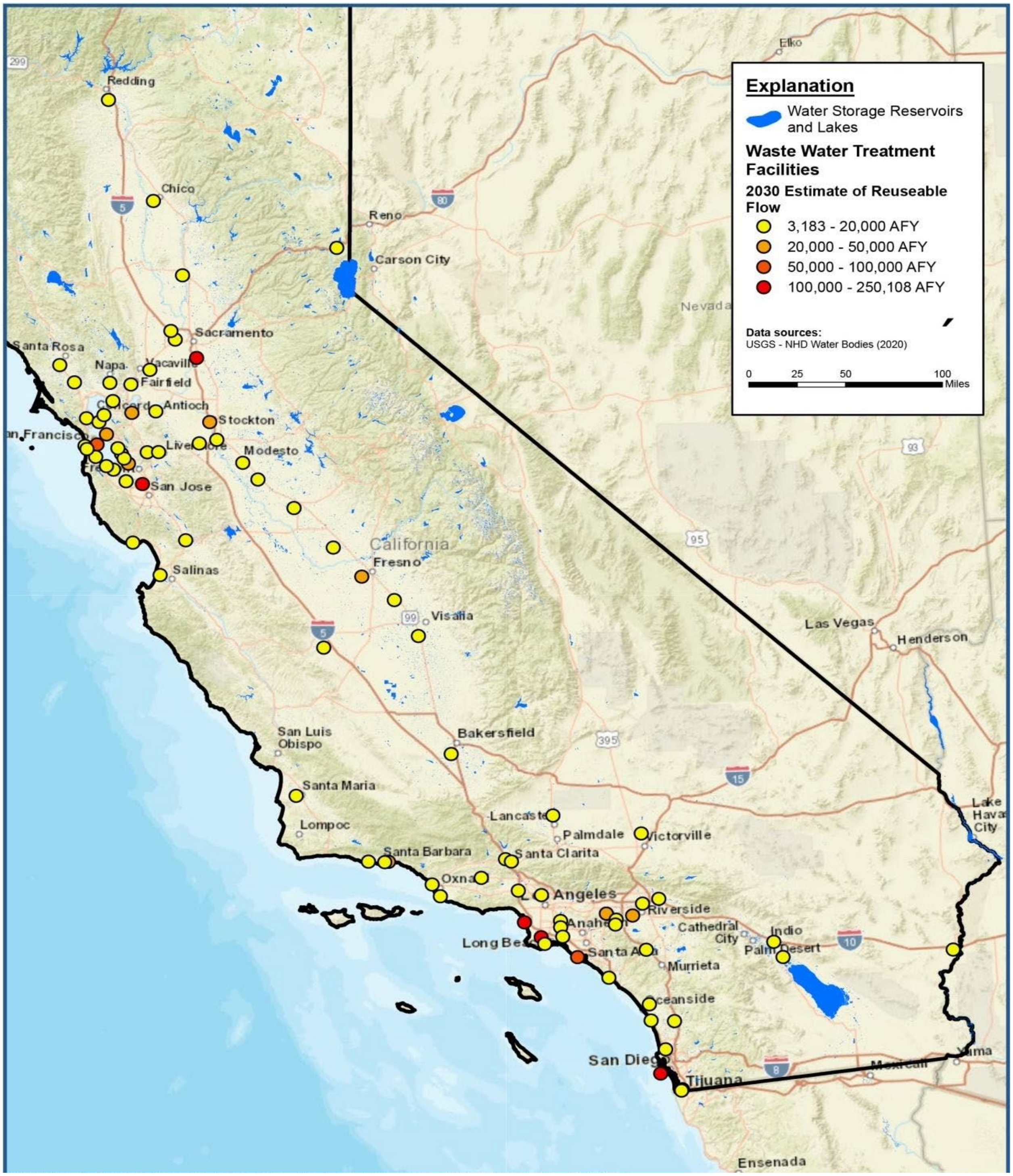


Figure 4-4. Potential reservoir locations considered for augmentation.

Table 4-6. Advantages and disadvantages of reservoir augmentation

Data Source: Asano et al., 2007

Advantages	Disadvantages
• Existing surface reservoirs are available in most locations and connected to water systems. • May be used for both input and withdrawal of recycled water • Potential large volumetric capacity • No additional equipment required at the reuse site.	• High pressure pumping may be required to reach reservoirs at high elevation • Relatively large reservoir is needed to provide dilution capacity • Hydrodynamic mixing studies needed • While secondary and tertiary effluent is suitable for unplanned potable reuse, reservoir augmentation requires advanced treatment. • Surface evaporative losses. • Potential water rights issues. • Potential degradation of advanced treated water in the environment.

For this study, it was assumed that the reservoir needed to be located within 20 miles of the WWTF; however, the distance could be extended for larger flows or if no local sites were found. The reservoir size in acres was also considered in assigning potential volumetric flow. A reservoir loading of 100 ft/y was assumed to allow adequate dilution and blending capacity.

4.4 Enhanced (Two-Stage) Advanced Treatment

The Safe Drinking Water Information System (SDWIS) database was used as the source of information for locating water treatment plant intake and blending locations, as shown on Figure 4-5. There are several advantages associated with direct potable reuse (DPR) because it does not require an environmental buffer, as discussed in Table 4-7. Reuse site selection was constrained to water systems serving sufficiently large populations. However, it is noted that the requirements for treatment, monitoring, and blending (expected by 2023) could be significant and therefore any DPR project will require careful consideration.

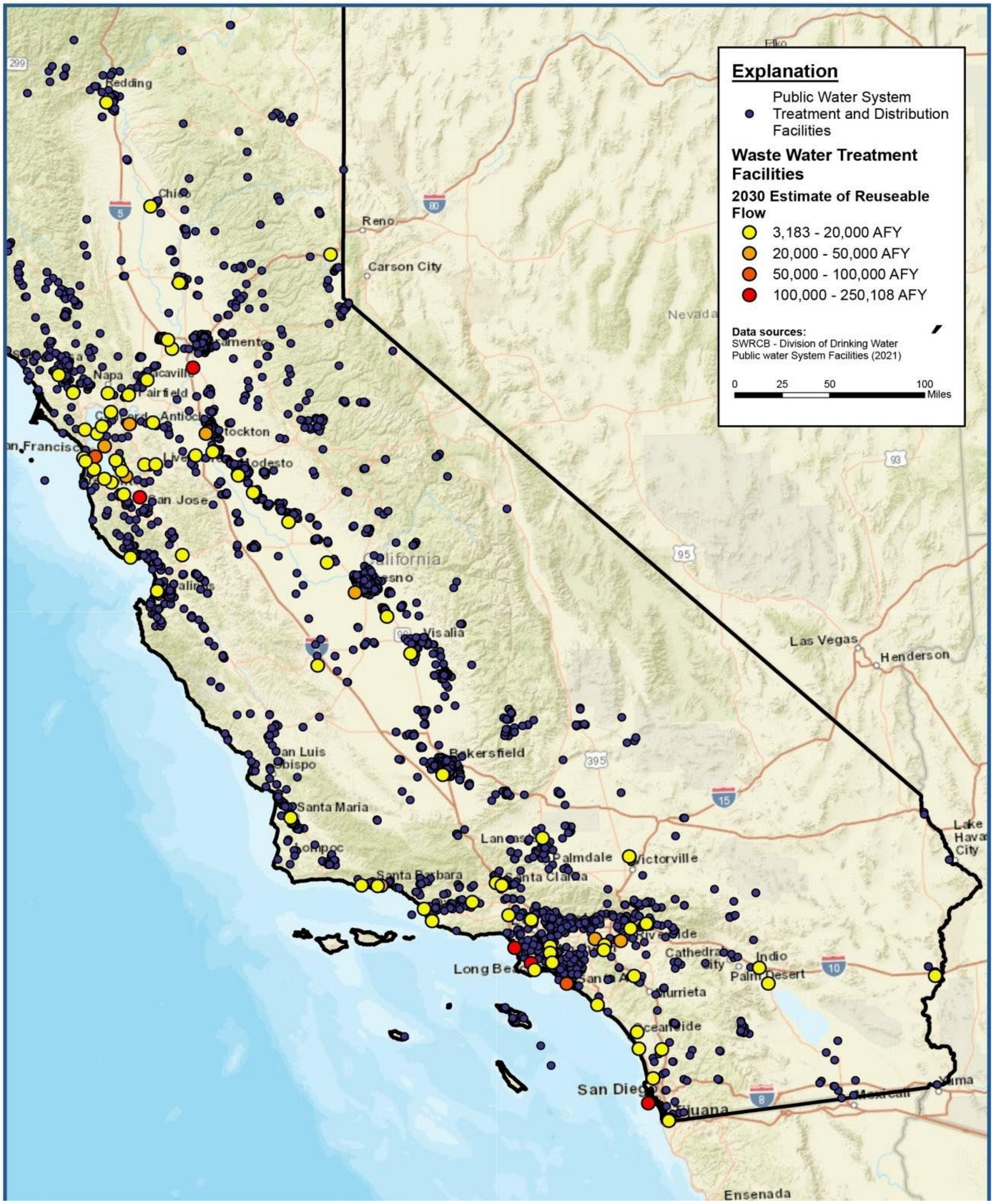


Figure 4-5. Connections to water treatment and distribution systems.

Table 4-7. Advantages and disadvantages of direct potable reuse

Data Source: Raucher and Tchobanoglous, 2014

Advantages	Disadvantages
• Most robust treatment train produces high purity water that can be safely blended with other water supplies. • Suitable for nearly any large water system; not limited by availability of environmental buffer. • Greater control over water quality compared with placement in reservoirs and aquifers. • Potential for reduced transport distance and pumping cost to reach local water treatment plant or intake structure. • May avoid some water rights issues. • Avoids need for access to – and permission for use of – reservoirs or GW aquifers (and avoid needing to construct new storage facilities, other than as desired for flow equalization).	• Treatment train required has the highest life cycle cost. • While the treatment train is extensive, there will always be real or perceived unknowns in the product water; however, the unknowns in environmental water are equivalent or greater. • Regulatory requirements are still developing. • It is anticipated that the California regulations for potable reuse will be finalized by December 2023.

4.5 Summary

In this analysis presented above, it was found that the distribution of WWTF effluent volumes and potential reuse sites are not always in close proximity. Most of the available effluent is located in areas with high population density in coastal regions and relatively smaller WWTFs located in inland areas. While secondary effluent has the lowest cost of production, the irrigation reuse sites are primarily located in inland areas. Tertiary effluent use for cooling towers is limited by the relatively small number of large cooling tower applications. Both irrigation and cooling tower use are also highly seasonal in nature which limits the total reuse potential. The potential for tertiary effluent water reuse in groundwater recharge basins is also limited by available sites in coastal regions, and more accessible in inland areas. Urban dual plumbed systems was not considered due to the high cost and site specific nature of this type of water reuse. The potential for indirect potable reuse through groundwater injection was found to be potentially feasible in all areas, but this type of water reuse requires site specific investigations that are beyond the scope of this study. Indirect reuse through reservoir augmentation is also limited by the availability of sufficiently large reservoirs that can meet the retention time restrictions put forth in the current recycled water regulations. The potential for direct potable reuse was found to be technically feasible in all areas because potable water and wastewater systems are generally located in the same areas, thus connections to potable water systems are widely available. The logistics of connecting recycled water supply with the potential reuse sites is developed in the following chapter.

CHAPTER 5

Costs for Recycled Water Transmission Pipelines and Projects

The transmission line is the pipeline that carries water from the point of production to the location where the water will be used. In this study, the transmission pipeline route and cost were determined using an ArcGIS modeling approach. The purpose of this chapter is to present an overview of the methodology and results of the transmission pipeline cost analysis. The costs of producing recycled water at the WWTF (Chapter 6) and the cost of transporting the water (this chapter) are combined for an estimate of the total project cost in Chapter 7.

5.1 Methodology

The spatially distributed expected 2030 effluent volume estimates were compared with reuse site databases described in Chap. 4 to identify preliminary linkages using ArcGIS.

5.1.1 Sources and Destinations for Least Cost Path (LCP)

The 86 WWTFs identified as having more than 4000 ac-ft/y of effluent flow projected to be available in 2030 were used as the sources for the least cost path (LCP) analysis. The probability distribution of flows considered for the WWTFs under consideration is shown on Figure 5.1. The probability distribution shown on Figure 5-1 was constructed by assigning a probability value to rank-ordered flow values (Asano et al., 2007). The interpretation of Figure 5-1 is as follows, the flow volume for 80% of WWTFs (i.e., 69 of 86 facilities total) is equal to or less than 20,000 ac-ft/y. As shown on Figure 5-1, there is a large variation in WWTF potential reuse flow volume, with flows from individual WWTFs ranging from about 3000 to 200,000 ac-ft/y. The mean and median flow value was approximately 7000 ac-ft/y.

5.1.2 Least Cost Path Analysis

The potential water reuse site targets were defined in Chapter 4. The linkage between the effluent source and reuse site was determined using the LCP of potential recycled water transmission pipelines. The LCP analyses use weighted geographic regions to select paths between WWTF effluent sources and potential reuse sites. The LCP between a source and a destination is the path such that the sum of (distance x cost per distance) of each region along the path is the lowest amount. This path does not always result in the shortest route but is expected to result in an order of magnitude approximation of potential cost and distance.

The outputs of the LCP analysis are distance between the source and destination along the derived path, and the estimate of cost to install the pipe, as well as the minimum, maximum, starting, and ending elevations (above mean sea level) of the path. In the current study, the weights are the costs per distance of installing pipelines, and the regions are based on broad land use types. Weights for more developed landscapes are increased relative to undeveloped regions. The initial weighting is overwritten by roads, with the weights (costs to install pipes) much lower along larger Rights of Way, and somewhat higher along smaller or urban Rights of Way. Costs along roads are significantly lower than costs associated with most non-road landscapes.

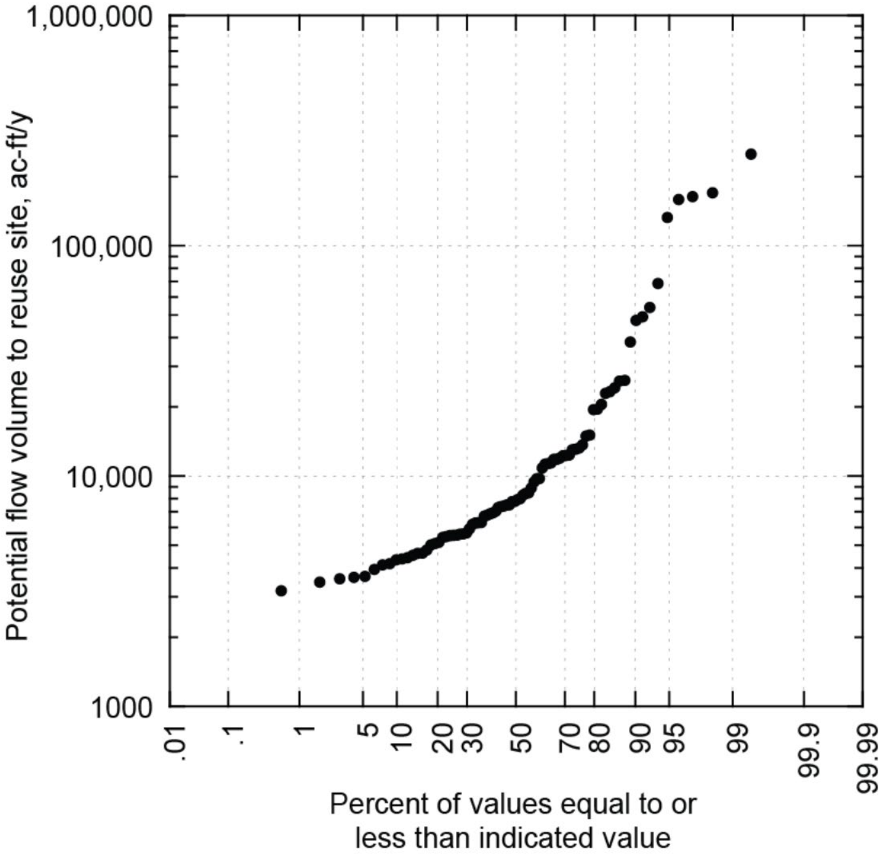


Figure 5-1. Distribution of recycled water flows from 86 facilities used as sources for LCP analysis.

5.2 Assumptions

As this analysis was applied to facilities located throughout the state, it was necessary to make a number of simplifying assumptions. As described below, these assumptions include cost estimates for the transmission pipeline installation and control parameters for the best path fit. Given the broad nature of the required simplifying assumptions, it must be understood that any results developed in this analysis are only hypothetical and based on a superficial analysis. An extensive and site-specific analysis would be required to identify water reuse alternatives that are actually viable.

5.2.1 Transmission Pipeline Capital Cost

For the purposes of sizing transmission pipelines, the relationship between the pipe diameter and flowrate through the transmission pipeline was estimated using a maximum average velocity in the pipe of 5 ft/s. The cost of the transmission pipe was scaled based on a factor of $25/inch diameter/foot length. Using these factors, the relationship between flowrate and cost per foot was developed and is shown on Figure 5-2.

5.2.2 Pumping Operations Cost

The energy required for recycled water transmission is site specific and will depend on both static and dynamic head loss during conveyance. The costs associated with the pumping of water from the WWTF to the potential site for reuse is estimated from the following equation:

$$Pumping\ cost, \frac{\$}{d} = \left(24\frac{h}{d}\right) * \frac{\left(\frac{\$0.2}{kWh}\right)(0.746\ Q{*}r{*}\ g{*}\ h)}{3960\ e} \qquad \text{(Equation 5-1)}$$

where: *C* = Cost of power, $/kWh ($0.2)
Q = Flowrate, ac-ft/d
r = Density of fluid
g = Acceleration of gravity
h= Total head loss, ft
e = Overall pump efficiency, assumed 0.8

Typical frictional loss was applied proportional to path length assuming a flow velocity of 5 ft/s.

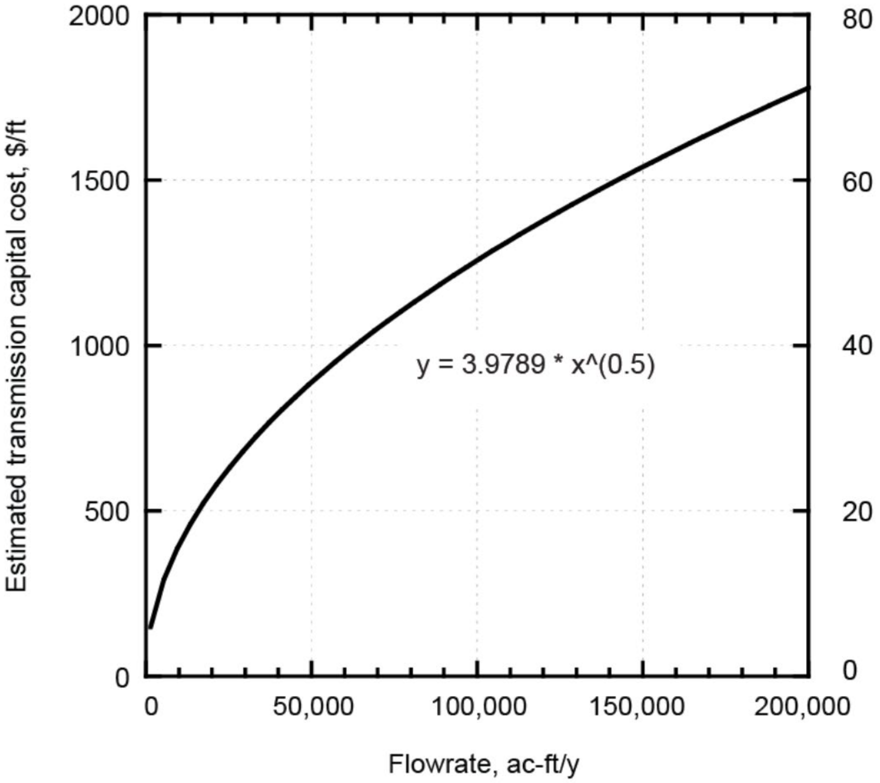


Figure 5-2. Pipeline capital cost curve used for estimating baseline capital cost for pipelines.

5.2.3 Total Transmission Cost

The total cost to deliver water from the WWTF to a potential reuse site was estimated using the equivalent annual cost (EAC) computation. The EAC for transmission of recycled water was assumed to have an interest rate of 5% and lifespan of 50 y. The total cost to install and operate the transmission pipeline infrastructure was estimated using the equivalent annual cost calculation shown on Eq. 5-2.

$$EAC = (capital\ cost)\ (capital\ recovery\ factor) + (annual\ operations\ cost) \qquad \text{(Equation 5-2)}$$

where: Capital recovery factor = $[I (I + I)^n] / [(1 + i)^n – 1]$
I = interest rate on capital, assumed to be 5%
n = lifespan, y, assumed to be 50 y

For purposes of the analysis, the EAC was then normalized by dividing by the total annual flow in ac-ft/y.

$$Normalized\ equivalent\ annual\ cost\ (NEAC) = \frac{EAC}{Q} \qquad \text{(Equation 5-3)}$$

Therefore, the final result of the total cost for installation and pumping of water is expressed in units of \$/ac-ft. The cost per ac-ft can then be added to the cost to upgrade expressed in the same units.

5.2.4 LCP Inputs

Application of the LCP methodology to locate the route and estimate the cost of delivering water to potential water reuse sites required a number of assumptions to be made. The assumptions include specification of the cell sizes and weighting factors for path selection. Input assumptions are summarized in Table 5-2 for a total installed cost basis for 6 in. pipe. The costs were scaled up for larger pipe sizes according to the curve presented on Figure 5-2.

LCP analysis raster parameters

The LCP analysis is a raster-based geoprocessing operation. The raster cell size used in this analysis was 100 ft by 100 ft. For each cell, the centroid of the cell determined the land use in that cell. The processing layers and rasters were projected into the NAD1983 Teale Albers projection designed for use throughout California, with the linear unit set to US feet.

LCP land use layers

The 2016 Land IQ land use data published by DWR was the basis for the land use assignment to cells. All land use categories in the LIQ data were grouped into one of the following classes shown in Table 5-1.

LCP analysis reuse site selection

To reduce processing times, and to eliminate unreasonable results, a search radius was developed for each WWTF beyond which reuse sites were not investigated. The distance for this selection was based on the 2030 AFY for reuse estimate. Search distance was set at a minimum of 20 miles. For larger volumetric flows, the search radius was estimated as the year 2030 flow in ac-ft/y divided by 5000. For the largest WWTF, this produced a search radius of approximately 47 miles.

Table 5-1. Summary of land use classes used in LCP modeling.

Land use class	Summary
Impassable	Water, wetlands, glaciers, etc.
Developed	Urban, industrial, commercial, high-density and medium-density residential
Perennial crops	Orchards, vineyards, and similar
Annual crops	All other non-pasture crops
Pasture	Irrigated or non-irrigated pasture
Undeveloped	All other lands

These land use classes were assigned costs based on typical land values. The 100x100 foot cells were then assigned a land use cost based on the location of the centroids of the cells. The TIGER Roads Layer published by the US Census for 2017 was the basis of the roads assessment. Each road type was assigned a cost per cell as shown in Table 5-2. These roads were then rasterized in GIS to 100x100 foot cells. The raster cells were merged with the land use rasters created from the LIQ 2016 dataset, with priority to the roads layer. Thus, in every cell, if a road is present, then the cost to travel that cell is based on the cost to travel that road, but where roads are not present, the cost is based on the land use.

Table 5-2. Summary of input parameters for LCP modeling

Land cover	Install cost factor	Install cost, $/cell	Install cost, $/mi
Primary road	1.3	42,249	2,230,765
Secondary road	1.1	35,749	1,887,570
Local neighborhood road, rural road, city street	1	32,499	1,715,973
Vehicular trail (4wd)	0.9	29,250	1,544,376
Ramp	Blocked from LCP analysis		
Service drive usually along a limited access hwy	0.9	29,250	1,544,376
Impassable	10	324,995	17,159,728
Developed	2.5	81,249	4,289,932
Perennial crops	1.75	51,187	2,702,657
Annual crops	1.2	35,099	1,853,251
Pasture	1	29,250	1,544,376
Undeveloped	1	29,250	1,544,376

5.3 Agricultural Reuse for Commercial Crop Irrigation

The DWR land use database was used to locate potential agricultural sites. Viable LCP pathways to sites for commercial crop irrigation were found for 58% of the 86 WWTFs analyzed. A summary of the agricultural LCP solutions is shown in Figure 5-3.

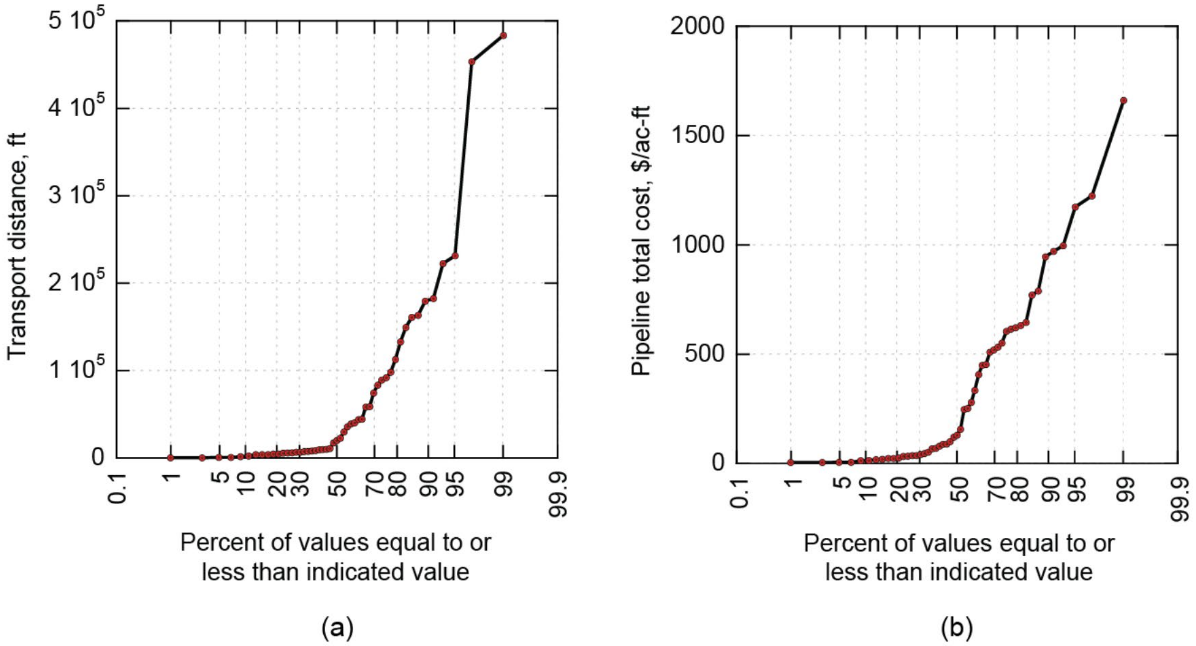


Figure 5-3. Summary of results from LCP to potential agricultural reuse sites: (a) path lengths and (b) total cost for pipeline installation.

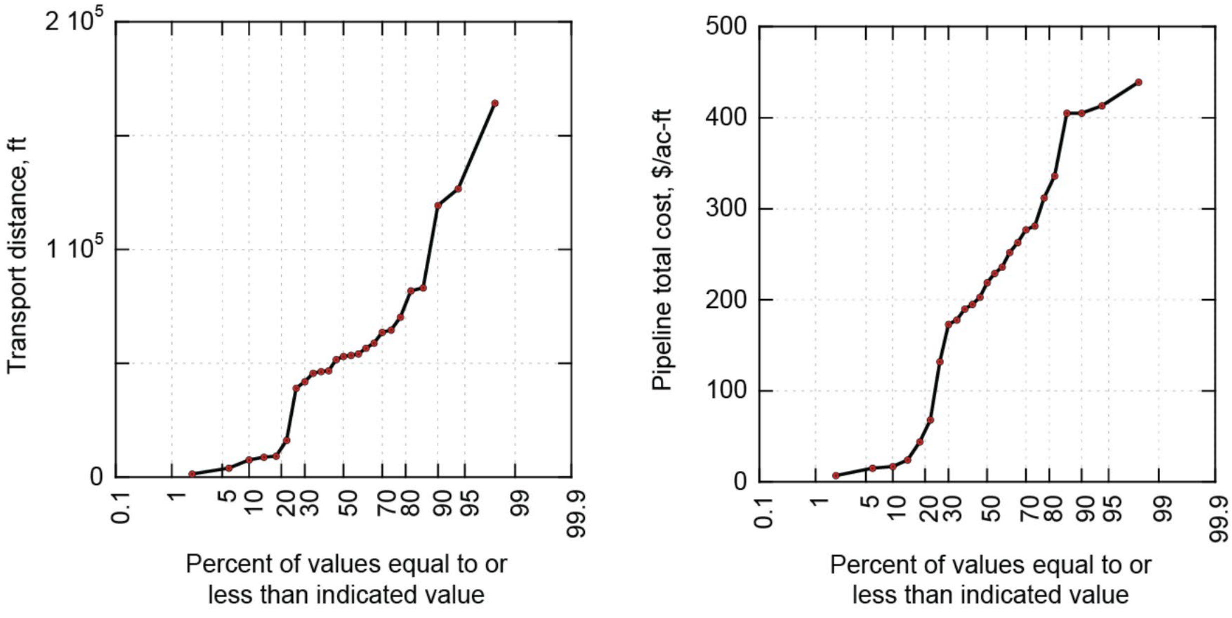
As shown on Figure 5-3, about 80% of the potential irrigation sites were located near agricultural land as indicated by the transport distance of less than about 105 ft, or slightly less than 2 mi. It was observed on the LCP paths that some urban areas were incorrectly identified as agricultural land, possibly due to the use of the 2016 database or due to errors in the LIDAR data used as the basis for the land use classification. A summary of the median cost for each WBR is presented in Table 5-3.

5.4 Cooling Towers for Power Generation

The database for power generation facilities was used to locate facilities that would have significant water needs for cooling based on generation capacity. Valid LCP pathways were found for 29% of the WWTFs considered. The distribution of transport distance and total pipeline cost is shown on Figure 5-4. The median cost and transport distance are summarized in Table 5-4.

Table 5-3. Median cost of LCP to potential agricultural reuse sites.

Region	Median transport cost, $/ac-ft	Median path length, ft
1	450	39,336
2	624	93,652
3	68	7454
4	280	83,344
5F	17	58,994
5R	229	3662
5S	50	115,468
6T	N/A	N/A
6V	407	2215
7	24	10,983
8	479	14,787
9	788	126,928



(a) (b)

Figure 5-4. Summary of results from LCP to potential power generation cooling tower reuse sites: (a) path lengths and (b) total cost for pipeline installation.

Table 5-4. Median cost of LCP to potential power generation cooling tower reuse sites.

Region	Median transport cost, $/ac-ft	Median path length, ft
1	N/A	N/A
2	173	39,128
3	405	119,407
4	190	51,704
5F	321	86,209
5R	N/A	N/A
5S	178	46,734
6T	N/A	N/A
6V	147	31,249
7	N/A	N/A
8	250	52,703
9	312	56,678

5.5 Groundwater Recharge Basins

The Soil Agricultural Groundwater Banking Index (SAGBI) was used to locate potential recharge areas. SAGBI was developed by the California Soil Resource Lab at UC Davis to evaluate the potential for recharge of groundwater for water storage. SAGBI is a spatially-distributed index derived from topographic, soil physical, and soil chemical inputs. These factors are based on the NRCS Soil Survey Geographic Database (SSURGO).

For the current analysis, the SAGBI was first processed to remove land areas that were considered not feasible, such as stream beds and high-value land uses.

- SAGBI data
- Two versions of the SAGBI exist. The first treats orchards based on the original soil service data derived from field investigations. The second treats all orchards as having been deep ripped prior to planting. For the purpose of the current analysis, the first version is used.
- Retain if rating group is excellent (SAGBI score 85.1% plus)
- Delete SAGBI sites within 1 mi. of the coast.
- Delete areas where a 0.1 mi. buffer around streams (Streams_CA_CARI_2016) overlies.
- Delete areas underlying urban or high value development.
- Retain area, attach elevation

For cost estimating purposes, the following assumptions on the implementation of spreading basins for groundwater recharge were used (Asano et al., 2007):

- Planning level recharge rate of 1 ft/d
- Blending with other water supply is not considered
- Land cost is assumed to be $10,000/ac
- Operational cost for maintaining/monitoring recharge basins is assumed to be $10,000/ac-y

- Local distribution pipes are included in the cost
- Transmission pipeline capital and operational costs were scaled from LCP results

The resulting cost curve as a function of facility size is shown on Figure 5-5. The LCP for SAGBI was initiated based on two selection criteria: search radius (SR), and recharge capacity (RC). First, the SR described in Section 5.2.2.3 was applied to each of the 86 WWTFs in turn to select potential SAGBI features. If any portion of a SAGBI feature fell within the SR, it was retained. Second, based on the recharge rate assumption above (1 ft/d), the recharge capacity of each basin was calculated. For each WWTF, the set of SAGBI features with RC greater than the 2030 WWTF effluent for reuse were selected from among those SAGBI features within the SA.
If the initial LCP attempt failed to find any SAGBI location within the SR with a high enough RC, then the RC was relaxed to RC/2. If this failed, the RC was relaxed further to RC/4. If this failed, the SR was relaxed to 2SR, and the RC set to RC/2. This resulted in finding a SAGBI site for 86% of WWTFs.

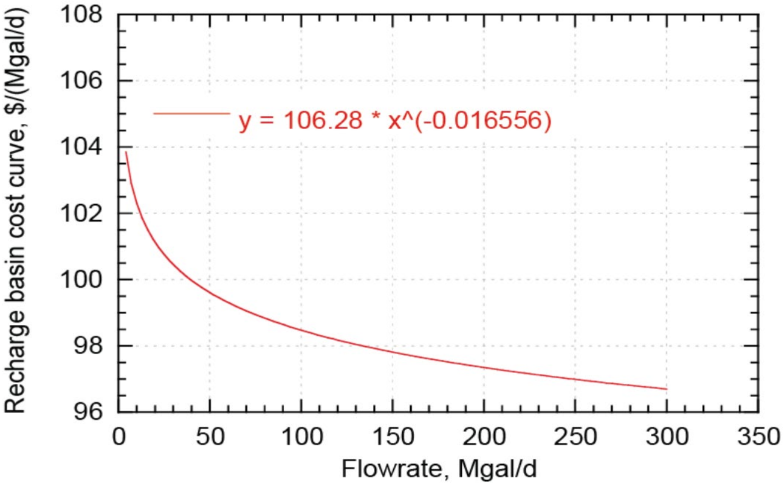


Figure 5-5. Recharge basin capital cost curve used for estimating total cost to install and operate recharge basins

The distribution of transport distance and total pipeline cost is shown on Figure 5-6. The median cost and transport distance are summarized in Table 5-5.

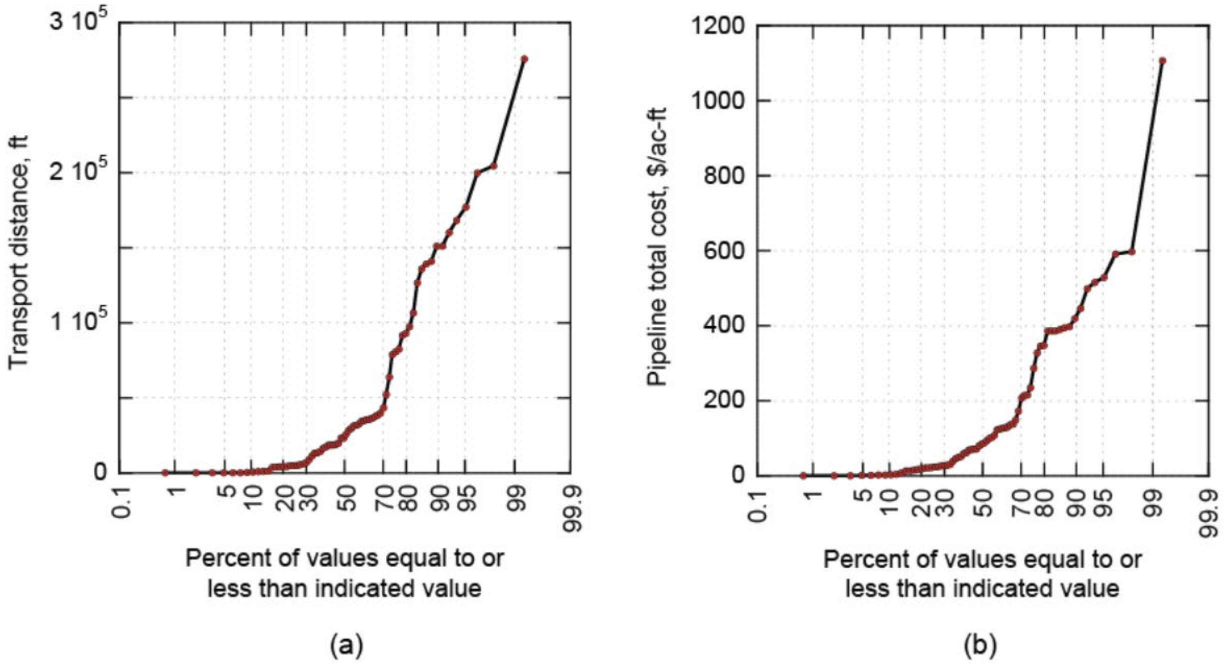


Figure 5-6. Summary of results from LCP to potential recharge basin reuse sites: (a) path lengths and (b) total cost for pipeline installation.

Table 5-5. Median cost of LCP to potential recharge basin reuse sites.

Region	Median transport cost, $/ac-ft	Median path length, ft
1	137	23,343
2	328	91,763
3	125	35,647
4	109	31,828
5F	7	1014
5R	1	468
5S	29	5678
6T	N/A	N/A
6V	77	19,670
7	14	4106
8	61	25,699
9	109	36,531

5.6 Groundwater Injection Wells

While there is some uncertainty associated with the structure of underground aquifers that are suitable for groundwater injection, as well as other unknowns, in general, aquifers are located below most areas. Therefore, for purposes of comparison, it was assumed that a recharge site was located approximately 5000 ft away from the WWTF. Additional assumptions used for developing the cost estimate are summarized below and the composite cost curve is shown on Figure 5-7.

- Distance between WWTF and injection site = 5000 ft; distance between wells = 500 ft
- Capacity of an injection well = 1.5 Mgal/d; capital cost of injection well $1M
- Operational energy was estimated from Schimoller et al. for TDH of 100 ft
- Additional operational cost per well = $0.15M/y

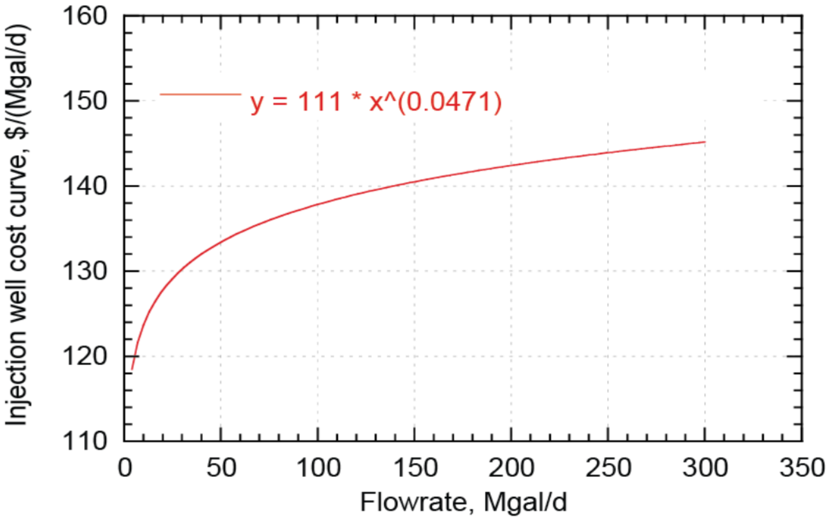


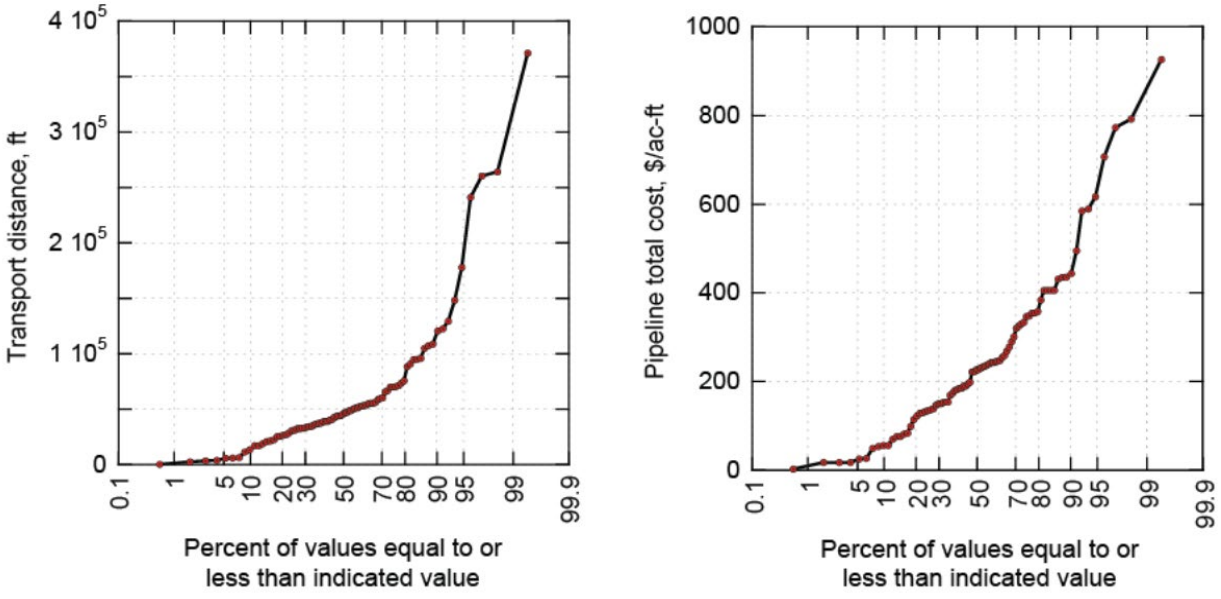
Figure 5-7. Capital cost curve used for estimating total cost to install and operate injection wells.

5.7 Reservoir Augmentation

The surface water hydrology database was used to identify potential potable water reservoirs that could be used for augmentation. Valid LCP pathways were found for all of the 86 WWTFs considered. The distribution of transport distance and total pipeline cost is shown on Figure 5-8. The median cost and transport distance are summarized in Table 5-6. While it is assumed that the reservoirs identified could meet the criteria required for surface water augmentation regulations, these types of projects would need to be approved on a case-by-case basis.

5.8 Direct Potable Reuse

The paths to potential direct potable reuse sites were approximated by finding the cost to reach the nearest water treatment plant locations. Valid LCP pathways were found for all 86 WWTFs considered. The distribution of transport distance and total pipeline cost is shown on Figure 5-9. The median cost and transport distance are summarized in Table 5-7.

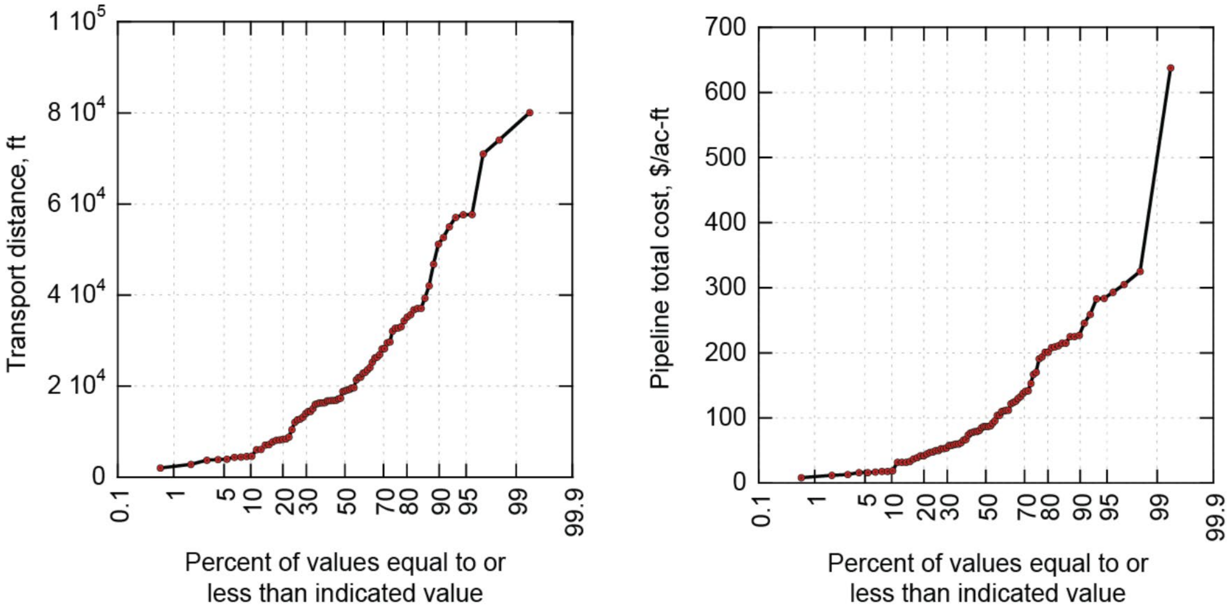


(a) (b)

Figure 5-8. Summary of results from LCP to potential reservoir augmentation sites: (a) path lengths and (b) total cost for pipeline installation.

Table 5-6. Median cost of LCP to potential reservoir augmentation reuse sites.

Region	Median transport cost, $/ac-ft	Median path length, ft
1	147	33,070
2	206	37,233
3	406	53,404
4	347	71,257
5F	245	53,205
5R	125	29,049
5S	188	49,813
6T	50	5904
6V	51	23,302
7	195	43,830
8	168	48,974
9	294	58,556



(a) (b)

Figure 5-9. Summary of results from LCP to potential direct potable reuse sites: (a) path lengths and (b) total cost for pipeline installation.

Table 5-7. Median cost of LCP to potential direct potable reuse sites.

Region	Median transport cost, $/ac-ft	Median path length, ft
1	77	15,117
2	131	27,589
3	74	16,810
4	111	17,227
5F	60	17,857
5R	80	21,307
5S	52	12,685
6T	45	4026
6V	71	19,102
7	194	50,147
8	60	20,186
9	137	26,801

5.9 Summary

A spatial modeling technique known as least cost path (LCP) analysis was presented in this chapter to determine hypothetical routing of recycled water distribution pipelines between WWTF sources and the potential reuse sites identified in Chapter 4. In this analysis it was found that the cost to deliver water to a potential reuse site is function of the surrounding land use, the required pipeline size to handle the volumetric flow, elevation changes between the source and potential reuse site. Some of the lowest delivery costs were associated with inland areas located adjacent to agricultural regions or potential surface recharge zones. It was also observed that the cost to deliver recycled water is generally higher in coastal regions for the reasons identified in the previous chapter. In all cases, it was found that there is a distribution of transport distances and pipeline cost. While the available data was used to develop the cost information presented in this chapter, it must be realized that the true cost to install distribution systems is highly site specific and can only be determined through detailed planning studies. Given this fact, the costs presented in this chapter represent the minimum baseline cost and the actual cost is likely to be significantly higher when all site specific limitations are quantified. The cost to upgrade WWTFs to supply the required water quality is developed in the following chapter.

CHAPTER 6

Cost of Treating Municipal Wastewater to Recycled Water Standards

The overall cost to implement a recycled water project includes the cost of treating effluent to the quality meeting required standards, the cost of storing and distributing the recycled water to the end use location(s), and any additional modification(s) to the current system or a new system to allow the use of recycled water at the end use site. The cost model for the treatment of municipal wastewater effluent to recycled water standards is presented in this chapter. The cost model developed in this chapter is based on the use of facility data imported from the VAR 2019 database with water quality upgrade cost calculations based on available literature. The overall cost model integrating all elements of recycled water projects is discussed in Chapter 7.

6.1 Methodology

The purpose of the cost model development is to develop order of magnitude cost projections to achieve set levels of recycled water use in California. Instead of developing a pre-design level cost estimate for an individual treatment facility with specific site conditions, the capital cost and O&M cost models available from literature were utilized to obtain estimates for water quality improvement upgrades suitable for a range of water reuse applications.

First, a generalized treatment target and representative treatment technologies to meet each treatment level were identified. Cost curves available from literature were applied to each unit process included in the specific treatment process upgrades, and the sum of capital and O&M costs for all unit processes in each treatment target were compiled to form a composite cost curve. The cost curves from literature were adjusted for the current (2021) cost using the California Construction Cost Index (dgs.ca.gov).

Additional costs required to integrate the added treatment processes with the existing facility were counted as a fixed percentage allowance. The total capital cost and annual O&M cost for each treatment process upgrade flow diagram were compiled to develop a composite annualized project cost. The project period assumed for the estimate is 30 years.

The annualized project cost was calculated by annualizing the total capital cost with a 30-year project period and an inflation rate of 5 percent and adding the annual O&M cost, divided by the annual treatment volume, expressed as dollars per acre-foot.

The cost models were applied to the 86 WWTFs in California with a treatment capacity greater than 4 Mgal/d, using the available wastewater for reuse as described in Chapter 3.

6.2 Recycled Water Treatment Requirements

The current treatment requirements to produce recycled water and the allowable water reuse applications in California are specified in Title 22. As of 2021, non-potable reuse and indirect potable reuse (IPR) are both specified in Title 22. The SWRCB is required to adopt uniform water recycling criteria for direct potable reuse (DPR) on or before December 31, 2023.

The levels of treatment for recycled water for non-potable applications are divided into the following categories:

- Undisinfected secondary
- Disinfected secondary-23
- Disinfected secondary-2.2
- Disinfected tertiary

The use of undisinfected secondary, disinfected secondary-23, and disinfected secondary-2.2 recycled water is limited to specific applications where exposure to humans is controlled according to Articles 3 and 4 of the Title 22 Water Recycling Criteria.

While the use of recycled water with secondary treatment is practiced in California, the target treatment level for non-potable water reuse applications in the cost model development was set at disinfected tertiary or higher for large treatment facilities. It was also assumed that the treatment plants to be included in the cost model have a treatment capacity equal to or greater than 4 Mgal/d, and that availability of agricultural land capable of utilizing large volumes of disinfected secondary recycled water would be limited for larger treatment facilities located in urban settings. Disinfected tertiary recycled water can be used for a wide range of recycled water end uses which will be beneficial for securing demand for a large volume of available water.

Indirect potable reuse (IPR) is defined as the planned use of recycled water to replenish drinking water supplies with a suitable environmental barrier, and as of 2022, two types of IPR projects are allowed under Title 22: Groundwater Replenishment Reuse Projects (GRRP) and Surface Water Source Augmentation Projects (SWSAP). As discussed previously, DPR, defined as the delivery of advanced treated water to a drinking water plant or a drinking water distribution system without an environmental buffer, is expected to become one of the critical water reuse applications in coming years even though it has not been implemented in California and regulations for DPR have not been adopted as of 2022.

6.2.1 Disinfected Tertiary Recycled Water

Disinfected tertiary recycled water is defined as wastewater that is oxidized, filtered, and disinfected to ensure the median concentration of total coliform bacteria as a most probable number (MPN) does not exceed 2.2 per 100 Ml in seven days, 23 per 100 Ml in more than one sample in any 30 day period, and an MPN of 240 per 100 Ml in any one sample. The typical disinfected tertiary recycled water production process involves secondary treatment to reduce organics and suspended solids (the secondary treatment process corresponds to the term “oxidized” in the treatment requirement; nutrient removal may be included if the discharge limits for nutrients are included in the permit), followed by tertiary filtration, and disinfection. Both tertiary filtration and disinfection must meet the specific treatment criteria specified in Title 22 unless the treatment facility proves that the required quality can be met by alternative treatment methods or design approach.

For tertiary filtration, the filtration rate shall not exceed 5 gal/min-ft2 at peak flow (unless otherwise proven to demonstrate the quality requirements) and turbidity in the filtered effluent may not exceed an average of 2 nephelometric turbidity units (NTU) within a 24 h period, 5 NTU for more than 5% of the time within a 24 h period, and never exceed 10 NTU. For disinfection, if chlorine disinfection is used, a CT (the product of total chlorine residual and modal contact time measured at the same point) value of not less than 450 mg·min/L at all times with a modal contact time of at least 90 minutes based on peak dry weather design flow is required. When an alternative disinfection method is used, the disinfection process must be demonstrated, in combination with the filtration process, to achieve 5-log reduction of the plaque forming units of F-specific bacteriophage MS2, or polio virus, in the wastewater. For ultraviolet (UV) disinfection, typically a dose of 100 Mj/cm2 will be required for conventional tertiary effluent, and 80 Mj/cm2 for MF/UF membrane permeate including membrane bioreactor (MBR).

6.2.2 Recycled Water Treatment Requirements for Indirect Potable Reuse

Surface application of recycled water in recharge basins is allowed for disinfected tertiary recycled water, as described above, if the recycled water receives treatment that achieves at least 12-log enteric virus reduction, 10-log Giardia cyst reduction, and 10-log Cryptosporidium oocyst reduction (see Table 6-1). A recharge basin that receives disinfected tertiary or advanced treated effluent and also demonstrates at least six months retention underground will be credited with the 10-log reduction of the protozoa. Applications with recharge basins are required to conduct additional measures to demonstrate treatment and underground retention for pathogenic microorganism removal.

For injection wells and reservoir augmentation, treatment using an RO and advanced oxidation process (AOP) is required to meet the log reduction of virus, Giardia cysts, and Cryptosporidium, as well as reduction of chemical constituents. Treatment of secondary effluent by MF/UF, RO and AOP was assumed for the cost model.

Table 6-1. Pathogen control requirements for potable reuse

Potable reuse application	Log reduction required		
	Enteric virus	Giardia cysts	Cryptosporidium oocysts
Indirect	12	10	10
Direct	20	14	15

6.2.3 Recycled Water Treatment Requirements for Direct Potable Reuse

The proposed (2021) treatment and operational requirements for DPR projects include a treatment train consisting of at least three sequential treatment processes including ozone/biological activated carbon (ozone/BAC), reverse osmosis (RO), and advanced oxidation (AOP). For microbial contaminants, the treatment process for a DPR project is proposed to achieve 20-log enteric virus, 14-log Giardia cysts, and 15-log Cryptosporidium oocyst reduction (see Table 6-1). The major differences between existing IPR requirements and the proposed DPR requirements are the level of chemical and microbial removal, and the level of reliability specified as the implementation of an operations plan, a pathogen and chemical control point monitoring and response plan, and a monitoring plan as summarized in Table 6-2. These additional requirements are proposed to alleviate the potential impact of critical failures of the treatment processes and thus address the lack of environmental buffer.

Table 6-2. Treatment train requirements for direct potable reuse

Data Source: NWRI 2021

Specification	Requirement
Number of separate unit processes for pathogen reduction	• At least 4
Number of treatment mechanisms	• At least 3
Validation of pathogen reduction	• To be validated by study • SWRCB approval of study protocol
Minimum UV dose	• 300 Mj/cm^2
Number of separate unit processes for chemical reduction	• At least 3: • Ozone/BAC (see note below) • Reverse Osmosis • Advanced Oxidation
Wastewater contribution (WWC)	• < 0.5 • Ozone/BAC required for 0.1 < WWC < 0.5 • Ozone/BAC not required for WWC < 0.1
Reduction of surrogate chemicals	• NDMA 1-log (90% reduction) • 1-4 Dioxane 0.5-log (69% reduction) • TOC < 0.5 ppm
Reverse Osmosis treatment	• Sodium chloride rejection > 99.0% minimum, 99.2% average • Permeate TOC < 0.25 mg/L • At least one form of continuous monitoring for integrity

6.3 Cost Model Assumptions

The following four treatment levels were assumed for the development of the cost models:

- Disinfected secondary 23 recycled water level (assumed for all existing secondary facilities as a baseline).
- Disinfected tertiary 2.2 (unrestricted) recycled water level for unrestricted agricultural uses, urban non-potable uses and industrial uses.
- Advanced treatment meeting indirect potable reuse requirements for indirect potable reuse with subsurface application for groundwater recharge, or surface water augmentation.
- Enhanced advanced treatment meeting direct potable reuse requirements.

The 86 treatment facilities considered were assumed to have at least secondary treatment, and the database defined the existing treatment system for each treatment facility. However, there are two treatment facilities above 4 Mgal/d capacity with primary treatment for discharge in

California as of 2022. For the purpose of cost model development, the cost of these two treatment facilities' upgrade from primary treatment to secondary treatment was not considered. A treatment facility upgrade cost model was developed for the matrix as shown below in Tables 6-3.

It was assumed that all treatment facilities considered have existing secondary treatment systems capable of producing effluent to meet disinfected secondary-23 recycled water quality with no capital improvements (see Figure 6-1).

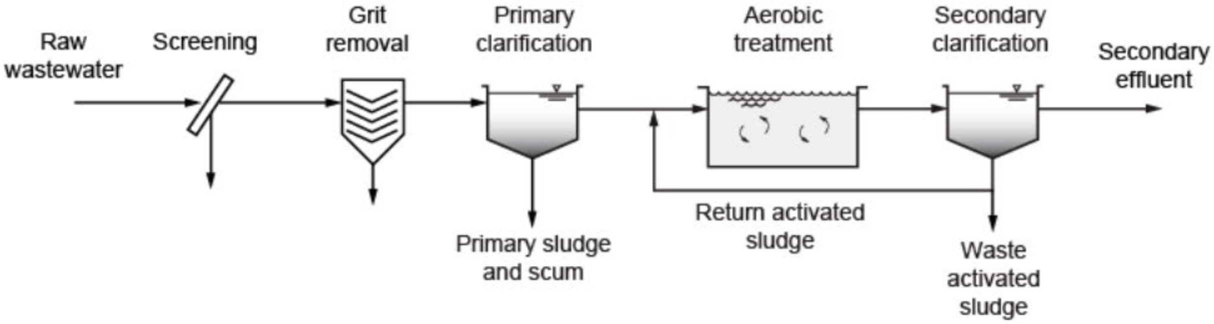


Figure 6-1. Representative secondary treatment process.
Note that disinfection is applied to secondary effluent in some cases.

Upgrades to a WWTF producing disinfected secondary effluent to produce disinfected tertiary recycled water assumed addition of tertiary filtration and enhanced disinfection processes to the existing secondary treatment process. The upgrade from a secondary treatment facility to a disinfected tertiary recycled facility could also be done by modifying the existing secondary biological process into MBR and adding disinfection tailored for the MBR effluent. For consistency in this analysis, it was assumed that all upgrades would be non-MBR. It is noted that the cost of upgrading to MBR systems would be higher and that some entities may elect to install MBR systems based on site specific considerations.

Disinfection system upgrade from the disinfected secondary-23 treatment level to disinfected tertiary-2.2 treatment level was assumed to be a complete replacement with chlorine disinfection to simplify the model, even though some of existing secondary treatment facilities use UV disinfection (see Figure 6-2). It is noted that many WWTFs in the Central Valley and elsewhere that have upgraded to tertiary have been required to move to UV to meet restrictive THM limits. Future WWTF upgrades to tertiary treatment with UV is likely to be required for effluent that is discharged to the environment.

Table 6-3. Matrix for upgrading existing facilities.

Existing facility treatment level	Required upgrade at planned end use and treatment level			
	Restricted agricultural use (disinfected secondary)	**Unrestricted non-potable (disinfected tertiary)**	**Potable (advanced treatment + environmental buffer)**	**Direct potable (enhanced advanced treatment + enhanced monitoring)**
Secondary + disinfection	No modification	Filtration + enhanced disinfection	Advanced treatment + environmental buffer	Enhanced advanced treatment + enhanced monitoring
Disinfected tertiary	No modification	No modification	Advanced treatment + environmental buffer	Enhanced advanced treatment + enhanced monitoring
Advanced treatment for IPR	No modification	No modification	No modification	Enhanced advanced treatment + enhanced monitoring
Advanced treatment for DPR	No modification	No modification	No modification	No modification

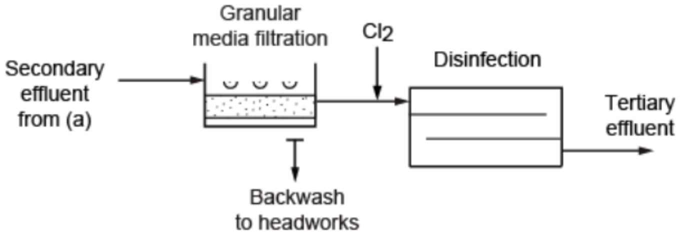


Figure 6-2. Upgrade of existing secondary facility to disinfected tertiary facility.

To upgrade secondary or tertiary facilities into IPR or DPR capable facilities, it was assumed both existing secondary treatment facilities and disinfected tertiary facilities will have the same add-on advanced treatment processes including membrane filtration with microfiltration/ultrafiltration (MF/UF), reverse osmosis (RO), and advanced oxidation (AOP) as shown on Figure 6-3.

For the DPR capable facility upgrade, the ozone/biological activated carbon (ozone/BAC) process was added in addition to all the processes included in the IPR upgrade, as shown on Figure 6-4.

For all options, in addition to the increased O&M cost due to higher level of treatment, additional O&M cost was added to comply with the Title 22 monitoring requirements. Details are discussed in the following subsections.

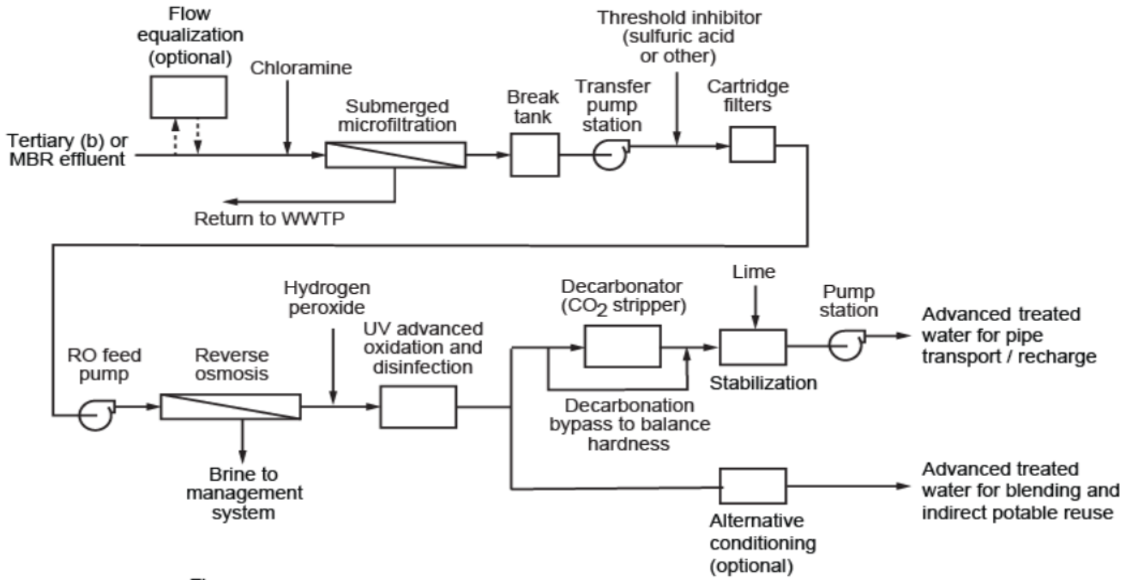


Figure 6-3. Add-on treatment processes to upgrade a secondary or tertiary facility for IPR projects

For the DPR capable facility upgrade, the ozone/biological activated carbon (ozone/BAC) process was added in addition to all the processes included in the IPR upgrade, as shown on Figure 6-4.

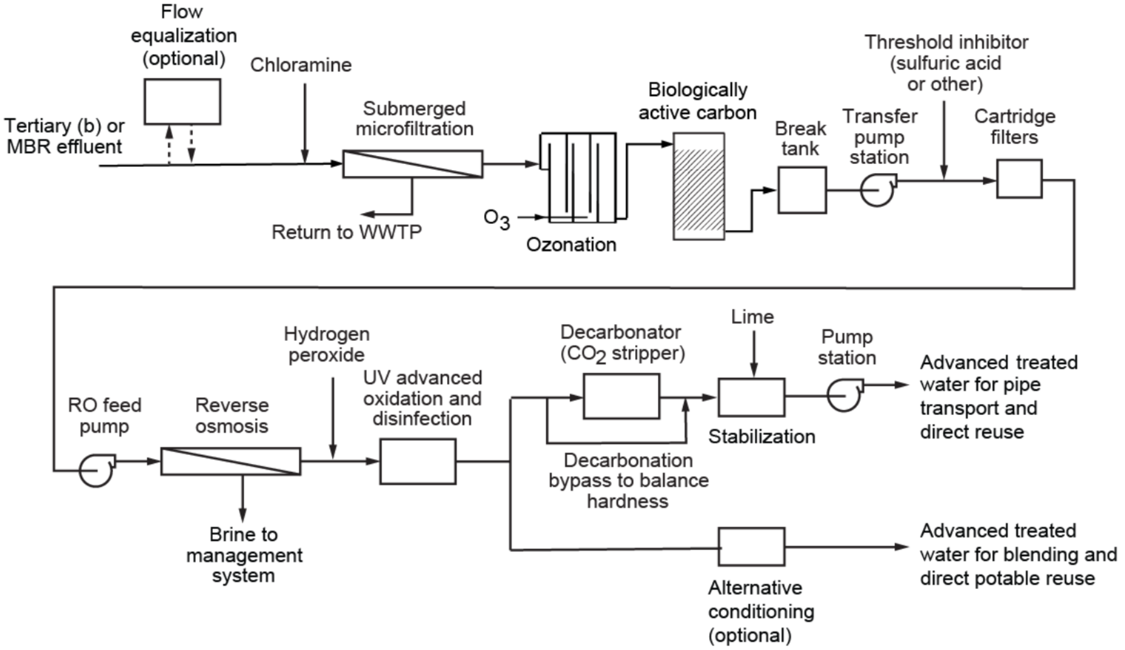


Figure 6-4. Add-on treatment to a secondary or tertiary facility for DPR projects

For all options, in addition to the increased O&M cost due to higher level of treatment, additional O&M cost was added to comply with the Title 22 monitoring requirements. Details are discussed in the following subsections.

6.4 Upgrade from Secondary Treatment to Disinfected Tertiary-2.2 Recycled Water

Treatment cost model information presented by Schimmoller and Kealy (2014) was used as a basis for the capital and O&M costs to upgrade from an existing secondary treatment plant to a disinfected tertiary WWTF. The construction cost for the tertiary treatment upgrade included equalization basins, raw water pump station, inline rapid mix, granular media tertiary filters, chlorine contactor, backwash supply pump station, chemical feed systems (ferric, polymer, chlorine), backwash waste EQ basin and pump station, and administration building (Schimmoller and Kealy, 2014). The estimated total construction costs for a range of flow rates were extracted and fit into a regression curve expressed as:

$$Construction\ Cost, \$M = 0.793 \times (process\ flowrate, Mgal/d) + 13.8$$

(Equation 6-1)

Similarly, the estimated annual O&M costs for a range of flow rates were extracted and fit into a regression curve expressed as:

$$O\&M\ Cost, \$M/y = 0.0876 \times (process\ flowrate, Mgal/d) + 0.0518$$

(Equation 6-2)

The capital and O&M costs were adjusted from the 2011 estimate year to 2021. An additional allowance of 10 percent was applied to the capital cost to account for the requirements to integrate the new disinfected tertiary treatment facility with the existing secondary facility. The estimated capital, O&M and 30-year NPV costs for the upgrade from a secondary to a disinfected tertiary system for a range of flowrate based on the cost curves are shown on Figure 6-5. As noted previously, the cost curves shown on Figures 6-5, 6-7, and 6-9 were developed for WWTFs with treatment capacity greater than 4 Mgal/d.

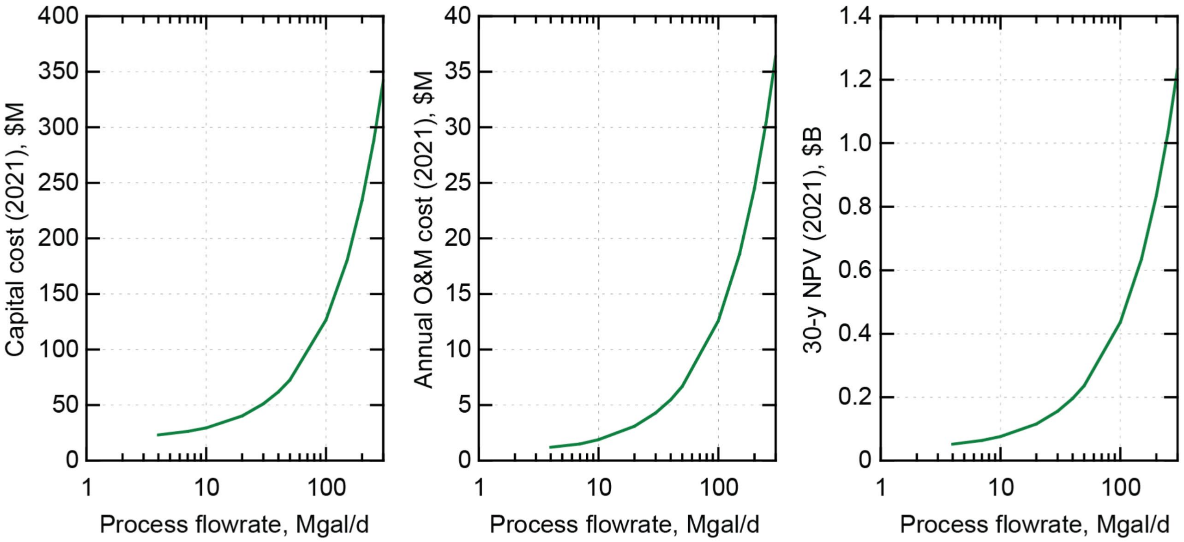


Figure 6-5. Cost for upgrade from conventional secondary treatment to disinfected tertiary recycled water treatment: (a) capital, (b) annual O&M, and (c) 30-y NPV.

The 30-year NPV values are then normalized to the annualized project cost per unit volume of water treated (in acre-foot). The resulting cost curve for the upgrade to meet treatment requirements for disinfected tertiary recycled water was expressed as:

$$Annualized\ project\ cost, \$/ac - ft\ =\ 751\ \times\ (process\ flowrate, Mgal/d) - 0.235$$

(Equation 6-3)

The cost curve for the plant upgrade for the disinfected tertiary treatment level is shown on Figure 6-6.

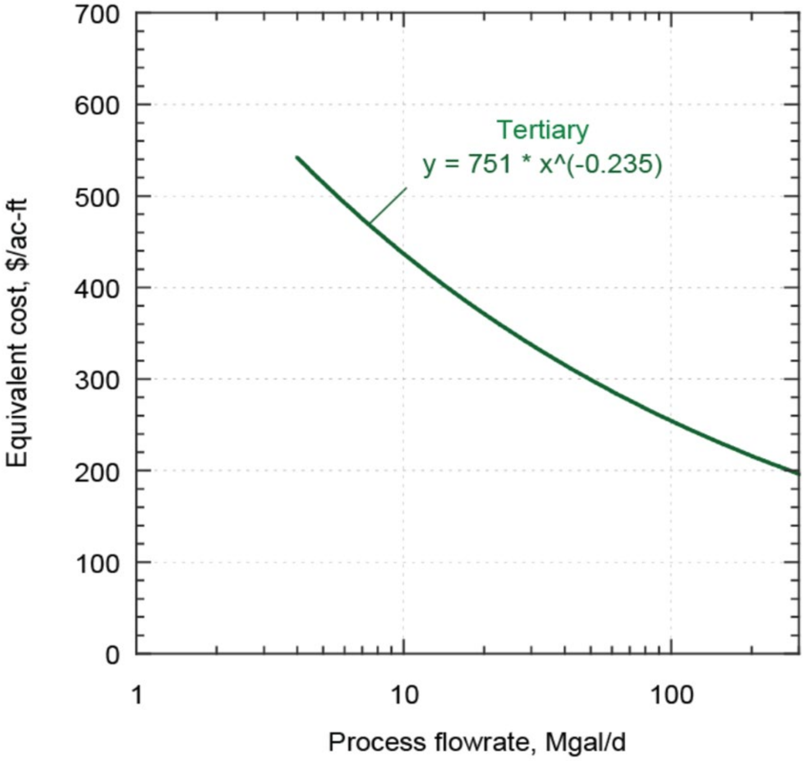


Figure 6-6. Upgrade cost curve for the production of disinfected tertiary recycled water from conventional secondary effluent.

6.5 Upgrade from Secondary/Tertiary Treatment to Advanced Treatment for Indirect Potable Reuse

The conceptual-level cost curve developed by Plumlee et al. (2014) was used as a basis for the capital and O&M costs for the treatment processes used for IPR applications using advanced treated water. The cost associated with securing an environmental buffer is accounted for separately, depending on the location of the facility. The conceptual-level cost curves for MF/UF, RO, and AOP processes were estimated with the following equations (Plumlee et al 2014):

MF/UF:

$$Capital\ cost, \$M/(Mgal/d)\ =\ 3.57\ \times\ (process\ flowrate, Mgal/d) - 0.22$$

(Equation 6-4)

RO:

$$Capital\ cost, \$M/(Mgal/d) = 7.14 \times (process\ flowrate, Mgal/d) - 0.22$$

(Equation 6-5)

AOP (assume UV/H_2O_2):

$$Capital\ cost, \$M/(Mgal/d) = 0.474\ x\ (process\ flowrate, Mgal/d) - 0.056$$

(Equation 6-6)

The sum of construction cost from these equations was then adjusted for the current (2021) cost. To account for the cost associated with the integration with the existing facility, a 10 percent additional cost was added to the total construction cost. O&M cost curves for the MF/UF, RO and AOP as developed by Plumlee et al (2014) are as follows:

MF/UF:

$$O\&M\ cost, \$M/(Mgal/d)/y = 0.30\ (process\ flowrate, Mg \times gal/d) - 0.22$$

(Equation 6-7)

RO:

$$O\&M\ cost, \$M/(Mgal/d)/y = 0.44 \times (process\ flowrate, Mgal/d) - 0.13$$

(Equation 6-8)

AOP (assume UV/H_2O_2):

$$O\&M\ cost, \$M/(Mgal/d)/y = 0.038 \times (process\ flowrate, Mgal/d) - 0.052$$

(Equation 6-9)

The O&M cost year was adjusted from 2011 to 2021 using the ENR cost index. The resulting capital, O&M and 30-year NPV costs for the IPR upgrade are shown on Figure 6-7.

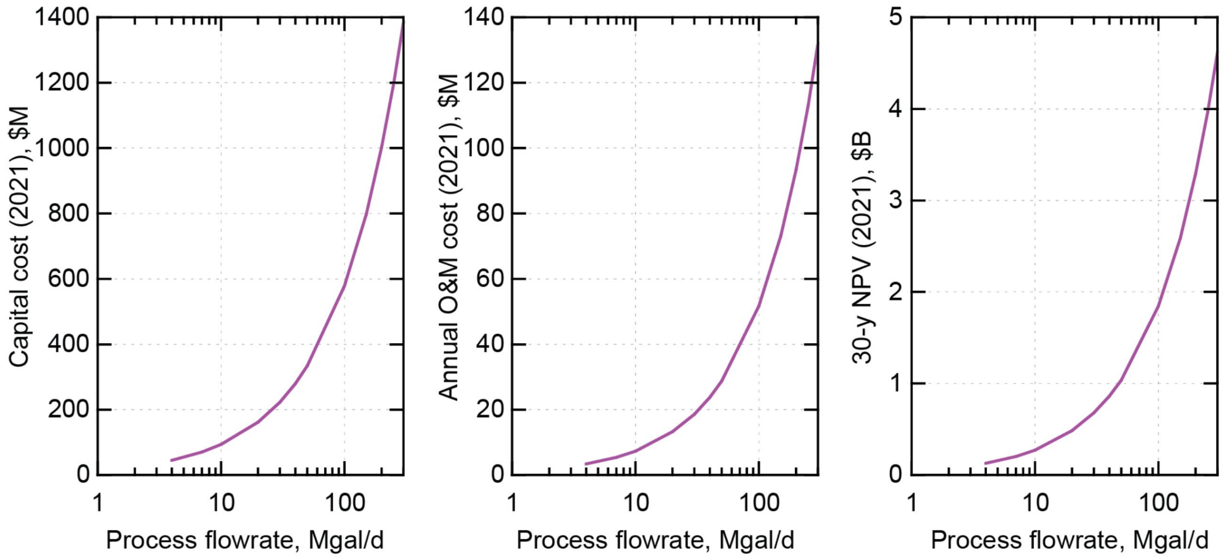


Figure 6-7. Cost for upgrade from secondary or tertiary treatment to advanced treatment for IPR applications: (a) capital, (b) annual O&M, and (c) 30-y NPV.

The resulting 30-year cost curve for the upgrade to meet treatment requirements for IPR projects is then normalized for the annualized project cost per unit volume of water (acre-foot), and expressed as:

$$Annualized\ project\ cost, \$/ac - ft\ =\ 2033\ \times (process\ flowrate, Mgal/d) - 0.173$$
(Eq. 6-10)

The cost curve for the plant upgrade for the IPR treatment level is shown on Figure 6-8.

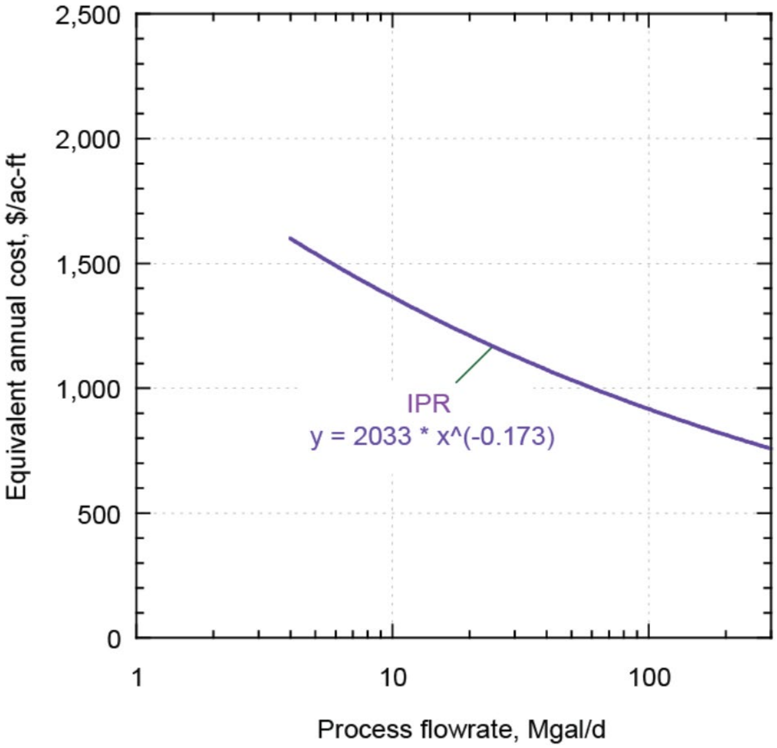


Figure 6-8. Upgrade cost for IPR Projects with MF/UF, RO, and AOP.

6.6 Enhanced Advanced Treatment for DPR Projects with MF/UF, Ozone/BAC, RO, and AOP

The assumed treatment process train for the DPR project includes the existing secondary treatment followed by an advanced water treatment facility including MF/UF, ozone/biological activated carbon (ozone/BAC), RO, and AOP. All the construction and O&M costs associated with MF/UF, RO and AOP developed for the IPR application apply to the DPR. In addition, the costs associated with the ozone/BAC process are added. The conceptual-level cost curves developed by Plumlee et al (2014) were used to estimate the total construction cost for the DPR project. An additional 10% was added to the total cost to account for the work necessary for the integration with the existing secondary/tertiary WWTF.

Ozone treatment

$$Capital\ cost, \frac{\$M}{\frac{Mgal}{d}} =\ 2.26 \times (process\ flowrate, Mgal/d) - 0.54$$
(Equation 6-11)

Biological activated carbon (20 min EBCT)

$$Capital\ cost, \$M/(Mgal/d) = 3.03 \times (process\ flowrate, Mgal/d) - 0.48$$

(Equation 6-12)

The sum of construction cost from these equations was then adjusted for the current (2021) cost. The O&M cost year was adjusted from 2011 to 2021 using the ENR cost index. For the O&M cost curve, the equations developed by Plumlee et al (2014) are as follows:

Ozone treatment

$$O\&M\ cost, \$M/(Mgal/d)/year = 0.0068 \times (process\ flowrate, Mgal/d) - 0.051$$

(Equation 6-13)

Biological activated carbon (20min EBCT)

$$O\&M\ cost, \$M/(Mgal/d)/year = 0.085 \times (process\ flowrate, Mgal/d) - 0.16$$

(Equation 6-14)

Adding these costs to the IPR costs, the capital, O&M and 30-year NPV cost estimates for enhanced advanced treatment for DPR were generated for a range of flows as shown on Figure 6-9.

The 30-year NPV cost curve for the upgrade to meet treatment requirements for DPR projects is then normalized for an annualized project cost per unit volume of water (ac-ft). The resulting cost curve is expressed as:

$$Annualized\ project\ cost, \$/ac - ft = 2459 \times (process\ flowrate, Mgal/d) - 0.170$$

(Equation 6-15)

The cost curve for enhanced advanced treatment for DPR is shown on Figure 6-10.

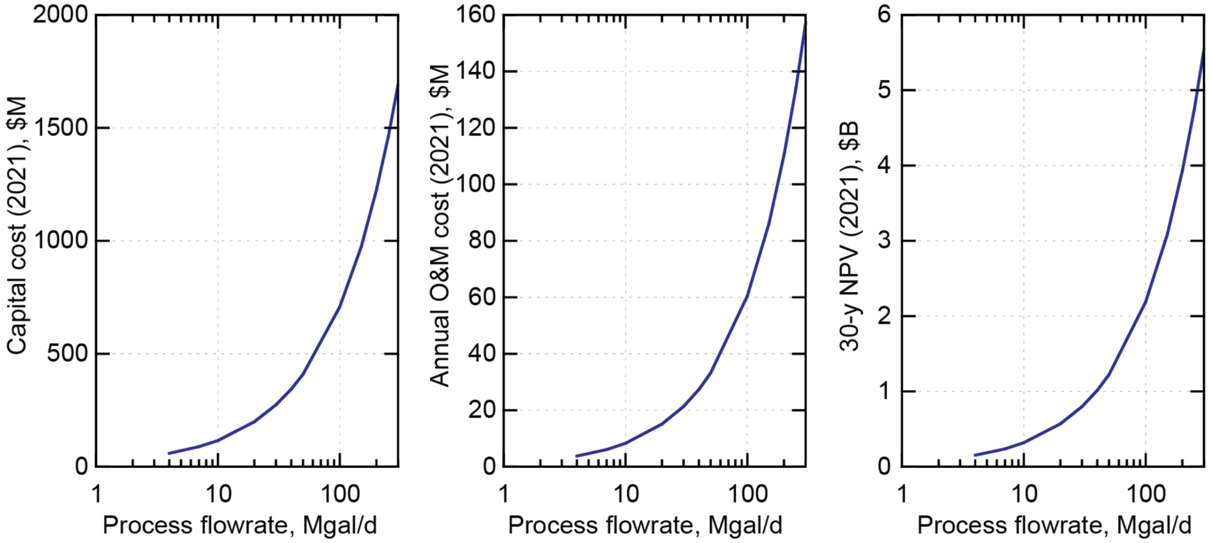


Figure 6-9. Cost for upgrade from secondary or tertiary treatment to enhanced advanced treatment for DPR applications: (a) capital, (b) annual O&M, and (c) 30-y NPV.

The 30-year NPV cost curve for the upgrade to meet treatment requirements for DPR projects is then normalized for an annualized project cost per unit volume of water (ac-ft). The resulting cost curve is expressed as:

$$Annualized\ project\ cost, \$/ac-ft\ =\ 2459 \times (process\ flowrate, Mgal/d) - 0.170$$

(Equation 6-16)

The cost curve for enhanced advanced treatment for DPR is shown on Figure 6-10.

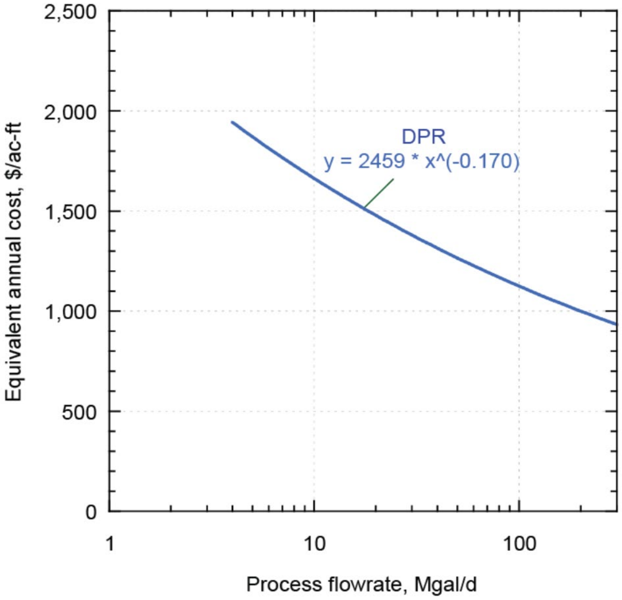


Figure 6-10. Upgrade cost for DPR projects with MF/UF, ozone/BAC, RO, and AOP.

6.7 Application of Cost Model to California Wastewater Treatment Plants

Capital, O&M and 30-year NPV costs for the disinfected tertiary, advanced treatment for IPR, and enhanced advanced treatment for DPR upgrades for a range of flowrates based on the cost curves described in this section are shown on Figure 6-11.

The annualized project costs (O&M plus capital recovery) for the disinfected tertiary, IPR, and DPR for a range of flowrates are summarized in Table 6-4. The cost curves were then applied to the available effluent flows developed in Chapter 3 and distributed among the Water Board Regions (WBR). The values presented in Table 6-5 represent the annualized cost of treating all available secondary effluent into the quality appropriate for the respective water reuse applications in each WBR. For some WBRs, all the treatment facilities with flows larger than 4 Mgal/d are already treating all flows up to the Title 22 disinfected tertiary level. For these regions, the annualized cost for the upgrade to disinfected tertiary level was not included.

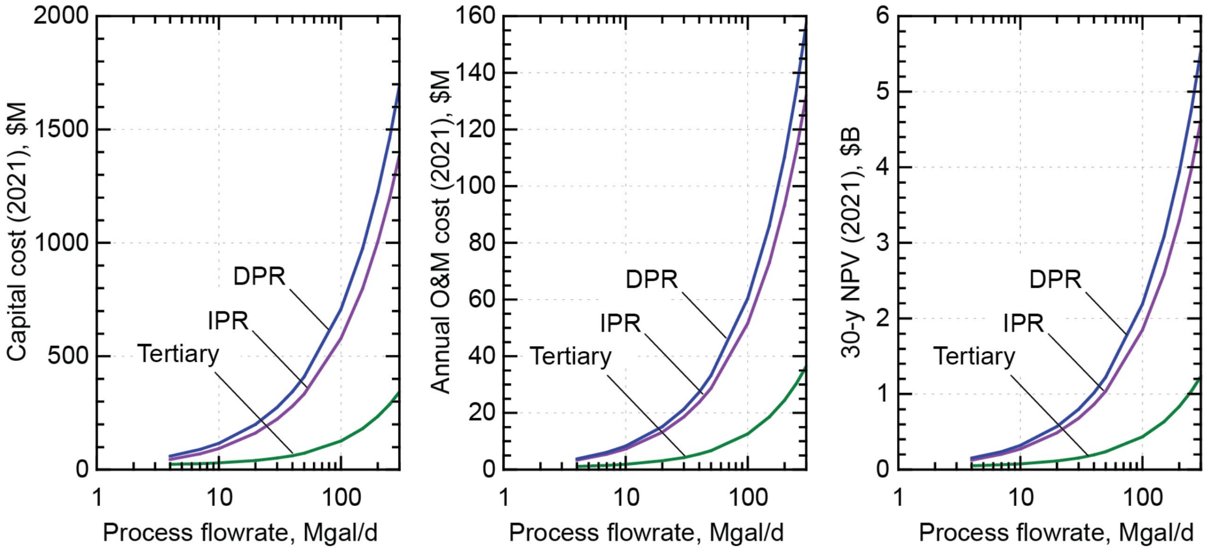


Figure 6-11. Comparison of conceptual level cost curves: (a) capital, (b) annual O&M, and (c) 30-y NPV.

Table 6-4. Estimated annualized project cost per acre foot for various treatment process upgrades as a function of treatment capacity

Flow, Mgal/d	Cost, $/ac-ft		
	Secondary to disinfected tertiary 2.2	Secondary/tertiary to IPR	Secondary/tertiary to DPR
4	718	1616	2003
7	505	1455	1768
10	420	1364	1653
20	321	1205	1460
30	288	1123	1362
40	271	1068	1298
50	261	1028	1251
100	241	914	1120
150	235	855	1051
200	231	815	1006
250	229	786	973
300	228	763	946

Table 6-5. Summary of annualized project total cost for wastewater recycle with tertiary treatment, advanced treatment for IPR, and enhanced advanced treatment for DPR from the 86 WWTFs with influent flowrate greater than 4 Mgal/d.

	Wastewater volume processed, Mgal/d	Annualized project cost to upgrade WWTFs to indicated level, $M/y		
WBR		**Tertiary**	**IPR**	**DPR**
1	4376	-	7	8.5
2	487,570	83.5	545.1	666.2
3	72,376	22	97.8	119.2
4	530,346	93.6	483.7	595.6
5F	94,695	12	117.3	143.1
5R	11,443	3.8	17.5	21.3
5S	206,193	33.2	219.8	268.9
6T	4334	-	7	8.4
6V	13,896	-	20.3	24.8
7	17,715	5.8	26.8	32.6
8	143,028	16.8	167.1	204.2
9	247,670	56.6	250.3	306.4
Total	1,940,435	327.3	1959.7	2399.2

6.8 Concentrate Management

As discussed in Chapter 3, diversion of effluent from coastal discharge is of greatest interest as waters discharged into sea water will not be utilized for beneficial purposes whereas discharge to inland surface waters may still be reused indirectly through unplanned reuse. Where a potable reuse treatment train includes reverse osmosis, the facilities with effluent discharge into inland surface water will face additional challenges, because RO treatment generates high TDS concentrate that must be disposed of properly. Concentrate management options for inland treatment facilities may include deep well injection, transportation and disposal through a coastal outfall, and zero liquid discharge (ZLD). Any of these concentrate management options could add prohibitively high costs in addition to the cost of treatment and distribution of the product water.

In the case of coastal discharge, even though increasing awareness of potential environmental impacts from the constituents in the RO concentrate may lead to more stringent concentrate discharge limits, for now the expectation is that concentrate discharge in coastal areas will be more manageable than in inland areas. The relative cost for alternative concentrate management options is summarized in Table 6-6. Because the costs associated with concentrate management are highly site specific, they were not included in the cost estimates presented in this study.

Table 6-6. Estimated cost of concentrate management

Data Source: Raucher and Tchobanoglous, 2014

Option	Cost, $/ac-ft	
	Range	Typical
Deep well injection	60-80	70
Evaporation ponds	140-175	155
Land application	130-160	140
Zero liquid discharge	600-750	700
Ocean disposal	100 – 150	115

6.9 Summary

The cost to upgrade WWTFs to produce higher levels of effluent quality presented in this chapter was based on and scaled from literature references. The costs considered included the cost to upgrade from secondary to tertiary treatment, tertiary to advanced treatment for indirect potable reuse, and tertiary to two-stage advanced treatment for direct potable reuse. The costs were further processed to estimate the total annualized costs that incorporates both the cost of capital improvements and operations. As with the transport costs presented in the preceding chapter, it was found that there is a distribution of costs that are a function of facility size and current level of applied treatment. Due to economy of scale considerations, the relative baseline cost to produce recycled water at a small WWTF is increased be a factor of 2 to 3 compared with a large WWTF. As expected, the treatment costs escalate rapidly to achieve advanced treatment, estimated to range from $1000 to 2000 per ac-ft. The cost to manage concentrate flows from membrane processes, which are an integral part of advanced treatment systems, were not included in this analysis due to the site-specific nature of managing this waste stream. Depending on the options available, the concentrate flows management could be a significant factor contributing to the total cost of advanced treatment facilities.

CHAPTER 7

Estimated Cost for Water Reuse Projects

In Chapter 5, cost curves and routing paths were developed for the installation of recycled water pipelines and required equipment/facilities (i.e., injection wells or recharge basins) to interconnect selected WWTFs with the potential reuse sites identified in Chapter 4. In Chapter 6, cost curves were developed for upgrading WWTFs to achieve higher levels of water quality. The costs for WWTF upgrades, pipelines, and required reuse equipment/facilities were then estimated for each of the 86 locations being considered for each reuse application, as summarized in the following sections.

When reviewing the cost estimates presented in this section it is important to consider the following:

- The basis for the cost estimates includes the cost to upgrade and operate the WWTF from the present to required treatment level, the cost to install and operate the recycled water transmission pipeline, and the cost to install and operate required reuse facilities, as needed.
- Concentrate management costs are not included but could potentially vary from $60 to 750 /ac-ft based on 2014 estimates.
- The estimated costs are based on 2021 market conditions and do not reflect possible subsequent hyper-escalation of cost.
- Region-specific cost correction factors have not been applied.
- Site-specific factors that impact cost have not been included in this analysis; therefore the costs represent the minimum estimated cost for any given project.

7.1 Distribution of Cost Data

The total cost data from each of the 86 sites is shown on a probability distribution on Figure 7-1. It is important to note that not all potential sources of recycled water had a model solution for each type of reuse. While all 86 facilities had model solutions for direct potable reuse, reservoir augmentation, and injection wells, only 51 of the 86 sites had solutions for agricultural reuse, 74 of 86 sites had solutions for recharge basins, and 25 of 86 sites had solutions for power plant cooling towers.

As shown on Figure 7-1, the costs for the recharge basins and agricultural sites are generally lower than the corresponding costs for injection wells, reservoir augmentation, and direct reuse sites because of the higher cost associated with advanced treatment. The path length to reach agricultural and recharge basin sites are highly variable and these sites are generally located at greater distances from the respective WWTF. In the modeling, it was found that most WWTFs are generally located close to potential WTP connection locations, and it was assumed that injection wells could be sited within a short distance of the WWTF. It is apparent from Figure 7-1 that the costs for water reuse at different facilities have a distribution. In this study, the costs varied as a function of facility capacity and travel distance to reach a site for water reuse.

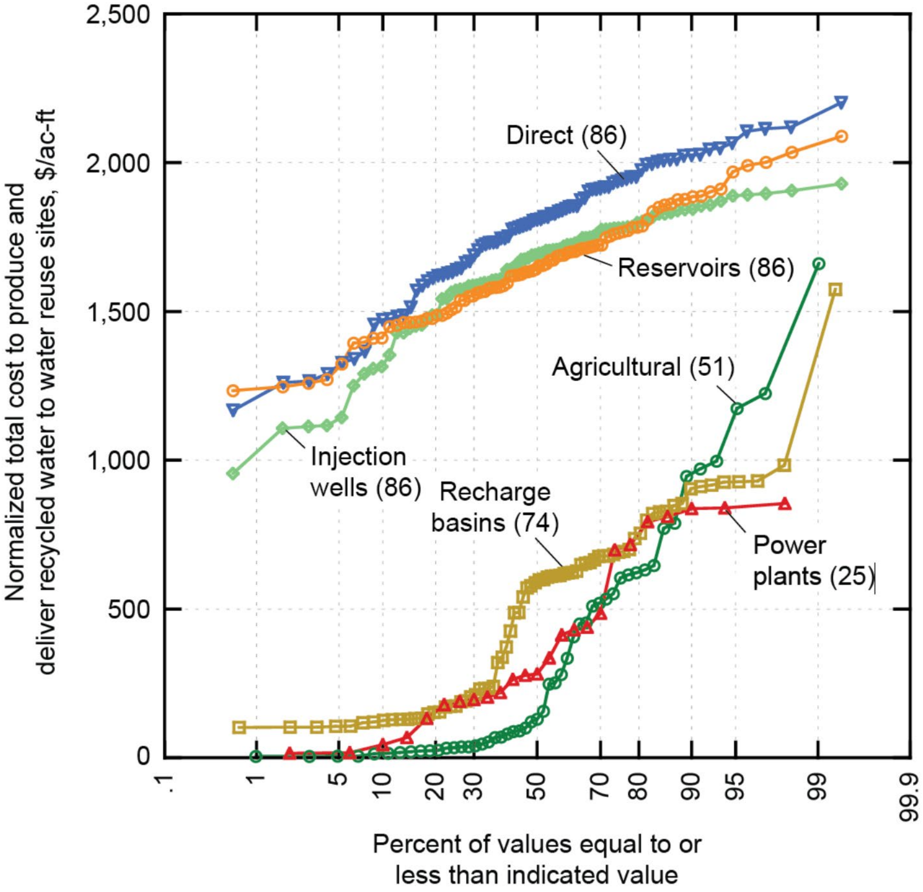


Figure 7-1. Summary of normalized total cost for various water reuse projects at 86 WWTFs with largest available effluent flows.

The number of WWTFs associated with each potential reuse option are given in parentheses.

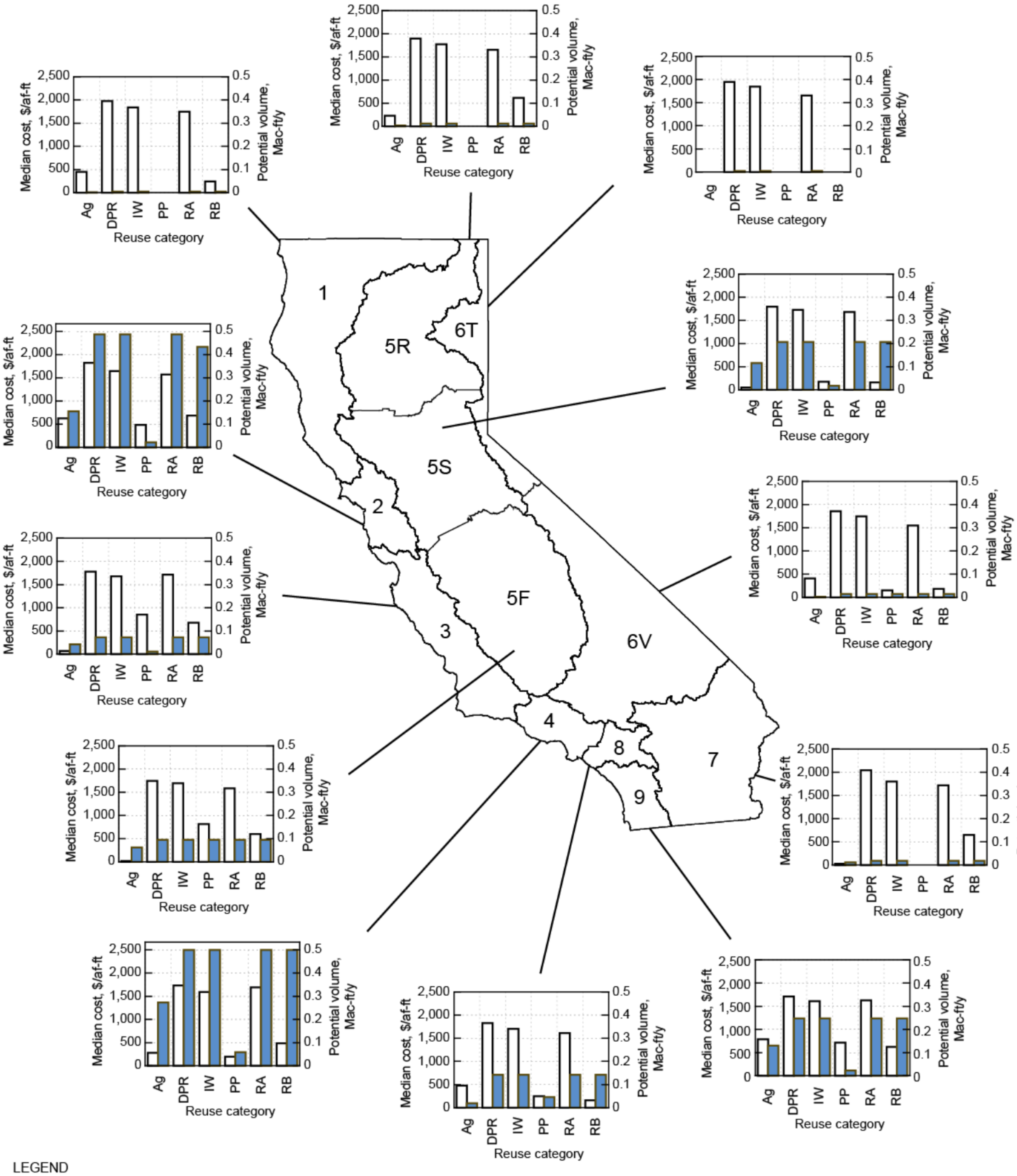
7.2 Median Costs for Water Reuse

The median total cost, as well as the minimum and maximum values, for each WBR for various applications are summarized in Table 7-1. Median total costs from Table 7-1 along with estimated potential reuse volume for each WBR are summarized on Figure 7-2. As shown on Figure 7-2, WBRs 2 and 4 have the greatest volumetric potential for effluent reuse, however, it was found that the median cost of agricultural irrigation and groundwater recharge basins are relatively larger in coastal WBRs.

The cost of agricultural reuse was found to be lowest in WBR 5 due to the closer proximity of WWTFs with potential reuse sites. It is also apparent from Figure 7-2 that there is limited potential for water reuse in WBRs 1, 5R, 6T, 6V, and 7 due to the low population density in these regions. A summary of the technical volumetric reuse potential for each WBR is summarized in Table 7-2.

Table 7-1. Total cost summary for potential water reuse projects organized by WBR.

	Total cost for applicable reuse projects, $/ac-ft median (minimum – maximum)					
WBR	**Agriculture**	**Direct reuse**	**Injection wells**	**Power plants**	**Reservoir augment.**	**Recharge basins**
1	450	1975	1842	N/A	1748	240
	(450 – 450)	(1975 – 1975)	(1842 – 1842)		(1748 – 1748)	(240 – 240)
2	624	1823	1645	486	1571	684
	(88 – 1174)	(1168 – 2066)	(1117 – 1905)	(263 – 698)	(1234 – 2035)	(105 – 983)
3	68	1779	1676	854	1713	678
	(5 – 771)	(1487 – 3351)	(1451 – 1827)	(854 – 854)	(1465 – 1991)	(571 – 1574)
4	280	1732	1593	195	1690	488
	(37 – 1661)	(1266 – 1937)	(955 – 1783)	(68 – 430)	(1396 – 1912)	(118 – 904)
5F	17	1746	1695	816	1583	598
	(5 – 33)	(1340 – 2028)	(1308 – 1871)	(793 – 840)	(1411 – 1876)	(102 – 700)
5R	229	1897	1772	N/A	1654	614
	(6 – 453)	(1875 – 1919)	(1763 – 1780)		(1538 – 1769)	(611 – 618)
5S	50	1799	1726	178	1679	163
	(26 – 121)	(1473 – 2114)	(1144 – 1929)	(15 – 837)	(1271 – 1877)	(103 – 690)
6T	N/A	1946	1844	N/A	1654	N/A
		(1946 – 1946)	(1844 – 1844)		(1654 – 1654)	
6V	407	1855	1743	147	1550	180
	(407 – 407)	(1706 – 2004)	(1648 – 1839)	(17 – 277)	(1477 – 1623)	(129 – 231)
7	24	2045	1801	N/A	1720	649
	(13 – 130)	(1721 – 2106)	(1688 – 1827)		(1685 – 1754)	(588 – 653)
8	479	1826	1706	250	1608	163
	(335 – 622)	(1291 – 2012)	(1250 – 1889)	(44 – 439)	(1247 – 1850)	(106 – 912)
9	788	1710	1613	717	1629	622
	(252 – 1224)	(1261 – 2202)	(1113 – 1892)	(413 – 810)	(1410 - 2089)	(129 - 848)



LEGEND

Ag = agricultural reuse, DPR = direct potable reuse, IW = aquifer injection wells, PP = power generation cooling, RA = reservoir augmentation, and RB = recharge basins.

Figure 7-2. Summary of median total cost (open bars) and potential volume (solid bars) for each WBR.

Table 7-2. Summary of technical volumetric potential water reuse projects organized by WBR.

WBR	Type of reuse application					
	Agricultural	Direct potable	Aquifer injection	Power gen. cooling	Reservoir augment.	Recharge basins
1	1838	4376	4376	0	4376	4376
2	150,351	487,572	487,572	19,166	487,572	435,388
3	35,199	72,376	72,376	9771	72,376	72,376
4	274,645	530,345	530,345	68,256	530,345	492,457
5F	58,994	94,695	94,695	15,270	94,695	94,695
5R	3662	11,444	11,444	0	11,444	11,444
5S	115,468	206,194	206,194	17,636	206,194	206,194
6T	0	4334	4334	0	4334	0
6V	2215	13,896	13,896	13,896	13,896	13,896
7	10,983	17,715	17,715	0	17,715	17,715
8	14,787	143,028	143,028	37,177	143,028	143,028
9	126,928	247,670	247,670	16,803	247,670	247,670
Total	795,072	1,833,644	1,833,644	197,976	1,833,644	1,739,238

7.3 Cost as a Function of Cumulative Volume

The NEAC data from Figure 7-1 can also be represented in terms of cumulative volume, as shown on Figure 7-3. The cumulative volume curves were developed for rank-ordered NEAC data for each of the 86 WWTFs for each water reuse application considered. For example, there is a small amount of water that may be reused through recharge basins at approximately $200/ac-ft. After approximately 0.3 Mac-ft/y of reuse capacity is achieved through groundwater recharge basins, the next available recharge basin reuse project is estimated to cost $350/ac-ft. There is an asymptotic cost for the most challenging sites where the transport costs are exceptionally high.

To determine the lowest cost to achieve increasing volumetric water reuse, the least cost reuse was selected for each facility. The lowest cost reuse application for each facility is assessed in terms of cumulative volume on Figure 7-4. When all reuse options were considered, a combination of agricultural irrigation sites (40%), recharge basins (38%), power plants (13%), reservoir augmentation (6%), and injection wells (3%) were selected. When considering only IPR and DPR, the reuse sites selected were recharge basins (85%), reservoir augmentation (7%), and injection wells (8%). As shown on Figure 7-4, an estimated 1 Mac-ft/y of water reuse potential could be achieved for about $750/ac-ft under various scenarios and consisting primarily of agricultural crop irrigation and surface recharge basins.

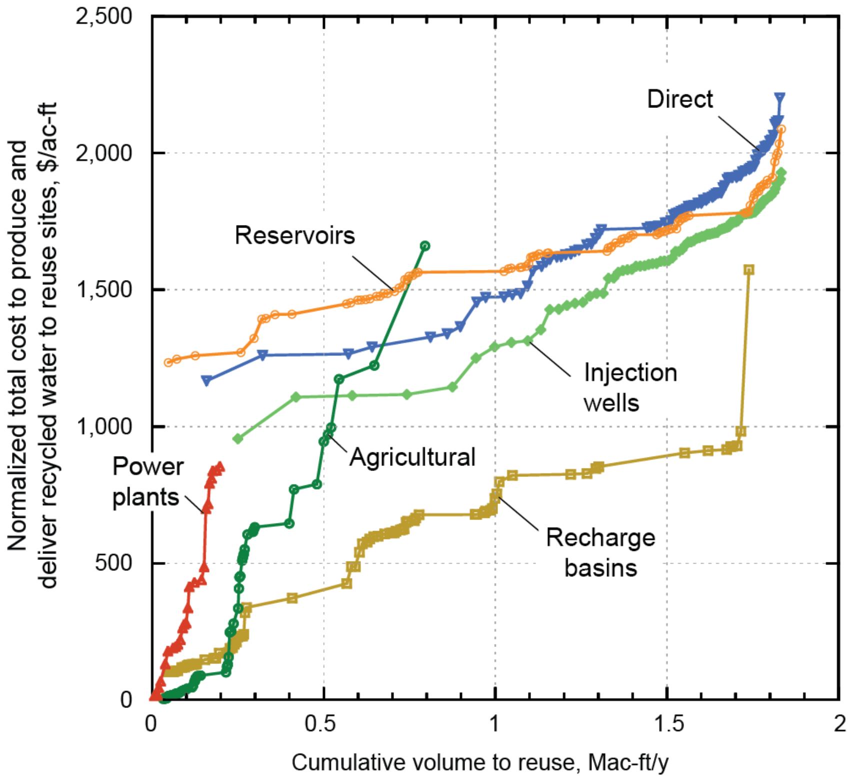


Figure 7-3. Summary of normalized total cost as a function of cumulative reuse volume.

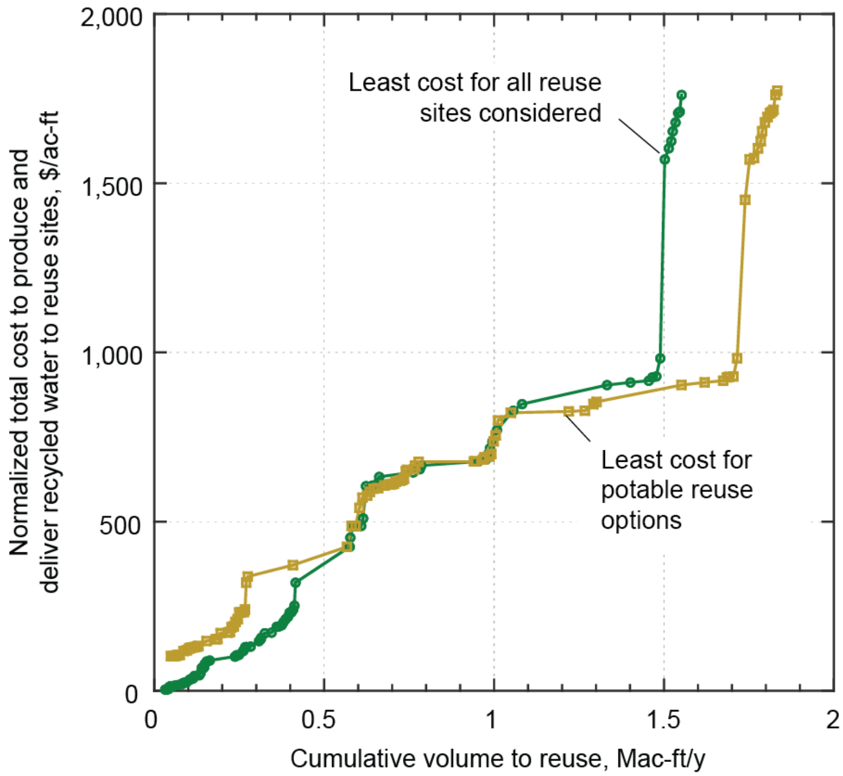


Figure 7-4. Summary of normalized total cost as a function on cumulative volume for the lowest cost option at each facility.

7.4 Comparison of Coastal and Inland Sites

As discussed in Chapter 3, diversion of effluent from coastal discharge is of greatest interest as water discharged into sea water is not utilized for any beneficial purpose, whereas discharge to inland surface water may still be reused indirectly through unplanned reuse. The discharge to coastal waters has been identified as the highest priority flow for reuse in the California Recycled Water Plan (SWRCP, 2019b). The comparative distribution of potential reuse volumes for coastal and inland discharge locations is summarized in Table 7-3.

Table 7-3. Summary of effluent diversions from inland and coastal waters under 2030 water reuse scenario for the 86 WWTFs with potential available effluent volumes greater than 4000 ac-ft/y

WBR	Source of effluent diversion under reuse scenario		Total
	Inland surface waters, land, wetlands	Coastal waters	
	(unplanned reuse)	(ocean disposal)	
1	4376		4376
2		487,570	487,570
3	13,970	58,406	72,376
4	81,097	449,249	530,346
5F	94,695		94,695
5R	11,443		11,443
5S	206,193		206,193
6T		4334	4334
6V	13,896		13,896
7	17,715		17,715
8	74,431	68,597	143,028
9		247,670	247,670
Total	517,816	1,315,826	1,833,642

The cumulative volume curves comparing inland and coastal sites are shown on Figure 7-5. As shown on Figure 7-5, while there is a greater potential volume of water for reuse in coastal areas, the cost for water reuse in coastal sites is higher because of the greater transport distances, relatively greater flow volumes, and logistical challenges associated with reaching potential reuse sites relative to the location of these WWTFs.

It is important to recognize that the results presented above are generalized in nature for the purposes of estimating the median cost. The results should not be taken as definitive for any particular site or location, but as a starting point for site specific investigations.

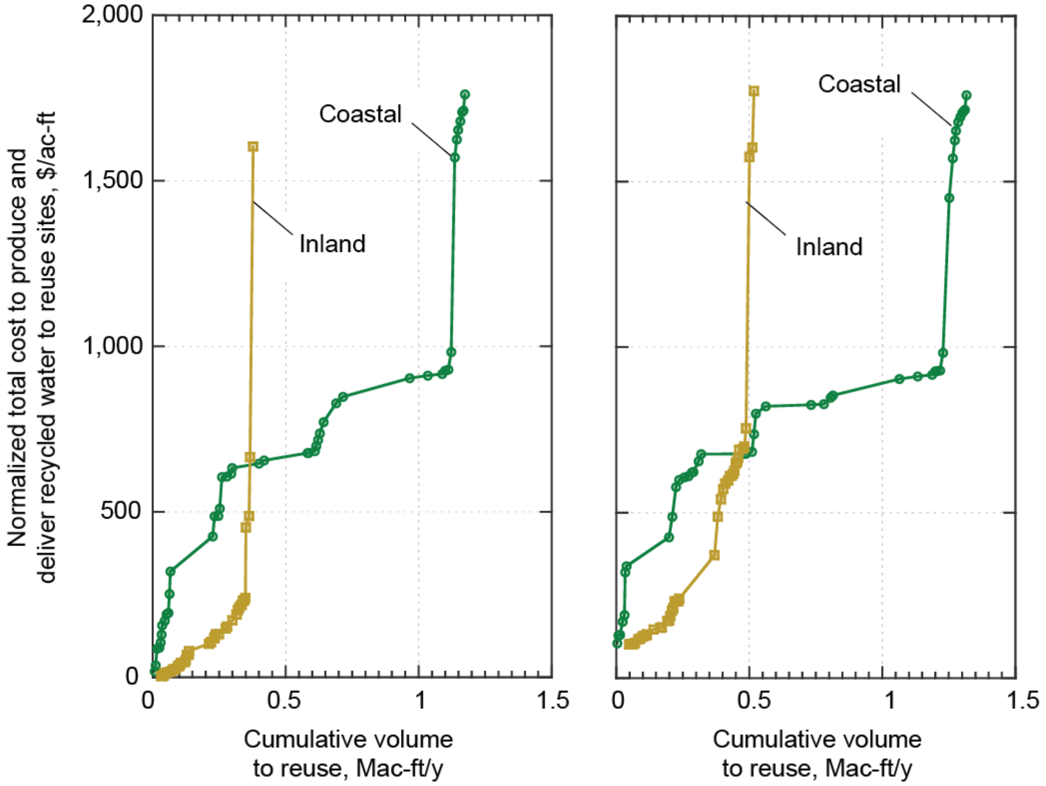


Figure 7-5. Summary of normalized total cost curves as a function of cumulative reuse volume for inland and coastal sites: (a) all reuse applications, and (b) potable reuse applications only.

It is important to recognize that the results presented above are generalized in nature for the purposes of estimating the median cost. The results should not be taken as definitive for any particular site or location, but as a starting point for site specific investigations.

7.5 Summary

In this chapter, the estimated minimum cost of producing and delivering recycled water to hypothetical sites for water reuse were determined. It was found that when the lowest cost reuse options for each facility are considered that there is a distribution of costs to achieve the technically feasible water reuse volume of 1.83 Mac-ft/y. In terms of cumulative volume, it was found that as low cost water reuse potential is exhausted, the cost escalates rapidly to recycle water from facilities that do not have any low cost water reuse options. Groundwater recharge basins were found to have the greatest potential volumetric reuse at the lowest cost, however, there are important water quality and site specific considerations involved with the development of this type of water reuse. It was found that direct potable reuse may be the best option for advanced treated water due to the relatively shorter transport costs associated with connecting to existing water systems. As described in the previous chapter, the costs associated with concentrate management and other site specific factors could not be considered in this analysis but could significantly increase the cost of any particular project.

CHAPTER 8

Findings and Implications

Preliminary findings based on the results of this study are summarized below in terms of the flow balance for effluent flows, legacy infrastructure models that are now being adapted for water reuse, the accounting of environmental water flows, economics of providing water to reuse sites, and future considerations for next steps.

8.1 Flow Balance

The practice of producing and distributing recycled water to planned and permitted uses embodies one type of water reuse, while another type is characterized by the disposal of effluent to inland surface waters, which may provide incidental benefits to the environment and downstream users. Historical targets and goals for water reuse are no longer relevant because these previous estimates for water reuse were based on legacy water use projections. As presented in Table 2-1, total water reuse, consisting of both planned and unplanned cases, is therefore extensive in California and estimated to be around 50% of the available effluent. Approximately 22% of this water is used in planned and permitted reuse projects, while the remaining 28% is used for unplanned reuse through effluent disposal into inland surface water which results in unquantified stream flow augmentation and groundwater recharge. The remaining 50%, equating to 1.8 Mac-ft/y of effluent, is being discharged into the ocean, which does not have any documented environmental benefits, but may provide important health and safety benefits and typically represents the lowest cost disposal option.

Modern water reuse has been in practice in California for approximately 60 years. During this time, a majority of the lower cost opportunities for water reuse have been implemented and may or may not be permitted as a recycled water project currently. In addition, the total cost of WWTF operations has continued to increase due to updated treatment requirements, maintenance of legacy infrastructure, and other regulatory constraints. Therefore, the remaining alternatives for water reuse are more challenging and costly to implement. However, under the current sustained drought conditions, it is inevitable that the price of potable water will increase, and a greater number of water reuse projects will become economically feasible over time. Many if not most of the remaining large, recycled water projects are expected to consist of augmentation of potable water supply, especially where there is a need to build water supply resilience, even though delivering recycled water to remote sites has high costs and less well-defined benefits.

8.2 Legacy Infrastructure and Logistical Challenges

Water reuse in coastal areas is challenging because coastal sites in general have high populations, but they are also the most challenging sites to find applications for water reuse as there are less local options for irrigation, recharge basins, and groundwater injection. The development of regional wastewater management systems in California occurred when wastewater was considered to be a disposal problem without resource value or revenue potential. The implementation of regional disposal systems has resulted in many of the largest WWTFs being located on the coast, originally placed there to take advantage of gravity flows and low-cost ocean discharge. The cost to recover and reuse water from these facilities is expected to increase in the future due to land use changes and continued development in the area.

Where there is a high cost to deliver recycled water, due to long transportation distances or installation challenges, there may be opportunities to re-plumb urban collection systems for satellite reuse. Satellite facilities consist of developing new WWTF and reuse facilities near the reuse application, thereby lowering the transmission cost. Although satellite reuse systems are desirable, they are challenging to locate, and may contribute to increased rates of odor and corrosion from transport of concentrated effluent flows to downstream WWTFs, especially as per capita indoor water use continues to decrease. Under corrosive flow conditions, the collection pipes and headworks should be fully lined, and accomplishing this will further increase the indirect cost of wastewater management and water reuse. In general, adapting existing infrastructure for efficient water reuse will be costly for most locations, and each potential reuse application needs to be evaluated using site-specific information.

8.3 Environmental Flows

While discharge to inland surface waters has not been considered recycled water historically, this water can have important benefits to the environment. Considering the impacts of the current historic drought on aquatic ecosystems, there is a desire to keep wastewater effluent flows in streams, where necessary, for the purpose of supporting habitat and other environmental benefits. Further, the diversion of current effluent flows from inland streams will not be feasible in cases where the SWRCB determines that it is in the best interest of the public to keep a particular wastewater flow in the stream. An alternative approach to diverting flows from inland waters to reuse projects may be to re-characterize these wastewater flows to inland waters as environmental reuse.

There are no habitat or environmental concerns associated with diverting wastewater effluent from discharge to coastal waters. It is likely that concentrates and other wastewater residual flows will continue to be dispersed in the ocean where that is feasible. The options for concentrate and brine management are more limited for inland regions.

In inland areas, while there are concerns about diverting wastewater effluent considered necessary for aquatic habitat to commercial uses, such as crop or golf course irrigation, the question becomes more complicated when considering the use of effluent flows to support instream flows versus water reuse for direct augmentation of potable water supplies. As discussed in Section 3.6, a better accounting system for actual volumetric requirements to support environmental needs could reduce the uncertainty and improve the planning for water reuse projects.

8.4 Cost Summary

In this study, potentially available effluent flows and reuse sites have been identified, but it was not possible to capture site-specific limitations that could make a project cost prohibitive. It is important to emphasize that RO concentrate costs were not included, which could be cost-prohibitive in particular for inland facilities. Therefore, it must be recognized that each agency may have other cost-prohibitive factors that may not have been included in this study and the costs reported here represent the minimum expected cost without consideration of site-specific factors and concentrate management.

Modern wastewater treatment systems were developed during a time when per capita water use and population were expanding. Drought and declining water supply have resulted in indoor water conservation to levels that were not anticipated, and that can dramatically increase the cost of meeting effluent quality requirements. Because of the reduced volume, the unit (normalized equivalent annual) cost to produce and deliver recycled water is increased. The recycled water produced under these conditions has elevated salinity and is more challenging to reuse. Further, there will be legal challenges and costs associated with competing water reuse projects and the growing demand to keep municipal effluent in streams. At the same time, municipalities must address new regulatory standards, manage unknowns associated with constituents of concern in effluent and residual solids, plan for replacing or upgrading aging underground infrastructure, and implement new process upgrades needed for changing wastewater characteristics.

In general, water reuse for commercial agricultural irrigation could be achieved for the lowest cost, but this may not directly improve the water security of urban water supply. Much of the water used for agricultural irrigation is used for crops that are exported out of the state or country, which raises questions about how to best account for the fate of recycled water. Urban reuse has the benefit of offsetting potable water use, but is difficult to model. For example, not much recycled water is available for power plant cooling towers, while dual distribution systems were not modeled.

Recharge basins operating with tertiary effluent are the lowest cost method to augment water supply, with potential to utilize 80% of available effluent at costs ranging from $250 to $1000/ac-ft. However, transporting water great distances to find permeable zones may not be a viable water supply alternative in many locations. Further, the presence of trace chemicals in tertiary effluent may result in the need for additional treatment prior to blending this effluent into a potable water supply.

Blending with a potable water supply (DPR) as well as augmenting surface and groundwater sources (IPR) provides improved water quality, removes salinity, and results in the greatest potential reuse volumes. It is estimated that recycled water could be developed as a source to augment potable water supplies, directly or indirectly, in most locations for a current cost of around $2000/ac-ft. Given the long planning horizon for these projects, initiating these projects early is advisable given the uncertainty around future water supply availability.

8.5 Further Studies

Following are suggestions for further work in support of the goals of this study:

- Explore options for disaggregation of regional WWTFs and implementation of upstream satellite or stand-alone treatment works, where they do not already exist or where reuse potential is not already built out. The management of solids from satellite WWTFs has implications on volumetric water recovery potential and pipeline corrosion and odor issues.

- Correct discrepancies in water reuse accounting methods; correctly identify where the downstream capture of blended effluent and natural stream flows are intercepted for indirect reuse and where these flows may support habitat and environmental reuse objectives.
- Incorporate existing and planned reuse projects into the flow accounting model.
- Perform better accounting for return and blowdown flows to assess water use efficiency. Collect supplemental VAR data in cases where influent flows are recycled or returned to WWTFs.
- Create a statewide real-time map of streams with potential flow-related impairment. This resource could help to accurately identify where WWTF flows can be used to support essential habitat.
- Develop cost models for dual plumbed urban areas.
- Develop models that are able to account better for site specific factors to better estimate actual cost for water reuse projects.
- Further improvements to the accuracy of water reuse site and economic models could improve the accuracy of the cost curves, but is not likely to change the findings.
- Concentrate management is a significant issue and has implications for both the salt and water balance of recycled water. Developing robust management options for concentrates will be essential to the expansion of potable reuse, particularly for inland areas.

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