Pairing Quality and Quantity in a Mass Balance of Water in California

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April 2022

This thesis is submitted for the degree of Doctor of Philosophy.

Supervisor: Prof Jonathan Cullen

Declaration

This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration, except as specified in the text. It is not substantially the same as any work that has already been submitted before for any degree or other qualification. It does not exceed the prescribed word limit set by the Engineering Degree Committee of sixty-five thousand words, including appendices, footnotes, tables and equations. It does not exceed one hundred and fifty figures.

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Abstract

Whether there is enough water in California to meet the needs of residents, businesses, agriculture, and the natural environment, now and in the future, is important to Californians. One of the tools used to assess water availability in California is the water budget, which quantifies how much water enters and leaves the state, and how it is used or stored each year. While this information is useful for tracking quantity, it does not provide any information regarding the quality of the water. The objective of this thesis is to determine whether a method can be established for defining the quality of the water in a water budget in California. To do so requires determining whether a method can be established for creating a scale of water quality using the applicable water quality definitions for the types of water in a water budget in California. That requires determining how water quality is defined. This thesis introduces a six-step method for creating a scale of water quality categories that includes water found in both the natural and built environments in California. The method involves: selecting a geographical context; collecting water quality data applicable to the selected location; compiling water quality parameter data; organising water quality parameters in a matrix; ordering the rows of water quality parameter data values to form categories of water quality; and documenting data sources and notes. This thesis also introduces a seven-step method for creating a water budget, in the form of a modified mass flow diagram, that depicts the quality of each quantity of water. The method involves: delineating the system boundary for the water balance: selecting the water budget time period to be used for analysis; collecting water quantity data applicable to the selected system

boundary and time period; drawing a modified mass flow diagram; selecting and assigning a colour code to the selected water quality scale; applying the colour code representing water quality to the modified mass flow diagram; and ordering diagram slices by level of water quality. The findings indicate that a water budget that includes water quality allows for areas of more efficient use, alternatives to over-extraction, and opportunities for reuse to be identified. Viewing the quantities and qualities depicted together on the same graphic allows like quantities and qualities to be matched, revealing opportunities for meeting demand using different water sources. Adding water quality to water budgets may not only show areas where there is room for improvement, but also depict areas where there are resources and opportunities that might not have been visually obvious from a table of numbers.

Dedication

This thesis is dedicated to the memory of my parents:

Jonette Whitehead
1945-2017

Kenneth Robert Bitting
1945-2021

Acknowledgements

This research was funded in part by Hughes Hall, Cambridge. I thank the college and its members for their support, especially my tutor, Dr Phillip Johnston. Many thanks to my supervisor, Prof Jonathan Cullen, and advisor, Prof Keith Richards, for their guidance in shaping this research. Thanks, also, to the Resource Efficiency Collective, for being such a supportive research community. I also thank my friends and family in the UK, Washington, D.C., New England, and California. *Soli Deo gloria.*

"Now the earth was formless and empty, darkness was over the surface of the deep, and the Spirit of God was hovering over the waters." – Genesis 1:2

Publications

The fourth chapter of this thesis has been published in the American Society of Civil Engineers' *Journal of Sustainable Water in the Built Environment*:

Bitting, J. J., and Cullen, J. M. 2021. Creating a Water Quality Scale Methodology Using California as a Case Study, *J. Sustainable Water in the Built Environ. 7 (2): 05021001. https://doi.org/10.1061/JSWBAY.0000937.*

The fifth chapter of this thesis has been accepted for publication by the American Society of Civil Engineers' *Journal of Sustainable Water in the Built Environment*:

Bitting, J. J., Gast L. T., and Cullen, J. M.. Expected 2022. Pairing Quantity and Quality in a Mass Balance of Water in California, *J. Sustainable Water in the Built Environ. 7 (2): 05021001. https://doi.org/10.1061/JSWBAY.0000937.*

Other works published during this doctoral programme that are not directly included in this thesis include:

Westbroek, C. D., Bitting J.J., Craglia, M., Asevedo, J.M.C., and Cullen, J.M.. 2021. Global Material Flow Analysis of Glass: From Raw Materials to End of Life, *Journal of Industrial Ecology*, Volume 25, Issue 2. https://doi.org/10.1111/jiec.13112

Table of Contents

Chapter 1

Introduction

This chapter introduces the context of the study, the problem statement, the aims and scope of the research, and the structure of this thesis.

1.1 Context of the Study

This section provides the study's context, situates the topic within the broader area of research, and describes why more research is needed.

1.1.1 Mass Balance of Water in California Excludes Water Quality

A mass balance, based on the law of conservation of mass, accounts for all the material entering and leaving a system. The reconciliation of mass flows in a balance, allowing flows that are unknown or difficult to measure directly to be estimated, since mass can neither disappear nor be created spontaneously. A mass balance, when applied to water, is referred to in California as a water budget, therefore that term is used here for consistency, although other terms for the same concept are used in other contexts.

Every five years, the State of California publishes a *California Water Plan Update* that includes a mass balance of water, referred to as a water budget (State of California, 2019b). It lists the amount of water that entered the state, was used or stored within the state, and the amount of water that exited the state for each of the preceding five water years (*i.e.*, precipitation measured from 1 October to 30 September) (State of California, 2019b).

The balanced water budget tables for water years 2011 through 2015, provided in Figure 1.1, show that each year more water entered and exited the state than was used for urban, irrigated agriculture, and environmental water applications combined, including water year 2014, the driest year in recorded state history (OG, 2014) with fifty-six percent of the average annual rainfall (Figure 1.1) (State of California, 2019b). Yet, water shortfalls caused the state Governor to declare a Drought State of Emergency in January 2014 in which he asked Californians to conserve water in every way possible (OG, 2014).

California's dedicated and developed water supply, the sources of the water used in the urban, irrigated agriculture, and environmental applications, are also listed in the water budget tables (Figure 1.1). However, the quality of each of the water supply sources is not specified in the tables. It is possible that those sources of water, which include groundwater extraction, reuse and recycled water, and Colorado River water, have varying levels of quality. It is also possible that the uses of water, which include residential use, landscape irrigation, crop production, managed wetlands, and groundwater recharge, require different levels of water quality.

1.1.2 Material Flow Analysis of Water in California Does Not Include Water Quality Definitions

Material Flow Analysis (MFA) is an analytical method used to quantify flows and stocks of materials in a well-defined system. MFA models can be depicted using Sankey diagrams. Sankey diagrams are used to visualise flows of materials or other resources in order to aid understanding of losses and inefficiencies, map out processes, and give a sense of scale across a system (Lupton and Allwood, 2017). Global flows of steel (Cullen *et al.*, 2012), aluminium (Cullen and Allwood, 2013), paper (Van Ewijk, 2017), and chemicals (Levi and

California Hydrologic Summary

	Water Year (Percent of Average Precipitation)					Average 1998–2015
	2011 (134%)	2012 (75%)	2013 (77%)	2014 (56%)	2015 (78%)	
Water Entering California						
Precipitation	249.4	138.9	142.0	102.6	143.3	182.2
Inflow from Oregon/Mexico	1.3	1.0	0.8	0.8	0.7	1.3
Inflow from Colorado River	4.2	4.7	5.3	5.8	5.0	4.9
Imports from Other Regions	NA	NA	NA	NA	NA	NA
Total	**254.9**	**144.6**	**148.1**	**109.2**	**149.0**	**188.4**
Water Leaving California						
Consumptive Use[a] of Applied Water (Agricultural, Municipal and Industrial, Wetlands)	26.5	30.6	30.9	30.8	29.4	27.3
Outflow to Oregon/Nevada/Mexico	2.1	0.9	0.9	0.6	0.4	1.1
Exports to Other Regions	NA	NA	NA	NA	NA	NA
Statutory Required Outflow to Salt Sink	32.6	22.6	18.8	13.1	16.6	25.3
Additional Outflow to Salt Sink	28.8	8.0	9.8	3.8	7.2	19.2
Evaporation, Evapotranspiration of Native Vegetation, Groundwater Subsurface Outflows, Natural/Incidental Runoff, Agricultural Effective Precipitation, and Other Outflows	164.7	102.7	107.4	84.4	115.2	126.8
Total	**254.6**	**164.8**	**167.8**	**132.7**	**168.8**	**199.6**
Storage Changes in the Region [+] Water added to storage [–] Water removed from storage						
Change in Supply — Surface Reservoir	6.2	-7.4	-4.1	-5.1	-0.8	-0.6
Change in Supply — Groundwater Storage	-5.9	-12.8	-15.8	-18.4	-19.0	-10.6
Total	**0.3**	**-20.2**	**-19.9**	**-23.5**	**-19.8**	**-11.2**

Note: NA = not applicable

[a] Consumptive use is the amount of applied water used and no longer available as a source of supply. Applied water is greater than consumptive use because it includes consumptive use, reuse, and outflows.

California Water Uses and Sources

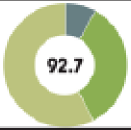
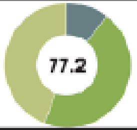
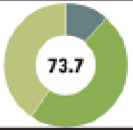
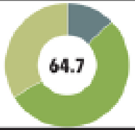
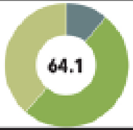
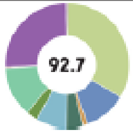
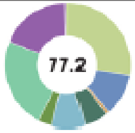
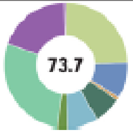
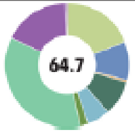
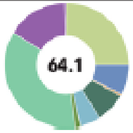
Water Year % Average Rainfall *Precipitation in millions of acre feet (MAF)*	2011 134% *248.1*	2012 75% *138.9*	2013 77% *142.0*	2014 56% *102.6*	2015 77% *143.3*
Applied Water Use - how water was used ...					millions of acre feet
Urban	**7.7**	**8.3**	**8.3**	**8.1**	**7.0**
Large Landscape	0.6	0.8	0.7	0.8	0.7
Commercial	1.1	1.1	1.2	1.1	1.0
Industrial	0.4	0.4	0.4	0.3	0.3
Energy Production	0.1	0.1	0.1	0.1	0.1
Residential - Interior	2.4	2.7	2.7	2.9	2.4
Residential - Exterior	2.3	2.4	2.5	2.4	1.9
Conveyance Applied Water	0.4	0.4	0.4	0.4	0.3
Groundwater Recharge Applied Water	0.5	0.5	0.2	0.1	0.2
Irrigated Agriculture	**31.7**	**35.0**	**35.7**	**35.0**	**32.4**
Applied Water - Crop Production	26.9	31.6	32.6	32.5	30.5
Conveyance Applied Water	3.4	3.0	2.9	2.3	1.8
Groundwater Recharge Applied Water	1.4	0.3	0.2	0.2	0.1
Environmental Water	**53.2**	**33.9**	**29.8**	**21.7**	**24.7**
Managed Wetlands	1.5	1.6	1.6	1.6	1.5
Minimum Req'd Delta Outflow	7.4	5.3	4.5	4.0	3.7
Instream Flow Requirements	7.9	6.8	6.6	5.6	5.3
Wild & Scenic Rivers	36.5	20.2	17.1	10.5	14.2
Total Uses	 **92.7**	 **77.2**	 **73.7**	 **64.7**	 **64.1**
Dedicated and Developed Water Supply - where it came from ...					millions of acre feet
Instream Enviro. Supply	31.3	21.6	18.0	12.4	16.2
Local Projects	10.3	8.2	6.8	6.3	4.9
Local Imported Deliveries	1.0	0.8	0.7	0.5	0.4
Colorado River Project	4.2	4.7	5.3	5.8	5.0
Federal Projects	7.1	6.4	5.7	3.9	3.3
State Project	2.9	2.8	2.0	1.3	0.9
Groundwater Extraction	12.1	18.1	20.8	23.0	22.9
Inflow & Return Flow for Carryover Storage	0.1	0.1	0.1	0.1	0.1
Reuse and Recycled Water	23.6	14.4	14.2	11.4	10.4
Total Supplies	 **92.7**	 **77.2**	 **73.7**	 **64.7**	 **64.1**

Figure 1.1. California Water Budget Tables for 2011 through 2015 as Depicted in the *California Water Plan Update* (State of California, 2019b, Table 2 and Fig. 1). Units are in Million Acre-Feet (MAF).

Cullen, 2018) have also been depicted using Sankey diagrams. However, these diagrams only depict the quantity involved in flows, not the quality.

Water budgets have been depicted using the MFA method. Singkran (2017) conducts a water budget for Bangkok Metropolis in Thailand using an MFA model and finds that only twenty-one percent of wastewater is collected and treated. Voskamp *et al.* (2017) uses a Eurostat MFA to analyse Amsterdam's current food, energy, and water flows, and compares them to natural resource use in 1998 to measure progress toward Amsterdam's goals. Curmi *et al.* (2013) develop an approach for analysing water supply and demand in California and use a Sankey diagram to present their results. When studying water use pathways, Sankey diagrams provide quantitative information on water flows as well as their relationships and transformations. Curmi *et al.* (2013) display water diagrams showing the allocation of water by tracing the source–service–sink route for each service and the processing of water in treatment and recycling facilities. The results depict the net changes in groundwater and surface water stocks, and the researchers conclude that Sankey diagrams are a useful tool for mapping water use even if 'water quality problems are not shown'.

1.2 Problem Statement

This section briefly describes why this research topic is worthy of investigation and identifies the key point of concern. A more detailed explanation is found in the following chapter.

Water availability in California is impacted by drought (Griffin and Anchukaitis, 2014), contaminated water (SWRCB, 2013), negative effects of past water management decisions (USGS, 2017), and the fact that seventy-five percent of the water supply is in the northern third of the state, while eighty percent of the water demand is in the southern two-thirds of the state (WEF, 2020a). Droughts have increased in frequency over the last century (USGS, 2017), with the recent drought (*i.e.*, 2012-2016) the most severe on record (Griffin and Anchukaitis, 2014). Contaminated groundwater is the sole source of water for 3.7 million people in California (SWRCB, 2013). Excessive groundwater pumping has mobilised toxins that impair water quality and caused irreversible land subsidence, resulting in damage to infrastructure and diminishing the capacity of aquifers to store water for the future (USGS, 2017). Intensive hydrologic alterations (*e.g.*, aqueducts, pipelines, and dams) have increased agricultural production and manufacturing (WEF, 2020a), and positioned the state as the fifth-largest economy in the world (CBS, 2018). However, they have also depleted fish populations, drained wetlands, altered natural water flow patterns, and impaired water quality (WEF, 2020a).

The future availability of water in California is expected to be impacted by increases in population (USGS, 2017) and climate change (CNRA, 2016). The *California Water Plan Update 2018* acknowledges that even with recently adopted state initiatives, California still faces challenges from flooding, unreliable or unsafe water supplies, groundwater overdrafts, habitat degradation, and declining species populations (State of California, 2019a). Many of California's ecosystems continue to decline, and much of the state's water supply and flood protection infrastructures either no longer function as intended or have exceeded their design lives (State of California, 2019a). If these trends continue, the state's water resources and prosperity will remain vulnerable to the consequences of droughts, floods, fire, environmental degradation, extinctions of species, and climate change (State of California, 2019a).

One of the tools used to assess water availability in California is the water budget, which quantifies how much water enters and leaves the state, and how it is used or stored each year

(State of California, 2019b). While this information is useful for tracking quantity, it does not provide any information regarding the quality of the water.

1.3 Aim and Scope of the Thesis

This section describes the single aim of this thesis and delimits the scope of the study.

The *2014 California Water Action Plan* (CNRA, 2014) identifies the need for better tools that address water quality and quantity objectives and aid communication by stating,

> ‘State natural resources and water quality agencies, in collaboration with their federal counterparts, will implement a series of administrative solutions through a transparent process to make water delivery decisions and propose options to address water quality and supply objectives in extreme conditions. The identification of such opportunities requires continued improved water forecasting and prompt inter and intra agency coordination and communication.’

Curmi *et al.* (2013) identify Sankey diagrams as a useful tool for mapping water use:

> ‘The Sankey diagrams can be used to demonstrate how water uses can be better managed to ensure sustainable future water resource management that balances human and ecosystem needs.’

They also identify the lack of water quality levels in the diagrams:

> 'Water quality problems are not shown; however, Sankey diagrams can be important complements to global water assessment maps that show annual water availability, runoff and water use.'

The *2014 California Water Action Plan* (CNRA, 2014) states,

> 'It is a fact that millions of Californians rely, at least in part, on contaminated groundwater for their drinking water. While most water purveyors blend or treat water to meet public health standards, many disadvantaged communities cannot afford to do so.'

Better tools are needed to address California's water quantity and quality objectives. MFA and Sankey diagrams have proven useful for mapping use, but don't include quality. Poor water quality is an issue in parts of California. The aim of this thesis is to explore adding water quality to water budgets in California.

1.4 Structure of the Thesis

This section describes how the thesis is structured, and how the following chapters are linked. The second chapter provides background information relating to the geographic context for this research, reviews the literature for the mass balance of water, material flow analysis, existing water quality scales, and the entities that define water quality. The third chapter explores the various ways of defining the quality of water, both the definitions and methods used, by the entities identified in the second chapter. The fourth chapter proposes a method for creating a scale of water quality needed to add water quality to a water budget in California, using the quality definition and method findings from the third chapter. The fifth chapter introduces a method for producing a water budget with water quality included, using the scale of water quality categories created in the fourth chapter. The sixth chapter discusses how these methods, and their results, provide new insights regarding water resources in California. The seventh chapter reflects on the aim of this thesis and summarises the contributions to knowledge.

Chapter 2

Background Context and Literature Review

2.1 Introduction

This chapter provides background information for the geographic context of this research, and a review of the literature related to: organisations that define water quality; existing water quality scales and formats; and the use of material flow analysis (MFA) to depict material flows, including water.

The first section explores why California is an appropriate geographic context for this type of research, the possible scales of application ranging from statewide, to a watershed, or a city. Next, the global, national, state, and city organisations that develop water quality definitions are explored. Then, existing water quality scales and their formats are reviewed. Next, the use of MFA, and Sankey diagrams, to depict quantities of water is explored. The final section of the chapter summarises the research gaps in the literature and outlines the research questions to be explored in the remaining chapters of this thesis.

2.2 Geographic Context

This section provides background information for the geographic context of this research and explores various scales of application (*e.g.,* state, watershed, city).

2.2.1 Why California is an Appropriate Geographic Context for this Research

California is a helpful geographic context for this research due to: the location of water supply and water demand; frequency and severity of drought; communities reliant upon contaminated groundwater; need for surface and groundwater management tools; climate change and population impacts on future water availability; and transparent and available water data and reporting, as described in the following corresponding sections.

2.2.1.1 Location of Water Supply and Water Demand

California's water resources support thirty-five million people and irrigate more than five million acres of farmland (WEF, 2020a). However, seventy-five percent of California's available water is in the northern third of the state (north of Sacramento), while eighty percent of the urban and agricultural water demands are in the southern two-thirds of the state (WEF, 2020a). To move water from where it originates to where it is needed, California uses aqueducts, pipelines, dams, and reservoirs under federal, state, or local jurisdiction. The largest of these systems is the California State Water Project (SWP), which is comprised of more than seven hundred miles (*i.e.*, eleven hundred km) of aqueducts, tunnels, siphons, and pipelines as well as thirty-four storage facilities, thirty dams, twenty-three pumping plants, and nine hydroelectric power generation plants supplying water to more than twenty-seven million people and seven hundred thousand acres of farmland (DWR, 2020). This intensive hydrologic alteration has increased agricultural production and manufacturing (WEF, 2020a) and made the state the fifth-largest economy in the world (CBS, 2018). Unfortunately, it has also depleted fish populations, drained wetlands, altered natural water flow patterns, and impaired water quality (WEF, 2020a). California's investments in water infrastructure do not, however, guarantee that there will be water to transport in times of drought.

2.2.1.2 Drought Frequency and Severity

Droughts have increased in frequency over a period of one hundred years (*i.e.*, 1918-2018), with six droughts in California: one in the first thirty-three years (*i.e.*, 1928-1934), one in the middle thirty-three years (*i.e.*, 1976-1977), and four in the last thirty-three years (*i.e.*, 1987-1992, 2001-2002, 2007-2009, 2012-2016) of this time frame (USGS, 2017). The analysis of tree borings from blue oaks that died as a result of the most recent drought shows that the 2012-2016 drought was the most severe in twelve hundred years (Griffin and Anchukaitis, 2014); while the low levels of precipitation seen in 2012-2016 have accompanied previous droughts, the concurrent high temperatures were unprecedented (Griffin and Anchukaitis, 2014). Climate projections for California include increased temperatures, which could make droughts, and their impacts, more severe (USGS, 2017). The most recent drought increased tree mortality, reduced native fish populations, and reduced energy generation, as described in the following three sections.

2.2.1.2.1 Tree Mortality and Wildfires

The usual tree mortality rate for California is one million trees per year but, from 2010 to 2017, one hundred and twenty-nine million trees died (USDA, 2017), which amounts to roughly sixteen million per year. Between 2002-2018, the only three years (*i.e.*, 2007, 2008, and 2017) in which more than one million acres burned occurred during the 2007-2009 drought and immediately following the 2012-2016 drought (NIFC, 2018).

2.2.1.2.2 Native Fish Population

Drought diminished the supply of cold river water that the winter-run Chinook salmon, an endangered species native to the Sacramento River, need to spawn and subsist (Reese *et al.*, 2016). In 2014, five percent of the juveniles survived (Reese *et al.*, 2016). In 2015, more water was held behind Shasta Dam to create deep, cold-water pools (Reese *et al.*, 2016). Despite these efforts, due to the high temperatures experienced during the drought, the river water reached temperatures too high for aquatic life (Reese *et al.*, 2016). The National Marine Fisheries Service reported that three percent of the juvenile salmon survived in 2015 (Reese *et al.*, 2016).

2.2.1.2.3 Energy Generation

Hydropower generation accounts for eighteen percent of California's energy (Gleick, 2017). During the most recent drought, there was only enough water flow to produce seven percent of the state's energy needs via hydropower (Gleick, 2017). The cost to California ratepayers of replacing hydroelectric generation was approximately $2.45 billion (Gleick, 2017). The additional combustion of fossil fuels for the generation of electricity led to a ten percent increase in carbon dioxide emissions from California's in-state power plants (Gleick, 2017).

2.2.1.3 Communities Reliant Upon Contaminated Groundwater

Contaminated groundwater is the sole source of water for 3.7 million people in California (SWRCB, 2013). Most water suppliers are able to treat the contaminated water before distributing it to the public (SWRCB, 2013). However, in 2010, a half million people were, at some point in the year, provided water with levels of contaminants that exceeded drinking water standards (SWRCB, 2013). Figure 2.1 depicts the number of active community water system wells with two or more naturally occurring and anthropogenic contaminant detections above the maximum contaminant level between 2002-2010 (SWRCB, 2013).

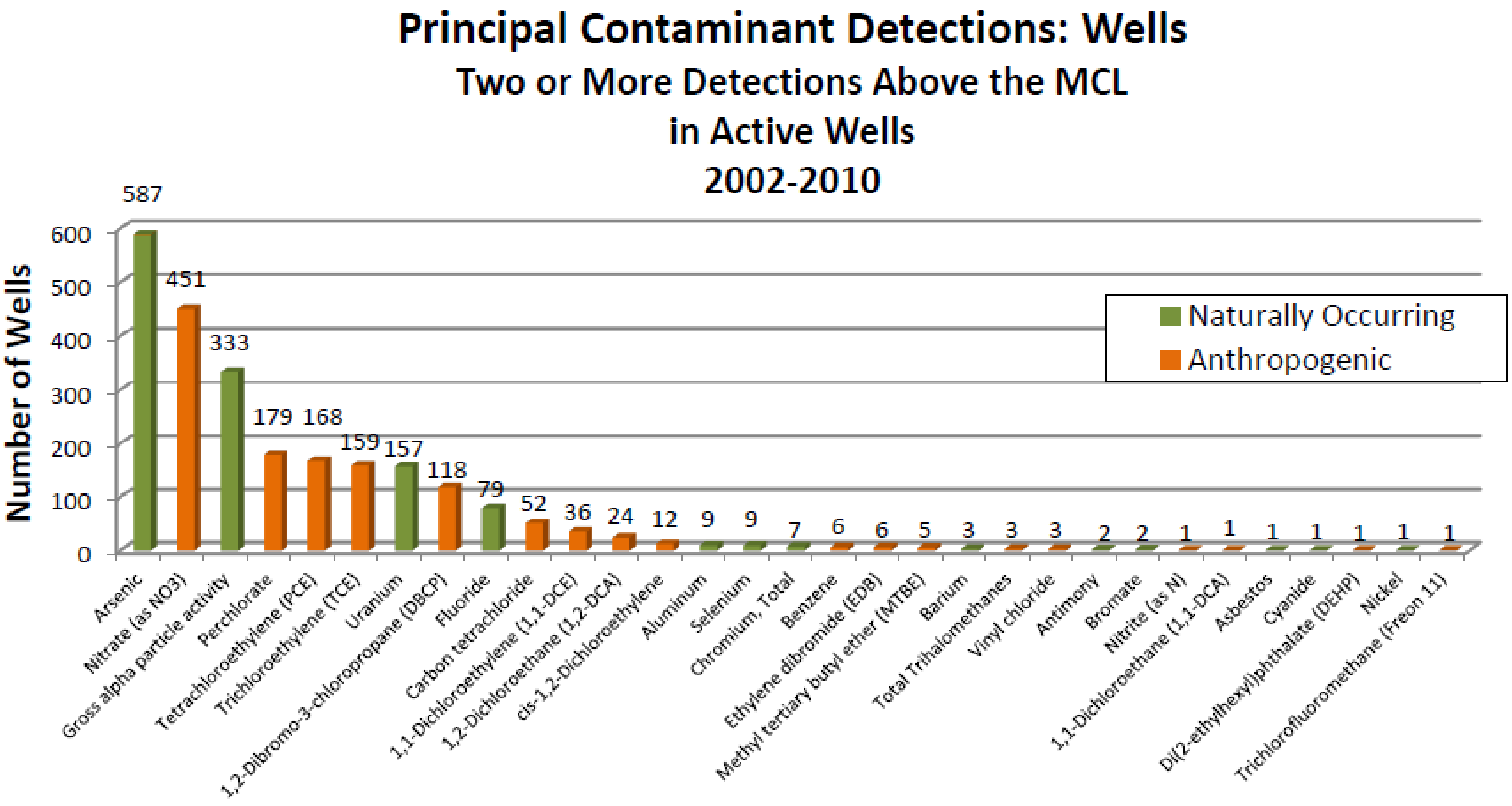


Figure 2.1 Number of Active Community Water System Wells with Two or More Contaminant Detections Above the Regulatory Water Quality Standard (*i.e.*, Maximum Contaminant Level (MCL)) (SWRCB, 2013, Figure 4).

2.2.1.4 Surface and Groundwater Management Tools, Resources, and Authorities

Inconsistent and inadequate tools, resources, and authorities have made managing groundwater in California difficult and prevented problems, such as overdraft, seawater intrusion, land subsidence, and water quality degradation, from being addressed sufficiently (USGS, 2017). Pumping more than is recharged lowers groundwater levels, which makes extracting water more expensive and energy intensive (USGS, 2017). Under certain conditions, excessive groundwater pumping can mobilise toxins that impair water quality and cause irreversible land subsidence, which damages infrastructure and diminishes the capacity of aquifers to store water for the future (USGS, 2017). Surface water users in California have different priorities to available water in times of water scarcity (Lord *et al.*, 2018). The most recent drought demonstrated that the state sometimes lacks sufficient data and authority to enforce the water rights priority system with the accuracy and efficiency that a drought crisis requires (USGS, 2017).

In the last decade, California has enacted legislation to help address water availability, including: the California Drought, Water, Parks, Climate, Coastal Protection, and Outdoor Access for All Act of 2018 which authorised four billion dollars in general obligation bonds for state and local parks, environmental protection and restoration projects, water infrastructure, and flood protection projects; Senate Bill 606 and Assembly Bill 1668, signed by Governor Brown in May 2018, which built on the ongoing efforts to 'make water conservation a California way of life'; the Sustainable Groundwater Management Act of 2014 which requires local agencies in high and medium priority basins to cease overdrafts and bring basins into balance; the Water Quality, Supply, and Infrastructure Improvement Act of 2014 which authorised $7.5 billion to finance safe drinking water and water-supply reliability programs in California; and the Human Right to Water policy which states that every human being has the right to safe, clean, affordable, and accessible water adequate for human consumption, cooking, and sanitation purposes (State of California, 2019a).

However, California still faces challenges from flooding, unreliable or unsafe water supplies, groundwater overdrafts, habitat degradation, and declining species (State of California, 2019a). Many of California's ecosystems continue to decline, and much of the state's water supply and flood protection infrastructures either no longer function as intended or have exceeded their design lives (State of California, 2019a). If these trends continue, the state's water resources and prosperity will remain vulnerable to the consequences of droughts, floods, fire, environmental degradation, extinctions of species, and climate change (State of California, 2019a).

2.2.1.5 Climate Change and Population Impacts on Future Water Availability

The state's population is projected to grow from thirty-nine million in 2017 to fifty million by 2049, which is a twenty-two percent increase over thirty-two years (USGC, 2017). Climate change is expected to bring more frequent drought conditions and could reduce, by half, the Sierra snowpack, California's largest natural storage system, as more precipitation falls as rain rather than snow and snow melts earlier and more rapidly (DWR, 2022a). The effects of climate change are already being felt in California (DWR, 2022a). The Sierra snowpack is decreasing, reducing natural water storage and altering winter and spring runoff patterns (DWR, 2022a). This decrease is most likely the result of higher temperatures. Higher river and ocean water temperatures will make it harder to maintain adequate habitats for native fish species (DWR, 2022a). The rising sea level amplifies the risk that the pumps that supply cities and farms with water will be inundated with seawater in a large earthquake or storms that breach levees (USGS, 2017).

2.2.1.6 Water Data Transparency and Availability

California has approximately one hundred and seventy state agencies, fifteen of which work on state-wide environmental issues (State of California, 2017a). Of the fifteen agencies listed in Table 2.1, two separate agencies are responsible for the quality and quantity of water in California. The State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards (Regional Boards) are responsible for protecting water quality and allocating surface water rights (SWRCB, 2022), while the Department of Water Resources (DWR) is responsible for the management of water usage, including the delivery of water through the SWP (DWR, 2020). The SWP's five hydroelectric power plants and three pumped-storage hydroelectric power plants produce a combined 6,500 GWh per year, however, the SWP requires 11,500 GWh per year to operate, making it the single largest consumer of power in the state (DWR, 2020).

Together, the SWRCB and the DWR develop plans that detail current and future strategies for the protection and management of water in California and report on progress made to date. The most pertinent documents include: *California Water Plan Update 2018* (State of California, 2019a); *California Water Action Plan Implementation Report 2014-2018* (State of California, 2015); *California Water Action Plan* (CNRA, 2014); and *Strategic Plan for the Future of Integrated Regional Water Management in California* (DWR, 2013).

In addition to the plans and reports that California's governmental agencies publish on their websites, multiple data repositories are maintained and available to the public. These data

Table 2.1. California State Agencies Responsible for Environmental Resource Management or Protection (State of California, 2017a).

CALIFORNIA STATE AGENCY	ROLE
Biodiversity Council	Improve coordination among federal, state, and local environmental protection organizations
Coastal Commission	Protect and enhance the state’s coast and ocean for present and future generations
Coastal Conservancy	Help people get to and enjoy the outdoors and sustain local economies along the coast
Colorado River Board	Represent the state in discussions with the Colorado River Basin States, federal and local governments, and Mexico regarding the management of the Colorado River
Dept. of Conservation	Promote environmental health, economic vitality, informed land-use decisions, and sound management of the state's natural resources
Cool California	Provide resources to help all Californians reduce their environmental impact and be part of the climate change solution
Fish & Game Commission	Set the regulations that the Dept. of Fish & Wildlife implements and enforces
Environmental Protection Agency	Restore, protect, and enhance the environment to ensure public health, environmental quality, and economic vitality
Air Resources Board	Gather air quality data for California, ensure the quality of this data, design and implement air models, and set ambient air quality standards
Dept. of Pesticide Regulation	Protect human health and the environment by regulating pesticide sales and use and fostering of reduced-risk pest management
Dept. of Resources Recycling and Recovery	Bring together the state’s recycling and waste management programs
Dept. of Toxic Substances Control	Restore contaminated resources, enforce hazardous waste laws, reduce hazardous waste generation, and encourage the manufacture of chemically-safer products
Office of Environmental Health Hazard	Protect and enhance public health and the environment by scientific evaluation of risks posed by hazardous substances
State Water Resources Control Board	Preserve, enhance, and restore the quality of California’s water resources and drinking water for the protection of the environment, public health, and all beneficial uses, and ensure proper water resource allocation and efficient use for the benefit of present and future generations
Dept. of Fish & Wildlife	Manage fish, wildlife, and plant resources and their habitats for their ecological value and for their enjoyment by the public
Dept. of Forestry & Fire Protection	Provide fire protection and stewardship for over 31 million acres of privately-owned wildlands and emergency services in 36 of the State's 58 counties
Natural Resources Agency	Restore, protect, and manage natural, historical, and cultural resources for current and future generations
Ocean Protection Council	Ensure that California maintains healthy, resilient, and productive ocean and coastal ecosystems for the benefit of current and future generations
Save Our Water	Offer ideas and inspiration for permanently reducing water use, regardless of whether California is in a drought
Dept. of Water Resources	Managing and protecting California’s water
Wildlife Conservation Board	Select, authorize, and allocate funds for the purchase of land and waters suitable for recreational purposes and the preservation, protection, and restoration of wildlife habitat

repositories contain water supply data, water quality data, land and water use data, well data, and groundwater data as detailed in Table 2.2.

2.2.2 Appropriate Geographic Scale for this Research

This section explores various scales of application for this research, including using political boundaries (*e.g.*, state, city) and watershed boundaries (*e.g.*, hydrologic region).

2.2.2.1 State-level Application

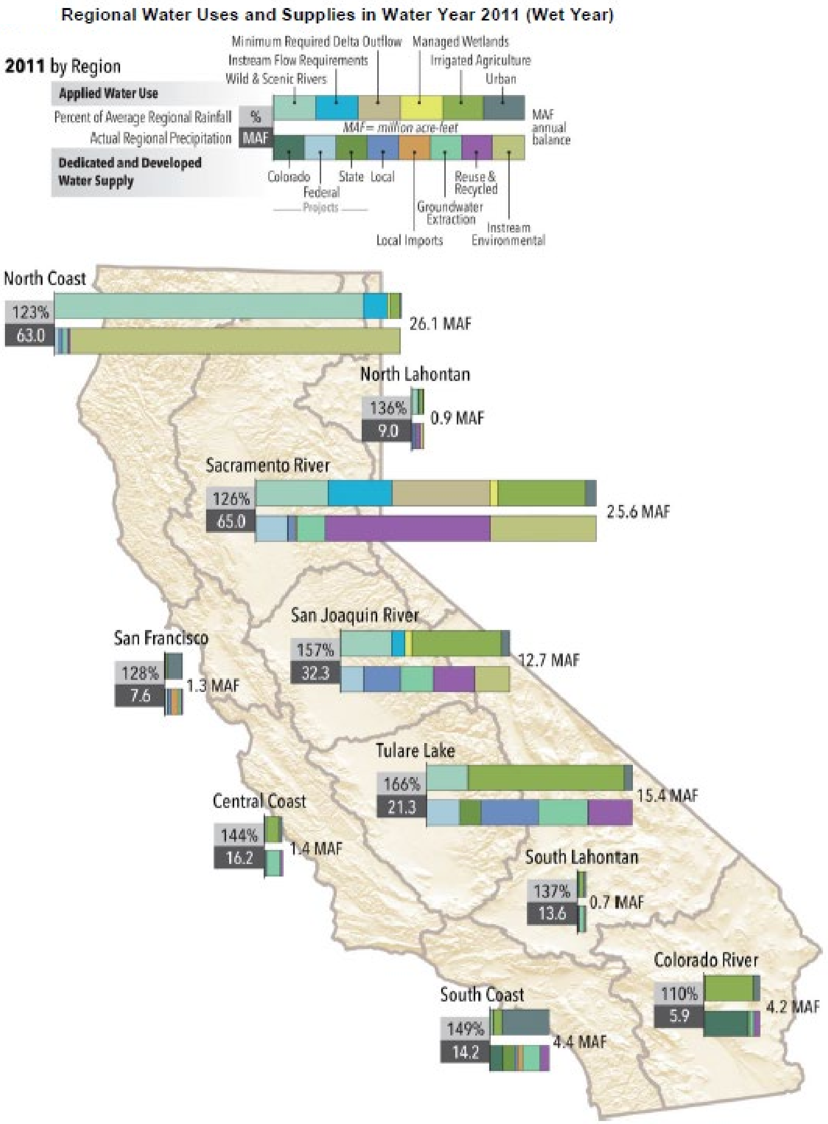
Conducting this research and applying the methods at the state-level, a political boundary, has advantages and disadvantages. A balanced water budget (*i.e.*, including anthropogenic and water in the natural environment) for the whole state is published (Figure 1.1), including the data used to create it (State of California, 2019b). As described earlier in this chapter, the State of California owns and operates statewide infrastructure that conveys water (*e.g.*, aqueducts, pipelines). However, potable water treatment, for example, occurs at the local level (*e.g.*, city, town) before the water is distributed to the user (*e.g.*, residents, businesses), as does wastewater treatment after water is collected from the user. State-level agencies define water quality by setting hydrologic region-level water quality standards, as mentioned earlier in this chapter and described in detail in the third chapter.

2.2.2.2 Hydrologic Region-level Application

Conducting this research and applying the methods at the hydrologic region-level, a watershed basin boundary, has advantages and disadvantages. Figure 2.2 depicts the ten hydrologic regions that correspond to the state's major drainage basins. Using the drainage basins as planning boundaries allows logical tracking of water runoff and accounting of supplies (State of California, 2019b). However, as depicted in Figure 2.3, there is movement

Table 2.2. California Water Data Types and Sources

Data Type	Data Location	Data Details
Water Supply	DWR California Data Exchange Center (DWR, 2022b)	• Precipitation (daily, monthly, by hydrological area) • Reservoirs (daily, statewide end of the month storage) • Snow (daily, forecast runoff) • River stages (seasonal: daily, monthly)
Water Quality	Water Boards' Data and Databases (CCRWQCB, 2019b) (SWRCB, 2019b)	• Contaminants • Groundwater • Surface water • Drinking water
Land and Water Use	DWR Land Use Viewer (DWR, 2022c)	• Irrigated crop area • Irrigated land area • Crop type • Evapotranspiration • Effective precipitation • Consumed fraction • Applied water • Evapotranspiration of applied water
Well	DWR Water Data Library (DWR, 2022d)	• Lat/long • Basin name • County • Groundwater depth • Measurement accuracy • Perforation heights (top and bottom)
Groundwater	DWR Statewide Groundwater Management (DWR, 2022e)	• Population • Population growth • Number of public supply wells • Irrigated acreage • Total wells • Groundwater use



Central Coast Water Balance by Water Years 2011–2015

Water Year	2011	2012	2013	2014	2015
% Average Rainfall	144%	69%	58%	42%	69%
Precipitation in thousands of acre feet (TAF)	16,193	7,688	6,461	4,672	7,791
Applied Water Use - how water was used ...					thousands of acre feet
Urban	**253**	**277**	**284**	**277**	**245**
Large Landscape	22	25	26	27	22
Commercial	36	42	42	39	40
Industrial	10	10	11	10	9
Energy Production	13	13	13	13	13
Residential - Interior	70	80	79	78	66
Residential - Exterior	87	94	98	92	74
Conveyance Applied Water	5	3	3	8	10
Groundwater Recharge Applied Water	10	11	12	9	10
Irrigated Agriculture	**922**	**1,012**	**1,259**	**1,270**	**1,088**
Applied Water - Crop Production	894	992	1,247	1,256	1,069
Conveyance Applied Water	10	5	6	7	9
Groundwater Recharge Applied Water	19	16	7	7	10
Environmental Water	**181**	**57**	**68**	**26**	**42**
Managed Wetlands	0	0	0	0	0
Minimum Req'd Delta Outflow	0	0	0	0	0
Instream Flow Requirements	25	25	25	12	13
Wild & Scenic Rivers	155	31	43	13	29
Total Uses	1,356	1,346	1,612	1,573	1,376
Dedicated and Developed Water Supply - where it came from ...					thousands of acre feet
Instream Enviro. Supply	0	30	0	13	0
Local Projects	21	19	26	21	22
Local Imported Deliveries	0	0	0	0	0
Colorado River Project	0	0	0	0	0
Federal Projects	99	105	87	66	76
State Project	26	25	24	25	22
Groundwater Extraction	1,003	1,111	1,381	1,403	1,189
Inflow & Return Flow for Carryover Storage	10	10	10	10	9
Reuse and Recycled Water	197	47	84	34	58
Total Supplies	1,356	1,346	1,612	1,573	1,376

Figure 2.2. Map of California with Ten Hydrologic Regions Delineated and Data Depicted from Water Budget Tables, Including the Central Coast Region (State of California, 2019b, Figures 2 & 9). Units are in Millions of Acre-Feet (MAF) and Thousands of Acre-Feet (TAF).

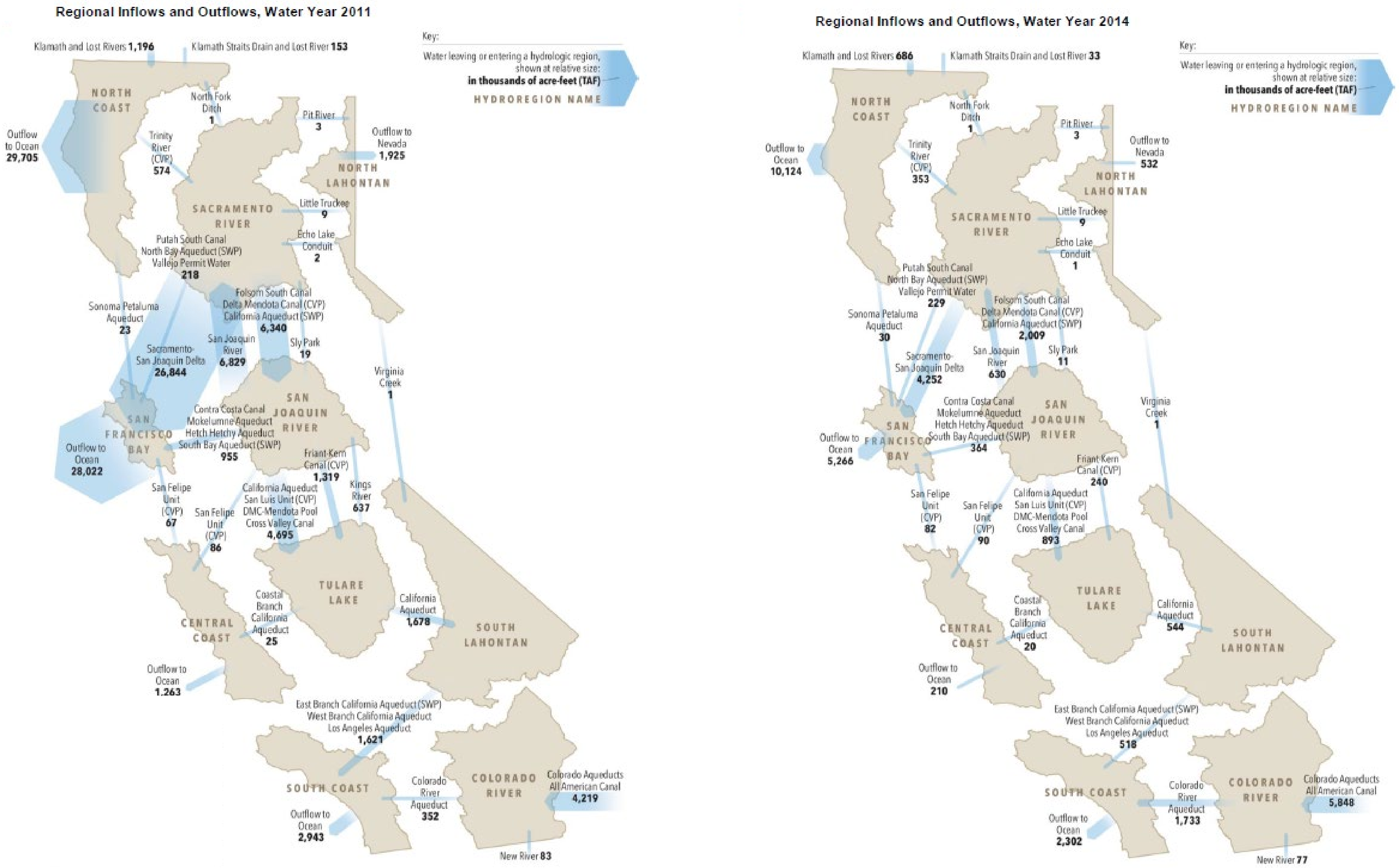


Figure 2.3. Map of California Depicting Movement of Water Between Hydrologic Regions in Water Years 2011 and 2014 (State of California, 2019b, Figures 17 & 18). Units are in Thousands of Acre-Feet (TAF).

of water between the hydrologic regions (State of California, 2019b). A balanced water budget for each hydrologic region is published (Figure 2.2) with the statewide water budget (State of California, 2019b). As described in detail in the third chapter, water quality definitions are set at the hydrologic region-level, however, each water body has a unique set of water quality standards. Within each hydrologic region are multiple cities, each with their own wastewater treatment plants, discharging to different water bodies, requiring different water quality permit limits and resulting in effectively different water quality definitions.

2.2.2.3 City-level Application

Conducting this research and applying the methods at the city-level, a political boundary, has advantages and disadvantages. The city-level includes a smaller number of rivers, lakes, and groundwater basins than at the state-level. The city-level also includes access to funds and decision-making authority (*e.g.*, city council) to treat water and wastewater, manage stormwater, and change infrastructure. The City of Paso Robles, for example, publishes multiple water-related reports on their web page that collected and compiled together includes most of the data needed for a water budget (Figure 2.4). Water quality definitions that apply, or are in place, at the city-level include definitions established by the Regional Water Quality Control Board (Regional Water Board) through permits for wastewater effluent discharge, stormwater discharge, or through the water quality standards found in the basin plan that apply to the region. National and global water quality definitions are available in the absence of local definitions.

2.2.3 Why Paso Robles is an Appropriate Geographic Context for this Research

In 2003, the City of El Paso de Robles was facing a long-term water supply problem (Paso Robles, 2004). The city relied completely on local groundwater for its water supply, despite

Dedicated and Developed Water Supply (Paso Robles, 2016a, Table 6-1)

Water Source (AFY)	2011	2012	2013	2014	2015
Paso Robles Groundwater Basin – Basin Wells	2,327	2,880	3,257	3,497	2,045
Salinas River – River Wells	4,069	3,814	3,743	2,772	3,021
Nacimiento Water Treatment Plant*	0	0	0	0	87
Total Groundwater and Surface Water	6,396	6,694	7,000	6,269	5,153

City of Paso Robles Yearly Rain Fall Totals

SEASON - JULY 1 - JUNE 30

YEAR	JULY	AUG.	SEP.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	TOTAL
2010/11	0.03	0.00	0.00	1.06	1.57	7.14	2.07	3.05	5.29	0.28	0.95	0.53	21.97
2011/12	0.00	0.00	0.03	0.90	1.93	0.12	2.38	0.25	2.44	2.60	0.18	0.00	10.83
2012/13	0.00	0.00	0.00	0.28	0.75	3.94	1.02	0.28	0.69	0.07	0.15	0.00	7.18
2013/14	0.00	0.00	0.00	0.01	0.26	0.30	0.00	2.75	1.96	0.85	0.00	0.00	6.13
2014/15	0.03	0.00	0.00	0.00	1.00	5.48	0.32	2.16	0.10	0.37	0.05	0.00	9.51

(Paso Robles, 2020a)

Applied Water Use (Paso Robles, 2016a, Table 4-1)

Water Use (AFY)	2005	2010	2011	2012	2013	2014	2015
Single Family	3,865	3,435	3,353	3,537	3,635	3,158	2,536
Multi-family	794	573	645	658	708	632	540
Commercial	1,197	656	779	795	840	799	589
Industrial	69	154	159	179	186	209	218
Institutional/ Governmental	Included in Other	91	Included in Commercial & Other	Included in Commercial & Other	Included in Commercial & Other	Included in Commercial & Other	294
Parks, Landscape Irrigation, Other	1,238	840	865	984	1,138	1,031	545
Non-Revenue Water	250	577	596	541	493	440	431
Total Water Use	7,413	6,326	6.397	6,694	7,000	6,269	5,153
Total Number of Connections	*9,736*	*10,276*	*10,487*	*10,441*	*10,737*	*10,626*	*10,627*

Applied Water Use (Paso Robles, 2016a, Table 6-3)

Table 6-3 Retail: Wastewater Treatment and Discharge Within Service Area in 2015										
☐	No wastewater is treated or disposed of within the UWMP service area. The supplier will not complete the table below.									
Wastewater Treatment Plant Name	Discharge Location Name or Identifier	Discharge Location Description	Wastewater Discharge ID Number *(optional)*	Method of Disposal Drop down list	Does This Plant Treat Wastewater Generated Outside the Service Area?	Treatment Level Drop down list	2015 volumes: Wastewater Treated	Discharged Treated Wastewater	Recycled Within Service Area	Recycled Outside of Service Area
Add additional rows as needed										
City of Paso Robles Wastewater Treatment Plant	Discharge Point 001C	Outfall into Salinas River	3 400105001	Percolation ponds	Yes	Secondary, Disinfected - 23	2,688	2,688	0	0
						Total	2,688	2,688	0	0
NOTES: The City's WWTP treats only a small amount (9%) of wastewater from outside its service area.										

Figure 2.4. Data Tables for the City of Paso Robles Water Budget Compiled from Separate Report Sections and Webpage.

documented over extraction of the local groundwater basin and with the city's population and water demand expected to grow (Paso Robles, 2004). These factors indicated that the city would be prudent to secure a new source of water to preserve the local groundwater basin and increase long-term supply reliability (Paso Robles, 2004). In 2003, the city also faced two wastewater discharge challenges: the city's effluent discharge to the Salinas River consistently failed to comply with numerical permit limits for total dissolved solids (TDS), chloride, sodium, and sulphate; and the Regional Water Board indicated that ceasing discharge to the river would likely become a future permit requirement (Paso Robles, 2004). Consequently, the city commissioned a *Water Quality Strategy* (Paso Robles, 2004) to be developed to address the wastewater quality and discharge compliance, water supply, and drinking water quality matters (Paso Robles, 2004).

2.2.3.1 Wastewater Effluent Quality Violations

In 2003, the city provided secondary treatment of an average of almost three million gallons per day (MGD) of wastewater with effluent discharge to the Salinas River (Paso Robles, 2004). The city had difficulty complying with its numerical effluent limit for TDS of 1100 mg/L, as well as its limits for the individual constituents sodium, chloride, and sulphate (Paso Robles, 2004). These limits were specified in the city's National Pollutant Discharge Elimination System (NPDES) permit administered by the Regional Water Quality Control Board (Paso Robles, 2004). The increase in TDS concentration due to use by the city is higher than average, likely reflecting the widespread use of home water softeners as well as commercial and industrial inputs (Paso Robles, 2004). The Regional Water Board encouraged the city to find alternatives to discharging its treated wastewater into the Salinas River (Paso Robles, 2004). Ceasing river discharge would eventually become an NPDES permit requirement for the city, which would require the city to desalinate its wastewater to a level suitable for either wastewater reuse or recharge (Paso Robles, 2004).

2.2.3.2 Reliant Upon Over Extracted Groundwater

In 2003, the city served approximately 26,000 customers and relied on groundwater for all of its water supply (Paso Robles, 2004). The city owns and operates eighteen wells in two major aquifer units (*i.e.*, the relatively shallow Salinas River underflow unit and the deeper Paso Robles formation) and provides disinfection of its groundwater with free chlorine (Paso Robles, 2004). The city had water rights to a specific quantity of water from the Salinas River underflow unit, but withdrawals from the deeper Paso Robles formation were not limited by water rights (Paso Robles, 2004). Localised areas of groundwater table decline were noted in a study commissioned by the county (Paso Robles, 2004). Wells extracting from the Salinas River underflow unit produced water with TDS concentrations ranging from 300 to 800 mg/L, averaging 540 mg/L. A wider range (*i.e.*, 300 to 1000 mg/L) of TDS concentration was observed in the deeper Paso Robles formation wells, although the average TDS from these deeper wells is generally lower (*e.g.*, 450 mg/L) (Paso Robles, 2004). The water delivered to city customers averaged 510 mg/L of TDS according to city water quality reports and consistent with the blend of these two sources (Paso Robles, 2004).

At present, the city operates deep wells that pump percolating groundwater from DWR Basin Number 3-004.06, the Paso Robles area subbasin (Paso Robles, 2021a). The Paso Robles area subbasin has been designated as high priority and critically over-drafted by the state, requiring management under the Sustainable Groundwater Management Act (Paso Robles, 2021a).

2.2.3.3 Population Impacts on Future Water Availability

The population of the City of Paso Robles is expected to increase thirty-seven percent between 2020 and 2045, an average rate of one and a half percent annually, and increase forty-one percent between 2020 and buildout (Paso Robles, 2021a). The city's buildout population threshold is forty-four thousand residents and is projected to occur by 2050 or later (Paso Robles, 2021a). At buildout, residential and non-residential water demand projections assume full development of available parcels (Paso Robles, 2021a). Projected non-revenue water is estimated at about seven percent of total water use based on the city's historical data (Paso Robles, 2021a). Unaccounted for urban water use in California generally ranges from six to fifteen percent (Paso Robles, 2021a). Projected water savings are included in the city's water demand projections (Paso Robles, 2021a). Figure 2.5 lists the projected population and water demand for the City of Paso Robles (Paso Robles, 2021a).

2.2.3.4 Water Data Transparency and Availability

Subsequent to the *Water Quality Strategy* (Paso Robles, 2004) report, the city has published a number of water-related reports including: *Paso Robles Groundwater Basin Management Plan* (Paso Robles, 2011); *City of Paso Robles, California Urban Water Management Plan* (Paso Robles, 2021a); *Annual Water Quality Report* (Paso Robles, 2020); *Salt/Nutrient Management Plan for the Paso Robles Groundwater Basin* (Paso Robles, 2015); *City of Paso Robles Recycled Water Master Plan* (Paso Robles, 2014); *Stormwater Technical Guide - Compliance with Post-Construction Requirements in the city of Paso Robles* (Paso Robles, 2016a); *Paso Robles Subbasin Groundwater Sustainability Plan* (PRSGA, 2019); and *City of El Paso de Robles Wastewater Treatment Plan 2020 Annual Report* (Paso Robles, 2021b). Under the California Public Records Act, members of the public have the right to request and inspect records (Paso Robles, 2022d). Public records include any writing containing

City of Paso Robles Water Use Projections

	2020	2025	2030	2035	2040	2045	Buildout (2050 or later)
Population	31,221	34,400	37,700	39,900	41,900	42,800	44,000
Water Demands (AFY)	5,745	6,515	7,102	7,689	8,277	8,863	9,451
Water Supply Sources to Meet Demands (AFY)							
Basin Wells	954	2,126	2,333	2,550	2,378	1,797	2,127
River Wells	3,609	3,000	3,200	3,500	4,200	4,400	4,558
Nacimiento Water from Water Treatment Plant	968	1,120	1,120	1,120	1,120	2,017	2,017
Nacimiento Water from the Recovery Well	214	269	269	269	269	269	269
Recycled Water for Potable Offset	0	0	180	250	310	380	450
Total Supply	**5,745**	**6,515**	**7,102**	**7,689**	**8,277**	**8,863**	**9,451**

***Note:** Supply amounts in Table ES-1 do not reflect total supply available to the City from each source, nor do they reflect any limits on the City's groundwater rights, but instead the water planned to supply projected demand.*

Figure 2.5. City of Paso Robles Projected Population Growth and Water Demand (Paso Robles, 2021a, Table ES-1).

information relating to the conduct of the public's business prepared, owned, used, or retained by any state or local agency, regardless of physical form or characteristics (Paso Robles, 2022d). These records include records the city has prepared and retained (Paso Robles, 2022d). Members of the public may request copies of a record and the city may have up to ten days to respond to a request (Paso Robles, 2022d).

2.3 Entities that Define Water Quality

Water quality definitions are developed at various levels (*e.g.*, global, national, state). The following sections explore entities that define water quality for the world, the US, California, and the City of Paso Robles.

2.3.1 Entities that Define Water Quality Globally

The United Nations and World Health Organization produce international norms on water quality (WHO, 2022a) as discussed in the two sections that follow.

2.3.1.1 United Nations

The United Nations (UN) is an international organisation founded in 1945 (UN, 2022). Currently made up of one hundred and ninety-three member states, the UN is where all the nations in the world can gather together, discuss common problems, and find shared solutions that benefit all of humanity (UN, 2022). There is no single UN entity dedicated exclusively to water issues (UN-Water, 2022b). Over thirty UN organisations carry out water and sanitation programs, reflecting the fact that water issues run through all of the UN's main focus areas (UN-Water, 2022b). UN-Water coordinates the efforts of UN entities and international organisations working on water and sanitation issues (UN-Water, 2022b). The overarching focus of the members and partners is to support UN member states to sustainably manage water and sanitation by informing policies, monitoring and reporting, and inspiring action (UN-Water, 2022b).

To meet this aim, UN-Water informs policy processes by identifying emerging issues and developing effective, collaborative responses (UN-Water, 2022c). One of UN-Water's key objectives is to provide coherent and reliable data and information on key water trends and management issues (UN-Water, 2022c). During past decades, several initiatives, mechanisms and programs, both within and outside the United Nations family, have been collecting information on the various components of the water cycle (UN-Water, 2022c). The SDG 6 Global Acceleration Framework is a unifying initiative that involves all sectors of society to speed up progress by improving support to countries (UN-Water, 2022c). UN-Water's members and partners have helped place water and sanitation at the heart of recent milestone agreements such as the 2030 Agenda for Sustainable Development, and the 2015 Paris Agreement within the UN Convention Framework on Climate Change (UN-Water, 2022b). UN-Water's consolidated technical advice from UN entities and external organisations helped shape Sustainable Development Goal 6 (SDG 6) to ensure availability and sustainable management of water and sanitation for all (UN-Water, 2022b). As a result, SDG 6 and its various targets take the entire water and sanitation cycle into account.

Publications are a major output of UN-Water (UN-Water, 2022a). These products are developed in different ways, take various forms and are used by many different stakeholders (UN-Water, 2022a). What they have in common is that they draw on the experience and expertise of UN-Water's members and partners (UN-Water, 2022a). UN-Water's publications can be divided into two main groups: the publications that represent all members and partners of UN-Water – the collective products – and the publications that are under the

UN-Water umbrella but produced by groups or individual UN-Water members and/or partners – the related products (UN-Water, 2022a). Four of the most recent reports related to water quality include (UN-Water, 2022a): *Progress on Wastewater Treatment – 2021 Update*; *Progress on Ambient Water Quality – 2021 Update*; *Progress on Water-related Ecosystem – 2021 Update*; and *Toward a Worldwide Assessment of Freshwater Quality* (2016).

2.3.1.2. World Health Organization

Founded in 1948, the World Health Organization (WHO) is the United Nations agency that connects nations, partners, and people to promote health (WHO, 2022a). The WHO produces international norms on water quality and human health in the form of guidelines that are used as the basis for regulation and standard-setting worldwide (WHO, 2022b).

The WHO has continually produced guidance on the management of drinking-water quality since 1958 when it published the international standards for drinking water (WHO, 2022b). These standards were subsequently revised in 1963 and in 1971 under the same title (WHO, 2022b). In 1984, the international standards for drinking water were replaced with the first edition of the *Guidelines for Drinking-water Quality* (GDWQ), recognising the advantage of using a risk-benefit approach in the establishment of national standards and regulations (WHO, 2022b). Subsequent editions of the GDWQ were published in 1993, 2004 and 2011 (WHO, 2022b). Since 1995, the GDWQ has been kept up to date through a process of rolling revision (WHO, 2022b).

The GDWQ promote the protection of public health by advocating for the development of locally relevant standards and regulations, adoption of preventive risk management approaches covering catchment to consumer, and independent surveillance to ensure that Water Safety Plans are being implemented and effective and that national standards are being met (WHO, 2022b). The GDWQ are updated through a rolling revision process which ensures that they present the latest scientific evidence and address key concerns raised by countries (WHO, 2022b). This has been achieved by systematically updating sections of the GDWQ as new or updated evidence becomes available (WHO, 2022b). The purpose of the rolling revision process is to maintain the relevance, quality and integrity of the GDWQ, whilst ensuring their continuing development in response to new, or newly appreciated, information and challenges (WHO, 2022b). The rolling revision approach also helps implementation of the GDWQ by national agencies by promoting regular, incremental improvement, rather than attempting to promote the implementation of major, comprehensive changes to drinking-water quality management all at once (WHO, 2022b).

The WHO also produces the *Guidelines on Recreational Water Quality* (WHO, 2021). These guidelines focus on water quality management for coastal and freshwater environments to protect public health (WHO, 2021). The guidelines describe the current state of knowledge about the possible adverse health impacts of various forms of water pollution, and set out recommendations for setting national health-based targets, conducting surveillance and risk assessments, putting in place systems to monitor and control risks, and providing timely advice to users on water safety (WHO, 2021). These guidelines are aimed at national and local authorities, and other entities with an obligation to exercise due diligence relating to the safety of recreational water sites (WHO, 2021). They may be implemented in conjunction with other measures for water safety (such as drowning prevention and sun exposure) and measures for environmental protection of recreational water use sites (WHO, 2021).

2.3.2 Entities that Define Water Quality for the United States

The United States Environmental Protection Agency is responsible for setting water quality definitions at the national level. Those definitions are published in the United States Code of Federal Regulations and in the laws related to water quality (*e.g.*, Clean Water Act, Safe Drinking Water Act), as described in the sections that follow.

2.3.2.1 United States Environmental Protection Agency

The United States Environmental Protection Agency (US EPA) was created on December 2, 1970 by President Richard Nixon (US EPA, 2022c). The mission of the US EPA is to protect human health and the environment (US EPA, 2022d). The United States Congress authorises the US EPA to write regulations *(i.e.*, mandatory requirements that can apply to individuals, businesses, state or local governments, non-profit institutions, or others) that explain the technical, operational, and legal details necessary to implement laws (US EPA, 2022a).

2.3.2.2 Code of Federal Regulations

US EPA regulations are codified annually in the US Code of Federal Regulations (CFR) (US EPA, 2022a). Title 40 (*i.e.*, Protection of Environment) is the section of the CFR that involves US EPA's mission of protecting human health and the environment (US EPA, 2022a). The Federal Register (FR) is the official daily publication for rules, proposed rules, and notices of federal agencies and organisations, as well as executive orders (US EPA, 2022a). The FR announces ongoing activities of the agencies and notifies the public when public comment periods open for a proposed regulation (US EPA, 2022a). Once a final decision is issued in the form of a final regulation, the regulation is then codified when it is incorporated into the CFR (US EPA, 2022a).

2.3.2.3 Primary National Laws Related to Water Quality in the United States

The primary national-level laws related to water quality in the US are, as described in the sections that follow, the: Clean Water Act; Marine Protection, Research and Sanctuaries Act; Shore Protection Act; Safe Drinking Water Act; and Beaches Environmental Assessment and Coastal Health Act.

2.3.2.3.1 Clean Water Act

The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters (US EPA, 2022b). The basis of the CWA was enacted in 1948 and was called the Federal Water Pollution Control Act, but the act was significantly reorganised and expanded in 1972 (US EPA, 2022b). Clean Water Act became the act's common name with amendments in 1972 (US EPA, 2022b). Under the CWA, the US EPA implements pollution control programs (*e.g.*, setting wastewater standards for industry) and develops national water quality criteria recommendations for pollutants in surface waters (US EPA, 2022b). The CWA makes it unlawful to discharge any pollutant from a point source into navigable waters, unless a permit is obtained (US EPA, 2022b). US EPA's National Pollutant Discharge Elimination System (NPDES) permit program controls point source (*e.g.*, pipes or man-made ditches) discharges (US EPA, 2022b).

2.3.2.3.2 Marine Protection, Research, and Sanctuaries Act

Titles I and II of the Marine Protection, Research, and Sanctuaries Act (MPRSA), also referred to as the Ocean Dumping Act, generally prohibit transportation of material from the United States for the purpose of ocean dumping, transportation of material from anywhere for the purpose of ocean dumping by US agencies or US-flagged vessels, and dumping of material transported from outside the United States into the US territorial sea (US EPA, 2022b). A permit is required to deviate from these prohibitions (US EPA, 2022b). Under MPRSA, the standard for permit issuance is whether the dumping will unreasonably degrade or endanger human health, welfare, or the marine environment (US EPA, 2022b). The US EPA is charged with developing ocean dumping criteria to be used in evaluating permit applications (US EPA, 2022b). The MPRSA provisions administered by US EPA are published in Title 33 of the US Code (US EPA, 2022b). The MPRSA provisions that address marine sanctuaries are administered by the National Oceanic and Atmospheric Administration and are published in Title 16 of the US Code (US EPA, 2022b).

2.3.2.3.3 Shore Protection Act

Title IV of the Ocean Dumping Ban Act of 1988 created the Shore Protection Act of 1988 (SPA), which prohibits the transportation of municipal or commercial waste within coastal waters by a vessel without a permit (US EPA, 2022b). Permits last for five years or until the vessel is sold (US EPA, 2022b). US EPA, in consultation with the United States Coast Guard, is responsible for developing regulations governing the loading, securing, offloading, and cleaning up of such wastes from waste sources, reception facilities, and vessels (US EPA, 2022b). The goals of the regulations are to minimise deposit of waste into coastal waters during vessel loading, transport, and unloading, and to ensure that any deposited waste is reported and cleaned up (US EPA, 2022b).

2.3.2.3.4 Safe Drinking Water Act

The Safe Drinking Water Act (SDWA) was established to protect the quality of drinking water in the US (US EPA, 2022b). This law focuses on all waters actually or potentially designed for drinking use, whether from above ground or underground sources (US EPA, 2022b). The act authorises US EPA to establish minimum standards to protect tap water and requires all owners or operators of public water systems to comply with these primary (*i.e.*, health-related) standards (US EPA, 2022b). The 1996 amendments to SDWA require that US EPA consider a detailed risk and cost assessment, and best available peer-reviewed science, when developing these standards (US EPA, 2022b). State governments, which can be approved to implement these rules for US EPA, also encourage attainment of secondary standards (*i.e.*, nuisance-related standards) (US EPA, 2022b). Under the act, US EPA also establishes minimum standards for state programs to protect underground sources of drinking water from endangerment by underground injection of fluids (US EPA, 2022b).

2.3.2.3.5 Beaches Environmental Assessment and Coastal Health Act

The Beaches Environmental Assessment and Coastal Health (BEACH) Act amended the Clean Water Act in 2000 (US EPA, 2022b). It is designed to reduce the risk of disease to users of the nation's coastal recreational waters (US EPA, 2022b). The act authorises the US EPA to award program development and implementation grants to eligible states, territories, tribes, and local governments to support microbiological testing and monitoring of coastal recreational waters, including the Great Lakes and waters adjacent to beaches or similar points of access used by the public (US EPA, 2022b). BEACH Act grants also provide support for developing and implementing programs to notify the public of the potential for exposure to microorganisms (*i.e.*, disease-causing organisms) in coastal recreational waters

(US EPA, 2022b). The act also authorises US EPA to provide technical assistance to states and local governments for the assessment and monitoring of floatable materials (US EPA, 2022b). US EPA created the Beach Advisory and Closing Online Notification (BEACON) system to meet the agency's requirement to provide to the public with a database of pollution occurrences for coastal recreational waters (US EPA, 2022b). BEACON contains state-reported beach monitoring and notification data and is available online (US EPA, 2022b).

2.3.2.4 Primary National Law Related to Public Access to Information

The Freedom of Information Act (FOIA), enacted in 1966, is a federal law that provides that any person has a right, enforceable in court, to obtain access to federal agency records (US EPA, 2022b). All federal agencies, including the US EPA, are required to make requested records available unless the records are protected from disclosure by one of the exemptions contained in the statute (US EPA, 2022b). FOIA applies only to federal agencies (US EPA, 2022b). Each state has its own public access laws for access to state and local records (US EPA, 2022b).

2.3.3 Entities that Define Water Quality for California

The State Water Resources Control Board (State Water Board) and the nine Regional Water Quality Control Boards (Regional Water Boards), collectively known as the California Water Boards (Water Boards), are dedicated to a single vision: abundant clean water for human uses and environmental protection to sustain California's future. Under the federal Clean Water Act (CWA) and the state's Porter-Cologne Water Quality Control Act, the State and Regional Water Boards have regulatory responsibility for protecting the water quality of nearly 1.6

million acres of lakes, 1.3 million acres of bays and estuaries, 211,000 miles of rivers and streams, and about 1,100 miles of coastline (SWRCB, 2022).

2.3.3.1 State Water Resources Control Board

The State Water Board was created by the California Legislature in 1967 (SWRCB, 2022). The mission of the Water Boards is to ensure the highest reasonable quality for waters of the state, while allocating those waters to achieve the optimum balance of beneficial uses (SWRCB, 2022). The joint authority of water allocation and water quality protection enables the Water Boards to provide comprehensive protection for California's waters (SWRCB, 2022). The State Water Board consists of five full-time salaried members, each filling a different specialty position, and each board member is appointed to a four-year term by the Governor and confirmed by the Senate (SWRCB, 2022).

2.3.3.2 Regional Water Quality Control Board

The mission of the nine Regional Water Boards is to develop and enforce water quality objectives and implementation plans that will best protect the beneficial uses of the state's waters, recognising local differences in climate, topography, geology and hydrology (SWRCB, 2022). Each Regional Water Board has seven part-time members also appointed by the Governor and confirmed by the Senate (SWRCB, 2022). Regional Water Boards develop basin plans for their hydrologic areas, issue waste discharge permits, take enforcement action against violators, and monitor water quality (SWRCB, 2022).

2.3.3.3 Porter-Cologne Water Quality Control Act

The Porter-Cologne Act is the principal law governing water quality in California (SWRCB, 2022). It establishes a comprehensive program to protect water quality and the beneficial uses of water. Unlike the federal CWA, the Porter-Colone Act applies to both surface water and groundwater (SWRCB, 2022). The act designates the State Water Board as the statewide water quality planning agency, and also gives authority to the nine semi-autonomous Regional Water Boards that were established twenty years earlier (SWRCB, 2022). The State Water Board is responsible for developing statewide water quality plans (*e.g*., Ocean Plan, Inland Surface Waters Plan), while the Regional Water Boards are responsible for developing Regional Water Quality Plans (*i.e*., basin plans) (SWRCB, 2022). The basin plans in turn are approved by the State Water Board and US EPA (SWRCB, 2022). These plans, both statewide and basin, include the identification of beneficial uses, water quality objectives, and implementation plans (SWRCB, 2022). Regional Water Boards have the primary responsibility for implementing the provisions in both statewide and basin plans (SWRCB, 2022).

2.3.4 Entities that Define Water Quality for the City of Paso Robles

The City of El Paso de Robles is a general law city organised, formed, and incorporated under the laws of the State of California on March 11, 1889 (Paso Robles, 2022a). It has a Council-Manager general law form of government where the City Council: establishes policies; adopts ordinances and approves resolutions; makes land use decisions; approves agreements and contracts; sets water and sewer rates; and approves the city's budget (Paso Robles, 2022a). The council appoints a City Manager, who is the chief executive officer of the municipal corporation (Paso Robles, 2022a). The manager hires staff, recommends policies to the council, and is responsible for the administration of all city programs (Paso Robles, 2022a). The council acts as the board of directors of the municipal corporation and meets in a public forum so that citizens may monitor and participate in the governmental process (Paso Robles, 2022a).

Ordinances are the laws of a municipality; they are the acts or laws of a local governmental agency, expressed in written ordaining form (Paso Robles, 2022b). They are the most binding form of action taken by the city council, the violation of which can be a misdemeanor (Paso Robles, 2022b). Approval of an ordinance requires a first and second reading, with at least five days between (Paso Robles, 2022b). Ordinances are codified into the Municipal Code Online Library following their second reading and adoption by the city council (Paso Robles, 2022b). The Municipal Code is a codified compilation of all regulatory ordinances of a municipality's rules, regulations or standards (Paso Robles, 2022b).

Title 14 of the Municipal Code is the Water and Sewers chapter (Paso Robles, 2022c). The purpose of this chapter is to ensure the health, safety and general welfare of citizens, and to protect and enhance the water quality of watercourses and water bodies in a manner pursuant to and consistent with the Federal Clean Water Act (33 U.S.C. § 1251 et seq.) and the Porter-Cologne Water Quality Control Act (Water Code § 13000 et seq.) by reducing pollutants in stormwater discharges to the maximum extent practicable and by effectively prohibiting non-stormwater discharges to the storm drain system (Paso Robles, 2022c). The sections that pertain to water quality include: 14.06 Groundwater; 14.07 Definitions; 14.08 Septic; 14.10 Local Limits; 14.16 Sewer Charges; and 14.20 Stormwater (Paso Robles, 2022c).

2.3.5 Research Gap

Water quality definitions are developed at various levels. The United Nations and World Health Organization produce international norms on water quality (WHO, 2022a). In the US, the EPA is responsible for setting water quality definitions at the national level (US EPA, 2022d). In California, the Water Boards ensure the highest reasonable quality for waters of the state (SWRCB, 2022). Paso Robles uses the municipal code to protect and enhance the water quality of watercourses and water bodies (Paso Robles, 2022c). The literature review above reveals the organisations responsible for defining water quality at various scales. How do each of these organisations define water quality? What method do they use? What are the resulting definitions? How do these definitions of water quality compare? Do they apply to California? Can these definitions be used to add water quality to a water budget for California?

How each of these organisations define water quality; the method they apply; the resulting definitions; how these definitions of water quality compare; whether they apply to California; and whether these definitions can be used to add water quality to a water budget for California, remains to be investigated.

2.4 Existing Water Quality Scales and Formats

Water quality scales organise categories of varying quality water for one or more constituents. Examples of existing water quality scales can be found in both the academic literature and in practice. These scales are organised in different ways to serve different purposes, as described in the following sections.

2.4.1 Single Constituents

Scales measuring the concentration of one constituent are organised in the form of steadily increasing concentration with each level of measurement. For example, the salinity scale (Hillel, 2000) (Figure 2.6) ranges from fresh water to brine with increasing concentrations of salinity. United Nations Environment Program's (UNEP 2016) river concentrations of faecal coliform scale (Figure 2.7) is an example of increasing levels of pollution organised into three classes (*i.e*., low, moderate, severe). These scales are easily organised, read, and understood, however, characterising water quality by a single parameter does not provide information about the other aspects of the water's quality (*e.g*.., bacteriological, chemical, physical).

2.4.2 Multiple Constituents

Scales measuring the concentrations of multiple constituents are organised in different ways to serve different purposes. This section provides seven examples, including water types and grades organised by: historical precedence; decreasing water quality; degree of restriction on use; degree of restriction on contact; water quality test measures; water quality index designations; and level of treatment required.

2.4.2.1 Water Types and Grades Organised by Historical Precedence

The American Society for Testing and Materials (ASTM) D1193-06 (2011) standard is an international standard specification for laboratory reagent water. It includes four types of water (*i.e*., I, II, III, and IV), each with three grades (*i.e*., A, B, and C). The four types of water are assigned in order of historical precedence and are not necessarily an indication of progression in water purity. The grade specifications specifically address contaminants of microbiological origin. The water quality parameters include: electrical conductivity;

Water Salinity

Salinity Status	Salinity (%)	Salinity (ppt)	Use
Fresh	< 0.05	< 0.5	Drinking and all irrigation
Marginal	0.05 – 0.1	0.5 – 1	Most irrigation, adverse effects on ecosystems become apparent
Brackish	0.1 – 0.2	1 – 2	Irrigation certain crops only; useful for most stock
Saline	0.2 – 1.0	2 – 10	Useful for most livestock
Highly Saline	1.0 – 3.5	10 – 35	Very saline groundwater, limited use for certain livestock
Brine	> 3.5	> 35	Seawater; some mining and industrial uses exist

Salinity increasing in concentration from fresh water to brine.

concentration

low

high

Single Constituent: Salinity.

Figure 2.6. Format Example of a Single Constituent Water Quality Scale Increasing in Concentration: Water Salinity (Hillel, 2000).

Water pollution class	Faecal coliform concentration (cfu/100 ml)	Description
Low pollution	x ≤ 200	Generally suitable for contact (including, e.g. swimming and bathing)
Moderate pollution	200 < x ≤ 1,000	Only suitable for contact during irrigation and fishing activities, but not for other contact
Severe pollution	x > 1,000	Generally unsuitable for contact

Three classes of increasing pollution levels: low; moderate; and severe.

Single Constituent: Faecal coliform.

pollution

low

high

Figure 2.7. Format Example of a Single Constituent Scale with Three Classes of Decreasing Water Quality: Classes of Pathogen Water Pollution According to River Concentrations of Faecal Coliform Bacteria in Colony Forming Units (CFU) per 100 Milliliters (UNEP, 2016, Table 3.1).

electrical resistivity; pH; total organic carbon; sodium; chloride ions; heterotrophic bacteria; and endotoxins (Figure 2.8).

2.4.2.2 Water Grades Organised by Decreasing Water Quality

Other industrial water standards include the International Organization for Standardization (ISO) Standard 3696, *Water for Analytical Laboratory Use* (Figure 2.9), and the Clinical and Laboratory Standards Institute (CLSI) Standard GP40-A4-AMD, *Preparation and Testing of Reagent Water in the Clinical Laboratory*. These standards are both organised in classes of decreasing water quality. The highest level of water quality is used for critical laboratory applications, the middle level of quality is used for general laboratory applications, and the lowest level is used for rinsing glassware, for example.

2.4.2.3 Organised by Degree of Restriction on Use

The US EPA collaborated with the US Agency for International Development (US AID) to develop the *2012 Guidelines for Water Reuse*. The report defines reclaimed water as municipal wastewater that has been treated to meet specific water quality criteria for a range of purposes (US EPA, 2012b). The US EPA has developed a scale of water quality for irrigation, adapted from the Food and Agricultural Organization (FAO) scale (Ayers and Westcot, 1985), that is organised by three degrees of restriction: none; slight to moderate; and severe (Figure 2.10). The scale's multiple constituents include: salinity (*i.e.*, electrical conductivity and total dissolved solids); sodium adsorption ratio; sodium; chloride; boron; nitrate; bicarbonate; and pH.

Multiple Constituents: Conductivity; Resistance; pH; Total Organic Carbon; Sodium; Chloride, Silicon; Bacteria; and Endotoxins.

ASTM D1193-06 (2011)

	Type	Grade	Conductivity (µS/cm), max.	Resistance (MΩ x cm), min.	pH	TOC (µg/l), max.	Sodium (µg/l), max.	Chloride (µg/l), max.	Silicon (µg/l), max.	Bacteria (CFU/ml), max.	Endotoxins (EU/ml), max.
Ultrapure Water	I*		0.056	18.0	–	50	1	1	3	–	–
	I*	A	0.056	18.0	–	50	1	1	3	10/1000	0.03
	I*	B	0.056	18.0	–	50	1	1	3	10/100	0.25
	I*	C	0.056	18.0	–	50	1	1	3	100/10	–
Pure water	II		1.0	1.0	–	50	5	5	3	–	–
	II	A	1.0	1.0	–	50	5	5	3	10/1000	0.03
	II	B	1.0	1.0	–	50	5	5	3	10/100	0.25
	II	C	1.0	1.0	–	50	5	5	3	100/10	–
Pure water	III		0.25	4.0	–	200	10	10	500	–	–
	III	A	0.25	4.0	–	200	10	10	500	10/1000	0.03
	III	B	0.25	4.0	–	200	10	10	500	10/100	0.25
	III	C	0.25	4.0	–	200	10	10	500	100/10	–
Pure water	IV		5.0	0.2	5.0–8.0	–	50	50	–	–	–
	IV	A	5.0	0.2	5.0–8.0	–	50	50	–	10/1000	0.03
	IV	B	5.0	0.2	5.0–8.0	–	50	50	–	10/100	0.25
	IV	C	5.0	0.2	5.0–8.0	–	50	50	–	100/10	–

*Using an appropriate 0,2 µm membrane filter.

Four Types: I; II; III; and IV.

Three Grades: A; B; and C.

Figure 2.8. Multi-constituent Water Quality Scale Example Organised into Four Types of Water Each with Three Grades: International Standard Specification for Laboratory Reagent Water (ASTM D1193-06, 2011).

Three grades of decreasing water quality: 1; 2; and 3.

ISO 3696:1987

Multiple Constituents: pH; conductivity; oxidizable matter; absorption; residue; and silicon content.

Parameter	Grade 1	Grade 2	Grade 3
pH value at 25 °C	–	–	5.0–7.0
Conductivity (µS/cm at 25 °C)	0.1	1.0	5.0
Oxidizable matter, oxygen content (mg/l, max.)	–	0.08	0.4
Absorption at 254 nm and a lenght of 1 cm (absorption units, max.)	0.001	0.01	–
Residue after evaporation by heating to 110 °C (mg/kg, max.)	–	1	2
Silicon content (mg/l, max.)	0.01	0.02	–

high → low

purity

Figure 2.9. Example of a Multi-constituent Scale with Three Grades of Decreasing Water Quality: International Standard for Analytical Laboratory Use Water (ISO 3696, 1987).

Three degrees of restriction: none; slight to moderate; and severe.

Multiple Constituents: Salinity (*i.e.*, electrical conductivity and total dissolved solids); Sodium Adsorption Ratio (SAR); Sodium; Chloride; Boron; Nitrate; Bicarbonate; and pH.

Guidelines for interpretation of water quality for irrigation[1]

Potential Irrigation Problem		Units	Degree of Restriction on Irrigation: None	Slight to Moderate	Severe
Salinity *(affects crop water availability)*[2]					
	EC_w	dS/m	< 0.7	0.7 – 3.0	> 3.0
	TDS	mg/L	< 450	450 – 2000	> 2000
Infiltration *(affects infiltration rate of water into the soil; evaluate using EC_w and SAR together)*[3]					
SAR	0 – 3	**and EC_w =**	> 0.7	0.7 – 0.2	< 0.2
	3 – 6		> 1.2	1.2 – 0.3	< 0.3
	6 – 12		> 1.9	1.9 – 0.5	< 0.5
	12 – 20		> 2.9	2.9 – 1.3	< 1.3
	20 – 40		> 5.0	5.0 – 2.9	< 2.9
Specific Ion Toxicity *(affects sensitive crops)*					
	Sodium (Na)[4]				
	surface irrigation	SAR	< 3	3 – 9	> 9
	sprinkler irrigation	meq/l	< 3	> 3	
	Chloride (Cl)[4]				
	surface irrigation	meq/l	< 4	4 – 10	> 10
	sprinkler irrigation	meq/l	< 3	> 3	
	Boron (B)	mg/L	< 0.7	0.7 – 3.0	> 3.0
Miscellaneous Effects *(affects susceptible crops)*					
	Nitrate (NO_3-N)	mg/L	< 5	5 – 30	> 30
	Bicarbonate (HCO_3)	meq/L	< 1.5	1.5 – 8.5	> 8.5
	pH		**Normal Range 6.5 – 8.4**		

[1] Adapted from FAO (1985)
[2] EC_w means electrical conductivity, a measure of the water salinity, reported in deciSiemens per meter at 25°C (dS/m) or in millimhos per centimeter (mmho/cm); both are equivalent.
[3] SAR is the sodium adsorption ratio; at a given SAR, infiltration rate increases as water salinity increases.
[4] For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; most annual crops are not sensitive. With overhead sprinkler irrigation and low humidity (< 30 percent), sodium and chloride may be absorbed through the leaves of sensitive crops.

pollution low → high

Figure 2.10. Three Degrees of Restriction Multi-constituent Water Quality Scale Format Example: Guidelines for Interpretation of Water Quality for Irrigation (US EPA, 2012b, Table 3-4).

2.4.2.4 Organised by Degree of Restriction on Contact

Abdul Azis *et al.* (2018) propose a methodology to determine the quality of coastal waters for recreational purposes in the Colombian Caribbean. The proposal includes seven variables indicative of water quality (*i.e.*, total coliform; faecal coliform; biochemical oxygen demand; total suspended solids; ammonium; nitrates; and soluble phosphorus), in three scenarios: normative; permissive; and restrictive, each with four categories of contamination (*i.e.*, low, medium, high, and very high), where high is the maximum allowable contaminant level and very high exceeds the maximum contaminant level allowed (Figure 2.11).

2.4.2.5 Classes of Effluent Organised by Water Quality Test Measures

The National Sanitation Foundation, now known as NSF International, and the American National Standard Institute (ANSI) developed NSF/ANSI Standard 350 for *Onsite Residential and Commercial Water Reuse Treatment Systems* in 2011. End uses appropriate for water from these systems include indoor restricted urban water use, such as toilet flushing, and outdoor unrestricted urban use, such as surface irrigation (US EPA, 2012b). The standard categorises effluent water quality criteria into two classes (*i.e*., class R for residential, and class C for commercial). The effluent criteria for each class include two measures of water quality (*i.e*., test average, and single sample maximum). The scale includes multiple constituents: 5-day carbonaceous biological oxygen demand; total suspended solids; turbidity; E. coli; pH; storage vessel disinfection; colour; odour; oily film and foam; and energy consumption (Figure 2.12).

2.4.2.6 Water Quality Index Designations

Similar to indices of economic strength, such as Gross National Product (GNP), the Water Quality Index (WQI) combines information from a number of sources to develop an overall

Four categories of water quality: low; medium; high; and very high.

Multiple constituents: total coliform; faecal coliform; biochemical oxygen demand; total suspended solids; ammonium; nitrates; soluble phosphorus.

Three scenarios: restrictive; normative; and permissive.

Scenario	Category	RANGES						
		TC (NMP/100 ml)	FC (NMP/100 ml)	BOD (mg/l)	TSS (mg/l)	NH4 (μg/l)	NO3 (μg/l)	PO4 (μg/l)
Restrictive	L	0–2	0–2	<0.5	0–1	<10	<10	<10
	M	3–19	3–19	0.5–0.8	2–3	10–15	10–50	10–17
	H	20–500	20–100	0.9–1.2	4–5	16–20	51–100	18–25
	VH	>500	>100	>1.2	>5	>20	>100	>25
Normative	L	0–2	0–2	<0.5	0–1	<10	<10	<10
	M	3–19	3–19	0.5–1.0	2–4	10–25	10–120	10–17
	H	20–1000	20–200	1.0–2.0	5–8	26–50	121–240	18–25
	VH	>1000	>200	>2.0	>8	>50	>240	>25
Permissive	L	0–2	0–2	0.4–1.0	0–10	0–50	10–120	0–25
	M	21–2000	21–400	1.1–4.0	11–20	51–100	121–240	26–50
	H	2001–5000	401–700	4.1–7.0	21–30	101–150	241–360	51–75
	VH	>5000	>700	>7.0	>30	>150	>360	>75

Figure 2.11. Multi-constituent Water Quality Scale Format Example of Three Degrees of Contact Restriction Each with Four Levels of Contamination: Recreational Water Contact Restriction in the Columbian Caribbean (Abdul azis *et al*., 2018, Table 2).

Two measures of water sampling test results: test average and single sample maximum.

Multiple Constituents: 5-day carbonaceous biological oxygen demand; total suspended solids; turbidity; E. coli; pH; storage vessel disinfection; colour; odour; oily film and foam; and energy consumption.

Summary of NSF Standard 350 Effluent Criteria for individual classifications

Parameter	Class R		Class C	
	Test Average	Single Sample Maximum	Test Average	Single Sample Maximum
$CBOD_5$ (mg/L)	10	25	10	25
TSS (mg/L)	10	30	10	30
Turbidity (NTU)	5	10	2	5
E. coli [2] (MPN/100 mL)	14	240	2.2	200
pH (SU)	6.0 – 9.0	NA[1]	6.0 – 9.0	NA
Storage vessel disinfection (mg/L)[3]	≥ 0.5 – ≤ 2.5	NA	≥ 0.5 – ≤ 2.5	NA
Color	MR[4]	NA	MR	NA
Odor	Nonoffensive	NA	Nonoffensive	NA
Oily film and foam	Nondetectable	Nondetectable	Nondetectable	Nondetectable
Energy consumption	MR	NA	MR	NA

1 NA: not applicable
2 Calculated as geometric mean
3 As total chlorine; other disinfectants can be used
4 MR: Measured reported only

Figure 2.12. Format Example of a Multi-constituent Water Quality Scale with Two Test Result Measures: Summary of NSF/ANSI Standard 350 Greywater Effluent Criteria for Residential (*i.e.*, Class R) and Commercial (*i.e.*, Class C) Use (US EPA, 2012b, Table 2-5).

snapshot of the state of the system (UNEP, 2007). Even though there is considerable debate as to which measures should be included in the derivation of an index, and which information the index provides to the general public and to policymakers, there is some agreement that water quality indices are useful tools for comparing water quality across systems and over time (UNEP, 2007). They can also provide a benchmark for evaluating successes and failures of management strategies aimed at improving water quality (UNEP, 2007). The water quality index (WQI) equation (Figure 2.13) generates a number between one and one hundred, with one being the poorest and one hundred indicating the best water quality (UNEP, 2007). Within this range, five designations have been set to classify water quality as: poor; marginal; fair; good; or excellent (UNEP, 2007). The designations are presented in Figure 2.13.

2.4.2.7 Water Quality Categories Organised by Level of Treatment Required

Guidelines for industrial water quality, outlined in the *South African Water Quality Guidelines*, consider water quality as it pertains to specific industrial processes, such that the overall water quality requirements of any industry can be defined as the sum of the specific water quality requirements of each process type (IWRA, 2018). Four water quality categories are defined, and industry-specific water uses are allocated to each of these four categories based on the stringency of water quality required for each use (IWRA, 2018). Category one covers processes that require high quality water, whereas category four incorporates water uses that can utilise water of basically any quality without serious repercussions (Figure 2.14). Water use requirements for each process type are defined according to common water quality problems associated with water use (*e.g.*, corrosion, fouling, scaling), the effects of inappropriate water quality, constituents of water identified as a source of concern, and specific cases that may influence water quality requirements (IWRA, 2018). Figure 2.14

Water Quality Index (WQI) allows multiple constituents to be evaluated at once using one number that represents compliance with multiple water quality parameter standards.

$$\text{WQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right)$$

pollution

low

high

Designation	Index value	Description
Excellent	95-100	All measurements are within objectives virtually all of the time
Good	80-94	Conditions rarely depart from natural or desirable levels
Fair	65-79	Conditions sometimes depart from natural or desirable levels
Marginal	45-64	Conditions often depart from natural or desirable levels
Poor	0-44	Conditions usually depart from natural or desirable levels

Five designations of water quality: excellent; good; fair; marginal; and poor.

F_1 represents <u>Scope</u>: The percentage of parameters that exceed the guideline

$$F_1 = \left(\frac{\#\ \text{failed parameters}}{\text{Total}\ \#\ \text{of parameters}}\right) \times 100$$

F_2 represents <u>Frequency</u>: The percentage of individual tests within each parameter that exceeded the guideline

$$F_2 = \left(\frac{\#\ \text{failed tests}}{\text{Total}\ \#\ \text{of tests}}\right) \times 100$$

F_3 represents <u>Amplitude</u>: The extent (excursion) to which the failed test exceeds the guideline. This is calculated in three stages. First, the excursion is calculated

$$\text{excursion} = \left(\frac{\text{failed test value}}{\text{guideline value}}\right) - 1$$

NB: in the case of pH where a minimum and maximum guideline is given, the excursion equation must be run as above as well as in reverse i.e. guideline value/failed test value.

Second, the normalized sum of excursions (nse) is calculated as follows:

$$\text{nse} = \left(\frac{\sum \text{excursion}}{\text{total}\ \#\ \text{of tests}}\right)$$

F_3 is then calculated using a formula that scales the nse to range between 1 and 100:

$$F_3 = \left(\frac{nse}{0.01\text{nse} + 0.01}\right)$$

Figure 2.13. Water Quality Index (WQI) Equation and Designations shown as published in the Global Drinking Water Quality Index Development and Sensitivity Analysis Report (UNEP, 2007, Table 6).

Category	Process	Water use
Category 1	Cooling water	Evaporative cooling (high recycle)
	Steam generation	High pressure (HP) boiler: demineralisation of feed water
	Process water	Phase separation
	Product water	Petrochemicals
		Pharmaceuticals
	Wash water	No residual washing (electronic parts)
Category 2	Cooling water	Evaporative cooling (high recycle)
		Solution cooling
		Water heating
	Steam generation	HP boiler: demineralisation feed
	Process water	Solvent
		Heat transfer medium
		Lubrication
		Gas cleaning
	Product water	Beverages
		Dairy products
		Petrochemicals
	Wash water	Reaction vessel washing
Category 3	Cooling water	Evaporative cooling: (once through)
		Bearing cooling
		Mould cooling
	Steam generation	Low pressure (LP) boiler: (softener feed)
	Process water	Solvent
		Dilution agent
		Transport agent
		Gland seal
		Vacuum seal
		Lubrication
		Descaling (iron and steel)
		Gas scrubbing
	Product water	Beverages
		Food products
		Baking
		Confectionary
		Chemicals
		Surface washing (table tops, walls)
	Utility water	Domestic use
		Fire fighting
Category 4	Cooling water	Ash quenching
	Process water	Transport agent
	Utility water	Dust suppression
		Fire fighting
		Irrigation
	Wash water	Rough washing (floors, rough apparatus, trucks, raw materials)

Four categories: 1; 2; 3; and 4.

Organised by level of treatment required.

Pollution level: low → high

Treatment level: high → low

Category	Water Quality	Technology & Costs Required
Category 1	Processes that require a high-quality water with relatively tight to stringent specifications of limits for most or all the relevant water quality constituents.	Standard or specialised technology is essential to provide water conforming to the required quality specifications. Consequently, costs of in-house treatment to provide such water are a major consideration in the economy of the process.
Category 2	Processes that require water of a quality intermediate between the high quality required for Category 1 processes and domestic water quality (Category 3).	Standard technology is usually sufficient to reach the required water quality criteria. Cost for such additional water treatment begins to be significant in the economy of the process.
Category 3	Processes for which domestic water quality is the baseline minimum standard.	Water of domestic quality may be used in the process without further treatment, or minimum treatment using low to standard technology may be necessary to reach the specifications. Costs of further in-house treatment are not significant in the economy of the process.
Category 4	Processes that, within certain limitations, can use water of more or less any quality for their purposes without creating any problems.	No additional treatment is usually required and there is therefore no further cost.

Figure 2.14. Four Categories of Water Quality for Industrial Use Organised by Level of Treatment Required: South African Water Quality Guidelines (IWRA, 2018, Table 12 & 13).

provides a full list of processes and water uses according to each category in the guidelines (IWRA, 2018).

2.4.3 Research Gap

A review of existing water quality scales in both the academic literature and industry has identified examples of single- and multi-tiered scales that group levels of water quality into categories. Existing water quality scales are used to organise, for example: laboratory reagent water into four types ordered by historical precedence (ASTM, 2011); irrigation water into three degrees of restricted use (US EPA, 2012b); effluent water quality criteria into commercial and residential classes (US EPA, 2012b); and multiple water quality parameters into a single water quality index value (UNEP, 2007).

Scales of water quality are a useful format for separating water into different quality levels. None of the scales found in the literature review include all of the types of water in a water budget in California. Cumulatively, they provide options for the organisation and structure of tiers of water quality that could be used to add water quality to a water budget in California.

2.5 Material Flow Analysis

This section reviews methods for quantifying mass and material flows. A mass balance, based on the law of conservation of mass, accounts for all of the material entering and leaving a system. The reconciliation of mass flows in a balance, allowing flows that are unknown or difficult to measure directly to be estimated by a simple calculation, since mass can neither disappear nor be created spontaneously.

Material Flow Analysis (MFA) is an analytical method used to quantify flows and stocks of materials in a well-defined system. MFA, a central methodology of industrial ecology, quantifies the ways in which the materials that enable modern society are used, reused, and lost (Graedel, 2019). MFA models can be depicted using Sankey diagrams which are termed the 'visible language of industrial ecology', and are often employed to present MFA results (Graedel, 2019). Sankey diagrams are used to visualise flows of materials or other resources in order to aid understanding of losses and inefficiencies, map out processes, and give a sense of scale across a system (Lupton and Allwood, 2017). Global flows of steel (Figure 2.15) (Cullen *et al.*, 2012), aluminium (Cullen and Allwood, 2013), paper (Figure 2.16) (Van Ewijk, 2017), chemicals (Levi and Cullen, 2018), and glass (Figure 2.17) (Westbroek *et al.*, 2021) have all been depicted using Sankey diagrams. However, these diagrams only depict the quantity involved in flows, not the quality.

2.5.1 Material Flow Analysis Applied to Water

In addition to the materials described above, MFA is used to track water flows, as described in the following sections which explore water budget MFA, anthropogenic water Sankey diagrams, and water budget Sankey diagrams.

2.5.1.1 Water Budget MFA

Water budgets have been depicted using the MFA method. For example, Singkran (2017) conducts a water budget for Bangkok Metropolis in Thailand using an MFA model and finds that only twenty-one percent of wastewater is collected and treated (Figure 2.18). This MFA depiction traces flows but they are not to scale and do not include water quality.

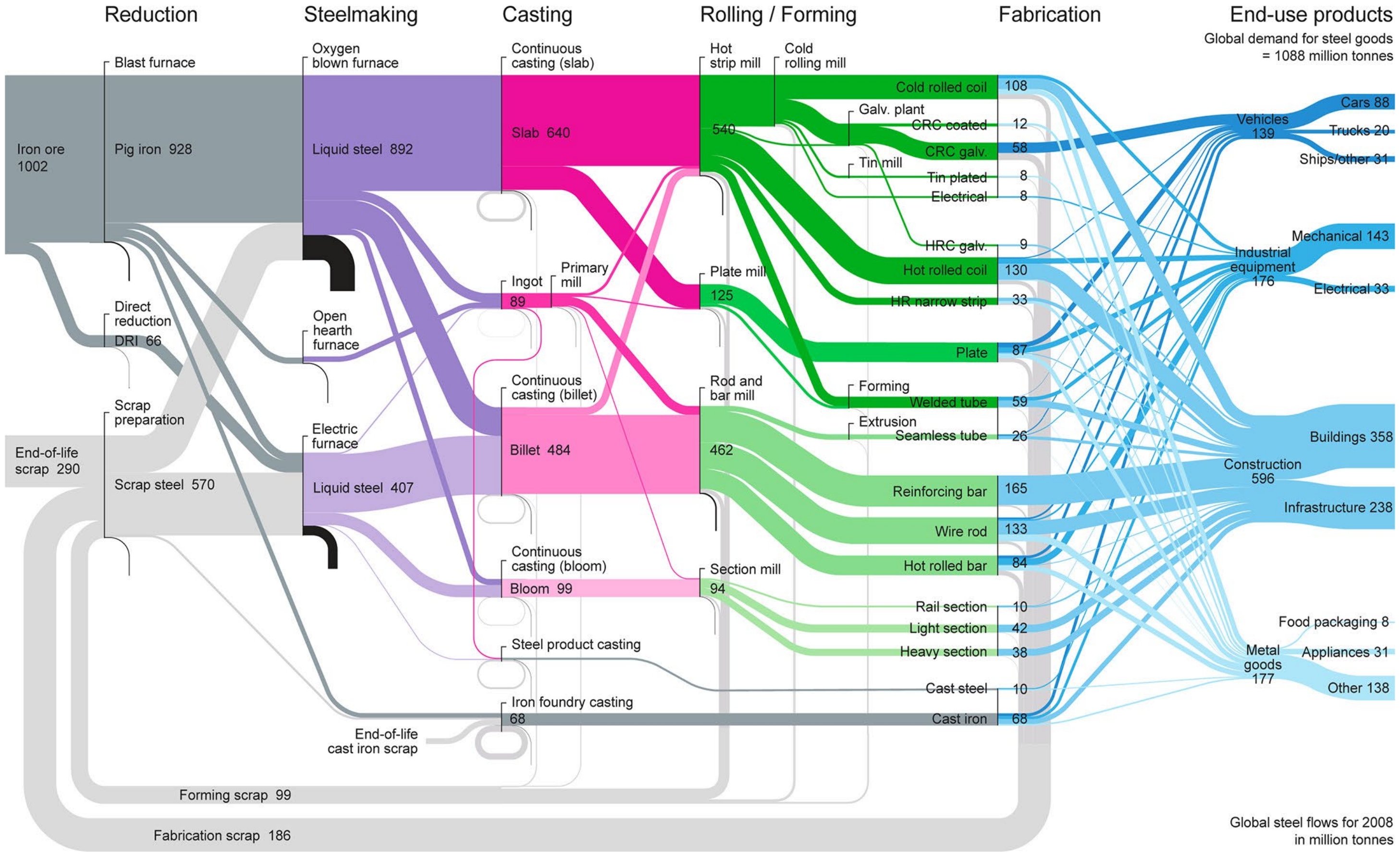


Figure 2.15. Example of a Material Flow Analysis in the Form of a Sankey Diagram: Global Flow of Steel from Liquid Metal to Final Product (Cullen *et al*., 2012, Figure 1).

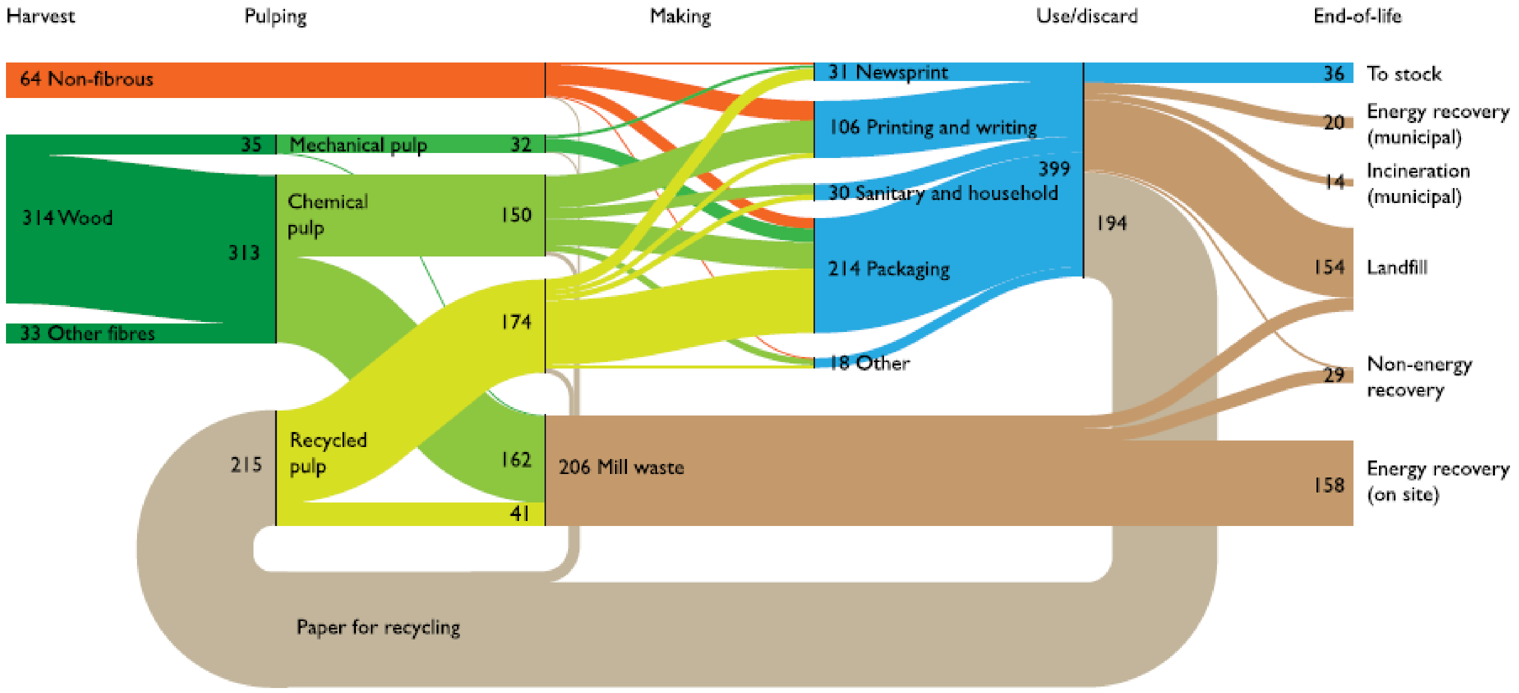


Figure 2.16. Example of a Material Flow Analysis in the Form of a Sankey Diagram: Global Paper Flows in 2012 in Megatonnes (Van Ewijk *et al.*, 2018).

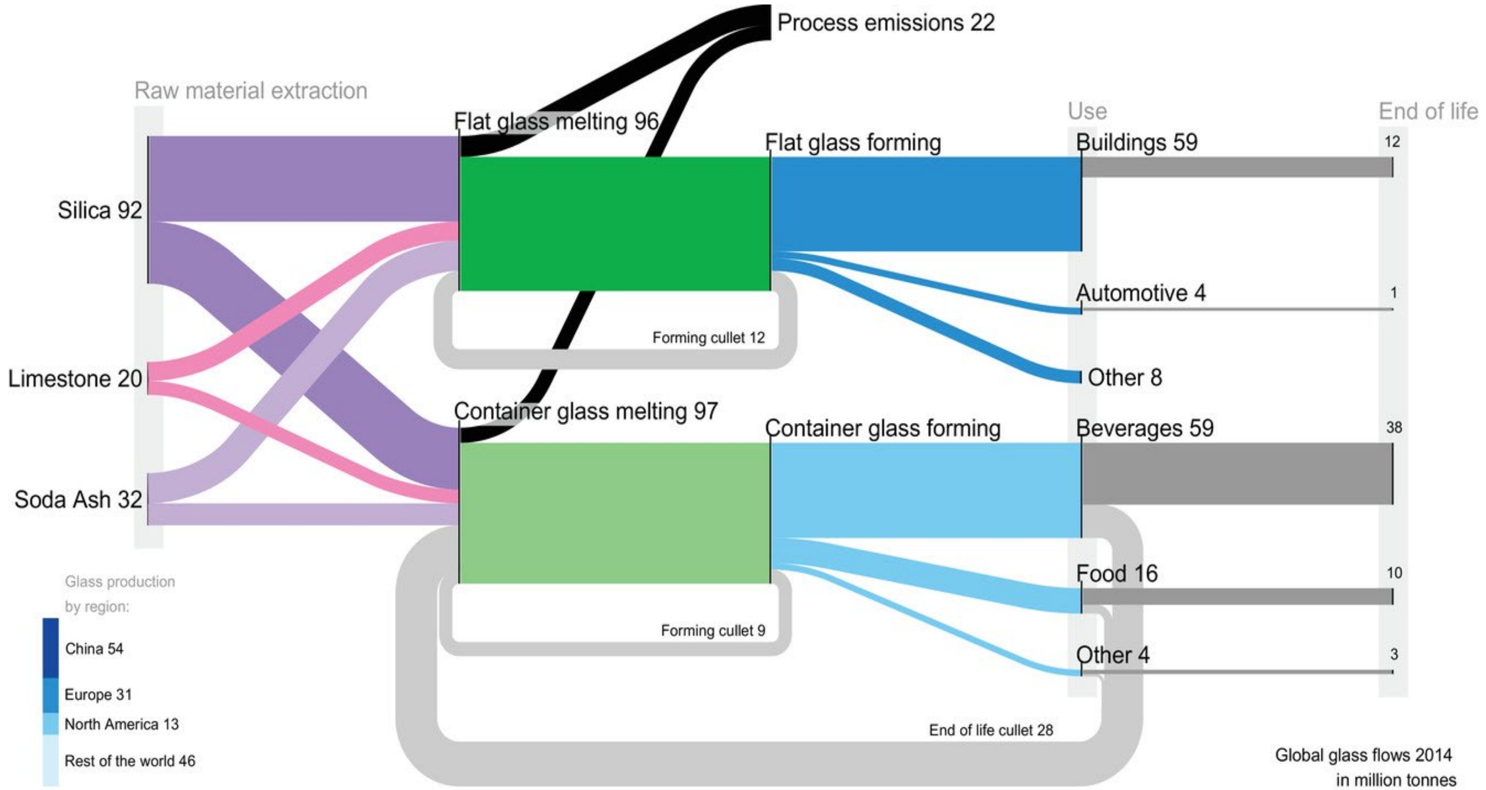


Figure 2.17. Example of a Material Flow Analysis in the Form of a Sankey Diagram: Global Material Flow Analysis of Glass from Raw Materials to End of Life (Westbroek *et al.*, 2021).

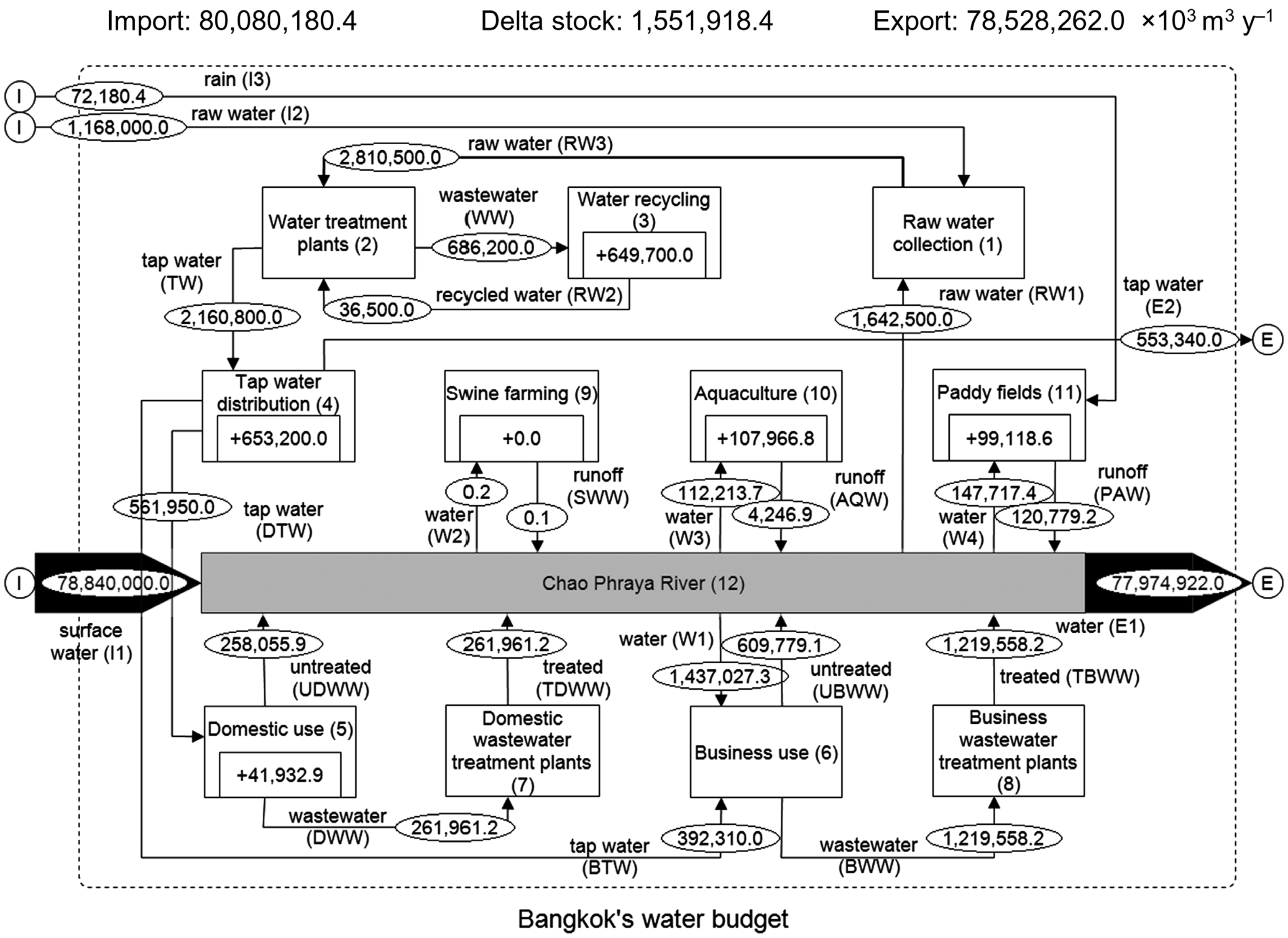


Figure 2.18. Example of a Water Budget Material Flow Analysis: Water Budget Analysis of the Bangkok Metropolis System Comprising Major Water-Related Activities (Singkran, 2017, Figure 2).

2.5.1.2 Anthropogenic Water Sankey Diagrams

Voskamp *et al.* (2017) use MFA to analyse Amsterdam's current water flows and compare them to natural resource use in 1998 to measure progress toward Amsterdam's goals (Figure 2.19).

Arora *et al.* (2022) develop a demand- and discharge-driven water circularity assessment framework for cities which integrates anthropogenic water flow data based on the water demand in an urban system and treated wastewater discharge for primary water demand substitution. They apply the framework in evaluating the state of water circularity in Singapore in 2019 (Figure 2.20). Arora *et al.* (2022) provide a quantitative tool to assess the scale of water circularity within engineered urban water infrastructure and its application to develop macro-level water systems planning and policy insights; however, water quality is not included (Figure 2.20).

2.5.1.3 Water Budget Sankey Diagrams

Agrawal *et al.* (2021) use Sankey diagrams to depict the water flow in Canada from intake to consumption and discharge, considering surface and ground water separately. A total of forty billion m^3 of water use is traced from source to either discharge or consumption (Agrawal *et al.*, 2021), however, water quality is not included (Figure 2.21).

Pronk *et al.* (2021) present a method to evaluate the potential of water reuse schemes in a regional context and demonstrate how water reuse propagates through the water system to potentially reduce pressure on groundwater resources. The use of Sankey diagram visualisation provides a valuable tool to explore and evaluate regional application of water reuse, its potential to reduce groundwater and surface water demand, and the possible

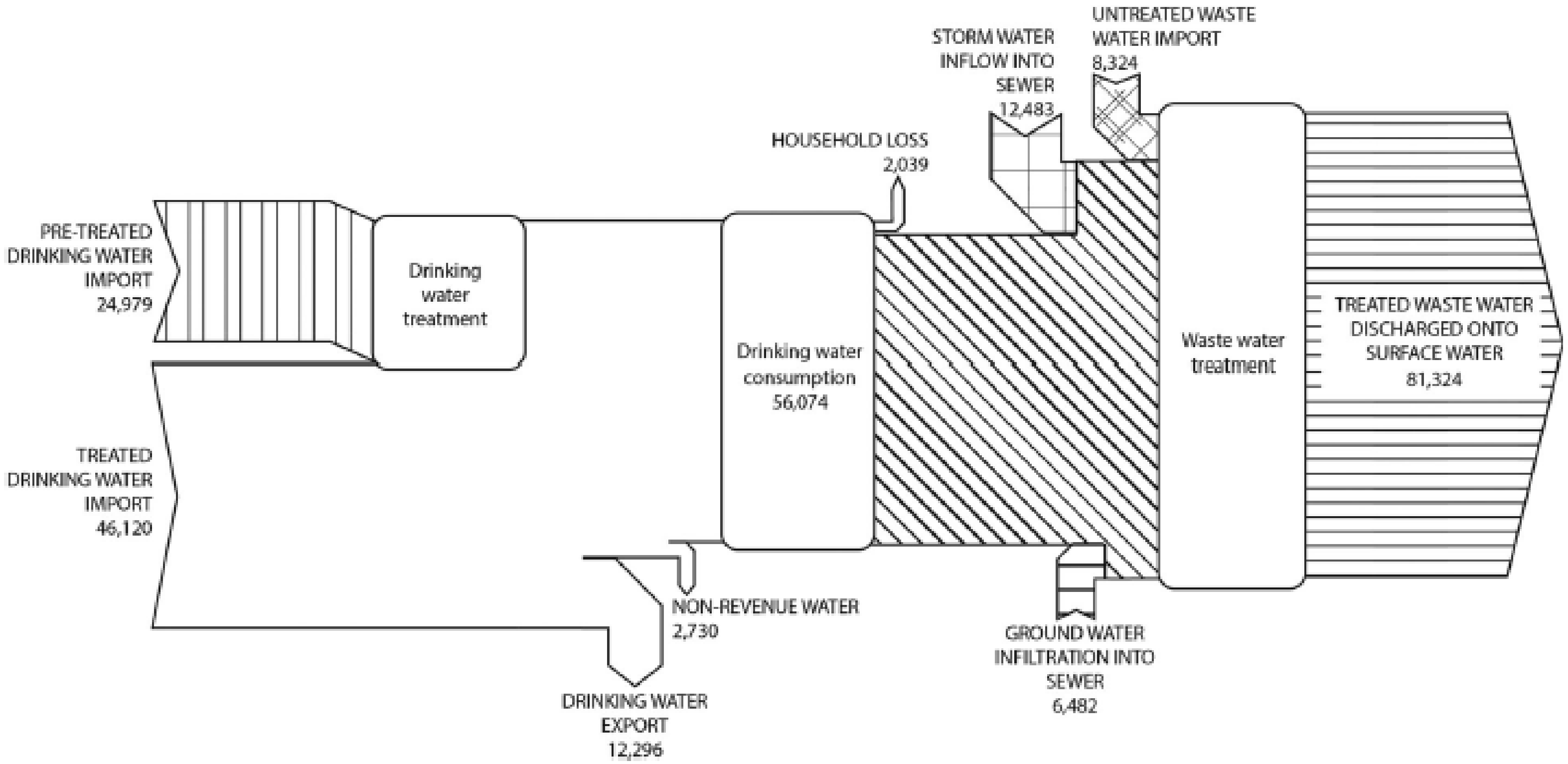


Figure 2.19. Example of a Water Material Flow Analysis: Overview of Water Flows in Kilotonnes in Amsterdam, Excluding Industry Water (Voskamp, 2017, Figure 4).

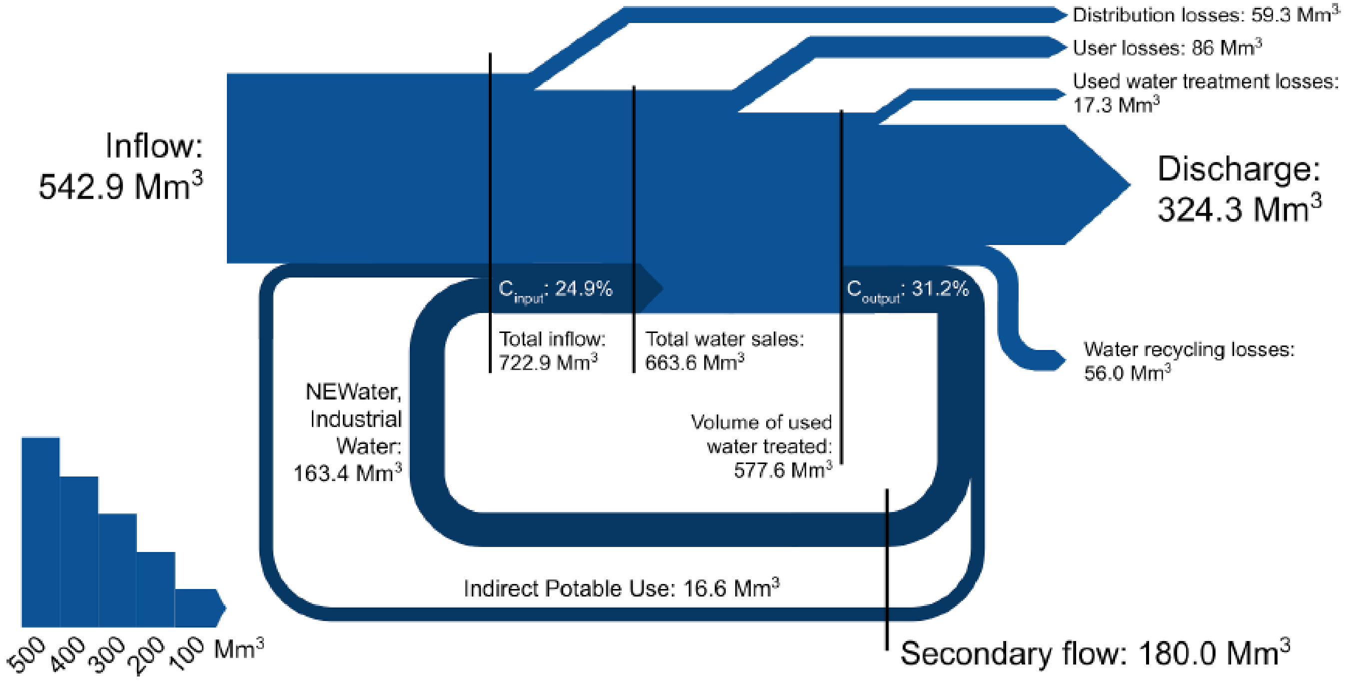


Figure 2.20. Example of a Water Material Flow Analysis in the Form of a Sankey Diagram: Singapore's Water Flows and the Scale of Water Circularity in 2019 (Arora *et al*., 2022, Figure 2).

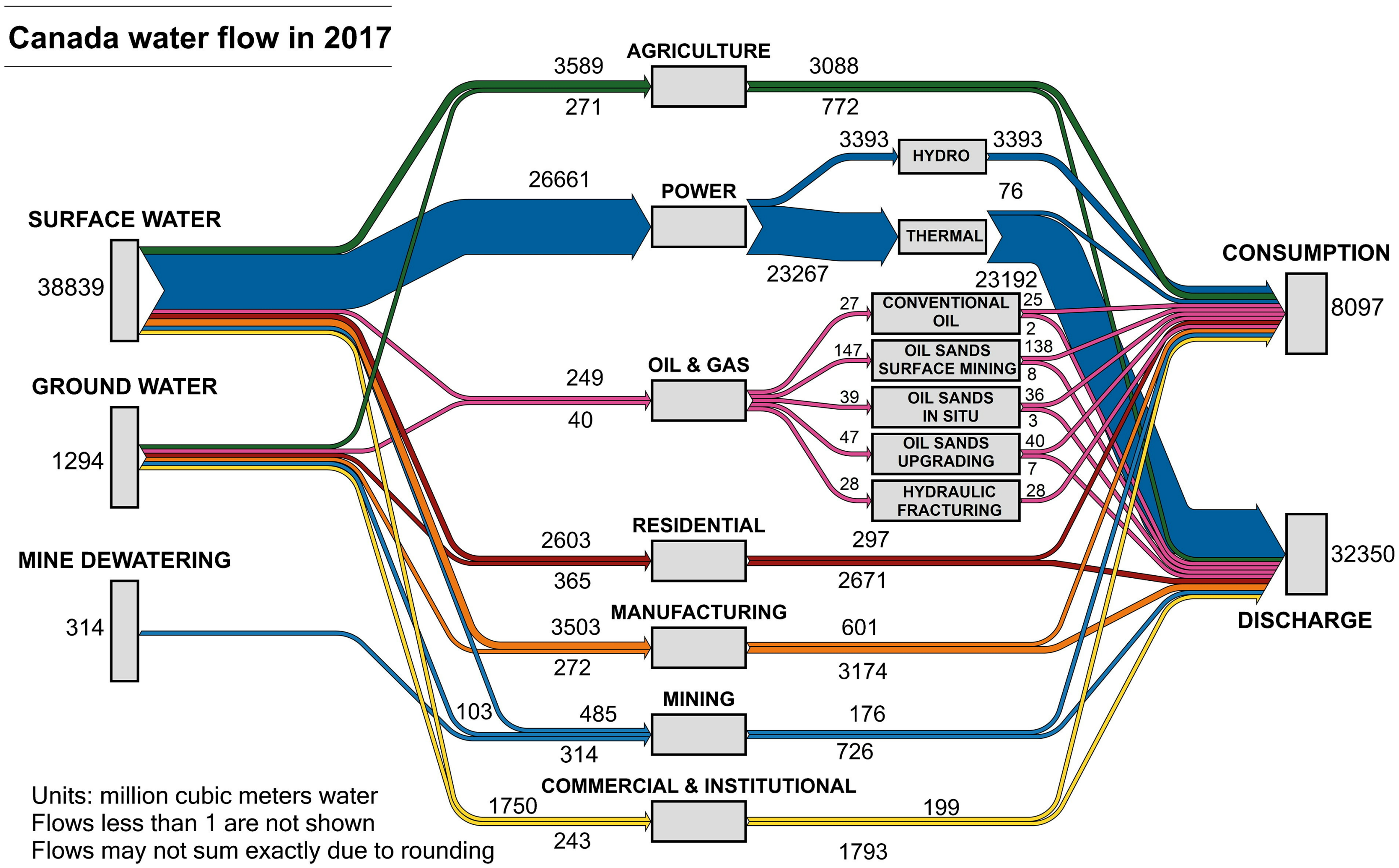


Figure 2.21. Example of a Water Material Flow Analysis in the Form of a Sankey Diagram: Tracing Water Flow in Canada from Source to End Use (Agrawal *et al*., 2021).

synergies and trade-offs between sectors (Pronk *et al.*, 2021). The approach is demonstrated for the Dutch anthropogenic water system in the current situation and for a future scenario with increased water demand and reduced water availability due to climate change (Pronk *et al.*, 2021). Three types of water reuse are evaluated by theoretically upscaling local or regional water reuse schemes based on local reuse examples currently in operation in the Netherlands or Flanders: municipal and industrial wastewater effluent reuse for irrigation; effluent reuse for industrial applications; and reuse for groundwater replenishment (Pronk *et al.*, 2021). In all cases, water reuse has the potential to significantly reduce groundwater extraction volume, and thus to alleviate the pressure on the groundwater system (Pronk *et al.*, 2021). The water-quantity based analysis is placed in the context of water quality demands (Pronk *et al.*, 2021), not existing water quality in the natural environment (Figure 2.22).

2.5.1.3.1 California Water Budget Sankey Diagrams

Curmi *et al.* (2013) develop an approach for analysing water supply and demand in California, and use Sankey diagrams to present their results (Figures 2.23 and 2.24). When studying water use pathways, Sankey diagrams provide quantitative information on water flows as well as their relationships and transformations. Curmi *et al.* (2013) display water diagrams showing the allocation of water by tracing the source–service–sink route for each service and the processing of water in treatment and recycling facilities, depicting the net changes in groundwater and surface water stocks, and conclude that Sankey diagrams are a useful tool for mapping water use, even if ‘water quality problems are not shown’.

Curmi *et al.* (2013) state that it is important to acknowledge in these analyses that studying water usage at different scales can give different insights into water stress and management.

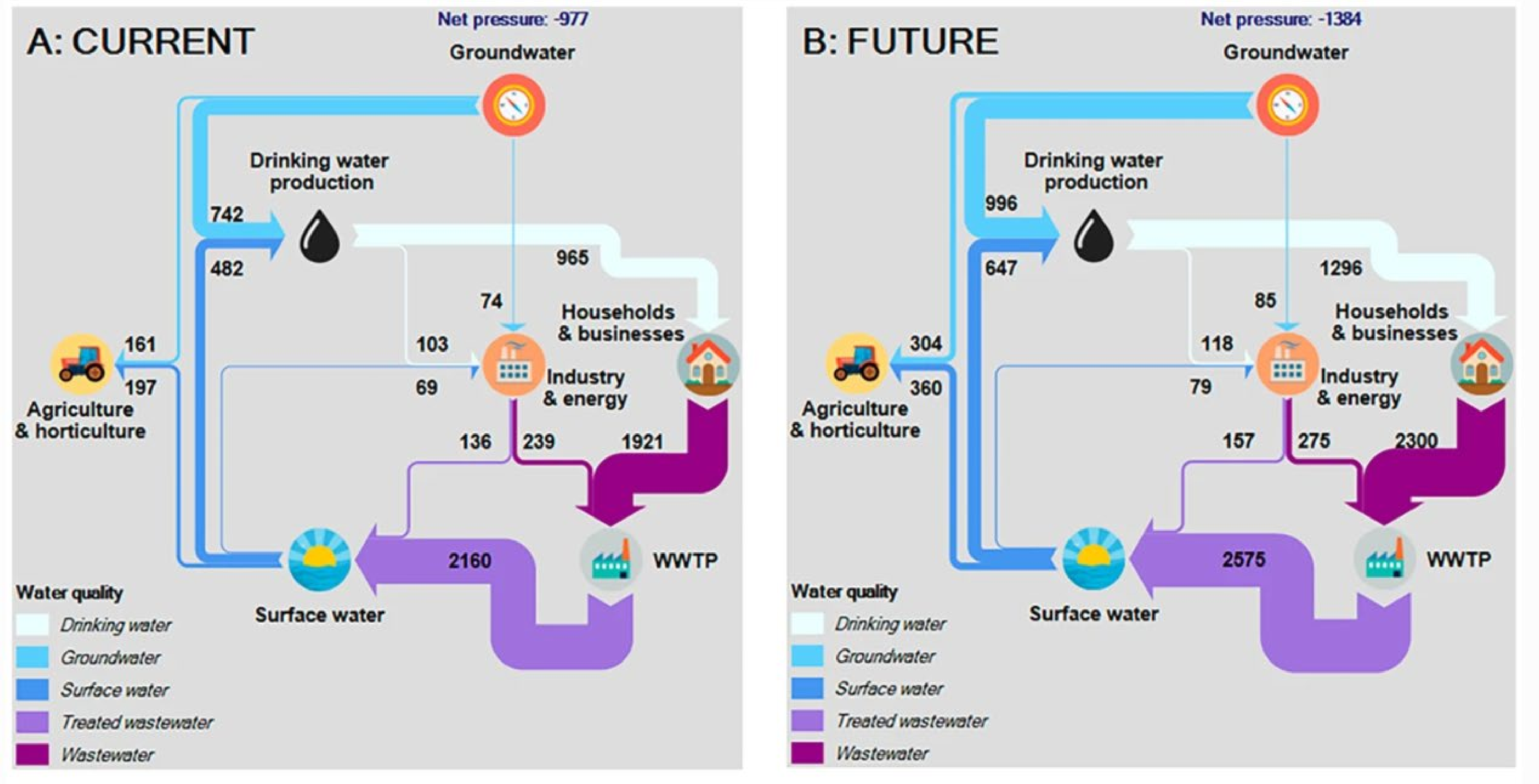


Figure 2.22. Sankey Diagrams of the Current and Future Anthropogenic Water System of the Netherlands (Pronk *et al*., 2021).

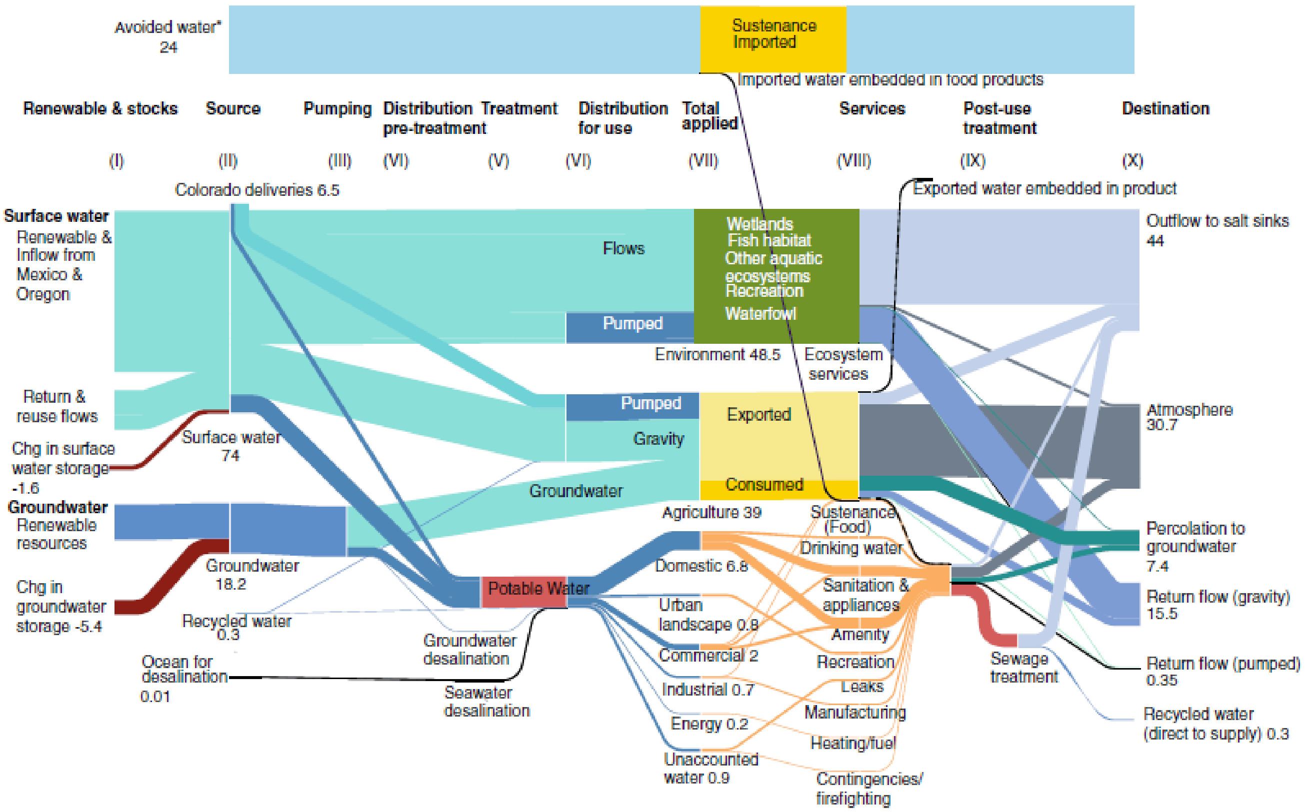


Figure 2.23. Sankey Diagram Tracing the Flow of Water from Source to Final Destination for California using 2000 Annual Data (Curmi *et al*., 2013, Figure 2).

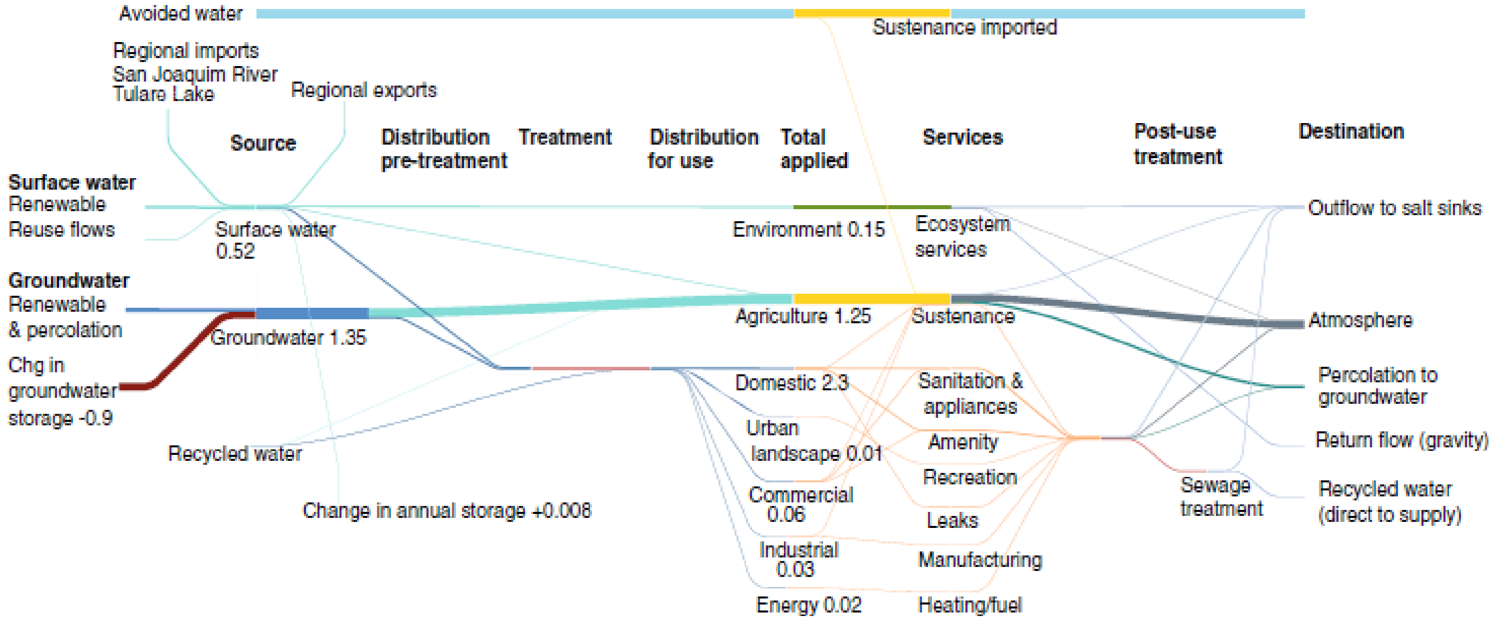


Figure 2.24. Sankey Diagram Tracing the Flow of Water from Source to Final Destination for the Central Coast Hydrological Region of California using 2000 Annual Data (Curmi *et al*., 2013, Figure 3a).

Curmi *et al.* (2013) include water Sankey diagrams for different hydrological regions in California, including the Central Coast region (Figure 2.24), to show that even though the Sankey diagram of the whole state provides a significant amount of information on the management of water resources in California, visualising individual regions can provide more insights into local problems and could be a valuable aid in supporting policy on water resources (Curmi *et al.*, 2013). Curmi *et al.* suggest that the regional Sankey diagram demonstrates different issues related to the availability and use of water resources, and shows a different picture compared to the diagram for the whole State of California (Figure 2.23). The Central Coast region has a limited supply of surface water, and the growing demand for water resources is leading to a dependence on groundwater, with some aquifers being pumped at a higher rate than the underground supply can be replenished, leading to a decrease in groundwater stocks of an estimated 0.9×109 m^3 in the year 2000 and also leading to a degradation of groundwater quality due to salinization (Curmi *et al.*, 2013). Uses of water in the different regions can also be easily compared in the Sankey diagrams (Curmi *et al.*, 2013).

2.5.2 Research Gap

MFA is an analytical method used to quantify flows and stocks of materials in a well-defined system. MFA models can be depicted using Sankey diagrams. Sankey diagrams are used to visualise flows of materials or other resources, in order to aid understanding of losses and inefficiencies, map out processes, and give a sense of scale across a system (Lupton and Allwood, 2017). MFA is used to track water flows, including water budgets. Curmi *et al.* (2013) develop an approach for analysing water supply and demand in California and use Sankey diagrams to present their results, even if ‘water quality problems are not shown’. This research is very helpful because it puts the statewide and hydrologic region water budgets into Sankey diagrams. While water MFAs and Sankey diagrams are being used effectively to depict changes to the quantity of water as it moves through a system, water quality is included only conceptually, and is not defined.

2.6 Research Questions

The literature review revealed the organisations responsible for defining water quality at various scales. How each of these organisations define water quality; the method they apply; the resulting definitions; how these definitions of water quality compare; whether they apply to California; and whether these definitions can be used to add water quality to a water budget for California, remain to be investigated.

Scales of water quality are a useful format for organising water quality definitions. Whether any of these scales can be used to add water quality to a water budget in California depends on the types of water included in the water budget. Neither in the academic literature nor in practice is there a scale of water quality that contains all of the types of water found in a water mass balance in California. However, they provide options for the organisation and structure of tiers of water quality that could be used to add water quality to a water budget in California.

MFA is used to track water flows, including water budgets. Curmi *et al.* (2013) develop an approach for analysing water supply and demand in California and use Sankey diagrams to present their results, even if 'water quality problems are not shown.' While water MFAs and Sankey diagrams are being used effectively to depict changes to the quantity of water as it moves through a system, water quality is not defined.

While California's intensive hydrologic alteration has increased agricultural production and manufacturing, it has also depleted fish populations, drained wetlands, altered natural water flow patterns, and impaired water quality (WEF, 2020a). Building aqueducts does not guarantee that there will be water to transport in times of drought. The 2012-2016 drought was the most severe in twelve hundred years (Griffin and Anchukaitis, 2014), and climate projections for California include increased temperatures, which could make droughts, and their impacts, more severe (USGS, 2017). In 2013, California reported that contaminated groundwater was the sole source of water for 3.7 million people in the state (SWRCB, 2013). California's governmental agencies maintain, on their websites, multiple data repositories that are available to the public and contain water supply, water quality, land and water use, well, and groundwater data.

Whether there is enough water, now and in the future, is important to Californians. The water budget, which quantifies how much water enters and leaves the state, and how it is used or stored each year (State of California, 2019b) is one of the tools used to assess water availability in California. While this tool is useful for tracking quantity, it does not provide any information regarding the quality of the water. To add water quality to a water budget, a set of applicable water quality definitions is required.

The 2014 California Water Action Plan (CNRA, 2014) identifies the need for better tools that address water quality and quantity objectives, and aid communication by stating that natural resources and water quality agencies will, through a transparent process, make water delivery decisions and propose options to address water quality and supply objectives in extreme conditions. The identification of such opportunities requires continued improved water forecasting (CNRA, 2014). The 2014 California Water Action Plan (CNRA, 2014) states that millions of Californians rely, at least in part, on contaminated groundwater for their drinking water. While most water purveyors blend or treat water to meet public health standards, many disadvantaged communities cannot afford to do so.

Better tools are needed to address California's water quantity and quality objectives. MFA and Sankey diagrams have proven useful for mapping use; however, they don't define water quality.

In response to the knowledge gaps identified above, this thesis focuses on the following research questions:

1. How is water quality defined, by the entities identified in the literature review, and what method do they use to establish these definitions?
2. Can a method be established for creating a scale of water quality using the applicable water quality definitions for the types of water in a water budget in California?
3. Can a method be established for defining the quality of the water in a water budget in California?

This thesis is organised around these three questions, with the third chapter investigating how different types of water quality (*e.g.*, drinking water, ambient water, wastewater) are defined at the global, national, state, and city levels, and the methods used. The fourth chapter explores how a water quality scale can be created using the water quality definitions that apply to the types of water in a California water budget, and the fifth chapter applies the defined water quality categories of the scale to a water budget in California.

Chapter 3

Defining Categories of Water Quality

3.1 Introduction

The first research question asks how water quality is defined, by the entities identified in the second chapter, and what method is used to establish these definitions. To add water quality to a water budget, a set of water quality definitions is needed for the types of water in the water budget (*i.e.*, water in the natural and built environments). The literature review in the second chapter provides examples of existing water quality scales and formats for organising sets of water quality definitions, but reveals no scale that can be used to add water quality to a California water budget. In response to the first research question, the aim of this chapter is to identify water quality definitions, and the methods used to establish them, for different types of water (*e.g.*, drinking water, ambient water, groundwater, wastewater, stormwater, water reuse) at the global, national, state, and city levels.

3.2 Defining Categories of Water Quality at the Global Level

This section investigates how drinking water, wastewater, ambient water, and aquatic ecosystem water quality are defined globally. In addition, water quality guidelines for domestic, agricultural, industrial, energy, and environmental use and reuse are reviewed. The concept of a global water quality index is explored, as well as academic literature related to changes and gaps in defining global water quality. The section ends with a summary of the key findings.

3.2.1 Defining Global Drinking Water Quality

The World Health Organization (WHO) publishes the *Guidelines for Drinking-water Quality* (GDWQ), one of the longest-standing normative publications and an international reference point for the establishment of national or regional regulations and standards for water safety (WHO, 2018).

The GDWQ include an assessment of the health risks presented by various microbial, chemical, radiological and physical contaminants that may be present in drinking water (WHO, 2018). Where applicable, they derive maximum concentration guideline values for hazardous constituents (WHO, 2018). Health-based values have been established for some chemicals in the GDWQ, rather than a formal guideline value, in order to provide guidance where there is reason for local concern (WHO, 2018). Establishing a formal guideline value for such substances may encourage member states to incorporate a value into their national standards when unnecessary (WHO, 2018). Numeric targets include 'guidance levels' (GL), 'guideline values' (GV) and 'health-based values' (HBV) for constituents in drinking water or indicators of water quality (WHO, 2018). The term 'guidance levels' is used for radiological parameters, while 'guideline values' or 'health-based values' is used for all other parameters (WHO, 2018). Provisional guideline values have been established based on the practical level of treatment performance or analytical achievability (WHO, 2018). In these cases, the guideline value is higher than the calculated health-based value (WHO, 2018).

Recognising the benefits of a risk management approach, the GDWQ are not promoted as mandatory international standards, but as guidance that should be adapted to the specific circumstances, needs and resources of countries (WHO, 2018). Therefore, national or regional drinking water quality regulations should only include a subset of the values included in the GDWQ and may have different parameter limits than specified (WHO, 2018).

The WHO conducted a global review of various country regulations and policies to better understand the extent to which the GDWQ are used (WHO, 2018). The report summarises values specified in national drinking water quality standards for aesthetic, chemical, microbiological and radiological parameters from one hundred and four countries and territories, however, the report indicates comparisons should be approached with caution (WHO, 2018). These countries and territories, which include the US and the UK, have a total population of approximately six and a half billion people, representing approximately eighty-nine percent of the world population (WHO, 2018).

The GDWQ encourage countries and territories to set their own water quality standards to ensure they are locally relevant in terms of parameters and limits (WHO, 2018). The GDWQ suggest values with a wide margin of safety, and countries and territories are advised to adapt their drinking water quality standards to local conditions and circumstances (WHO, 2018). The report uses the terms 'higher' or 'above' for values greater than those specified in the GDWQ and 'lower' or 'below' for values less than those specified in the GDWQ (WHO, 2018).

3.2.1.1 Inorganic Parameters

The GDWQ include GVs or HBVs for twenty-four inorganic parameters (WHO, 2018). All one hundred and four countries and territories specify values for copper, lead and nitrate, and all but one specify values for manganese (WHO, 2018). Arsenic is one of the parameters with a value set by most countries and territories (102/104). The majority of countries (79/102) specified the provisional GV; only one country set a value below the provisional GV (WHO, 2018). Uranium is one of the least specified parameters, with only seventeen out of the one hundred and four countries and territories setting a value (WHO, 2018).

Chlorine is the inorganic parameter with the largest range between minimum and maximum (WHO, 2018). It is possible to reduce the concentration of chlorine effectively to zero (<0.1 mg/l) by reduction; however, it is normal practice to supply water with a chlorine dioxide residual of a few tenths of a milligram per litre to provide some protection against microbial regrowth during distribution (WHO, 2018). None of the sixty-six countries had a value above the GV (WHO, 2018). Thirty-two countries and territories specified a level below 1 mg/l (WHO, 2018). Eleven countries and territories specified the GV (WHO, 2018). Some countries and territories set a range, specifying minimum and maximum levels. It was not always clear if the set value referred to free or total chlorine (WHO, 2018).

3.2.1.2 Organic Parameters

The GDWQ include GVs or HBVs for eighty-nine organic parameters (WHO, 2018). The most specified organic parameters are: aldrin and dieldrin (71 out of 104 countries and territories); benzene (77); tetrachloroethene (PCE) (71); and 1,2 dichloroethane (67) (WHO, 2018). PCE is among the most specified organic parameters, and one of few parameters for which the majority of countries and territories specifying a value set it below the GV (WHO, 2018). Only five out of twenty-one countries and territories set values that differed from the GV for 1,2-Dibromo-3-chloropropane (DBDP) (WHO, 2018).

3.2.1.3 Acceptability, Taste, Odour and Appearance

The GDWQ identify twenty-six chemically derived parameters and four biologically derived parameters relating to acceptability, taste, odour and appearance (WHO, 2018). The importance of these parameters is that if the water is unacceptable to consumers, it may lead to rejection of the water, and use of other aesthetically more acceptable but potentially less-safe waters (WHO, 2018). Generally, the concentrations that cause rejection are significantly lower than those of concern for health (WHO, 2018). As such, with the exception of manganese, which is widely found in drinking-water sources, it may not be appropriate to directly regulate or monitor such parameters, as they may be addressed through a general requirement in the national standards or regulations that water be acceptable to the majority of consumers (WHO, 2018).

The acceptability parameters most often specified were pH (hydrogen ion) (specified by 103 countries and territories), chloride (100), iron (99), aluminium and sulphate (97) (WHO, 2018). Eighty-five countries and territories set numerical values for turbidity (WHO, 2018). An additional fifteen countries and territories had descriptive statements only such as 'acceptable to consumers and no abnormal change' (WHO, 2018). The GDWQ note that at room temperature, the average taste threshold for sodium is 200 mg/l (WHO, 2018). Seventy-one of the eighty-one countries and territories set this value, and only seven set a higher value (WHO, 2018). Sixty-six countries and territories set a value for Total Dissolved Solids (TDS) (WHO, 2018) and there was a wide range of values; from 200 mg/l to 2,500 mg/l. Thirty-six countries and territories specified 1000 mg/l, eleven specified 500 mg/l (WHO, 2018). Petroleum oils can give rise to the presence of a number of low molecular weight hydrocarbons that have low odour thresholds in drinking-water (WHO, 2018). Benzene, toluene, ethylbenzene and xylenes (BTEX) are considered in the organic parameters section

(WHO, 2018). Only three countries and territories set values for this parameter. None of the values for temperature were mandatory, being guiding levels or operational goals (WHO, 2018). None of the countries and territories' documents indicated what would happen if temperatures rose above the suggested value (WHO, 2018). In addition to those with numerical values, seven countries and territories had descriptive levels such as: 'not objectionable'; 'acceptable'; and 'ambient' (WHO, 2018).

3.2.1.4 Radiological Parameters

The GDWQ suggest screening levels for gross alpha and gross beta activity, as the process of identifying individual radionuclides is too cost-intensive for routine monitoring given their generally low concentration (WHO, 2018). If the screening levels for gross alpha and gross beta activity suggested by the WHO are not being exceeded, the individual dose criterion (*i.e.*, total dose) of 0.1 milliSieverts per year (mSv/year) will usually not be exceeded either (WHO, 2018). Countries and territories that specified values for radiological parameters did not deviate significantly from the GDWQ (WHO, 2018). Forty-eight countries and territories specified screening values for gross alpha and gross beta activity (WHO, 2018). The GDWQ list guidance levels for one hundred and ninety-one radionuclides. However, most countries and territories specified values for only a few of these, including radon (seven), radium-226 (seven), and strontium-90 (five) (WHO, 2018).

3.2.1.5 Microbiological Parameters

The GDWQ identify forty-three microbial parameters, which include bacterial, viral, protozoan, and helminth pathogens, as well as toxic cyanobacteria (WHO, 2018). The verification of microbial water safety is normally based on testing of indicator organisms, and the GDWQ include a GV for Escherichia coli (E. coli) or thermotolerant coliforms (WHO, 2018). Countries and territories in the survey designated numerical standards for 24 microbiological parameters (WHO, 2018).

For the purposes of this survey, faecal coliforms and thermotolerant coliforms have not been counted separately where they have been specified in addition to E. coli because the value has always been zero per 100 ml (WHO, 2018). The GDWQ advise that the presence of E. coli (or thermotolerant coliforms) provides evidence of recent faecal contamination (WHO, 2018). Values for E. coli (or faecal coliforms or thermotolerant coliforms) were specified by 102 countries and territories, then total coliforms (97 countries and territories), enterococci (faecal streptococci) (46 countries and territories), sulphite-reducing Clostridia (Clostridium perfringens) (44 countries and territories), total heterotrophic bacteria at 22°C (19 countries and territories) and total heterotrophic bacteria at 37°C (13 countries and territories) (WHO, 2018).

3.2.1.6 Additional Parameters

In the documentation used for this survey, countries and territories specified eight hundred and sixty-five numerical values for two hundred and eighty-seven inorganic, organic, aesthetic and physical parameters that do not have a WHO GV, HBV or aesthetic limit (WHO, 2018). The additional parameters with numerical standard values most often specified and reported in this section are: conductivity (51 countries and territories); total polynuclear aromatic hydrocarbons (PAH) (44); oxidizability (permanganate value) (43); phenols (35); formaldehyde (19); silver (24); potassium (12); and propanil (11) (WHO, 2018).

The GDWQ emphasise the importance of setting risk-based standards and adopting the specifications in the guidelines to local resources and needs (WHO, 2018). Direct comparison is difficult and should be approached with caution, as national standards should be developed considering the local context (WHO, 2018). Countries and territories review their specification for drinking-water quality with a different rhythm than the updates to the GDWQ (WHO, 2018). However, the values included in the GDWQ and their role in providing orientation to countries and territories is underlined by the number of countries and territories making reference to the GDWQ in their specifications, and in many cases specifying GVs (WHO, 2018).

The GDWQ, as the name suggests, are only intended to address drinking water quality. The next section explores how wastewater quality is defined at the global level.

3.2.2 Defining Global Wastewater Quality

The United Nations General Assembly put wastewater on the global development agenda for the first time when it approved the global indicator monitoring framework developed by the Inter-Agency and Expert Group on Sustainable Development Goal Indicators (IAEG-SDG) in 2017 (UN-Habitat, 2021). Sustainable Development Goal (SDG) 6 is about ensuring the availability and sustainability of water and sanitation for all by 2030 and addresses the entire sanitation chain from the safe management of household sanitation services (indicator 6.2.1a) to the safe treatment and discharge of domestic and industrial wastewater flows (indicator 6.3.1) (UN-Habitat, 2021). Beyond the public health benefits associated with the safe treatment of wastewater, there are social, environmental and economic benefits (UN-Habitat, 2021). The SDG framework on sanitation differs from the previous target 7.C of the Millennium Development Goals (MDGs) in that it applies to high- as well as low- and middle-income countries across which levels of service vary widely from basic household sanitation services through to safe management and safe treatment of wastewater from both domestic and industrial sources (UN-Habitat, 2021).

Currently, wastewater statistics are typically compiled by national statistical offices (NSOs) or in some cases national wastewater or utility regulators (UN-Habitat, 2021). Efforts have been made to introduce standardised methodologies and protocols to promote international compilation and comparison (UN-Habitat, 2021). A clear definition of the terminology and methodology for wastewater statistics is essential to contribute to harmonising international data-collection practices and SDG 6.3.1 reporting (UN-Habitat, 2021).

3.2.2.1 Global Wastewater Quality Definition

'Safely treated' wastewater is defined as water treated in compliance with national or local discharge standards and safe management practices (UN-Habitat, 2021). The composition of discharged wastewater quality may differ from country to country as compliance norms are defined nationally (or in some cases locally) and are not internationally standardised (UN-Habitat, 2021). Safely treated discharges are defined based on whether they meet national or local discharge standards, and as such are comparable based on whether they comply but are not comparable in terms of specific wastewater quality parameters (UN-Habitat, 2021).

3.2.2.2 Global Wastewater Data Collection Method

The compilation of total and industrial wastewater statistics for reporting on indicator 6.3.1 relies explicitly on the existing international methodologies for the global or regional monitoring of wastewater flows generated and treated, namely the UNSD/UNEP Questionnaire and Manual on the Basic Set of Environment Statistics of the FDES 2013 Water Resources Statistics (UN-Habitat, 2021) and the OECD/Eurostat Joint Questionnaire on Inland Waters for OECD and EU Member States (UN-Habitat, 2021). These questionnaires use a comparable set of definitions and terminology to define, collect and analyse water statistics in a coherent way, with reported volumes of generated wastewater being disaggregated based on the International Standard Industrial Classification of All Economic Activities (ISIC) to attribute wastewater generation to economic activities (UN-Habitat, 2021).

The WHO developed a database including a set of forty variables that were defined and used in calculations covering wastewater volumes and proportions generated and safely treated across all relevant wastewater streams (UN-Habitat, 2021). The data compiled (or assumptions applied) for each of these variables was presented in publicly available Excel files that were also circulated for feedback which was received from forty-seven countries and estimates were revised as needed and finalised (UN-Habitat, 2021). The main challenges related to data collection included a lack of metadata on how reported data were measured or estimated, inconsistencies in definitions, terminology or methods applied to populate some variables, and a general lack of data, particularly in low- and middle-income countries (UN-Habitat, 2021).

In summary, UN-Habitat (2021) obtains data using questionnaires, they don't recommend a global standard for wastewater, and they acknowledge that local standards are most appropriate, as does UNEP (2021) regarding ambient water quality, described in the following section.

3.2.3 Defining Global Ambient Water Quality

Through the UN-Water Integrated Monitoring Initiative for SDG 6 (IMI-SDG6), the United Nations supports countries in monitoring water- and sanitation-related issues within the framework of the 2030 Agenda for Sustainable Development, and in compiling country data to report on global progress towards SDG 6 (UNEP, 2021). If target 6.3 is to be reached and water quality improved by 2030, an essential prerequisite is information (UNEP, 2021). As a result, ambient water quality data was collected, in 2020, for over seventy-five thousand water bodies in forty-nine countries (UNEP, 2021).

3.2.3.1 Global Ambient Water Quality Definitions

In the UNEP (2021) report, *Progress in Ambient Water Quality*, three types of water bodies (*i.e.*, a section or a tributary of a river, a lake, an aquifer), are classified as having either 'good' or 'not good' water quality. To classify whether a water body is of 'good ambient water quality' or not, a threshold is applied where eighty percent or more of monitored values meet their targets (UNEP, 2021). This is applied at the monitoring location level, using data collected over the three-year reporting period to classify a monitoring location as either 'good' or 'not good', and if there is more than one within a water body, this binary classification is aggregated up to the water body level (UNEP, 2021).

A target-based approach is used to classify ambient water quality (UNEP, 2021). This means that the measured values are compared with numerical values that represent 'good water quality' (UNEP, 2021). Targets can be nationwide values or, alternatively, they can be water-body-specific or even site-specific. The more specific a target, the better it is at indicating potential pollution problems (UNEP, 2021).

3.2.3.2 Global Ambient Water Quality Classification Method

Reporting requires data to be collected systematically on basic water quality parameters over a wide spatial scale and in a consistent and regular manner (UNEP, 2021). The ambient water quality parameter data collected is organised into two levels. Level 1 monitoring maintains the global comparability of the indicator and focuses on parameters that can be analysed in the field and do not require laboratory facilities, whereas Level 2 goes further and provides the flexibility for countries to include information that may be of national concern or relevance (UNEP, 2021).

Level 1 includes nutrient enrichment, oxygen depletion, salinization, and acidification (Figure 3.1) (UNEP, 2021). Other water quality parameters that are often routinely measured (*e.g.*, heavy metals, pesticides), as well as alternative monitoring approaches (*e.g.*, those that look at the species that live in the water, and Earth observation techniques that rely on satellite imagery) are captured under Level 2 monitoring (Figure 3.2) (UNEP, 2021).

Using this method, sixty percent of water bodies (*i.e.*, 45,966 out of 76,151) assessed in 2020 were classified as having good ambient water quality (UNEP, 2021). However, over three-quarters of the water bodies included are in twenty-four high-GDP countries. The poorest twenty countries reported on just over one thousand water bodies. Of the eighty-nine countries reporting data, only fifty-two reported information about groundwater (UNEP, 2021).

Ambient water quality within the indicator 6.3.2 framework is not considered with any particular use of water in mind (UNEP, 2021). There was a wide range of target values

Parameter group	Parameter	River	Lake	Groundwater	Reason for inclusion
Oxygen	Dissolved oxygen	•	•		Measures oxygen depletion
	Biological oxygen demand, chemical oxygen demand	•			Measures organic pollution
Salinity	Electrical conductivity Salinity, total dissolved solids	•	•	•	Measures salinization and helps characterize the water body
Nitrogen*	Total oxidized nitrogen Total nitrogen, nitrite, ammoniacal nitrogen	•	•		Measures nutrient pollution
	Nitrate**			•	Consumption threatens human health
Phosphorus*	Orthophosphate Total phosphorus	•	•		Measures nutrient pollution
Acidification	pH	•	•	•	Measures acidification and helps characterizes the water body

* Countries should include the fractions of nitrogen and phosphorus which are most relevant in the national context.

** Nitrate is suggested for groundwater due to the associated human health risks.

Figure 3.1. Suggested parameters for Level 1 parameter groups, the relevant water body types and reasons for their inclusion in the global ambient water quality indicator (UNEP, 2021, Table 1).

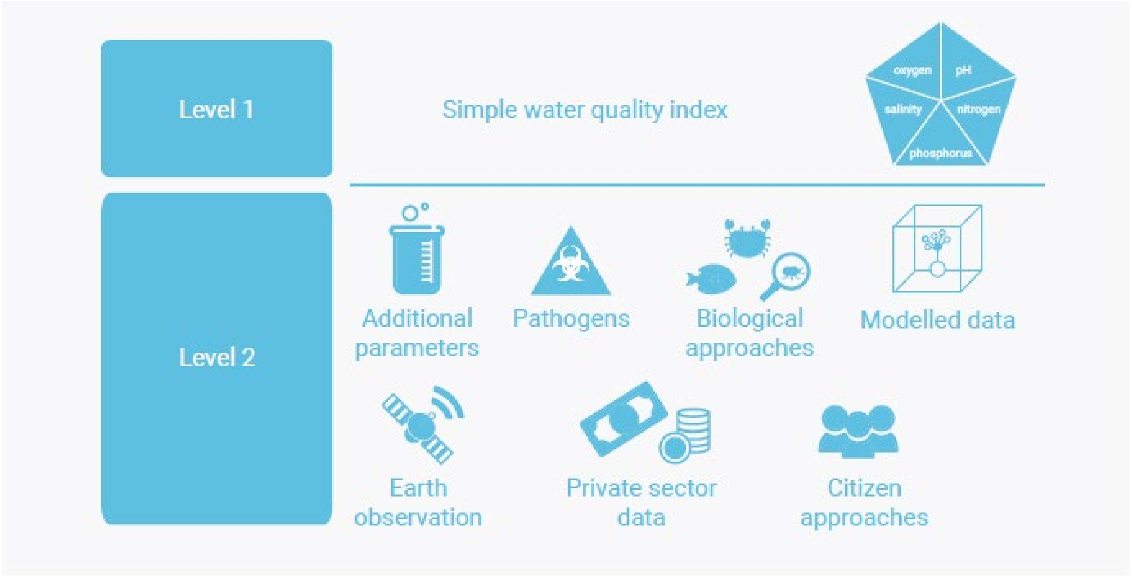


Figure 3.2. Examples of Level 1 and Level 2 data sources that can be used for SDG indicator reporting in the global ambient water quality indicator (UNEP, 2021, Fig. 2).

reported. (UNEP, 2021). Using the same target for all water bodies is not recommended due to the natural variation of water bodies (UNEP, 2021).

Some countries (*e.g*., Malaysia) apply their ambient water quality standards to their aquatic ecosystems, while other countries use separate classification systems to define aquatic water quality, as detailed in the following section.

3.2.4 Defining Global Aquatic Ecosystem Water Quality

The UN-Water Thematic Priority Area (TPA) on Water Quality leads a global initiative to develop guidelines for aquatic ecosystems that can be adapted or applied globally for various water management scenarios (UN-Water, 2012). In 2012, water quality guidelines for aquatic ecosystems with an international dimension did not exist and, consequently, a scoping study on water quality guidelines for aquatic ecosystems was commissioned (UN-Water, 2012).

The purpose of the scoping study was to provide an overview of existing water quality standards/guidelines for aquatic ecosystems, and identify ongoing and planned initiatives to develop such standards/guidelines (UN-Water, 2012). The focus of the study was on the exposition of the conceptual framework and approach used in developing those guidelines rather than the reproduction and interpretation of the recommended criteria (UN-Water, 2012).

3.2.4.1 Global Aquatic Ecosystems Water Quality Definitions

The Water Framework Directive (WFD) is a legal framework to protect and restore the water environment across Europe by a specified date, initially 2015, and ensure the long-term sustainable use of water resources in Europe (UN-Water, 2012). Article 4.1 defines the general objective to be achieved in all surface and groundwater bodies (*i.e.*, good status) and introduces the principle of preventing any further deterioration (UN-Water, 2012). The normative definitions for the environmental objective of 'good status' are described in great detail in Annex V of the WFD (UN-Water, 2012).

Norms can also be used to evaluate the effects of a water quality constituent for a particular use (UN-Water, 2012). The following are some examples of norms that are in use for aquatic ecosystem guidelines: Total Maximum Daily Load – a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards; Target Water Quality Range (TWQR) – a particular water use is defined as the range of concentrations or levels at which the presence of the constituent would have no known adverse or anticipated effects on the fitness on the water assuming long-term continuous use, and for safeguarding the health of aquatic ecosystems; Acute Effect Value – a criterion used to identify those cases requiring urgent management attention because the aquatic environment is threatened, even if the situation persists only for a brief period; Chronic Effect Value – a criterion that is used, in certain special cases where the TWQR is exceeded (UN-Water, 2012).

3.2.4.2 Global Aquatic Ecosystems Water Quality Classifications

Generally, guidelines specify multiple levels of protection (UN-Water, 2012). Typically, the level of protection corresponds to whether the conditions within a particular region or water body within it is of: i) high conservation value; ii) slightly to moderately disturbed; or iii) highly disturbed. Ideally, the level of protection applied to most aquatic ecosystems is the one suggested for 'slightly to moderately disturbed' ecosystems (UN-Water, 2012).

In India, the Central Pollution Control Board (CPCB) developed a designated best use concept to establish water quality criteria (UN-Water, 2012). Five water quality classes are designated (*i.e.*, A–E) on the basis of the water quality requirements for a particular use, namely: Class A – waters for use as drinking water source without conventional treatment but after disinfection; Class B – waters for use for organised outdoor bathing; Class C – waters for use as a drinking water source with conventional treatment followed by disinfection; Class D –waters to maintain aquatic life including wildlife and fisheries; and finally Class E – waters for use for irrigation, industrial cooling and controlled waste disposal (UN-Water, 2012).

In Malaysia, ambient water quality standards are applied to surface waters and marine waters (UN-Water, 2012). The six water use classes designated in their National Water Quality Standards are: CLASS I Conservation of natural environment, Water Supply 1 – practically no treatment necessary, and Fishery 1 – very sensitive aquatic species; CLASS IIA Water Supply 2 – conventional treatment required, and Fishery 2 – sensitive aquatic species; CLASS IIB Recreational use with body contact; CLASS III Water Supply 3 – extensive treatment required, and Fishery 3 – common species of economic value, and tolerant species, also livestock drinking; CLASS IV Irrigation and; CLASS V None of the above (UN-Water, 2012).

The procedure for deriving the Korean Water Quality Standards follows a tiered approach with consideration for current analytical techniques, best available treatment technology, economic aspects and relations with current drinking water standards (UN-Water, 2012). For surface waters (*e.g.*, rivers, lakes and reservoirs), water quality management objectives are based on a system of water quality classes, namely, Class I – Water Supply Class 1, plus

Conservation of the Natural Environment; Class II – Water Supply Class 2 plus Fisheries Water Class 1 and Swimming Water; Class III – Water Supply Class 3 plus Fisheries Water Class 2 and Industrial Water Class 1; Class IV – Industrial Water Class 2 plus Agricultural Water; Class V – Industrial Water Class 3 plus Conservation of the Environment (UN-Water, 2012).

These aquatic water quality classifications are grouped by intended use of the water. The next section reviews water quality guidelines for domestic, agricultural, industrial, energy, and environmental use and water reuse.

3.2.5 Global Compendium of Water Quality Guidelines for Domestic, Agricultural, Industrial, Energy, and Environmental Use and Reuse

IWRA, ONEMA/AFB, and the World Water Council collaborated on a report that introduces a structure for a global water quality guidelines compendium providing concise but detailed information about existing water quality guidelines for several different uses (IWRA, 2018). The report includes examples of existing recommendations for influent water quality, as applied to various human and ecosystem uses (IWRA, 2018). It provides examples and analysis of existing water quality guidelines, depicted in Figure 3.3, to demonstrate the type of content that should be included in a future larger online compendium (IWRA, 2018). The report focuses on five main categories of water use: domestic, agriculture, industry, energy, and ecosystems (IWRA, 2018).

IWRA, ONEMA/AFB, and the World Water Council found that water quality guidelines in reference to the domestic sector (specifically for drinking water and other household uses) are well established internationally by the World Health Organization (WHO) and

Scale	Name	Date	Location
DOMESTIC WATER QUALITY GUIDELINES			
International	WHO Guidelines for Drinking Water Quality (GDWQ) - fourth edition incorporating the first addendum	2017	All
International	Global Drinking Water Quality Index (GDWQI)	2007	All
International	RAIN Water Quality Guidelines: Guidelines and Practical Tools on Rainwater Quality	2008	All
Regional	EU Drinking Water Directive (with latest amendments)	2015	European Union
Regional	UNECE Protocol on Water and Health	2005	Europe
	Taking policy action to improve small-scale water supply and sanitation systems. Tools and good practices from the pan-European Region	2016	
	Guidelines on the Setting of Targets, Evaluation of Progress and Reporting	2010	
National	Guidelines for Canadian Drinking Water Quality (GCDWQ) (updated version)	2017	Canada
National	Code of Practice on Piped Drinking Water Sampling and Safety Plans	2008	Singapore
National	Australian Drinking Water Guidelines (ADWG)	2011	Australia
AGRICULTURAL WATER QUALITY GUIDELINES			
International	FAO Water Quality for Agriculture	1994	All
International	WHO-FAO Guidelines for the Safe Use of Wastewater, Excreta and Greywater Volume 2: Wastewater use in Agriculture	2006	All
International	ISO Guidelines for Treated Wastewater use for Irrigation Projects	2015	All
International	Codex Alimentarius Code of Hygiene Practice for Fresh Fruits and Vegetables	2003	All
National	Guidelines for Water Reuse	2012	U.S.A.
National	Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses	1999	Canada
	Protocols for Deriving Water Quality Guidelines for the Protection of Agricultural Water Uses (Irrigation and Livestock Water)		
National	Guidelines on the Procedures and Technical Requirements for the Issuance of a Certification allowing the Safe Re-Use of Wastewater for Purposes of Irrigation and Other Agricultural Uses	2007	Philippines
INDUSTRIAL WATER QUALITY GUIDELINES			
International	WHO-FAO General Principles of Food Hygiene	2009	All
International	WHO Good Manufacturing Practices: Water for Pharmaceutical Use	2012	All
Regional	Water Quality Demands in Paper, Chemical, Food and Textile Companies	2010	EU
National	South African Water Quality Guidelines Volume 3	1996	South Africa
National	Canadian Water Quality Guidelines (Chapter 5)	1987	Canada
ENERGY WATER QUALITY GUIDELINES			
International	Efficient Water Management in Water Cooled Reactors	2012	All
National	Cooling Water Options for the New Generation of Nuclear Power Stations in the UK	2010	United Kingdom
ENVIRONMENTAL WATER QUALITY GUIDELINES			
International	UNEP International Water Quality Guidelines for Ecosystems (IWQGES)	2016	All
Regional	EU Water Framework Directive	2000	European Union
National	Australian and New Zealand Guidelines for Fresh and Marine Water Quality	2000	Australia, New Zealand
National	Canadian Water Quality Guidelines for the Protection of Aquatic Life (CWQG-PAL)	1999	Canada
National	South African Water Quality Guidelines for Aquatic Ecosystems	1996	South Africa

Figure 3.3. List of Selected Guidelines (IWRA, 2018, Table 16).

comprehensive drinking water quality guidelines on regional and national levels (IWRA, 2018). Most guidance for water used in the agriculture sector is directed at safe wastewater reuse, especially for irrigation practices (IWRA, 2018). There is a distinct difference in agricultural water use between developed and developing countries, with developed countries requiring guidelines to encourage the use of reclaimed water, and developing countries requiring guidelines to assist in making their practices of unplanned water reuse safer (IWRA, 2018). Defined water quality guidelines for the total industrial sector are not available. International guidelines on water inputs for secondary industries are aimed primarily at food processing, pharmaceuticals and high-tech industries, all of which require sophisticated water treatment facilities (IWRA, 2018).

IWRA, ONEMA/AFB, and the World Water Council recommend defining water quality requirements based on both application and geographical setting to allow water resources to be applied more effectively (IWRA, 2018). They encourage refining the quality of outflow from treatment facilities to match the needs of uses such as agricultural areas, landscapes, recreational areas and sports grounds (IWRA, 2018). Water inflow into ecosystems consists increasingly of water discharges from domestic, agriculture, industry, and energy water use (IWRA, 2018). Water is cyclical so a cross-sectoral perspective including water discharges from the domestic, agricultural and industrial sectors needs to be considered to safeguard environmental systems (IWRA, 2018).

A key takeaway from this report is that wastewater and greywater offer alternative options for water sources, and appropriate guidance could encourage its use and ensure it meets health-related values for all water uses (IWRA, 2018). The private ownership structure of industry is unique compared with centralised water management, allowing for this sector to undergo fast change when opportunities exist to use alternative and potentially cost-effective water sources (IWRA, 2018). They suggest the production of more guiding documents on water quality across all industrial and energy sectors, particularly for processes that require low quality water where little guidance is available, to encourage and assist companies to use water of the appropriate quality (IWRA, 2018).

IWRA, ONEMA/AFB, and the World Water Council conclude that water quality remains a key consideration for global water management, not only for addressing low quality discharges that affect other uses and have environmental impacts, but also for examining the most efficient water quality for a specific purpose (IWRA, 2018). The report represents a sectoral analysis of water qualities; however, it is clear that a nexus exists between water and all the main sectors explored (IWRA, 2018). They encourage refining the quality of outflow from treatment facilities to match the needs of uses such as agriculture, landscapes, recreational areas and sports grounds (IWRA, 2018).

Promoting the integrated use of these guidelines, while acknowledging the water cycle as a whole and that all outputs are eventually released to the environment, will contribute to smarter water management (IWRA, 2018). Directing water more appropriately across all sectors based on water quality needs could ultimately improve water use efficiencies, health outcomes, decision making, and management processes (IWRA, 2018). Furthermore, it could help relieve stress on scarce water resources and ensure adequate water quality inputs to various applications, with the end goal of contributing to water security (IWRA, 2018).

While the water quality definitions reviewed thus far often use multiple parameters to describe the quality of each type of water, the following section describes how water quality can be compared using a single value.

3.2.6 Global Water Quality Index

Any number of water quality measurements can serve, and have already been used, as indicators of water quality (UNEP, 2007). However, there is no single measure that can describe overall water quality for any one body of water, let alone at a global level (UNEP, 2007). Although there is no globally accepted composite index of water quality, some countries and regions have used, or are using, aggregated water quality data in the development of water quality indices (UNEP, 2007). Most water quality indices rely on normalising, or standardising, data parameter by parameter according to expected concentrations and some interpretation of 'good' versus 'bad' concentrations (UNEP, 2007). Parameters are often then weighted according to their perceived importance to overall water quality and the index is calculated as the weighted average of all observations of interest (Figure 2.13) (UNEP, 2007).

Similar to indices of economic strength, such as Gross National Product (GNP), these water quality indices take information from a number of sources and combine them to develop an overall snapshot of the state of the national system (UNEP, 2007). Even though there is considerable debate as to which measures should be included in the derivation of an index, and which information the index provides to the general public and to policymakers, there is some agreement that water quality indices are useful tools for comparing water quality across systems and over time (UNEP, 2007). They can also provide a benchmark for evaluating successes and failures of management strategies aimed at improving water quality (UNEP, 2007).

3.2.7 Academic Literature Related to Changes and Gaps in Defining Global Water Quality

In addition to the water quality definitions established by international organisations, there is discussion of the changes and gaps related to defining water quality in the academic literature. This section aims to capture the broadening of water quality definitions, adding to water quality parameter analysis an accounting for use and function.

Karr (1993) identifies a shift in emphasis in environmental protection from attention to human health, primarily, to a more balanced consideration of human and ecological health. Karr asserts that while ecological health is inextricably tied to concepts such as biological diversity and biological integrity, water chemistry and toxicity testing have dominated water quality programs for decades. Success in protecting the ecological health of water resources depends on supplementing those methods with ecologically robust approaches (Karr, 1993). Karr believes existing definitions and approaches for measuring the quality of water resources provide a template to guide development of procedures to assess ecological health. Karr identifies critical components of successful monitoring programs, including evaluations relative to regional expectations, multi-metric indexes that reflect the multivariate nature of biological systems, and index components that evaluate conditions from individual, population, assemblage, and landscape perspectives.

Meybeck (1996) proposes some redefinitions of river water quality, noting that chemical water quality has been defined by a set of concentrations, speciations and physical partitions of inorganic and organic substances; a definition that refers to the chemical composition of waters and which is an objective description resulting from analysis. Maybeck suggests that the term water quality is more appropriate for the set of subjective attributes related to the modification of the natural water chemical composition and the relevance of chemical composition with regard to human uses.

Hamilton *et al.* (2010) identify the need for an objective scale for characterising reference ecosystem conditions including defined categories with sufficient scope to maintain protection and support antidegradation. Hamilton *et al.* believe there is both a fundamental and applied need to define expectations of changes in aquatic ecosystems due to global changes. Global changes influence all aspects of water resource management decisions based on comparisons to reference conditions with impacts making it increasingly problematic to find an ‘undisturbed’ water body to define acceptable conditions of ecological integrity (Hamilton *et al.*, 2010). They argue for using a more objective scale for characterising reference conditions that is anchored in expectations for what would be attainable under undisturbed conditions. More refined aquatic uses could create more narrowly defined categories, which could accommodate potentially ‘irreversible’ changes, but with sufficient scope to maintain protection and support antidegradation from regulated causes (Hamilton *et al.*, 2010). Additionally, it would define the scale against which future reference station degradation from combined global change impacts could be tracked and quantified (Hamilton *et al.*, 2010). Hamilton *et al.* define the need for a scale of categories, but don’t propose specific categories.

Srebotnjak *et al.* (June 2012) make a first attempt to create a globally comparable freshwater quality index. The 2008 Environmental Performance Index (EPI) published by the Yale

Center for Environmental Law and Policy (YCELP) and the Center for International Earth Science Information Network (CIESIN) at Columbia University includes a Water Quality Index (WATQI). The WATQI provides a first global effort at reporting and estimating water quality on the basis of five commonly reported quality parameters: dissolved oxygen, electrical conductivity, pH value, and total nitrogen and phosphorus concentrations (Srebotnjak *et al.*, 2012). These parameters have demonstrated utility as indicators of the main ecological water quality impairment issues: oxygen depletion; nutrient pollution; acidification; and salinization (Srebotnjak *et al.*, 2012). These five water quality parameters were selected following extensive consultation with UNEP GEMS/Water and other experts, and taking into account data availability in GEMStat and Waterbase (Srebotnjak *et al.*, 2012). The UNEP GEMS/Water Programme is in a position to monitor the state of inland water quality as it maintains the only global database of water quality for inland waters, GEMStat, with over two million entries for lakes, reservoirs, rivers and groundwater systems (Srebotnjak *et al.*, 2012). Its approximately three thousand two hundred monitoring stations located in slightly more than one hundred countries include baseline (*e.g.*, reference or non-impacted), trend (*e.g.*, impacted) and flux (*i.e.*, estuarine or brackish water) stations (Srebotnjak *et al.*, 2012).

3.2.8 Section Summary: Defining Categories of Water Quality at the Global Level

In summary, three decades ago, Karr (1993) and Maybeck (1996) identify the need for a shift in traditional water quality definitions. Karr identifies a shift in emphasis in environmental protection from attention to human health, primarily, to a more balanced consideration of human and ecological health. Maybeck suggests that the term water quality is more appropriate for the set of subjective attributes related to the modification of the natural water chemical composition, and the relevance of chemical composition with regard to human uses.

Now, three decades later, water quality definitions include intention to balance analytic water quality parameter values with specific use requirements and considerations, as summarised in the following five sections.

3.2.8.1 International Drinking Water Standards Intended for Nation-specific Adaptation

The GDWQ are not promoted as mandatory international standards, but as guidance that should be adapted to the specific circumstances, needs, and resources of countries (WHO, 2018). Therefore, national or regional drinking water quality regulations should only include a subset of the values included in the GDWQ and may have different parameter limits than specified in the GDWQ (WHO, 2018). The WHO (2018) report cautions against comparison. The GDWQ encourage countries to set their own water quality standards to ensure they are locally relevant in terms of parameters and limits (WHO, 2018). Countries are advised to adapt their drinking water quality standards to local conditions and circumstances (WHO, 2018).

3.2.8.2 Ambient Water Quality and Wastewater Quality Classified Using Site-Specific Targets

UNEP (2021) uses a target-based approach to classify ambient water quality, meaning that the measured values are compared with numerical values that represent good water quality. Targets can be nationwide values, water-body-specific, or site-specific (UNEP, 2021). The more specific a target, the better it is at indicating potential pollution problems (UNEP, 2021). Using the same target for all water bodies is not recommended due to natural variation. UN-Habitat (2021) define safely treated wastewater as water treated in compliance with national or local discharge standards and safe management practices. The composition of discharged wastewater quality may differ from country to country as compliance norms are defined nationally (or locally) and are not internationally standardised (UN-Habitat, 2021). Safely treated discharges are defined based on whether they meet national or local discharge standards, and as such are comparable based on whether they comply but are not comparable in terms of specific wastewater quality parameters (UN-Habitat, 2021).

3.2.8.3 Refining Treatment Facilities Outflow Quality to Match Use Requirements

IWRA(2018) conclude that water quality remains a key consideration for global water management, not only for addressing low quality discharges that affect other uses and have environmental impacts, but also for examining the most efficient water quality for a specific purpose. IWRA (2018) encourage refining the quality of outflow from treatment facilities to match the needs of uses such as agriculture, landscapes, recreational areas and sports grounds (IWRA, 2018). Directing water more appropriately based on water quality needs could ultimately improve water use efficiencies, health outcomes, decision making, and management processes (IWRA, 2018). Furthermore, it could help relieve stress on scarce water resources and ensure adequate water quality inputs to various applications, with the end goal of contributing to water security (IWRA, 2018).

3.2.8.4 Global Water Quality Index Limitations

Srebotnjak *et al.* (June 2012) describe a first attempt to create a globally comparable freshwater quality index which provides a first global effort at reporting and estimating water quality on the basis of five commonly reported quality parameters selected following extensive consultation with experts and taking into account data availability (Srebotnjak *et al.*, 2012). UNEP (2007) identified that there is considerable debate as to which measures should be included in the derivation of an index, however, there is some agreement that water quality indices are useful tools for comparing water quality across systems and over time (UNEP, 2007).

3.2.8.5 Use of and Need for Water Quality Scales

Globally, aquatic ecosystem guidelines generally specify multiple levels of protection (UN-Water, 2012). UN-Water found that typically the level of protection corresponds to whether the conditions within a particular region, or water body within it, is of high conservation value, moderately disturbed, or highly disturbed.

Hamilton *et al.*, (2010) argue for using a more objective scale for characterising environmental water quality reference conditions that is anchored in expectations for what would be attainable under undisturbed conditions. Hamilton *et al.* believe more refined aquatic uses could create more narrowly defined categories, which could accommodate potentially irreversible changes, but with sufficient scope to maintain protection and support antidegradation of water quality (Hamilton *et al.*, 2010). Additionally, it would define a scale against which future reference station degradation from combined global change impacts could be tracked and quantified (Hamilton *et al.*, 2010). They define the need for a scale of categories but don’t propose specific categories.

Following this review of how water quality is defined at the global level, the next section narrows the focus to a single nation, and explores how water quality is defined in the US.

3.3 Defining Categories of Water Quality at the National Level for the United States of America

This section investigates nationwide water quality definitions in the US, the methods used to develop them, and whether those definitions are applicable and appropriate for use in California. First, the use of water quality standards to define surface water is explored, and then groundwater, drinking water, stormwater, wastewater, and water reuse quality are each addressed. Next, the US water quality definitions discussed in the academic literature are identified, and the section ends with a summary of the findings.

3.3.1 Water Quality Standards for the USA

Water quality standards (WQS) are provisions of state, territorial, tribal or federal law approved by the US Environmental Protection Agency that describe the desired condition of a water body and the means by which that condition will be protected or achieved (US EPA, 2014). Water bodies are used for purposes such as recreation, scenic enjoyment, and fishing, and as habitat for aquatic organisms (US EPA, 2014). To protect human health and aquatic life in these waters, states, territories and tribes establish WQS which form a legal basis for controlling pollutants entering the waters of the United States (US EPA, 2014).

Water quality standards consist of three core components: designated uses of a water body; criteria to protect designated uses; and antidegradation requirements to protect existing uses and high quality or high value waters (US EPA, 2014). States, territories and tribes also have the choice of including additional components in their water quality standards, such as general policies and WQS variances (US EPA, 2014).

3.3.1.1 Method for Using Water Quality Standards to Define Surface Water Quality in the USA

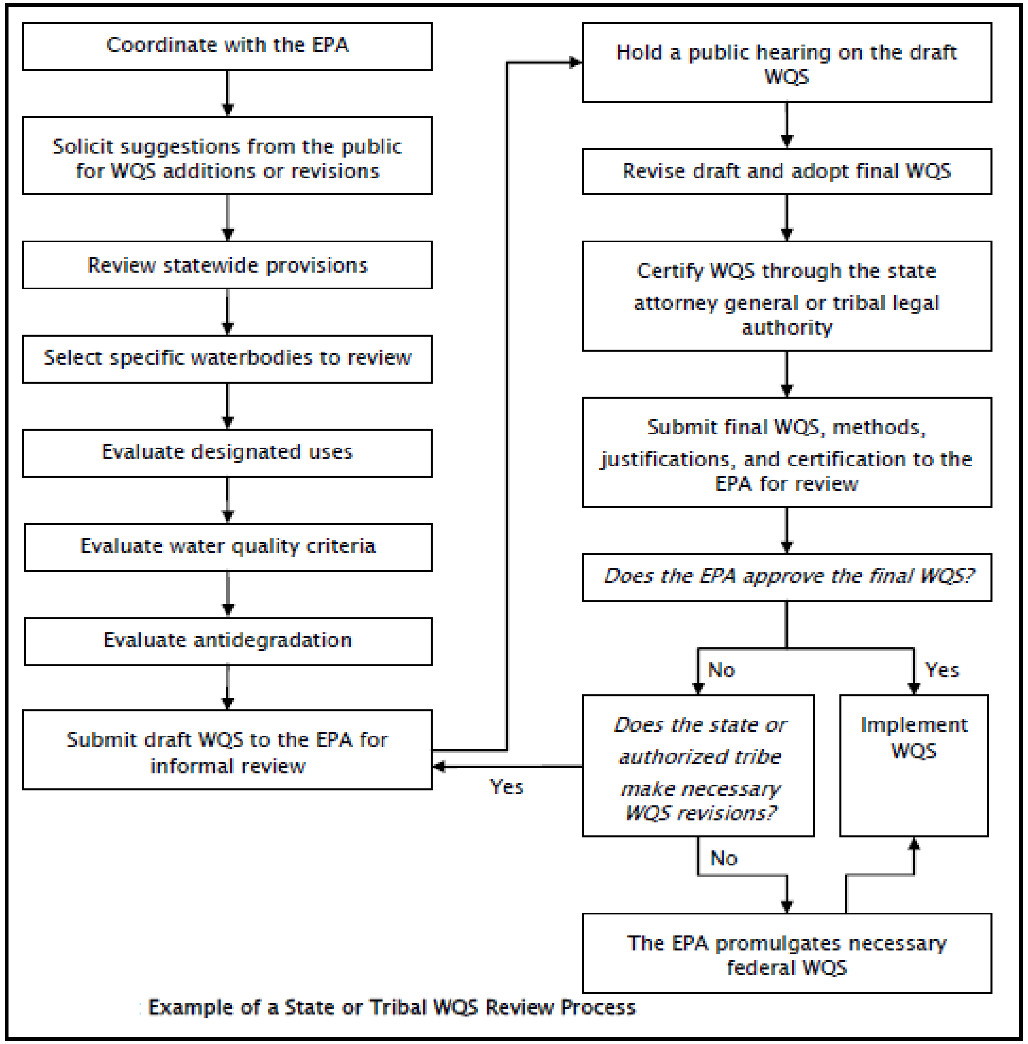
The WQS regulation in 40 CFR Part 131 describes the requirements and procedures for states and tribes to develop, adopt, review, revise, and submit WQS (Figure 3.4) as well as requirements and procedures for the EPA to review, approve, disapprove, and promulgate WQS (Figure 3.5) as authorised by Section 303(c) of the Clean Water Act (CWA) (US EPA, 2014). The term ‘states’ means the fifty states, the District of Columbia, the Commonwealth of Puerto Rico, the Virgin Islands, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands. The term ‘tribe’ means an Indian tribe authorised for treatment in a manner similar to a state under CWA Section 518.

3.3.1.1.1 States and Tribes Establish Water Quality Standards

States and tribes establish WQS to meet the objectives set forth in Section 101(a), which are as follows: restore and maintain the chemical, physical, and biological integrity of the nation's waters, and, wherever attainable, achieve a level of water quality that provides for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water (US EPA, 2014). Section 303(c) instructs states and tribes to consider these objectives in establishing WQS as well as the water’s use and value for public water supplies and agricultural, industrial, and other purposes including navigation (US EPA, 2014). The CWA requires states and tribes to establish WQS for ‘waters of the United States’ (US EPA, 2014).

When states or tribes submit new or revised WQS for the US EPA to review, they must include both the WQS provisions themselves as well as certain accompanying information, consistent with 40 CFR 131.6 and 131.20(c). The submitted WQS provisions may include one or more of the following elements: use designations consistent with the provisions of

Figure 3.4. A diagram of the steps of the process used by a state, territory, or authorised tribe, to propose water quality standards to U.S. EPA for approval (US EPA, 2022e).



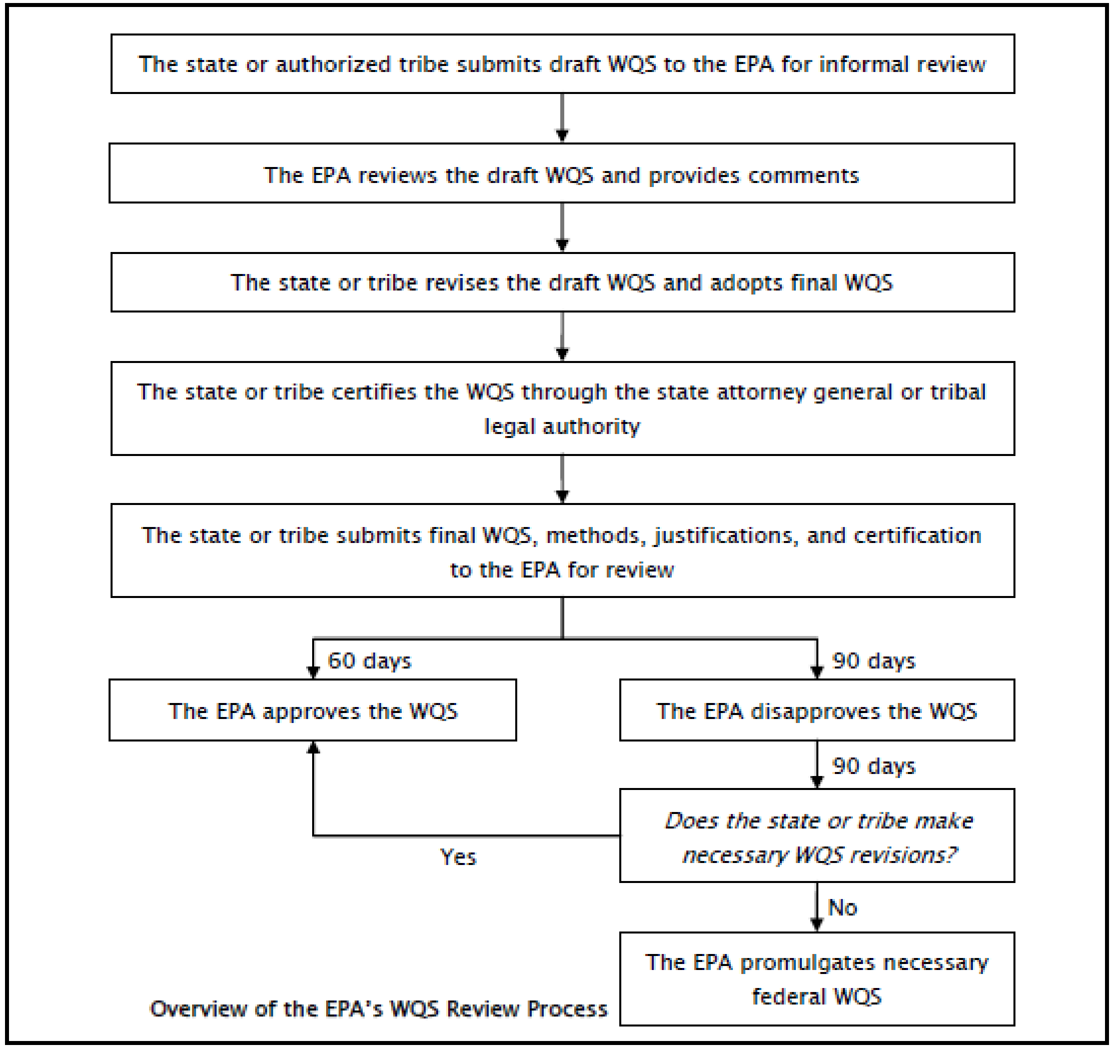


Figure 3.5. A diagram of the water quality standards review process steps for a state or tribe (left) and US EPA (right) (US EPA, 2014).

Sections 101(a)(2) and 303(c)(2) of the CWA; water quality criteria sufficient to protect the designated uses; and an antidegradation policy consistent with 40 CFR 131.12. Additionally, under 40 CFR 131.13, states and tribes may, at their discretion, include in their WQS general policies affecting the application and implementation of WQS (*e.g.*, mixing zone, variance, and critical low-flow policies) (US EPA, 2014).

Whenever a state or tribe submits new or revised WQS provisions, the submission must also include the following items: methods used and analyses conducted to support the WQS provisions; certification by the state attorney general, tribal legal authority, or other appropriate legal authority within the state or tribe that the WQS were duly adopted pursuant to state or tribal law; and general information to aid the US EPA in determining the adequacy of the scientific bases of the WQS that do not include the uses specified in Section 101(a)(2), as well as information on general policies applicable to state and tribal WQS that may affect their application and implementation. The US EPA may request additional information from the state or tribe to aid in determining the adequacy of the WQS (US EPA, 2014).

3.3.1.1.2 Federal Water Quality Standards Review Process

States and authorized tribes are responsible for reviewing, revising, and adopting WQS and submitting the WQS to US EPA (US EPA, 2014). US EPA has the authority and the duty under the CWA to review and approve or disapprove new or revised WQS based on the requirements of the CWA (US EPA, 2014).

States and tribes may develop WQS that are more stringent than required by the CWA and the 40 CFR Part 131 (US EPA, 2014). Consistent with Section 510, states and tribes may adopt any requirements regarding control or abatement of pollution as long as such requirements are not less stringent than the requirements of the CWA (US EPA, 2014). Thus, the US EPA is generally not authorised to disapprove a state or tribal WQS on the basis that the EPA considers the WQS to be too stringent (US EPA, 2014).

If the US EPA determines that the new or revised state or tribal WQS are consistent with the CWA and 40 CFR Part 131, the US EPA approves the WQS (US EPA, 2014). However, if they are not consistent with the CWA, the US EPA disapproves the WQS (US EPA, 2014). In the case of disapproval, the US EPA must propose federal WQS and promulgate such WQS within ninety days of proposal, provided that the state or tribe does not make appropriate corrections within ninety days. The US EPA may approve some provisions and not others within the same WQS submission (US EPA, 2014).

The US EPA may also promulgate a new or revised federal WQS where the Administrator determines under Section 303(c)(4)(B) that such WQS were necessary to meet the requirements of the CWA, and no WQS have been submitted for the US EPA to disapprove under Section 303(c)(4)(A) (US EPA, 2014).

3.3.1.1.3 Public Participation

An important element of the method used to establish WQS is the opportunity for the public (*e.g.*, university professors, PhD students, environmental professionals, experts) to comment upon the state, territory and tribal water quality standards (US EPA, 2021a). The review process provides the general public with an opportunity to become involved in protecting the water bodies in their area (US EPA, 2021a). US EPA encourages everyone to attend public events to share their knowledge of how water bodies in their area are used or could be used (US EPA, 2021a).

In addition to activities at the state, territory or tribal level, EPA also provides an opportunity for public involvement (US EPA, 2021a). As part of the rulemaking process, EPA must consider the public comments received on proposed federal regulation (US EPA, 2021a). EPA publishes a notice in the Federal Register prior to formal comment periods on proposed rulemaking or other applicable activities (US EPA, 2021a). Generally, comment periods last for thirty to ninety days.

3.3.1.2 Defining Surface Water Quality in the US Using Water Quality Standards

The WQS regulation requires states, territories and tribes to specify how each water body is used (US EPA, 2021b). These designated uses include: protection and propagation of fish, shellfish and wildlife; recreation; public drinking water supply; agricultural, industrial, navigational and other purposes (US EPA, 2021b). States, territories and tribes adopt water quality criteria to protect the designated uses of a water body (US EPA, 2021b). Water quality criteria can be numeric, narrative, or both (US EPA, 2021b). One of the principal objectives of the Clean Water Act is to maintain the chemical, physical and biological integrity of the nation's waters. Antidegradation requirements provide a framework for maintaining and protecting water quality (US EPA 2021b). States, territories and tribes may adopt WQS variance policies, mixing-zone policies, and low-flow policies, however, such policies are subject to US EPA review and approval.

3.3.1.2.1 Designated Uses of a Water Body

A water quality standard defines the water quality goals for a water body, in part, by designating the use or uses to be made of the water (US EPA, 2012c). States adopt water quality standards to protect public health and welfare, and enhance the quality of water (US

EPA, 2012c). The Clean Water Act requires that water quality standards provide, wherever attainable, water quality for the protection and propagation of fish, shellfish, and wildlife, and recreation in and on the water, and consider the use and value of State waters for public water supplies, agriculture and industrial purposes, and navigation (US EPA, 2012c).

The state selects the level of specificity it desires for identifying designated uses and subcategories of uses (such as whether to treat recreation as a single use or to define a subcategory for secondary recreation). However, the state must be at least as specific as the uses listed in sections 101(a) and 303(c) of the Clean Water Act (US EPA, 2012c), described in the following six sections.

3.3.1.2.1.1 Public Water Supplies Designated Use

The public water supplies classification includes waters that are the source for drinking water supplies and often includes waters for food processing. Waters for drinking water may require treatment prior to distribution in public water systems (US EPA, 2012c).

3.3.1.2.1.2 Protection and Propagation of Fish, Shellfish, and Wildlife Designated Use

The protection and propagation of fish, shellfish, and wildlife classification is often divided into several more specific subcategories, including cold water fish, warmwater fish, and shellfish. For example, some coastal states have a use specifically for oyster propagation. The use may also include protection of aquatic flora. Many states differentiate between selfsupporting fish populations and stocked fisheries. Wildlife protection includes waterfowl, shore birds, and other water-oriented wildlife (US EPA, 2012c).

3.3.1.2.1.3 Recreational Designated Use

Recreational uses are divided into primary contact and secondary contact recreation. The primary contact recreation classification protects people from illness due to activities involving the potential for ingestion of, or immersion in, water. Primary contact recreation usually includes swimming, water-skiing, skin-diving, surfing, and other activities likely to result in immersion. The secondary contact recreation classification is protective when immersion is unlikely. Examples are boating, wading, and rowing. These two broad uses can be subdivided into a number of subcategories (*e.g.*, wading, fishing, sailing, powerboating, rafting) (US EPA, 2012c).

3.3.1.2.1.4 Agricultural Designated Use

The agricultural use classification defines waters that are suitable for irrigation of crops, consumption by livestock, support of vegetation for range grazing, and other uses in support of farming and ranching, and protects livestock and crops from injury due to irrigation and other exposures (US EPA, 2012c).

3.3.1.2.1.5 Industrial Designated Use

The industrial use classification includes industrial cooling and process water supplies. This classification protects industrial equipment from damage from cooling and/or process waters. Specific criteria depend on the industry involved (US EPA, 2012c).

3.3.1.2.1.6 Other Designated Uses

States may adopt other uses as necessary including coral reef preservation, marinas, groundwater recharge, aquifer protection, and hydroelectric power (US EPA, 2012c).

Once a use has been designated for a particular water body or segment, the water body or water body segment cannot be reclassified for a different use except under specific conditions. If a designated use is an existing use, as defined in 40 CFR 131.3, for a particular water body, the existing use cannot be removed unless a use requiring more stringent criteria is added. However, uses requiring more stringent criteria may always be added because doing so reflects the goal of further improvement of water quality (US EPA, 2012c).

States and tribes may choose to expand their coverage of WQS beyond waters of the United States to include other waters as 'waters of the state'. For example, a state or tribe may specifically designate isolated wetlands (*e.g.*, that do not meet the definition of waters of the United States) as waters to which state and tribal WQS apply (US EPA, 2012c).

3.3.1.2.2 Criteria to Protect Designated Uses

Under Section 303(c)(2)(A) of the CWA, states and tribes are responsible for adopting water quality standards that consist of the designated uses of navigable waters and the water quality criteria for such waters. These standards must protect the public health or welfare and enhance the quality of water. 40 CFR 131.3(b) further defines criteria as elements of state water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use. Water quality criteria represent the conditions (*e.g.*, concentrations of particular chemicals, levels of certain parameters) sufficient to restore and maintain the chemical, physical, and biological integrity of water bodies and protect applicable designated uses (US EPA, 2017). Generally, criteria provide for the protection and propagation of fish, shellfish, and wildlife as well as recreation in and on the water (US EPA, 2017). If a criterion is exceeded, the water quality may pose a human health or ecological risk, and protective or remedial action may be needed (US EPA, 2017).

To provide scientific guidance to states and tribes, the US EPA publishes criteria for water quality under Section 304(a) that accurately reflect the latest scientific knowledge (US EPA, 2017). The US EPA's Section 304(a) national criteria recommendations (referred to as 304(a) criteria) provide quantitative concentrations and qualitative measures of pollutants that, if not exceeded, will provide adequate water quality for protection of a designated use (US EPA, 2017). The US EPA's supporting documentation for 304(a) criteria also includes evaluations of available scientific data on the effects of pollutants such as effects on public health and welfare, aquatic life, and recreation (US EPA, 2017). The US EPA develops 304(a) criteria based on the best available science, scientific literature review, established procedures for risk assessment, US EPA policies, external scientific peer review, and public input (US EPA, 2017).

However, states and tribes may adopt, where appropriate, other scientifically defensible criteria that differ from the US EPA's recommendations (US EPA, 2017). The US EPA recommends states and tribes develop a record describing the scientific justification for their adopted criteria and the public participation process (US EPA, 2017). Where the state or tribe adopts site-specific criteria or uses an approach that differs from that of the US EPA's current recommendations, the approach must meet the requirements of 40 CFR 131.11(a) and should be clearly documented and transparent (US EPA, 2017). In the case where a state has chosen not to adopt a new criterion or update a criterion for a parameter for which the US EPA has provided new or updated CWA section 304(a) criteria, the US EPA's provision at 40 CFR 131.20(a) requires states and tribes to provide an explanation for why it is choosing not to adopt the new or revised criterion at that time (US EPA, 2017). This explanation must be provided to the US EPA when the state submits the results of its triennial review, consistent with 40 CFR 131.20(c) (US EPA, 2017). This explanation, while not approved or disapproved by the US EPA, is an important method for a state or tribe to use to explain its rationale to the public and be transparent in its decision-making process (US EPA, 2017).

3.3.1.2.2.1 Human Health Water Quality Criteria

Human health water quality criteria protect any designated uses related to ingestion of water, ingestion of aquatic organisms, or other waterborne exposure from surface waters (US EPA, 2017). Such designated uses can include, but are not limited to, consumption of fish or shellfish (including consumption associated with fishing or shellfish harvesting), and protection of sources of drinking water (US EPA, 2017).

The US EPA's current recommended approach for deriving 304(a) criteria for protection of human health is the *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health* (2000) (referred to as the *2000 Human Health Methodology*) (US EPA, 2017). It outlines the process for establishing water quality criteria for human health that reflect the latest scientific information, including exposure factors (body weight, drinking water consumption rates, fish consumption rate), bioaccumulation factors, and toxicity factors (reference dose, cancer slope factor) (US EPA, 2017).

The *2000 Human Health Methodology* also provides states and tribes with scientifically sound options for developing their own human health criteria that consider local conditions

(US EPA, 2017). If states and tribes choose to derive their own human health criteria or modify the US EPA's 304(a) criteria recommendations, the US EPA recommends that they use the *2000 Human Health Methodology* and consider updated and scientifically defensible data to guide their actions (US EPA, 2017). In addition, the *2000 Human Health Methodology* defines the default factors that the US EPA uses in evaluating the soundness and consistency of state and tribal WQS in accordance with Section 303(c) of the CWA (US EPA, 2017).

3.3.1.2.2.2 Recreational Water Quality Criteria

The US EPA's *Ambient Water Quality Criteria Recommendations for Recreational Waters* include criteria that are designed to protect primary contact recreational uses including swimming, bathing, surfing, water-skiing, tubing, water play by children, and similar water contact activities where a high degree of bodily contact with the water, immersion and ingestion are likely (US EPA, 2017). These recommendations rely on the latest research and science including studies that show a link between gastrointestinal and respiratory illnesses and faecal contamination in recreational waters (US EPA, 2017). In addition, the US EPA issued *Human Health Recreational Ambient Water Quality Criteria and/or Swimming Advisories for Microcystins and Cylindrospermopsin*, which include recommended concentrations of the cyanotoxins in recreational waters to protect primary contact recreational uses (US EPA, 2017).

The US EPA has developed documents that provide information for states and tribes on flexible approaches for developing site-specific recreational criteria that reflect the latest science including: *Overview of Technical Support Materials: A Guide to the Site-Specific Alternative Recreational Criteria TSM Documents* (2014), an overarching guide designed to help water quality managers evaluate their site information and choose the best technical approach for developing site-specific recreational criteria; *Site-Specific Alternative Recreational Criteria Technical Support Materials for Alternative Indicators and Methods* (2014), which describes how to evaluate and compare alternative methods for measuring microbes in water using an existing US EPA-approved method; and *Microbial Risk Assessment (MRA) Tools, Methods, and Approaches for Water Media* (2014), which assists risk assessors and scientists in developing rigorous and scientifically defensible risk assessments for waterborne pathogens (US EPA, 2017).

3.3.1.2.2.3 Aquatic Life Water Quality Criteria

Aquatic life water quality criteria are necessary to support any designated uses related to protection and propagation of fish, shellfish, and wildlife (US EPA, 2017). The 304(a) criteria recommendations to *Protect Aquatic Life from the Effects of Toxic Pollutants* describe an objective way to estimate the highest concentration of a substance in water that will not present a significant risk to the aquatic organisms within it (US EPA, 2017). This US EPA method relies primarily on acute and chronic laboratory toxicity data for aquatic organisms from eight taxonomic groups reflecting the distribution of aquatic organisms' taxa that are intended to be protected by water quality criteria (US EPA, 2017). Acute criteria are derived using short-term (forty-eight to ninety-six hour) toxicity tests on aquatic plants and animals (US EPA, 2017). Chronic criteria can be derived using longer-term (seven day to greater than twenty-eight day) toxicity tests, if available, or by using an acute-to-chronic ratio procedure if there are insufficient chronic data (US EPA, 2017). If justified, acute and chronic aquatic life criteria may be related to other water quality characteristics such as pH, temperature, or hardness (US EPA, 2017). Separate criteria are typically developed for freshwater and saltwater organisms. Other information from mesocosms (*i.e.*, controlled field experiments) and field data are considered when available and as appropriate (US EPA, 2017).

Aquatic life water quality criteria are typically expressed in two forms, with different recommended magnitude and duration: as acute criteria to protect against mortality or effects that occur due to a short-term exposure to a chemical, and as chronic criteria to protect against mortality, growth and reproductive effects that may occur due to a longer-term exposure to a chemical (US EPA, 2017). Where appropriate, the calculated criteria may be made more stringent to protect commercially or recreationally important species, and criteria may also be made more stringent to protect endangered or threatened species (US EPA, 2017). Both the acute and chronic criteria have three components: criterion magnitude (*i.e.*, the criterion maximum concentration (CMC) for acute criteria, and criterion continuous concentration (CCC) for chronic criteria), duration of the CMC and CCC (*i.e.*, averaging period), and a maximum allowable frequency of exceedance of the CMC and CCC (US EPA, 2017). For aquatic life criteria based on standard laboratory toxicity tests, the US EPA typically recommends average durations of one hour for the CMC and four days for the CCC (US EPA, 2017).

The US EPA's regulation at 40 CFR 131.11(b)(1)(ii) provides that states and tribes may adopt water quality criteria that are modified to reflect site-specific conditions. Site-specific criteria, as with all criteria, must be based on a sound scientific rationale and protect designated uses, and are subject to US EPA review and approval or disapproval under Section 303(c) of the CWA. A site-specific criterion is developed to protect aquatic life at a particular site, taking into account a site's physical, chemical, and/or biological conditions (*i.e.*, water quality characteristics or species composition) (US EPA, 2017).

3.3.1.2.2.4 Nutrient Water Quality Criteria

Nutrient pollution can cause numerous adverse effects to aquatic life, impair recreational designated uses, and threaten human health by polluting drinking water supplies (US EPA, 2017). The US EPA encourages states and tribes to develop numeric nutrient water quality criteria to create effective tools to help prevent and manage nutrient pollution (US EPA, 2017). Specifically, the US EPA recommends that states and tribes adopt numeric criteria into WQS for both total nitrogen and total phosphorus to help prevent eutrophication and the proliferation of harmful algal blooms in rivers and streams, lakes and reservoirs, and estuaries and coastal areas (US EPA, 2017).

To develop numeric nutrient criteria, the US EPA recommends a variety of approaches such as the reference condition approach, empirical stressor-response models, and mechanistic water quality models (US EPA 2017). The EPA has published technical guidance describing the techniques for developing numeric nutrient criteria for different water body types, including nationally recommended CWA Section 304(a) numeric nutrient criteria on an ecoregional basis for most rivers, streams, lakes and reservoirs across the country (US EPA, 2017). Additionally, the US EPA's *Nutrient Scientific Technical Exchange Partnership and Support (N-STEPS)* program provides technical support to states and tribes for the development of scientifically sound numeric nutrient criteria (US EPA, 2017). N-STEPS provides the US EPA, states, and tribes with a mechanism to work in partnership in addressing scientific issues related to numeric nutrient criteria derivation (US EPA, 2017).

In addition to technical guidance documents for developing nutrient criteria, the US EPA provides a toolkit of additional resources (US EPA, 2017). This toolkit compiles available US EPA resources to facilitate state and authorized tribal adoption of numeric nutrient criteria (US EPA, 2017). It includes information on criteria and WQS development; water quality monitoring, assessment, reporting, and planning; WQBELs and water quality trading; economics and financing; and communications materials (US EPA, 2017).

3.3.1.2.2.5 Biological Water Quality Criteria

Biological criteria are numeric values or narrative expressions that describe the desired biological condition of an aquatic community within a water body with an aquatic life use designation (US EPA, 2017). Evaluation of the biological condition of a water body includes measures of the structure and function of the aquatic community within a specified habitat (US EPA, 2017). The development and implementation of biological criteria involves the following: selection of surface waters to use in developing reference conditions for each designated use; measurement of the structure and function of aquatic communities in reference surface waters to establish biological criteria; measurement of the physical habitat and other environmental characteristics of the water resource; and establishment of a protocol to compare the biological criteria to biota in comparable test waters to determine whether impairment has occurred (US EPA, 2017).

The US EPA supports the use of biological data to refine aquatic life designated uses and the development of biological water quality criteria as part of state and tribal WQS by providing *A Primer on Using Biological Assessments to Support Water Quality Management* (2011) and the *Practitioner's Guide to the Biological Condition Gradient: A Framework to Describe Incremental Change in Aquatic Ecosystems* (2016). These help states, tribes, and the US EPA achieve the biological integrity objective in Section 101 of the CWA and comply with the statutory requirements under Sections 303 and, for the US EPA, 304 (US EPA, 2017).

3.3.1.2.2.6 Flow Considerations

The natural flow regime, defined as the characteristic pattern of flow magnitude, timing, duration, frequency, and rate of change, plays a central role in supporting the chemical, physical, and biological integrity of streams and rivers and the services they provide (US EPA, 2017). Hydrologic alteration is a change to a natural flow regime and can include an increase or decrease in water volume, seasonal pulse flow disruption, dramatic variation in water temperature, and other factors. Hydrologic alteration can affect aquatic species' ability to spawn, gather nutrients from a stream system, access high-quality habitat, and more. In contrast, maintaining normal flow regimes may help increase river or stream resilience to a variety of stressors including climate change (US EPA, 2017). Several states and tribes have adopted a narrative form of flow criteria in their WQS, such as *Stream or water body flows shall support the designated aquatic life use* (US EPA, 2017).

The US EPA and the United States Geological Survey's technical report *Protecting Aquatic Life from Effects of Hydrologic Alteration* provides information about protecting aquatic life from the effect of hydrologic alteration in flowing waters (US EPA, 2017). The report discusses the natural hydrologic flow regime and potential effects of flow alteration on aquatic life, examples of states that have adopted narrative flow standards, and a flexible, non-prescriptive framework that could be used to establish targets for flow that are protective of aquatic life (US EPA, 2017).

3.3.1.2.2.7 Sediment Benchmarks

Sediments are loose particles of sand, clay, silt, and other substances that settle at the bottom of a water body (US EPA, 2017). Suspended and bedded sediments (SABS) are defined by the US EPA as particulate organic and inorganic matter that suspends in or is carried by the water and/or accumulates in a loose, unconsolidated form on the bottom of natural water bodies (US EPA, 2017). SABS in excessive amounts constitute a major ecosystem stressor and are a leading cause of waterbody impairment (US EPA, 2017). Contaminated sediments are soils, sand, organic matter, or minerals that accumulate on the bottom of a water body and contain toxic or hazardous materials that may adversely affect human health or the environment (US EPA, 2017). The US EPA has dealt directly with the toxicity of chemicals in sediments in fresh and marine waters through equilibrium partitioning sediment benchmarks (ESBs) (US EPA, 2017).

The equilibrium partitioning approach focuses on predicting the chemical interaction between sediments and contaminants (US EPA, 2017). ESBs are the US EPA's recommendation of the concentration of a substance in sediment that will not unacceptably affect benthic organisms or their associated designated uses (US EPA, 2017). The US EPA chose the equilibrium partitioning approach because it accounts for the varying biological availability of chemicals in different sediments and allows for the incorporation of the appropriate biological effects' concentration (US EPA, 2017). This provides for the derivation of benchmarks that are causally linked to the specific chemical, applicable across sediments, and appropriately protective of benthic organisms (US EPA, 2017). ESBs may be useful as a complement to existing sediment assessment tools to help assess the extent of sediment contamination, identify chemicals causing toxicity, and serve as targets for pollutant loading control measures (US EPA, 2017). *Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms* have been published for*: PAH Mixtures* (2003); *Dieldrin* (2003); *Endrin* (2003); *Cadmium, Cooper, Lead, Nickel, Silver, and Zinc* (2005); and *Nonionic Organics* (2012) (US EPA, 2017).

3.3.1.2.2.8 Temperature Water Quality Criteria

Water temperature is an important aspect of protecting aquatic life, such as in cold water habitats where certain species may require cold water to survive (US EPA, 2017). Some waters are naturally warm at certain times of the year due to factors including increased solar radiation and warm air temperature (US EPA, 2017). However, human activities (*e.g.*, removal of streamside vegetation that provides shade, discharges of heat from municipal and industrial facilities) can also increase water temperature by increasing the heat load into the water body, reducing the water body's capacity to absorb heat, and eliminating or reducing the amount of groundwater flow, which helps to moderate temperatures (US EPA, 2017). Some human activities can also decrease water temperatures, for example, when cold water is released from the bottom of a thermally stratified reservoir behind a dam (US EPA, 2017).

State and tribal water quality criteria for temperature aid in meeting the CWA Section 101(a)(2) goal of protection and propagation of fish, shellfish, and wildlife by protecting the habitat in which such aquatic life live (US EPA, 2017). The US EPA's current 304(a) criteria recommendations for temperature are found in *Quality Criteria for Water 1986*. US EPA has also developed guidance on the development of temperature criteria for the protection of salmonids, as well as other supporting materials and technical products including a primer for identifying cold water refuges to protect and restore thermal diversity in riverine landscapes (US EPA, 2017).

3.3.1.2.2.9 Wildlife Water Quality Criteria

Water quality criteria are developed to protect terrestrial and avian wildlife species that are dependent upon aquatic food sources and may be exposed to contaminants through diet (US EPA, 2017). Bioaccumulation is the accumulation of chemicals in the tissue of organisms through any route including ingestion or direct contact with contaminated water (US EPA, 2017). The US EPA's *304(a) Criteria Recommendations Intended to Protect Aquatic Life* (*e.g*., fish, benthic invertebrates, zooplankton) include provisions to protect wildlife that consume aquatic organisms from the bioaccumulation potential of a compound (US EPA, 2017). The guidelines recommend deriving final wildlife residue values based on available data (US EPA, 2017).

US EPA's *Water Quality Guidance for the Great Lakes System* at 40 CFR Part 132 Appendix D describes a methodology applicable to the Great Lakes system for developing criteria for the protection of avian and mammalian wildlife from adverse effects resulting from the ingestion of water and aquatic prey (US EPA, 2017). The methodology is similar to that used to derive non-cancer human health criteria (US EPA, 2017). Separate wildlife values are derived for birds and mammals using taxonomic class-specific toxicity data and exposure data for five representative Great Lakes wildlife species (*i.e*., bald eagle, herring gull, belted kingfisher, mink, and river otter) which are likely to experience the highest exposures to bioaccumulative contaminants through the aquatic food web in the Great Lakes (US EPA, 2017). In addition, the US EPA published the *Great Lakes Water Quality Initiative Technical Support Document for Wildlife Criteria* (1995), which includes the methodology for deriving wildlife values for pollutants with limited toxicological data to derive a value for only one of the two taxonomic classes specified (*i.e*., birds and mammals) (US EPA, 2017).

3.3.1.2.2.10 Water Quality Criteria for Wetlands

Numeric aquatic life 304(a) water quality criteria recommendations are designed to be protective of aquatic life for surface waters and are generally applicable to most wetland types (US EPA, 2017). The US EPA's *An Approach for Evaluating Numeric Water Quality Criteria for Wetlands Protection* (1991) provides an approach, based on the site-specific guidelines, for detecting wetland types that might not be protected by direct application of 304(a) criteria recommendations (US EPA, 2017). The evaluation can be simple for those wetland types for which sufficient water chemistry and species assemblage data are available, but will be less useful for wetland types for which these data are not (US EPA, 2017). States and tribes can use the results of this type of evaluation, combined with information on local or regional environmental threats, to prioritise wetland types, and individual criteria, for further site-specific evaluations or additional data collection (US EPA, 2017). The US EPA recommends close coordination among regulatory agencies, wetland scientists, and criteria experts in developing criteria for wetlands (US EPA, 2017).

The US EPA published a wetland-specific *Nutrient Criteria Technical Guidance Manual* (2008) to assist states and tribes in developing numeric nutrient criteria for wetlands (US EPA, 2017). Additionally, the US EPA developed narrative templates for wetlands WQS to simplify development of protective WQS for wetlands. States and tribes may choose to develop different types of criteria for wetlands protection, including site-specific numeric or narrative criteria, as long as they are scientifically defensible and protective of the designated uses, and otherwise consistent with 40 CFR 131.11 and CWA section 303(c)(2)(B) (US EPA, 2017).

3.3.1.2.2.11 Water Quality Criteria for Priority Pollutants

Section 303(c)(2)(B) of the CWA and 40 CFR 131.11 require states and tribes to adopt numeric water quality criteria for Section 307(a) toxic pollutants, as necessary, to support state and tribal designated uses where the discharge or presence of such pollutants in the affected waters could reasonably be expected to interfere with those designated uses adopted by the state or tribe (US EPA, 2017). Where numeric criteria are not available, the state or tribe must adopt criteria based on biological monitoring or assessment methods consistent with the US EPA guidance published pursuant to Section 304(a)(8) (US EPA, 2017).

For regulatory purposes, the US EPA has translated the sixty-five compounds and families of compounds listed under Section 307(a), which potentially include thousands of specific compounds, into one hundred and twenty-six specific toxic substances, which the US EPA refers to as priority pollutants, and has published national criteria recommendations for most of these pollutants consistent with the authority provided in Section 304(a) (US EPA, 2017). The Section 307(a)(1) list of toxic pollutants is codified at 40 CFR 401.15 (US EPA, 2017).

For priority pollutants for which the US EPA has not published 304(a) numeric water quality criteria, CWA Section 303(c)(2)(B) requires states and tribes to adopt criteria based on biological monitoring or assessment methods consistent with information published by the US EPA in accordance with Section 304(a)(8) (US EPA, 2017).

3.3.1.2.2.12 Water Quality Criteria for Agricultural and Industrial Designated Uses

Criteria developed for human health and aquatic life will usually be sufficiently stringent to protect agricultural and industrial designated uses because those uses are generally less sensitive than human health and aquatic life designated uses (US EPA, 2017). There could be situations where such designated uses require more stringent criteria to protect them; salts could be a problem in crop water, for example, or hardness or other contaminants could cause issues at industrial facilities (US EPA, 2017). States and tribes may establish criteria specifically designed to protect such designated uses and should ensure that they apply the criteria protective of the most sensitive use of the water body, as required by 40 CFR 131.11(a) (US EPA, 2017).

3.3.1.2.3 Antidegradation Requirements

Designated uses and water quality criteria are the primary tools states and tribes use to achieve the objectives and goals of the Clean Water Act. However, antidegradation requirements complement these tools by providing a framework for three tiers of protection: maintaining existing uses; protecting waters that are of a higher quality than necessary to support the Clean Water Act goals; and protecting waters identified by states and tribes as Outstanding National Resource Waters (ONRWs) (US EPA, 2012d). Antidegradation implementation by the states is based on a set of procedures to be followed when evaluating activities that may impact the quality of the waters of the United States (US EPA, 2012d).

3.3.1.2.3.1 Tiers of Antidegradation Water Quality Protection Definitions

This section describes the three tiers of antidegradation protection detailed in the Clean Water Act, and one additional tier that developed organically.

3.3.1.2.3.1.1 Tier 1: Maintaining Existing Uses

Section 131.12(a)(l) provides the absolute floor for water quality in all waters of the United States. This paragraph applies a minimum level of protection to all waters (US EPA, 2012d).

3.3.1.2.1.2 Tier 2: Protecting High Quality Waters

Section 131.12(a)(2) applies to waters whose quality exceeds that necessary to protect the section 101(a)(2) goals of the act (US EPA, 2012d). In this case, water quality may not be lowered to less than the level necessary to fully protect the fishable and swimmable uses and other existing uses, and may be lowered even to those levels only after following all the provisions described in section 131.12(a)(2) (US EPA, 2012d).

3.3.1.2.1.3 Tier 3: Protecting Outstanding National Resource Waters

Section 131.12(a)(3) applies to Outstanding National Resource Waters (ONRWs) where the ordinary use classifications and supporting criteria may not be sufficient or appropriate (US EPA, 2012d). As described in the preamble to the Water Quality Standards regulation, states may allow some limited activities which result in temporary and short-term changes in water quality, but such changes in water quality should not impact existing uses or alter the essential character or special use that makes the water an ONRW (US EPA, 2012d).

3.3.1.2.1.4 Creation of Tier 2½

As the states implemented their antidegradation policies, they developed a new tier, which US EPA has accepted even though it is not directly mentioned in the regulation (US EPA, 2012d). Tier 2½ is an application of the antidegradation policy that has implementation requirements that are more stringent than for Tier 2 (*i.e.*, high-quality waters), but somewhat less stringent than the prohibition against any lowering of water quality in Tier 3 (*i.e.*, ONRWs) (US EPA, 2012d). US EPA accepts this additional tier in state antidegradation policies because it is clearly a more stringent application of the Tier 2 provisions of the antidegradation policy and, therefore, permissible under section 510 of the CWA (US EPA, 2012d). Concern by the states that the Tier 3 ONRW provision was so stringent that its application would likely prevent states from taking actions in the future that were consistent with important social and economic development on, or upstream of, ONRWs led to the development of the Tier 2½ concept (US EPA, 2012d). This concern is a reason that relatively few water bodies are designated as ONRWs. The Tier 2½ approach allows states to provide a very high level of water quality protection without precluding unforeseen future economic and social development considerations (US EPA, 2012d).

3.3.1.2.3.2 Method Used to Develop Tiers of Antidegradation Water Quality Protection

Each state must develop, adopt, and retain a statewide antidegradation policy regarding water quality standards and establish procedures for its implementation through the water quality management process (US EPA, 2012d). The state antidegradation policy and implementation procedures must be consistent with the components detailed in 40 CFR 131.12. States may adopt antidegradation statements more protective than the federal requirement (US EPA, 2012d).

State antidegradation polices and implementation procedures are subject to review by the regional administrator (US EPA, 2012d). US EPA has clear authority to review and approve or disapprove and promulgate an antidegradation policy for a state. If a state's antidegradation policy does not meet the federal regulatory requirements, either through state action to revise its policy or through revised federal requirements, the state would be given the opportunity to make its policy consistent with the regulation (US EPA, 2012d). If this is not done, US EPA has the authority to promulgate the policy for the state pursuant to section 303(c)(4) of the Clean Water Act (US EPA, 2012d).

3.3.1.2.4 Water Quality Standard Variances and General Policies

As specified in 40 CFR 131.13, states and tribes may, at their discretion, adopt certain policies into their water quality standards that affect how their standards are applied or implemented (US EPA, 2014). Examples of such policies include those affecting mixing zones, critical low flows, and variances. As the regulation indicates, states and tribes are not required to adopt general policies (US EPA, 2014). However, if a state or tribe chooses to adopt a general policy, such policies are subject to US EPA review and approval or disapproval under Section 303(c) of the Clean Water Act (CWA) if they constitute new or revised WQS (US EPA, 2014).

3.3.1.3 Waters of the United States

The Clean Water Act indicates that all of its programs protect waters of the United States and, as a result, there is only one definition for that key threshold term (US EPA, 2014). The US Code of Federal Regulations states in section 40 CFR 230.3(s):

> 'The term waters of the United States means:
>
> 1. All waters which are currently used, or were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide;
> 2. All interstate waters including interstate wetlands;
> 3. All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds, the use, degradation or destruction of which could affect interstate or foreign commerce including any such waters:
>   a. Which are or could be used by interstate or foreign travelers for recreational or other purposes; or
>   b. From which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or
>   c. Which are used or could be used for industrial purposes by industries in interstate commerce;

4. All impoundments of waters otherwise defined as waters of the United States under this definition;
5. Tributaries of waters identified in paragraphs (s)(1) through (4) of this section;
6. The territorial sea;
7. Wetlands adjacent to waters (other than waters that are themselves wetlands) identified in paragraphs (s)(1) through (6) of this section; waste treatment systems, including treatment ponds or lagoons designed to meet the requirements of CWA (other than cooling ponds as defined in 40 CFR 423.11(m) which also meet the criteria of this definition) are not waters of the United States.

> Waters of the United States do not include prior converted cropland. Notwithstanding the determination of an area's status as prior converted cropland by any other federal agency, for the purposes of the Clean Water Act, the final authority regarding Clean Water Act jurisdiction remains with EPA.'

States and tribes may choose to expand their coverage of water quality standards beyond waters of the United States to include other waters as waters of the state (US EPA, 2014). For example, a state or tribe may specifically designate isolated wetlands that do not meet the definition of waters of the United States as waters to which state and tribal water quality standards apply (US EPA, 2014).

The definition of waters of the US does not include groundwater, however, the focus of the following section is groundwater quality.

3.3.2 Defining Groundwater Quality for the USA

The US EPA issued the Ground Water Rule (GWR) to improve drinking water quality and provide protection from disease-causing microorganisms. Water systems that have groundwater sources may be susceptible to faecal contamination. In many cases, faecal contamination can contain disease-causing pathogens. The purpose of the Ground Water Rule (GWR) is to reduce disease incidence associated with harmful microorganisms in drinking water (US EPA, 2021d). The GWR's targeted, risk-based strategy addresses risks through an approach that relies on four major components: routine sanitary surveys of systems that require the evaluation of eight critical elements of a public water system and the identification of significant deficiencies (*e.g.*, a well located near a leaking septic system); triggered source water monitoring for a system that identifies a positive sample during regular Total Coliform monitoring or assessment monitoring targeted at high-risk systems; corrective action is required for any system with a significant deficiency or source water faecal contamination; and compliance monitoring to ensure that treatment technology installed to treat drinking water reliably achieves 99.99 percent (4-log) inactivation or removal of viruses. Groundwater systems that are at risk of faecal contamination must take corrective action (US EPA, 2021d).

The GWR describes analytical methods for source water monitoring for three faecal indicators: E.coli; Enterococci; and coliphage. It doesn't define groundwater quality; it requires testing of at-risk groundwater to be compared with standards and limits already defined in the WQS and the National Primary Drinking Water Regulations (NPDWR), which is the focus of the following section.

3.3.3 Defining Drinking Water Quality for the USA

The US EPA has issued a number of drinking water regulations that strengthen public health protection since the adoption of the Safe Drinking Water Act (SDWA) (US EPA, 2021c). These regulations include those designed to reduce risks from disinfection byproducts, arsenic, surface water pathogens such as Cryptosporidium, pathogens in groundwater, and water served on aircraft (US EPA, 2021c). US EPA reviews existing national primary drinking water regulations and, as appropriate, revises them to improve public health protection (US EPA, 2021c).

3.3.3.1 Method for Establishing Drinking Water Quality Definitions for the USA

The SDWA requires processes to ensure that the US EPA establishes regulations for new contaminants that present a meaningful opportunity to improve public health protection (US EPA, 2021c). Every five years, US EPA must publish a list of contaminants, known as the Contaminant Candidate List (CCL), that are known or anticipated to occur in public water systems and are not currently subject to US EPA drinking water regulations (US EPA, 2021c). US EPA publishes draft CCLs for public comment and considers those prior to issuing final lists (US EPA, 2021c). While the final CCL is typically used to determine which contaminants to monitor under US EPA's Unregulated Monitoring Program (UCMR), its primary purpose is for making Regulatory Determinations (RegDet). Using the final CCL, US EPA determines whether to regulate five or more contaminants using the RegDet Process (US EPA, 2021c). This involves determining whether: a contaminant may have adverse health effects; a contaminant is found or substantially likely to be found in public water systems with a frequency and at levels of concern; and there is a meaningful opportunity for health risk reduction through a national drinking water regulation (US EPA, 2021c). US EPA publishes preliminary regulatory determinations for public comment and considers those comments prior to making a final regulatory determination (US EPA, 2021c). If US EPA makes a positive regulatory determination for any contaminant, it will begin the process to establish a national primary drinking water regulation, which typically includes a Maximum Contaminant Level (MCL) (US EPA, 2021c). Every six years, US EPA reviews existing national primary drinking water regulations and, as appropriate, revises them to improve public health protection (US EPA, 2021c).

3.3.3.2 Definitions of Drinking Water Quality for the USA

The NPDWR are legally enforceable primary standards and treatment techniques that apply to public water systems. Primary standards and treatment techniques protect public health by limiting the levels of contaminants in drinking water (US EPA, 2009). The six-page-long NPDWR table lists the eighty-seven contaminants in alphabetical order, with an icon to denote the seven microorganisms, three disinfectants, four disinfection byproducts, sixteen inorganic chemicals, fifty-three organic chemicals, and four radionuclides. Beside the column listing the contaminant name is a column titled ‘MCL or TT’, which either specifies the Maximum Contaminant Level (MCL) (*i.e.*, the highest level of a contaminant that is allowed in drinking water), or the Treatment Technique (TT) required to reduce the level of the contaminant in drinking water (US EPA, 2009). However, the disinfectants listed in the table specify a Maximum Residual Disinfectant Level (MRDL) (*i.e.*, the highest level of a disinfectant allowed in drinking water) rather than an MCL, as there is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants (US EPA, 2009). The next column lists the potential health effects from long-term exposure above the MCL. Another column lists the common sources of the contaminant in drinking water, and the last column lists the public health goal. Units are in milligrams per litre (mg/L) unless otherwise noted. Milligrams per litre are equivalent to parts per million (PPM). The format of the table is shown in Figure 3.6.

Conversely, the National Secondary Drinking Water Regulations, shown in Figure 3.7, are non-enforceable guidelines regarding contaminants that may cause cosmetic effects (*e.g*., skin or tooth discolouration) or aesthetic effects (*e.g*., taste, odour, colour) in drinking water (US EPA, 2019). EPA recommends drinking water meets secondary standards but does not require compliance (US EPA, 2019). However, some states may choose to adopt them as enforceable standards.

3.3.4 Defining Stormwater and Wastewater Quality for the USA

National Pollutant Discharge Elimination System (NPDES) permits establish discharge limits and conditions for discharges from municipal wastewater treatment facilities to waters of the United States, and NPDES stormwater permits regulate stormwater discharges from three potential sources: municipal separate storm sewer systems; construction activities; and industrial activities (US EPA, 2021e).

The National Pollutant Discharge Elimination System (NPDES) permit program, created by the Clean Water Act (CWA), helps address water pollution by regulating point sources (*e.g*., pipe, ditch, channel, tunnel, conduit) that discharge pollutants (*i.e*., any type of industrial, municipal, or agricultural waste) to waters of the United States (US EPA, 2021e). An NPDES permit grants permission for a facility to discharge a specified amount of a pollutant into a receiving water under certain conditions (US EPA, 2021e). The permit provides two levels of control: technology-based limits and water quality-based limits (US EPA, 2021e). The two basic types of NPDES permits issued are individual permits and general permits. An

National Primary Drinking Water Regulations

EPA

Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from long-term[3] exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal (mg/L)[2]
Acrylamide	TT[4]	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/ wastewater treatment	zero
Alachlor	0.002	Eye, liver, kidney, or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops	zero
Alpha/photon emitters	15 picocuries per Liter (pCi/L)	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation	zero
Antimony	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder	0.006
Arsenic	0.010	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards; runoff from glass & electronics production wastes	0
Asbestos (fibers >10 micrometers)	7 million fibers per Liter (MFL)	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits	7 MFL
Atrazine	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops	0.003

LEGEND DISINFECTANT · DISINFECTION BYPRODUCT · INORGANIC CHEMICAL · MICROORGANISM · ORGANIC CHEMICAL · RADIONUCLIDES

NOTES

1 Definitions

- **Maximum Contaminant Level Goal (MCLG)**: The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.
- **Maximum Contaminant Level (MCL)**: The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.
- **Maximum Residual Disinfectant Level Goal (MRDLG)**: The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.
- **Maximum Residual Disinfectant Level (MRDL)**: The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.
- **Treatment Technique (TT)**: A required process intended to reduce the level of a contaminant in drinking water.

2 Units are in milligrams per liter (mg/L) unless otherwise noted. Milligrams per liter are equivalent to parts per million (ppm).

3 Health effects are from long-term exposure unless specified as short-term exposure.

4 Each water system must certify annually, in writing, to the state (using third-party or manufacturers certification) that when it uses acrylamide and/or epichlorohydrin to treat water, the combination (or product) of dose and monomer level does not exceed the levels specified, as follows: Acrylamide = 0.05 percent dosed at 1 mg/L (or equivalent); Epichlorohydrin = 0.01 percent dosed at 20 mg/L (or equivalent).

Figure 3.6. Format of the US National Primary Drinking Water Regulations (US EPA, 2009). The table lists eighty-seven contaminants, of which the first seven are shown here as an example of the six page-long table.

Contaminant	Secondary Maximum Contaminant Level
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 (color units)
Copper	1.0 mg/L
Corrosivity	Noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

Figure 3.7. The US National Secondary Drinking Water Regulations are optional guidelines regarding contaminants that may cause cosmetic or aesthetic effects in drinking water (US EPA, 2019).

individual permit is a permit specifically tailored to a facility (US EPA, 2021e). The facility submits an application and the permitting authority develops a permit for that particular facility based on the type of activity, nature of discharge, and receiving water quality. The authority issues the permit to the facility for a specific time period, not to exceed five years, with a requirement that the facility reapply prior to the expiration date (US EPA, 2021e). A general permit covers a group of dischargers with similar qualities (*e.g.*, aquaculture, animal feeding operations) within a given geographical location (US EPA 2021e). Under the CWA, US EPA authorises the NPDES permit program to state, tribal, and territorial governments, enabling them to perform many of the permitting, administrative, and enforcement aspects of the NPDES program, however, US EPA retains oversight responsibilities (US EPA 2021e).

3.3.4.1 Stormwater and Wastewater Effluent Limitations

Effluent limitations serve as the primary mechanism in NPDES permits for controlling discharges of pollutants to receiving waters (US EPA, 2021e). When developing effluent limitations for an NPDES permit, a permit writer must consider limits based on both the technology available to control the pollutants (*i.e.*, technology-based effluent limits (TBELs)) and limits that are protective of the water quality standards of the receiving water (*i.e.*, water quality-based effluent limits (WQBELs)) (US EPA, 2021e).

3.3.4.1.1 Technology-based Effluent Limitations

NPDES permits require a level of treatment of pollutants for point source discharges based on available treatment technologies, while allowing the discharger to use any available control technique to meet the limits (US EPA, 2021e). For industrial facilities, technology-based effluent limits are derived by using national effluent limitations guidelines and standards established by US EPA or using best professional judgement (BPJ) on a case-by-case basis in the absence of national guidelines and standards (US EPA, 2021e).

3.3.4.1.2 Water Quality-based Effluent Limitations

Section 303(d) of the Clean Water Act (CWA) establishes a process for states to identify waters within their boundaries where implementing technology-based controls is inadequate to achieve water quality standards (US EPA, 2021e). States establish a priority ranking of these waters and, for the priority waters, develop total maximum daily loads (TMDLs) (US EPA, 2021e). A TMDL identifies the amount of a specific pollutant or property of a pollutant, from point, nonpoint, and natural background sources, including a margin of safety, that may be discharged to a water body and still ensure that the water body attains water quality standards (US EPA, 2021e). The allocations of pollutant loadings to point sources are called waste-load allocations (US EPA, 2021e). Effluent limits in NPDES permits must be consistent with the assumptions used to derive the waste-load allocations (US EPA, 2021e). Also, in the absence of a TMDL, permitting authorities must still assess the need for effluent limits based on water quality standards and, where necessary, develop appropriate waste-load allocations and effluent limits. This analysis could be done for an entire watershed or separately for each individual discharge (US EPA, 2021e). Permit writers must consider the potential impact of every proposed surface water discharge on the quality of the receiving water (US EPA, 2021e). If TBELs are not sufficient to meet the water quality standards in the receiving water, the CWA (section 303(b)(1)(c)) and NPDES regulations (40 CFR 122.44(d)) require that the permit writer develop more stringent, water quality-based effluent limits (WQBELs) (US EPA, 2021e).

3.3.4.2 Method for Defining Stormwater and Wastewater Quality in the USA

The NPDES administrative procedures require that the public (*e.g.*, university professors, PhD students, environmental professionals and experts) be notified and allowed to comment on NPDES permit applications. When US EPA authorises a state to issue NPDES permits, US EPA requires that the state provide the public with this same access (US EPA, 2021e). There are various methods used to monitor NPDES permit conditions. The permit requires the facility to sample its discharge and notify US EPA and the state regulatory agency of these results. In addition, the permit requires the facility to notify US EPA and the state regulatory agency when the facility determines it is not in compliance with the requirements of a permit. US EPA and state regulatory agencies send inspectors to companies in order to determine if they are in compliance with the conditions imposed in their permit (US EPA, 2021e). Federal laws provide US EPA and authorised state regulatory agencies with various methods of taking enforcement actions against violators of permit requirements. For example, US EPA and state regulatory agencies may issue administrative orders which require facilities to correct violations and that assess monetary penalties. The laws also allow US EPA and state agencies to pursue civil and criminal actions that may include mandatory injunctions or penalties, as well as jail sentences for persons found wilfully violating requirements and endangering the health and welfare of the public or environment. Equally important is how the general public can enforce permit conditions. The facility monitoring reports are public documents, and the general public can review them. If any member of the general public finds that a facility is violating its NPDES permit, that member can independently start a legal action (US EPA, 2021e).

In some cases, rather than discharging treated stormwater or wastewater, it is reused. The focus of the following section is water reuse quality.

3.3.5 Defining Water Reuse Quality for the USA

Recognising the need to provide national guidance on water reuse regulations and program planning, US EPA developed comprehensive water reuse guidelines in support of regulations and guidelines developed by states, tribes, and other authorities (US EPA, 2012b). Water reclamation and reuse standards in the US are the responsibility of state and local agencies. There are no federal regulations for reuse (US EPA, 2012b). The first US EPA *Guidelines for Water Reuse* was developed in 1980 as a technical research report for the US EPA Office of Research and Development (US EPA, 2012b). It was updated in 1992 to support both project planners and state regulatory officials seeking US EPA guidance on appropriate water quality, uses, and regulatory requirements for development of reclaimed water systems in the various states (US EPA, 1992). The primary purpose of the update issued in 2004 was to summarise water reuse guidelines, with supporting research and information, for the benefit of utilities and regulatory agencies, particularly in the United States (US EPA, 2004). As of the publication of the 2012 updated document, thirty states and one US territory have adopted regulations and fifteen states have guidelines or design standards that govern water reuse (US EPA, 2012b). The updated guidelines serve as a national overview of the status of reuse regulations and clarify some of the variations in the regulatory frameworks that support reuse in different states and regions of the United States (US EPA, 2012b). The *Guidelines for Water Reuse* define water reuse as the use of treated municipal wastewater (*i.e.*, reclaimed water) (US EPA, 2012b).

3.3.5.1 Method for Defining Water Reuse Quality in the USA

In 2009, US EPA and USAID began facilitating workshops and informational sessions at water events and conferences around the world to solicit feedback on what information should be repeated, updated, added, or removed from the 2004 document for an updated 2012 document (US EPA, 2012b). In addition, a committee of national and international experts in the field of water reclamation and related subjects was established to approve the document outline, develop new text and case studies, and review interim drafts of the document (US EPA, 2012b). Ten stakeholder consultations were carried out in 2009 to 2011 (US EPA, 2012b). The consultations included: stakeholder workshops at the Annual WateReuse Symposium in Seattle, Washington, and Water Environment Federation Technical Exhibition and Conference (WEFTEC) in Orlando, Florida, were conducted to collect feedback on the format and scope of the update; brainstorming sessions at the American Water Works Association (AWWA) Water Quality Technology conference in Savannah, Georgia, were held to identify major focus areas in the 2004 document and to identify potential authors and contributors; the International Water Association (IWA) Efficient 2011 conference in Jordan and the Singapore International Water Week (SIWW) in Singapore were used to collect input on international water reuse practices that encompass a range of treatment technologies, market-based mechanisms for implementation of reuse, and strategies for reducing water reuse-related health risks in developing countries (US EPA, 2012b). Status reports were presented at the IWA International Conference on Water Reclamation and Reuse in Barcelona, Spain; New England Water Environment Association conference in Boston, Massachusetts; the WateReuse California conference in Dana Point, California; the Annual WateReuse Symposium in Phoenix, Arizona; and in a special session at the WEFTEC in Los Angeles, California (US EPA, 2012b). Professionals from the private sector also attended these events, as did representatives from government and state agencies, universities, and nonprofit water-advocacy organisations (US EPA, 2012b). Non-governmental organisations, including the World Bank, World Health Organization (WHO), and International Water Management Institute (IWMI), were also represented (US EPA, 2012b).

The stakeholder input process identified a number of themes to update or emphasise in the updated guidelines, including: the role of reuse in integrated water resources management; energy use and sustainability associated with water reuse; agricultural reuse; wetlands polishing and stream augmentation; expanding opportunities for industrial reuse; groundwater augmentation and managed aquifer recharge; individual on-site and greywater reuse systems; new information on direct and indirect potable reuse practices; and international trends in water reuse (US EPA, 2012b).

In addition to the stakeholder input, the final document was researched, written, and reviewed by more than three hundred experts in the field, including authors who contributed to case studies or chapters and reviewers (US EPA, 2012b). The contributors included participants from consulting firms, state and federal agencies, local water and wastewater authorities, and academic institutions. The formal review process included a two-stage technical review. The first stage of review was conducted by additional technical experts who were not involved in writing the document, who identified gaps or edits for further development (US EPA, 2012b). The text was edited based on these recommendations. The second stage of review was conducted by the peer review team; a group of reviewers who are experts in various areas of water reuse (US EPA, 2012b). The peer review team provided written technical review and in-person comments during a meeting in June 2012 (US EPA, 2012b). Technical comments and recommendations were incorporated into the document. The final draft and review record was presented to EPA and USAID for final approval in August 2012 (US EPA, 2012b).

3.3.5.2 Defining Categories of Water Reuse Quality in the USA

Many states have rules, regulations or guidelines for a wide range of reclaimed water end uses or reuses and prescribe different requirements for each reuse (US EPA, 2012b). The most common water reuses regulated by states have been inventoried and divided into water reuse categories (US EPA, 2012b). The categories include: urban reuse (*i.e.*, restricted and unrestricted); agricultural reuse (*i.e.*, food crops, processed food crops, non-food crops); impoundments (*i.e.*, restricted and unrestricted); environmental reuse; industrial reuse (*i.e.*, once-through cooling, recirculating cooling towers); groundwater recharge; and indirect potable reuse (*i.e.*, spreading, injection, reservoirs) (US EPA, 2012b).

Suggested regulatory guidelines are presented in Figure 3.8, which lists suggested treatment processes, reclaimed water quality, monitoring frequency, and setback distances for water reuses in various categories (US EPA, 2012b). These guidelines apply to domestic wastewater from municipal or other wastewater treatment facilities having a limited input of industrial waste (US EPA, 2012b). The rationale for the suggested treatment processes, reclaimed water quality, monitoring frequency, and setback distances in porous media is based on: water reuse experience in the US and elsewhere; research and pilot plant or demonstration study data; technical material from the literature; various states' reuse rules, regulations, policies, or guidelines; attainability; sound engineering practice; and use with a multiple barrier approach (US EPA, 2012b). These guidelines are not intended to be used as definitive water reclamation and reuse criteria, but are intended to provide reasonable guidance for water reuse opportunities, particularly in states that have not developed their own criteria or guidelines (US EPA, 2012b).

Adverse health consequences associated with the use of raw or improperly treated wastewater are well documented (US EPA, 2012b). As a consequence, water reuse regulations and guidelines are principally directed at public health protection and generally are based on the control of pathogenic microorganisms for non-potable reuse applications and control of both

Suggested guidelines for water reuse

Reuse Category and Description	Treatment	Reclaimed Water Quality [2]	Reclaimed Water Monitoring	Setback Distances [3]	Comments
Urban Reuse					
Unrestricted The use of reclaimed water in nonpotable applications in municipal settings where public access is not restricted.	▪ Secondary[(4)] ▪ Filtration[(5)] ▪ Disinfection[(6)]	▪ pH = 6.0-9.0 ▪ ≤ 10 mg/l BOD [(7)] ▪ ≤ 2 NTU [(8)] ▪ No detectable fecal coliform /100 ml [(9,10)] ▪ 1 mg/l Cl2 residual (min.) [(11)]	▪ pH – weekly ▪ BOD - weekly ▪ Turbidity - continuous ▪ Fecal coliform - daily ▪ Cl2 residual – continuous	▪ 50 ft (15 m) to potable water supply wells; increased to 100 ft (30 m) when located in porous media [(18)]	▪ At controlled-access irrigation sites where design and operational measures significantly reduce the potential of public contact with reclaimed water, a lower level of treatment, e.g., secondary treatment and disinfection to achieve < 14 fecal coli/100 ml may be appropriate. ▪ Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. ▪ The reclaimed water should not contain measurable levels of pathogens. [(12)] ▪ Reclaimed water should be clear and odorless. ▪ Higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. ▪ Chlorine residual > 0.5 mg/l in the distribution system is recommended to reduce odors, slime, and bacterial regrowth. ▪ See Section 3.4.3 in the 2004 guidelines for recommended treatment reliability requirements.
Restricted The use of reclaimed water in nonpotable applications in municipal settings where public access is controlled or restricted by physical or institutional barriers, such as fencing, advisory signage, or temporal access restriction	▪ Secondary [(4)] ▪ Disinfection [(6)]	▪ pH = 6.0-9.0 ▪ ≤ 30 mg/l BOD [(7)] ▪ ≤ 30 mg/l TSS ▪ ≤ 200 fecal coliform /100 ml [(9, 13, 14)] ▪ 1 mg/l Cl2 residual (min.) [(11)]	▪ pH – weekly ▪ BOD – weekly ▪ TSS – daily ▪ Fecal coliform - daily ▪ Cl2 residual – continuous	▪ 300 ft (90 m) to potable water supply wells ▪ 100 ft (30 m) to areas accessible to the public (if spray irrigation)	▪ If spray irrigation, TSS less than 30 mg/l may be necessary to avoid clogging of sprinkler heads. ▪ See Section 3.4.3 in the 2004 guidelines for recommended treatment reliability requirements. ▪ For use in construction activities including soil compaction, dust control, washing aggregate, making concrete, worker contact with reclaimed water should be minimized and a higher level of disinfection (e.g. < 14 fecal coli/100 ml) should be provided when frequent worker contact with reclaimed water is likely.
Agricultural Reuse					
Food Crops [15] The use of reclaimed water for surface or spray irrigation of food crops which are intended for human consumption, consumed raw.	▪ Secondary [(4)] ▪ Filtration [(5)] ▪ Disinfection [(6)]	▪ pH = 6.0-9.0 ▪ ≤ 10 mg/l BOD [(7)] ▪ ≤ 2 NTU [(8)] ▪ No detectable fecal coliform/100 ml [(9,10)] ▪ 1 mg/l Cl_2 residual (min.) [(11)]	▪ pH – weekly ▪ BOD - weekly ▪ Turbidity - continuous ▪ Fecal coliform - daily ▪ Cl_2 residual – continuous	▪ 50 ft (15 m) to potable water supply wells; increased to 100 ft (30 m) when located in porous media [(18)]	▪ See Table 3-5 for other recommended chemical constituent limits for irrigation. ▪ Chemical (coagulant and/or polymer) addition prior to filtration may be necessary to meet water quality recommendations. ▪ The reclaimed water should not contain measurable levels of pathogens. [(12)] ▪ Higher chlorine residual and/or a longer contact time may be necessary to assure that viruses and parasites are inactivated or destroyed. ▪ High nutrient levels may adversely affect some crops during certain growth stages. ▪ See Section 3.4.3 in the 2004 guidelines for recommended treatment reliability requirements.
Processed Food Crops [15] The use of reclaimed water for surface irrigation of food crops which are intended for human consumption, commercially processed. ***Non-Food Crops*** The use of reclaimed water for irrigation of crops which are not consumed by humans, including fodder, fiber, and seed crops, or to irrigate pasture land, commercial nurseries, and sod farms.	▪ Secondary [(4)] ▪ Disinfection [(6)]	▪ pH = 6.0-9.0 ▪ ≤ 30 mg/l BOD [(7)] ▪ ≤ 30 mg/l TSS ▪ ≤ 200 fecal coli/100 ml [(9,13, 14)] ▪ 1 mg/l Cl2 residual (min.) [(11)]	▪ pH – weekly ▪ BOD - weekly ▪ TSS - daily ▪ Fecal coliform - daily ▪ Cl_2 residual – continuous	▪ 300 ft (90 m) to potable water supply wells ▪ 100 ft (30 m) to areas accessible to the public (if spray irrigation)	▪ See Table 3-5 for other recommended chemical constituent limits for irrigation. ▪ If spray irrigation, TSS less than 30 mg/l may be necessary to avoid clogging of sprinkler heads. ▪ High nutrient levels may adversely affect some crops during certain growth stages. ▪ See Section 3.4.3 in the 2004 guidelines for recommended treatment reliability requirements. ▪ Milking animals should be prohibited from grazing for 15 days after irrigation ceases. A higher level of disinfection, e.g., to achieve < 14 fecal coli/100 ml, should be provided if this waiting period is not adhered to.

Figure 3.8. Format of the Guidelines for Water Reuse Table (US EPA, 2012b, Table 4-4). The table lists seven categories, of which the first two (*i.e*., Urban Reuse, Agricultural Reuse) are shown here as an example of the three page-long table.

health-significant microorganisms and chemical contaminants for IPR applications (US EPA, 2012b).

3.3.6 Academic Literature Related to Gaps in Defining Water Quality for the USA

In addition to the water quality definitions established by the US government and associated regulations, there is discussion of the misunderstanding and gaps related to defining water quality in the academic literature. This section aims to capture the barriers to implementation caused by unclear definitions and the proposed recommendations offered, including a mass flow-based approach to definitions.

Two decades ago, Coffman (2002) believed that despite the demonstrated environmental and economic advantages of low impact development (LID) over conventional approaches, there were numerous barriers to its widespread acceptance and utilisation, due in part to confusion regarding the definition and objectives of LID. LID provides economically and environmentally sustainable tools to better address nonpoint pollution wet weather flow challenges for the protection of receiving waters (Coffman, 2002). Through the implementation of LID tools, it is possible to have better environmental protection for significantly less cost (Coffman, 2002). A literal interpretation of low impact development, to lesson development impacts, could also be used to describe more traditional approaches that heavily favour the use of less effective and costly BMPs (Coffman, 2002). Many within the established professional organisations and consulting services have a vested economic interest in continuing to market conventional technologies, lump LID into the popularised impact minimisation strategies of better site design, conservation design or growth management (Coffman, 2002). However, LID goes beyond the goal of impact mitigation of these conventional approaches by providing many more technological tools to plan and engineer a site to maintain or restore a watershed's hydrologic and ecological functions (Coffman, 2002). LID requires strategic and customised use of conservation measures, multifunctional small-scale controls, and pollution prevention to address site-specific stormwater pollutant loads, timing, flow rate, and volume needs (Coffman, 2002). This is not the same as a broad-brushed set of generic site design or conservation tools that merely reduce impacts or sacrifice the environmental quality of urban watersheds for greater protection of conservation areas (Coffman, 2002). LID is an approach that uses decentralised integrated source control practices making more cost-effective and efficient use of a site to maintain the watershed hydrology and water quality (Coffman, 2002). The conventional strategy uses a separate and centralised approach that results in the creation of a large stormwater infrastructure to convey and treat runoff that also competes with valuable space (Coffman, 2002).

Bloetscher (2004) believes the definition of acceptable risk is not clearly understood. The US EPA has defined acceptable risk for drinking water purposes as 1:10,000 (Bloetscher, 2004). However, defining a number for risk leads only to more questions from the public as to what risk is acceptable and what is not. Aquifer storage and recovery involves the injection of vast amounts of treated or treatable water beneath the ground surface, rather than discharging it into rivers, reservoirs, oceans or other sources (Bloetscher, 2004). The intent is to manage drought demands or significant fluctuations in seasonal demands where water is both injected and withdrawn at the same point. Because waters may remain limited, in some areas the use of alternative groundwater injection programs have been proposed or pursued to address these needs using waters of impaired quality, mostly with significant resistance caused by the risk of effects to the public should these waters be recovered in water supply wells at a later point (Bloetscher, 2004). The intent of this investigation is to develop a mechanism whereby the distances required to reach a given risk factor for these projects can be defined. It is assumed that any distance in excess of that required to obtain the risk number does not pose a concern that would prevent its installation and operation (Bloetscher, 2004). The groundwater modelling yields contours of the movement of the injected fluids. Assuming conservative tracers with no decay, the contours can be applied to a risk model as defined above (Bloetscher, 2004). The contours will provide a relative risk probability.

Cardwell *et at.* (2006) note that despite general endorsement of IWRM in the US, full implementation of IWRM is hampered by inconsistent concept definition and a basic framework for concept implementation. As demands placed on water resources in the US and elsewhere have grown, organisations are promoting more collaborative, integrated approaches to water resources management (Cardwell *et al.*, 2006). Cardwell *et al.* believe that out of that concern, many terms and definitions for more integrated approaches to management have proliferated with apparently small differences in core concepts. The need for more integrated management of water resources is widely stressed, as indicated by the proliferation of related terms and the concepts they represent. Cardwell *et al.*'s contribution to the debate about how to implement integrated approaches to water management in the US is to develop a basic definition of IWRM as a goal-centred process, and a rudimentary framework for organising integration in public water resources management. In reviewing IWRM in the public water resources management sector of the US, a national goal for focusing IWRM is emerging in the concept of sustainable development (Cardwell *et al.*, 2006). This concept has roots in US environmental law passed decades ago but has been much influenced by concept development and advocacy at the United Nations and the World Bank (Cardwell *et al.*, 2006). In the US, the Army Corps of Engineers referred to sustainable development as a basis for its Environmental Operating Principles and identified it in one of five goals to be pursued (Cardwell *et al.*, 2006). To further the discussion of how to integrate the different approaches, Cardwell *et al.* (2006) suggest a conceptual framework for looking at what to integrate by proposing four axes of integration: space, institutions, objectives, and time. This simplistic look implies a basic working definition: Integrated Water Resource Management is a coordinated, goal-directed process for controlling the development and use of river, lake, ocean, wetland, and other water assets (Cardwell *et al.*, 2006). An analysis of other definitions of IWRM, derived almost entirely from international organisations, shows that some organisations go considerably beyond the idea of IWRM as a process operating through spatial, institutional, objective, and temporal integration to touch on goals reflecting organisational values (Cardwell *et al.*, 2006). They reflect the consensus that the process of water resources management needs to consider social and environmental aspects of water resource systems, and endorse a democratic concept that the public must be involved in decision-making (Cardwell *et al.*, 2006).

More recently, Buchwalter *et al.* (2017) are concerned that the rules for how science is used to develop water quality criteria (WQC) were created in 1985. Most rely only on data and knowledge obtained through a single methodology, the single-species laboratory toxicity test. The development of WQC for the protection of aquatic life is a fundamental component of the Clean Water Act, the primary US legislation responsible for protecting aquatic ecosystems from pollution. Water quality criteria define acceptable levels of contamination in the environment and thus play an important role in society. Since 1985, understanding of the fate and effects of environmental contaminants has advanced markedly from multiple perspectives and disciplines. However, many of these advances are routinely discarded in WQC development because they do not adhere to data limits imposed by the 1985 guidelines. Multiple lines of inquiry have played important roles in improving understanding of the ecological implications of environmental contaminants. Buchwalter *et al.* (2017) focus on gains in understanding that would not have been possible through traditional toxicity bioassays alone and argue that more robust scientific understanding can be used to modernise WQC development. In particular, Buchwalter *et al.* highlight ways to increase the relevance of toxicity testing at different spatiotemporal scales and incorporate all relevant lines of evidence into WQC modernisation.

Allende *et al.* (2018) found that the US Food Safety Modernization Act (US FSMA) regulation provides a relevant definition of agricultural water and specific criteria for different water uses and circumstances. Allende *et al.* report key messages related to agricultural water quality as discussed by an ad hoc panel at the 1st International Symposium of Food Safety. Participating representatives of academia, industry and government, with diverse geographical backgrounds, discussed topics such as: implications of the US FSMA on agricultural water quality; comparisons between MPN and CFU in analysing water quality; alternatives to faecal indicator bacteria to be used as indicators to evaluate water quality; and vegetative buffers as an alternative to reduce pathogen loads in agricultural surface waters (Allende *et al.*, 2018). Panellists identified the following key messages for each topic discussed that are related to agricultural water quality: the US FSMA regulation and the new guidance document are highly relevant as they provide a definition of agricultural water and specific criteria for different water uses and circumstances; the US FSMA supports modification from MPN to CFU; growers require more alternatives for treatment of agricultural water; vegetative buffers are a potential practical and feasible alternative for agriculture producers to reduce the pathogen and faecal pollution loads in their agricultural waters (Allende *et al.*, 2018). The emphasis on food safety requirements for European countries is on pesticide residues and heavy metals, while for the US, as per the FSMA, emphasis is on biological hazards, including monitoring of indicator and foodborne pathogens (Allende *et al.*, 2018). Therefore, the aim of this legislation is to ensure that the US food supply is safe by shifting the focus from responding to contamination to preventing it (Allende *et al.*, 2018). FSMA defines agricultural water as the water that has direct contact with the produce in any stage of production. The main, and new, distinguishing point of the FSMA final rule is that it establishes two sets of criteria for microbial quality of agricultural water, both of which are based on the level of generic E. coli depending on the uses of the agricultural water (Allende *et al.*, 2018). For agricultural water that is directly applied to growing produce, other than sprouts, a maximum geometric mean of 126 CFU and a maximum statistical threshold of 410 CFU of generic E. coli in 100 mL of water has been established (Allende *et al.*, 2018). In contrast, no detectable generic E. coli has been established as the rule for water used during harvest and post-harvest activities including washing hands or making ice (Allende *et al.*, 2018).

Grubert *et al.* (2020) believe that the value of water use quantification assessments is hindered by the use of inconsistent terminology and reporting standards. They identify terminology conflicts and recommend a mass flow-based approach to definitions. Challenges associated with data collection and maintenance are made unnecessarily worse by the community's lack of agreement on definitions and reporting standards. Grubert *et al.* identify three problems: terminology conflicts; imprecise units; and data integrity. They illustrate the impact of these problems using water use in the US energy system as a case study. Relatively minor changes to the definition of water consumption can change reported water consumption by negative fifty percent to positive two hundred and seventy percent, with no change to underlying data. Quantitative impacts of imprecise units and data integrity are more difficult to estimate, but Grubert *et al.* (2020) demonstrate that minor changes to reporting standards in these realms can substantially improve certainty. They believe providing as much information as available is best practice, noting water source, quality, location, and discharge point, and including relevant conversion factors for units, can dramatically improve interoperability with other analyses in the future. The water resource research community would benefit from more specificity in stating water's quality and origin and from using a mass flow–based approach to definitions for use metrics. Here, a mass flow–based approach refers to a set of definitions focused primarily on where water physically starts and ends rather than on questions of future accessibility, user availability, and other context-specific questions (Grubert *et al.*, 2020). Preserving water quantity metrics as mass flow–based and developing additional terminology and reporting standards to capture additional decision-relevant characteristics, like thermal, chemical, temporal, and other quality transformations, can promote more targeted management decisions (Grubert *et al.*, 2020).

3.3.7 Section Summary: Defining Categories of Water Quality for the USA

In summary, a review of the US water quality definitions reveals a robust method for developing scientifically defensible water quality definitions. States can adopt more stringent water quality requirements that reflect site-specific conditions. Water quality definitions are subject to external scientific peer review and public review. Groundwater is not included in the definition of waters of the US. The academic literature reveals: confusion regarding water quality related definitions that impacted implementation; an inflexible methodology that limits water quality protection; a relevant water quality definition that includes specific criteria for different water uses and circumstances; a recommendation for mass flow–based definitions that include water quality, as illustrated in the sections that follow.

3.3.7.1 Robust Method for Developing Water Quality Definitions That Are Reviewed Regularly

WQS form a legal basis for controlling pollutants entering the waters of the United States (US EPA, 2014). WQS are provisions of state or federal law approved by the US EPA that describe the desired condition of a water body and the means by which that condition will be protected or achieved (US EPA, 2014). To protect human health and aquatic life in these waters, states establish WQS. The WQS regulation requires states to specify how each water body is used (US EPA, 2021b). These designated uses include: protection and propagation of fish, shellfish and wildlife; recreation; public drinking water supply; agricultural, industrial, navigational and other purposes. States adopt water quality criteria to protect the designated uses of a water body (US EPA, 2021b). Water quality criteria can be numeric, narrative, or both. One of the principal objectives of the CWA is to maintain the chemical, physical and biological integrity of the nation's waters (US EPA, 2021b). Antidegradation requirements provide a framework for maintaining and protecting water quality (US EPA, 2021b). US EPA has clear authority to review and approve or disapprove and promulgate an antidegradation policy for a state. If a state's antidegradation policy does not meet the federal regulatory requirements, either through state action to revise its policy or through revised federal requirements, the state would be given the opportunity to make its policy consistent with the regulation. If this is not done, US EPA has the authority to promulgate the policy for the state (US EPA, 2012d).

The National Primary Drinking Water Regulations (NPDWR) are legally enforceable primary standards that apply to public water systems. Every six years, US EPA reviews existing national primary drinking water regulations and, as appropriate, revises them to improve public health protection (US EPA, 2021c). US EPA has issued a number of drinking water regulations that strengthen public health protection since the adoption of the Safe

Drinking Water Act (SDWA) (US EPA, 2021c). These regulations include those designed to reduce risks from disinfection byproducts, arsenic, and pathogens. Every five years, US EPA publishes a list of contaminants, known as the Contaminant Candidate List (CCL), that are known or anticipated to occur in public water systems and are not currently subject to US EPA drinking water regulations. US EPA publishes draft CCLs for public comment and considers those prior to issuing final lists (US EPA, 2021c).

3.3.7.2 States Can Adopt More Stringent Water Quality Requirements

States are responsible for adopting WQS that consist of the designated uses of navigable waters, and the water quality criteria for such waters, according to the CWA. States also have the choice of including additional components in their water quality standards, such as general policies (US EPA, 2014). Whenever a state submits new or revised WQS provisions, the submission must also include the methods used and analyses conducted to support the WQS provisions, certification by the state attorney general that the WQS were duly adopted pursuant to state law, and general information to aid the US EPA in determining the adequacy of the scientific bases of the WQS (US EPA, 2014). States may develop WQS that are more stringent than required by the 40 CFR. Each state must develop, adopt, and retain a statewide antidegradation policy regarding water quality standards and establish procedures for its implementation through the water quality management process. The state antidegradation policy and implementation procedures must be consistent with the components detailed in 40 CFR. States may adopt antidegradation statements more protective than the federal requirement (US EPA, 2012d). States may choose to expand their coverage of WQS beyond waters of the United States to include other waters as ‘waters of the state’ (US EPA, 2012c).

3.3.7.3 Scientifically Defensible Water Quality Definitions

States may adopt, where appropriate, other scientifically defensible criteria that differ from the US EPA's recommendations (US EPA, 2017). The US EPA recommends states develop a record describing the scientific justification for their adopted criteria and the public participation process. Where the state adopts site-specific criteria or uses an approach that differs from that of the US EPA's recommendations, the approach should be clearly documented and transparent.

The *2000 Human Health Methodology* provides states with scientifically sound options for developing their own human health criteria that consider local conditions (US EPA, 2017). If states choose to derive their own human health criteria or modify the EPA's recommendations, the US EPA recommends that they use the *2000 Human Health Methodology* and consider updated and scientifically defensible data to guide their actions (US EPA, 2017). In addition, the *2000 Human Health Methodology* defines the default factors that the US EPA uses in evaluating the soundness and consistency of state WQS in accordance with the CWA (US EPA, 2017). For priority pollutants for which the US EPA has not published numeric water quality criteria, the CWA requires states to adopt criteria based on biological monitoring or assessment methods consistent with information published by the US EPA (US EPA, 2017). States may choose to develop different types of criteria for wetlands protection, including site-specific numeric or narrative criteria, as long as they are scientifically defensible and protective of the designated uses (US EPA, 2017).

3.3.7.4 Water Quality Definitions Reflect Site-specific Conditions

The 40 CFR provides that states may adopt water quality criteria that are modified to reflect site-specific conditions. Site-specific criteria, as with all criteria, must be based on a sound scientific rationale and protect designated uses and are subject to US EPA review and approval or disapproval under the CWA. A site-specific criterion is developed to protect aquatic life at a particular site, taking into account a site's physical, chemical, or biological conditions (US EPA, 2017).

The US EPA's *An Approach for Evaluating Numeric Water Quality Criteria for Wetlands Protection* (1991) provides an approach, based on the site-specific guidelines, for detecting wetland types that might not be protected by direct application of 304(a) criteria recommendations (US EPA, 2017). States can use the results of this type of evaluation, combined with information on local or regional environmental threats, to prioritise wetland types, and individual criteria for further site-specific evaluations or additional data collection. The US EPA recommends close coordination among regulatory agencies, wetland scientists, and criteria experts in developing criteria for wetlands (US EPA, 2017).

3.3.7.5 External Scientific Peer Review of Water Quality Definitions

To provide scientific guidance to states, the US EPA publishes criteria for water quality that accurately reflect the latest scientific knowledge. The US EPA's national criteria recommendations provide quantitative concentrations and qualitative measures of pollutants that, if not exceeded, will provide adequate water quality for protection of a designated use. The US EPA develops criteria based on the best available science, scientific literature review, established procedures for risk assessment, US EPA policies, external scientific peer review, and public input (US EPA, 2017).

US EPA and USAID facilitated workshops and informational sessions at water events and conferences around the world to solicit feedback on what information should be repeated, updated, added, or removed from the 2004 document for an updated 2012 water reuse guidelines document. In addition, a committee of national and international experts in the field of water reclamation and related subjects was established to approve the document outline, develop new text and case studies, and review interim drafts of the document. Ten stakeholder consultations were carried out (US EPA, 2012b). Professionals from the private sector attended these events, as did representatives from government and state agencies, universities, and nonprofit water-advocacy organisations. Non-governmental organisations, including the World Bank, WHO, and IWMI, were also represented (US EPA, 2012b). In addition to the stakeholder input, the final document was researched, written, and reviewed by more than 300 experts in the field, including authors who contributed to case studies or chapters and reviewers. The contributors included participants from consulting firms, state and federal agencies, local water and wastewater authorities, and academic institutions (US EPA, 2012b).

3.3.7.6 Use of Available Data and Best Professional Judgement

The US EPA's *304(a) Criteria Recommendations Intended to Protect Aquatic Life* include provisions to protect wildlife that consume aquatic organisms from the bioaccumulation potential of a compound (US EPA, 2017). The guidelines recommend deriving final wildlife residue values based on available data. The US EPA's supporting documentation for 304(a) criteria also includes evaluations of available scientific data on the effects of pollutants such as effects on public health and welfare, aquatic life, and recreation (US EPA, 2017).

NPDES permit technology-based effluent limits for industrial facilities are derived by using national effluent limitations guidelines and standards established by US EPA or using best professional judgement (BPJ) on a case-by-case basis in the absence of national guidelines and standards (US EPA, 2021e).

3.3.7.7 Public Review of Water Quality Definitions

An important element of the method used to establish WQS is the opportunity for the public to comment upon the state water quality standards (US EPA, 2021a). The review process provides the general public with an opportunity to become involved in protecting the water bodies in their area. US EPA encourages everyone to attend public events to share their knowledge of how water bodies in their area are used or could be used (US EPA, 2021a).

The NPDES administrative procedures require that the public be notified and allowed to comment on NPDES permit applications. When US EPA authorises a state to issue NPDES permits, US EPA requires that the state provide the public with this same access (US EPA, 2021e).

This part of the method to develop water quality definitions involves anyone, including interested parties such as university professors, PhD students, water engineers, biologists, environmental groups (*e.g*., Earth First, Greenpeace), and other federal agencies (*e.g*., NOAA, USGS, Fish and Wildlife Services, National Marine Fisheries Service).

3.3.7.8 Enforcement and Third-Party Lawsuits

Federal laws provide US EPA and authorised state regulatory agencies with various methods for taking enforcement actions against violators of permit requirements (US EPA, 2021e). For example, US EPA and state regulatory agencies may issue administrative orders which require facilities to correct violations and that assess monetary penalties. The laws also allow US EPA and state agencies to pursue civil and criminal actions that may include mandatory injunctions or penalties, as well as jail sentences for persons found wilfully violating requirements and endangering the health and welfare of the public or environment (US EPA, 2021e). Equally important is the fact that the general public can enforce permit conditions. The facility monitoring reports are public documents, and the general public can review them (US EPA, 2021e). If any member of the general public finds that a facility is violating its NPDES permit, that member can independently start a legal action.

3.3.7.9 Groundwater Not Included in Definition of Waters of the US

Groundwater is not included in the definition of water of the US (US EPA, 2014). However, the US EPA issued the GWR to improve drinking water quality and provide protection from disease-causing microorganisms (US EPA, 2021d). The purpose of the GWR is to reduce disease incidence associated with harmful microorganisms in drinking water. The GWR describes analytical methods for source water monitoring for three faecal indicators: for E.coli; Enterococci; and coliphage. However, it does not define groundwater quality but requires testing of at-risk groundwater to be compared with standards and limits already defined in WQS and the NPDWR (US EPA, 2021d).

3.3.7.10 Definition Confusion Impacts Technology Implementation

Two decades ago, Coffman (2002) believed that despite the demonstrated environmental and economic advantages of low impact development (LID) over conventional approaches, there were numerous barriers to its widespread acceptance and utilisation, due in part to confusion regarding the definition and objectives of LID. Bloetscher (2004) believed the definition of acceptable risk was not clearly understood. The US EPA has defined acceptable risk for drinking water purposes as 1:10,000 (Bloetscher, 2004). However, defining a number for risk leads only to more questions by the public as to what risk is acceptable and what is not (Bloetscher, 2004). Cardwell *et al.* (2006) noted that despite general endorsement of IWRM in the US, full implementation of IWRM was hampered by inconsistent concept definition and a basic framework for concept implementation.

3.3.7.11 Inflexible Methodology Limiting Water Quality Protection

Buchwalter *et al.* (2017) are concerned that the rules for how science is used to develop WQC were created in 1985, and most rely only on data and knowledge obtained through a single methodology, the single-species laboratory toxicity test. Since 1985, understanding of the fate and effects of environmental contaminants has advanced markedly from multiple perspectives and disciplines. However, many of these advances are routinely discarded in WQC development because they do not adhere to data limits imposed by the 1985 guidelines. Multiple lines of inquiry have played important roles in improving understanding of the ecological implications of environmental contaminants. Buchwalter *et al.* focus on gains in understanding that would not have been possible through traditional toxicity bioassays alone and argue that more robust scientific understanding can be used to modernise WQC development. In particular, Buchwalter *et al.* (2017) highlight ways to increase the relevance of toxicity testing at different spatiotemporal scales and incorporate all relevant lines of evidence into WQC modernisation.

3.3.7.12 Relevant Water Quality Definition that Includes Specific Criteria for Different Water Uses and Circumstances

Allende *et al.* (2018) report key messages related to agricultural water quality as discussed by an ad hoc panel at the 1st International Symposium of Food Safety, with participating representatives from academia, industry and government, with diverse geographical backgrounds. Panellists identified the key messages for each topic discussed, which included that the US FSMA regulation and the new guidance document are highly relevant as they provide a definition of agricultural water and specific criteria for different water uses and circumstances (Allende *et al.*, 2018).

3.3.7.13 Recommend Mass Flow–based Definitions that Include Water Quality

Grubert *et al.* (2020) believe providing as much information as available is best practice, noting water source, quality, location, and discharge point, and including relevant conversion factors for units, can dramatically improve interoperability with other analyses in the future. The water resource research community would benefit from more specificity in stating water's quality and origin and from using a mass flow–based approach to definitions for use metrics. Here, a mass flow–based approach refers to a set of definitions focused primarily on where water physically starts and ends rather than on questions of future accessibility, user availability, and other context-specific questions (Grubert *et al.*, 2020). Preserving water quantity metrics as mass flow–based and developing additional terminology and reporting standards to capture additional decision-relevant characteristics, like thermal, chemical, temporal, and other quality transformations, can promote more targeted management decisions (Grubert *et al.*, 2020).

Standards set by the US EPA are requirements, however, states can set more stringent standards. The following section investigates how water quality is defined in California.

3.4 Defining Categories of Water Quality for the State of California, USA

This section investigates the water quality definitions established for California, and the methods used to develop them. First, the use of water quality control plans to establish water quality standards is explored, and then wastewater, industrial wastewater, stormwater, and water reuse quality are each addressed. Next, the California water quality definitions discussed in the academic literature are identified, and the section ends with a summary of the findings.

3.4.1 Definition of Waters of the State of California

While the federal CWA focuses on waters of the United States, navigable surface waters and their tributaries, the term 'waters of the state' under the California Water Code is broader (SWRCB, 2022). 'Waters of the state' means any surface water or groundwater, including saline waters, within the boundaries of the state (SWRCB, 2022). Also included are surface waters that are not tributary to navigable waters. California has water quality standards that apply to all of these waters (SWRCB, 2022).

3.4.2 Water Quality Standards for California

The CWA defines water quality standards as provisions of state or federal law which consist of designated uses and water quality criteria (SWRCB, 2022). For California, division seven of the California Water Code, referred to as the Porter-Cologne Water Quality Control Act (hereafter Porter-Cologne), the designated uses of water are called 'beneficial uses' and the water quality criteria based on those uses are called 'water quality objectives' (SWRCB, 2022). California's water quality standards are found in the *Water Quality Control Plans* adopted by the State Water Resources Control Board and the nine Regional Water Quality Control Boards (California Water Boards) (SWRCB, 2022). Because the plans adopted by the Regional Water Boards cover one water basin, they are often referred to as 'Basin Plans' (SWRCB, 2022). One water basin (*i.e.*, hydrologic region), the Central Coastal Basin, is selected as an example to demonstrate how water quality is defined in California in a watershed-specific manner.

3.4.2.1 Method for Establishing Water Quality Standards for California

California's Porter-Cologne Water Quality Control Act (1969), which became Division Seven (*i.e.,* Water Quality) of the California Water Code, establishes the responsibilities and authorities of the nine Regional Water Quality Control Boards and the State Water Resources Control Board (CCRWQCB, 2019a). Porter-Cologne names these boards the principal state agencies with primary responsibility for the coordination and control of water quality (Section 13001) (CCRWQCB, 2019a). Each Regional Board is directed to formulate and adopt water quality control plans (*i.e.*, Basin Plan) for all areas within the region (CCRWQCB, 2019a). A water quality control plan for the waters of an area is defined as having three components: beneficial uses which are to be protected; water quality objectives which protect those uses; and an implementation plan which accomplishes those objectives (Section 13050) (CCRWQCB, 2019a). Such plans shall be periodically reviewed and may be revised (Section 13240) (CCRWQCB, 2019a).

The federal CWA provides for the delegation of certain responsibilities in water quality control and water quality planning to the states (CCRWQCB, 2019a). Where the US EPA and the State Board have agreed to such delegation, the Regional Boards implement portions of the CWA, such as the NPDES program and toxic substance control programs (CCRWQCB, 2019a).

Porter-Cologne and the CWA also describe how enforcement of waste discharge regulations is to be carried out (CCRWQCB, 2019a). Enforcement tools available to the Regional Board range from simple letters to the discharger, through formal Regional Board order and direct penalty assessments, to judicial abatement for civil or criminal penalties (CCRWQCB, 2019a). Legally noticed public hearings are required for most actions, but some enforcement actions (*e.g*., clean-up or abatement orders) have been delegated to staff to allow for a quicker response than regularly scheduled Regional Board meetings can provide (CCRWQCB, 2019a).

The federal CWA (Section 303(c)) requires states to hold public hearings for the review of water quality standards at least once every three years (CCRWQCB, 2019a). Water quality standards consist of beneficial use designations and water quality criteria (objectives) necessary to protect those uses (CCRWQCB, 2019a). While a major part of the review process consists of identifying potential problems, an important part of the review is the reaffirmation of those portions of the plan where no potential problems are identified (CCRWQCB, 2019a). At the conclusion of the triennial review public hearing, Regional Board staff prepare a priority list of potential problems to the Basin Plan that may result in amendments (CCRWQCB, 2019a). Other items completed after the public hearing include: detailed workplans of each issue; Regional Board identification of issues that can be completed within existing resource allocations over a three-year period; and a list of issues requiring additional resources to complete (CCRWQCB, 2019a). Once the triennial review process is complete, Regional Board staff begin investigating the issues in order of rank. After each investigation, staff determine the need for a Basin Plan amendment (CCRWQCB, 2019a). Basin Plan amendments can also occur for issues not identified during the triennial review, and amendments can occur for urgent issues to reflect new legislation (CCRWQCB, 2019a).

Basin Plan amendment hearings are advertised in the public notice section of a newspaper circulated in areas affected by the amendment (CCRWQCB, 2019a). Persons interested in a particular issue can also notify the Regional Board staff of their interest in being notified of hearings on that topic (CCRWQCB, 2019a). Basin Plan amendments do not become effective until approved by the State Board. Surface water standards also require the approval of the US EPA to become effective (CCRWQCB, 2019a).

3.4.2.1.1 Water Quality Control Plan for the Central Coastal Basin of California

The objective of the Water Quality Control Plan for the Central Coastal Basin, or Basin Plan, is to show how the quality of surface water and groundwater in the central coast hydrologic region should be managed to provide the highest water quality reasonably possible (CCRWQCB, 2019a). Water uses and water benefits vary. Water quality is an important factor in determining use and benefit (CCRWQCB, 2019a). For example, the quality requirements for irrigation are different from those for domestic use (CCRWQCB, 2019a). The plan recognises such variations.

The Basin Plan lists the various water uses (*i.e.*, beneficial uses) and describes the water quality which must be maintained to allow those uses (*i.e.*, water quality objectives). Federal terminology is somewhat different, in that beneficial uses and water quality objectives are combined and the combination are called water quality standards (CCRWQCB, 2019a). The implementation chapter describes the programs, projects, and other actions which are necessary to achieve the standards established in the Basin Plan (CCRWQCB, 2019a). Another chapter summarises State Water Resources Control Board (State Board) and Regional Water Quality Control Board (Regional Board) plans and policies to protect water quality. The last chapter of the Basin Plan describes both statewide and regional surveillance and monitoring programs (CCRWQCB, 2019a).

The beneficial surface and groundwater uses in the Central Coastal Basin are identified and defined in the following section.

3.4.2.2 Definitions of Beneficial Use Categories for the Central Coastal Basin of California

State policy for water quality control in California is directed toward achieving the highest water quality consistent with maximum benefit to the people of the state (CCRWQCB, 2019a). Therefore, all water resources must be protected from pollution and nuisance that may occur as a result of waste discharges (CCRWQCB, 2019a). Once the beneficial uses are recognised, as depicted in Figure 3.9, compatible water quality standards can be established, as well as the level of treatment necessary to maintain the standards and ensure the continuance of the beneficial uses (CCRWQCB, 2019a). Beneficial uses for surface water and groundwater include: municipal and domestic supply; agricultural supply; industrial process supply; industrial service supply; groundwater recharge; fresh water replenishment;

Identified Uses of Inland Surface Waters

Waterbody Names	MUN	AGR	PROC	IND	GWR	REC1	REC2	WILD	COLD	WARM	MIGR	SPWN	BIOL	RARE	EST	FRSH	NAV	POW	COMM	AQUA	SAL	SHELL
Big Basin Hydrologic Unit 304																						
Lucerne Lake Estuary						X	X	X	X			X	X	X	X				X			X
Lucerne Lake	X	X				X	X	X	X							X			X			
Arroyo de los Frejoles Creek	X	X			X	X	X	X	X	X	X	X	X	X		X			X			
Arroyo de los Frejoles Reservoir	X	X			X	X	X	X	X	X						X	X		X			
Gazos Creek Lagoon/Estuary						X	X	X	X	X	X	X	X	X	X				X			X
Gazos Creek	X	X			X	X	X	X	X		X	X				X			X			
Old Woman's Creek	X					X	X	X	X		X	X	X						X			
Whitehouse Creek	X					X	X	X	X		X	X	X		X	X			X			
Cascade Creek Lagoon/Estuary						X	X	X	X		X	X	X	X	X				X			X
Cascade Creek	X	X			X	X	X	X	X		X	X	X	X		X			X			
Green Oaks Creek Lagoon/Estuary						X	X	X	X			X		X	X				X			X
Green Oaks Creek	X	X			X	X	X	X	X	X	X	X	X		X	X			X			
Año Nuevo Creek	X	X			X	X	X	X	X		X	X	X	X	X	X			X			
Finney Creek	X	X				X	X	X	X				X		X	X			X			
Elliot Creek	X	X				X	X	X	X				X		X	X			X			
Waddell Creek Estuary					X	X	X	X	X		X	X	X	X	X				X			X
Waddell Creek (Main Stem)	X	X		X	X	X	X	X	X		X	X	X	X		X			X			
Waddell Creek, east branch	X				X	X	X	X	X		X	X	X	X		X			X			
Last Chance Creek	X	X			X	X	X	X	X		X	X		X					X			
Blooms Creek	X				X	X	X	X	X			X	X	X					X			
Sempervirens Creek	X				X	X	X	X	X		X	X	X						X			
Union Creek	X					X	X	X	X				X						X			
Sempervirens Res.	X					X	X	X	X				X			X			X			X

Figure 3.9. Format of the Basin Plan thirteen page-long table which lists the beneficial uses of the approximately 530 waterbodies in the Central Coast Region, of which the first twenty-three are shown here as an example (CCRWQCB, 2019a, Table 2-1).

navigation; hydropower generation; water contact recreation; non-contact water recreation; commercial and sport fishing; aquaculture; warm freshwater habitat; cold freshwater habitat; inland saline water habitat; estuarine habitat; marine habitat; wildlife habitat; preservation of biological habitats of special significance; rare, threatened, or endangered species; migration of aquatic organisms; spawning, reproduction, and early development; and shellfish harvesting. The definitions for these twenty-three categories of beneficial uses are defined in the following sections, including the three, or four, letter abbreviation used to identify the categories.

3.4.2.2.1 Municipal and Domestic Water Supply Beneficial Use

The municipal and domestic supply (MUN) beneficial use is defined as uses of water for community, military, or individual water supply systems including, but not limited to, drinking water supply. According to State Board Resolution No. 88-63, *Sources of Drinking Water Policy* all surface waters are considered suitable, or potentially suitable, for municipal or domestic water supply except where: TDS exceeds 3000 mg/L (5000 uS/cm electrical conductivity); contamination exists that cannot reasonably be treated for domestic use; the source is not sufficient to supply an average sustained yield of 200 gallons per day; the water is in the collection or treatment systems of municipal or industrial wastewaters, process waters, mining wastewaters, or stormwater runoff; or the water is in systems for conveying or holding agricultural drainage waters (CCRWQCB, 2019a).

3.4.2.2.2 Agricultural Water Supply Beneficial Use

The agricultural supply (AGR) beneficial use is defined as uses of water for farming, horticulture, or ranching including, but not limited to, irrigation, stock watering, or support of vegetation for range grazing (CCRWQCB, 2019a).

3.4.2.2.3 Industrial Process Water Supply Beneficial Use

The industrial process supply (PROC) beneficial use is defined as uses of water for industrial activities that depend primarily on water quality (*e.g.*, waters used for manufacturing, food processing) (CCRWQCB, 2019a).

3.4.2.2.4 Industrial Service Water Supply Beneficial Use

The industrial service supply (IND) beneficial use is defined as uses of water for industrial activities that do not depend primarily on water quality including, but not limited to, mining, cooling water supply, hydraulic conveyance, gravel washing, fire protection, or oil well repressurisation (CCRWQCB, 2019a).

3.4.2.2.5 Groundwater Recharge Beneficial Use

The groundwater recharge (GWR) beneficial use is defined as uses of water for natural or artificial recharge of groundwater for purposes of future extraction, maintenance of water quality, or halting of saltwater intrusion into freshwater aquifers. Groundwater recharge includes recharge of surface water underflow (CCRWQCB, 2019a).

3.4.2.2.6 Freshwater Replenishment Beneficial Use

The freshwater replenishment (FRSH) beneficial use is defined as uses of water for natural or artificial maintenance of surface water quantity or quality (*e.g.*, salinity) which includes a water body that supplies water to a different type of water body, such as streams that supply reservoirs and lakes or estuaries, or reservoirs and lakes that supply streams. This includes only immediate upstream water bodies and not their tributaries (CCRWQCB, 2019a).

3.4.2.2.7 Navigation Beneficial Use

The navigation (NAV) beneficial use is defined as uses of water for shipping, travel, or other transportation by private, military, or commercial vessels (CCRWQCB, 2019a). Any stream, lake, arm of the sea, or other natural body of water that is actually navigable and that, by itself, or by its connections with other waters, for a period long enough to be of commercial value, is of sufficient capacity to float watercraft for the purposes of commerce, trade, transportation, and including pleasure; or any waters that have been declared navigable by the Congress of the United States or the California State Lands Commission (CCRWQCB, 2019a).

3.4.2.2.8 Hydropower Generation Beneficial Use

The hydropower generation (POW) beneficial use is defined as uses of water for hydropower generation (CCRWQCB, 2019a).

3.4.2.2.9 Water Contact Recreational Activities Beneficial Use

The water contact recreation (REC-1) beneficial use is defined as uses of water for recreational activities involving body contact with water, where ingestion of water is reasonably possible (CCRWQCB, 2019a). These uses include, but are not limited to, swimming, wading, water-skiing, skin and scuba diving, surfing, white water activities, fishing, or use of natural hot springs.

3.4.2.2.10 Non-contact Water Recreational Activities Beneficial Use

The non-contact water recreation (REC-2) beneficial use is defined as uses of water for recreational activities involving proximity to water, but not normally involving body contact with water where ingestion of water is reasonably possible (CCRWQCB, 2019a). These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing, camping, boating, tidepool and marine life study, hunting, sightseeing, or aesthetic enjoyment in conjunction with the above activities (CCRWQCB, 2019a).

3.4.2.2.11 Commercial and Sport Fishing Beneficial Use

The commercial and sport fishing (COMM) beneficial use is defined as uses of water for commercial or recreational collection of fish, shellfish, or other organisms including, but not limited to, uses involving organisms intended for human consumption or bait purposes (CCRWQCB, 2019a).

3.4.2.2.12 Aquaculture Beneficial Use

The aquaculture (AQUA) beneficial use is defined as uses of water for aquaculture or mariculture operations including, but not limited to, propagation, cultivation, maintenance, or harvesting of aquatic plants and animals for human consumption or bait purposes (CCRWQCB, 2019a).

3.4.2.2.13 Warm Freshwater Habitat Beneficial Use

The warm freshwater habitat (WARM) beneficial use is defined as uses of water that support warm water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates (CCRWQCB, 2019a).

3.4.2.2.14 Cold Freshwater Habitat Beneficial Use

The cold freshwater habitat (COLD) beneficial use is defined as uses of water that support cold water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish or wildlife, including invertebrates (CCRWQCB, 2019a).

3.4.2.2.15 Inland Saline Water Habitat Beneficial Use

The inland saline water habitat (SAL) beneficial use is defined as uses of water that support inland saline water ecosystems including, but not limited to, preservation or enhancement of aquatic saline habitats, vegetation, fish, or wildlife, including invertebrates (CCRWQCB, 2019a).

3.4.2.2.16 Estuarine Habitat Beneficial Use

The estuarine habitat (EST) beneficial use is defined as uses of water that support estuarine ecosystems including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (*e.g.*, estuarine mammals, waterfowl, shorebirds) (CCRWQCB, 2019a). An estuary is generally described as a semi-enclosed body of water having a free connection with the open sea, at least part of the year and within which the seawater is diluted at least seasonally with freshwater drained from the land. Included are water bodies which would naturally fit the definition if not controlled by tide gates or other such devices (CCRWQCB, 2019a).

3.4.2.2.17 Marine Habitat Beneficial Use

The marine habitat (MAR) beneficial use is defined as uses of water that support marine ecosystems including, but not limited to, preservation or enhancement of marine habitats, vegetation such as kelp, fish, shellfish, or wildlife (*e.g.*, marine mammals, shorebirds) (CCRWQCB, 2019a).

3.4.2.2.18 Wildlife Habitat Beneficial Use

The wildlife habitat (WILD) beneficial use is defined as uses of water that support terrestrial ecosystems including, but not limited to, preservation and enhancement of terrestrial habitats, vegetation, wildlife (*e.g.*, mammals, birds, reptiles, amphibians, invertebrates), or wildlife water and food sources (CCRWQCB, 2019a).

3.4.2.2.19 Biological Habitats of Special Significance Beneficial Use

The preservation of biological habitats of special significance (BIOL) beneficial use is defined as uses of water that support designated areas or habitats, such as established refuges, parks, sanctuaries, ecological reserves, or Areas of Special Biological Significance (ASBS), where the preservation or enhancement of natural resources requires special protection (CCRWQCB, 2019a). ASBS are those areas designated by the State Water Resources Control Board as requiring protection of species or biological communities to the extent that alteration of natural water quality is undesirable (CCRWQCB, 2019a).

3.4.2.2.20 Rare, Threatened, or Endangered Species Habitat Beneficial Use

The rare, threatened, or endangered species (RARE) beneficial use is defined as uses of water that support habitats necessary, at least in part, for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened, or endangered (CCRWQCB, 2019a).

3.4.2.2.21 Migration of Aquatic Organisms Habitat Beneficial Use

The migration of aquatic organisms (MIGR) beneficial use is defined as uses of water that support habitats necessary for migration or other temporary activities by aquatic organisms, such as anadromous fish (CCRWQCB, 2019a).

3.4.2.2.22 Spawning Habitat Beneficial Use

The spawning, reproduction, and/or early development (SPWN) beneficial use is defined as uses of water that support high-quality aquatic habitats suitable for reproduction and early development of fish (CCRWQCB, 2019a).

3.4.2.2.23 Shellfish Harvesting Habitat Beneficial Use

The shellfish harvesting (SHELL) beneficial use is defined as uses of water that support habitats suitable for the collection of filter-feeding shellfish (*e.g.*, clams, oysters, and mussels) for human consumption, commercial, or sport purposes. This includes waters that have in the past, or may in the future, contain significant shellfisheries (CCRWQCB, 2019a).

Once the beneficial uses are recognised, compatible water quality objectives can be established to protect the beneficial uses. Categories of water quality objectives are the focus of the following section.

3.4.2.3 Definitions of Water Quality Objective Categories for the Central Coastal Basin of California

Water quality standards consist of beneficial uses and water quality objectives (CCRWQCB, 2019a). The water quality objectives described below satisfy state and federal requirements. Water quality objectives are considered to be necessary to protect those present and probable future beneficial uses and to protect existing high-quality waters of the state (CCRWQCB, 2019a). These objectives are achieved primarily through the establishment of waste discharge requirements and through implementation of the Basin Plan (CCRWQCB, 2019a). In setting waste discharge requirements, the Regional Board considers the potential impact on beneficial uses within the area of influence of the discharge, the existing quality of receiving waters, and the appropriate water quality objectives. The Regional Board makes a finding of beneficial uses to be protected and establishes waste discharge requirements to protect those uses and to meet water quality objectives (CCRWQCB, 2019a).

Controllable water quality must conform to the water quality objectives listed below (CCRWQCB, 2019a). When other conditions cause degradation of water quality beyond the levels or limits established as water quality objectives, controllable conditions shall not cause further degradation of water quality (CCRWQCB, 2019a). Controllable water quality conditions are defined as those actions or circumstances resulting from human activities that may influence the quality of the waters of the state and that may be reasonably controlled (CCRWQCB, 2019a). Point sources of water pollution are defined as waste-loads from identifiable sources (*e.g.*, municipal discharges, industrial discharges, vessels, controllable stormwaters, fish hatchery discharges, confined animal operations, and agricultural drains) (CCRWQCB 2019a). Nonpoint sources of water pollution are defined as waste-loads resulting from land use practices where wastes are not collected and disposed of in any readily identifiable manner (*e.g.*, urban drainage, agricultural runoff, road construction activities, mining, grassland management, logging and other harvest activities, and natural sources) (CCRWQCB, 2019a).

The Regional Board has established separate sets of water quality objectives for ocean waters, surface waters, and groundwater within the Central Coastal Basin. The sections that follow describe each of these separate categories of water quality objectives.

3.4.2.3.1 Water Quality Objectives for Ocean Waters in the Central Coastal Basin of California

The provisions of the State Board's *Water Quality Control Plan for Ocean Waters of California* and *Water Quality Control Plan for Control of Temperature in the Coastal and Interstate Waters and Enclosed Bays and Estuaries of California* apply in their entirety to affected waters of the Central Coastal Basin including Monterey Bay and Carmel Bay. In addition, the following three water quality objectives, described below, also apply to all ocean waters, including Monterey and Carmel Bays: dissolved oxygen; pH; and radioactivity.

3.4.2.3.1.1 Dissolved Oxygen Water Quality Objective

The dissolved oxygen water quality objective for ocean waters states that the mean annual dissolved oxygen concentration shall not be less than 7.0 mg/L, nor shall the minimum dissolved oxygen concentration be reduced below 5.0 mg/L at any time (CCRWQCB, 2019a).

3.4.2.3.1.2 pH Water Quality Objective

The pH water quality objective for ocean waters states that the pH value shall not be depressed below 7.0, nor raised above 8.5 (CCRWQCB, 2019a).

3.4.2.3.1.3 Radioactivity Water Quality Objective

The radioactivity water quality objective for ocean waters states that radionuclides shall not be present in concentrations that are deleterious to human, plant, animal, or aquatic life, or result in the accumulation of radionuclides in the food web to an extent which presents a hazard to human, plant, animal, or aquatic life (CCRWQCB, 2019a).

3.4.2.3.2 Water Quality Objectives for All Inland Surface Waters, Enclosed Bays, and Estuaries in the Central Coastal Basin of California

Three separate sets of water quality objectives, described in the following three sections, apply to inland surface waters, enclosed bays, and estuaries: general objectives; objectives for specific beneficial uses; and objectives for specific water bodies.

3.4.2.3.2.1 General Water Quality Objectives for All Inland Surface Waters, Enclosed Bays, and Estuaries in the Central Coastal Basin of California

The following seventeen water quality objectives apply to all inland surface waters, enclosed bays, and estuaries of the Central Coastal Basin, including: colour; tastes and odours; floating material; suspended material; settleable material; oil and grease; biostimulatory substances; sediment; turbidity; pH; dissolved oxygen; temperature; toxicity; pesticides; chemical constituents; other organic substances; and radioactivity.

3.4.2.3.2.1.1 Colour Water Quality Objective

The colour water quality objective for all inland surface waters, enclosed bays, and estuaries states that waters shall be free of colouration that causes nuisance or adversely affects beneficial uses (CCRWQCB, 2019a). Colouration attributable to materials of waste origin shall not be greater than fifteen units or ten percent above natural background colour, whichever is greater (CCRWQCB, 2019a).

3.4.2.3.2.1.2 Tastes and Odours Water Quality Objective

The tastes and odours water quality objective for all inland surface waters, enclosed bays, and estuaries states that waters shall not contain taste or odour-producing substances in concentrations that impart undesirable tastes or odours to fish flesh or other edible products of aquatic origin, that cause nuisance, or that adversely affect beneficial uses (CCRWQCB, 2019a).

3.4.2.3.2.1.3 Floating Material Water Quality Objective

The floating material water quality objective for all inland surface waters, enclosed bays, and estuaries states that waters shall not contain floating material, including solids, liquids, foams, and scum, in concentrations that cause nuisance or adversely affect beneficial uses (CCRWQCB, 2019a).

3.4.2.3.2.1.4 Suspended Material Water Quality Objective

The suspended material water quality objective for all inland surface waters, enclosed bays, and estuaries states that waters shall not contain suspended material in concentrations that cause nuisance or adversely affect beneficial uses (CCRWQCB, 2019a).

3.4.2.3.2.1.5 Settleable Material Water Quality Objective

The settleable material water quality objective for all inland surface waters, enclosed bays, and estuaries states that waters shall not contain settleable material in concentrations that result in deposition of material that causes nuisance or adversely affects beneficial uses (CCRWQCB, 2019a).

3.4.2.3.2.1.6 Oil and Grease Water Quality Objective

The oil and grease water quality objective for all inland surface waters, enclosed bays, and estuaries states that waters shall not contain oils, greases, waxes, or other similar materials in concentrations that result in a visible film or coating on the surface of the water or on objects in the water, that cause nuisance, or that otherwise adversely affect beneficial uses (CCRWQCB, 2019a).

3.4.2.3.2.1.7 Biostimulatory Substances Water Quality Objective

The biostimulatory substances water quality objective for all inland surface waters, enclosed bays, and estuaries states that waters shall not contain biostimulatory substances in concentrations that promote aquatic growths to the extent that such growths cause nuisance or adversely affect beneficial uses (CCRWQCB, 2019a).

3.4.2.3.2.1.8 Sediment Water Quality Objective

The sediment water quality objective for all inland surface waters, enclosed bays, and estuaries states that the suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses (CCRWQCB, 2019a).

3.4.2.3.2.1.9 Turbidity Water Quality Objective

The turbidity water quality objective for all inland surface waters, enclosed bays, and estuaries states that waters shall be free of changes in turbidity that cause nuisance or adversely affect beneficial uses (CCRWQCB, 2019a). Increase in turbidity attributable to controllable water quality factors shall not exceed the following limits: where natural turbidity is between 0 and 50 Nephelometric Turbidity Units (NTU), increases shall not exceed twenty percent; where natural turbidity is between 50 and 100 NTU, increases shall not exceed 10 NTU; and where natural turbidity is greater than 100 NTU, increases shall not exceed ten percent (CCRWQCB, 2019a). Allowable zones of dilution within which higher concentrations will be tolerated will be defined for each discharge in discharge permits (CCRWQCB, 2019a).

3.4.2.3.2.1.10 pH Water Quality Objective

The pH water quality objective for all inland surface waters, enclosed bays, and estuaries states that for waters not mentioned by a specific beneficial use, the pH value shall not be depressed below 7.0 or raised above 8.5 (CCRWQCB, 2019a).

3.4.2.3.2.1.11 Dissolved Oxygen Water Quality Objective

The pH water quality objective for all inland surface waters, enclosed bays, and estuaries states that for waters not mentioned by a specific beneficial use, dissolved oxygen concentration shall not be reduced below 5.0 mg/L at any time (CCRWQCB, 2019a). Median values should not fall below eighty-five percent saturation as a result of controllable water quality conditions (CCRWQCB, 2019a).

3.4.2.3.2.1.12 Temperature Water Quality Objective

The temperature water quality objective for all inland surface waters, enclosed bays, and estuaries states that temperature objectives for enclosed bays and estuaries are as specified in the *Water Quality Control Plan for Control of Temperature in the Coastal and Interstate Waters and Enclosed Bays and Estuaries of California* (CCRWQCB, 2019a). Natural receiving water temperature of intrastate waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Board that such alteration in temperature does not adversely affect beneficial uses (CCRWQCB, 2019a).

3.4.2.3.2.1.13 Toxicity Water Quality Objective

The toxicity water quality objective for all inland surface waters, enclosed bays, and estuaries states that all waters shall be maintained free of toxic substances in concentrations which are toxic to, or which produce detrimental physiological responses in, human, plant, animal, or aquatic life (CCRWQCB, 2019a). Compliance with this objective will be determined by use of indicator organisms, analyses of species diversity, population density, growth anomalies, toxicity bioassays of appropriate duration, or other appropriate methods as specified by the Regional Board. Survival of aquatic life in surface waters subjected to a waste discharge or other controllable water quality conditions shall not be less than that for the same water body in areas unaffected by the waste discharge or, when necessary, for other control water that is consistent with the requirements for experimental water as described in *Standard Methods for the Examination of Water and Wastewater* (CCRWQCB, 2019a). As a minimum, compliance with this objective shall be evaluated with a 96-hour bioassay (CCRWQCB, 2019a). In addition, effluent limits based on acute bioassays of effluents will be prescribed where appropriate, additional numerical receiving water objectives for specific toxicants will be established as sufficient data become available, and source control of toxic substances is encouraged (CCRWQCB, 2019a). The discharge of wastes shall not cause concentrations of un-ionized ammonia (NH3) to exceed 0.025 mg/L (as N) in receiving waters (CCRWQCB, 2019a).

3.4.2.3.2.1.14 Pesticides Water Quality Objective

The pesticides water quality objective for all inland surface waters, enclosed bays, and estuaries states that no individual pesticide or combination of pesticides shall reach concentrations that adversely affect beneficial uses (CCRWQCB, 2019a). There shall be no increase in pesticide concentrations found in bottom sediments or aquatic life (CCRWQCB, 2019a). For waters where existing concentrations are presently nondetectable or where beneficial uses would be impaired by concentrations in excess of nondetectable levels, total identifiable chlorinated hydrocarbon pesticides shall not be present at concentrations detectable within the accuracy of analytical methods prescribed in *Standard Methods for the Examination of Water and Wastewater* or other equivalent methods approved by the Executive Officer of the Regional Board (CCRWQCB, 2019a).

3.4.2.3.2.1.15 Chemical Constituents Water Quality Objective

The chemical constituents water quality objective for all inland surface waters, enclosed bays, and estuaries states that where wastewater effluents are returned to land for irrigation uses, regulatory controls shall be consistent with Title 22 of the California Code of Regulations and other relevant local controls (CCRWQCB, 2019a).

3.4.2.3.2.1.16 Water Quality Objectives for Other Organic Substances

All inland surface waters, enclosed bays, and estuaries shall not contain organic substances in concentrations greater than the following: Methylene Blue Activated Substances, 0.2 mg/L; Phenols, 0.1 mg/L; PCBs, 0.3 μg/L; and Phthalate Esters, 0.002 μg/L (CCRWQCB, 2019a).

3.4.2.3.2.1.17 Radioactivity Water Quality Objective

The radioactivity water quality objective for all inland surface waters, enclosed bays, and estuaries states that radionuclides shall not be present in concentrations that are deleterious to human, plant, animal, or aquatic life; or result in the accumulation of radionuclides in the food web to an extent which presents a hazard to human, plant, animal, or aquatic life (CCRWQCB, 2019a).

3.4.2.3.2.2 Water Quality Objectives for Specific Beneficial Uses of Inland Surface Waters, Enclosed Bays, and Estuaries in the Central Coastal Basin of California

In addition to the general water quality objectives that apply to all inland surface waters, enclosed bays, and estuaries, there are also nine beneficial uses with specific water quality objectives that also apply to inland surface waters, enclosed bays, and estuaries: municipal and domestic supply; agricultural supply; water contact recreation; non-contact water recreation; cold freshwater habitat; warm freshwater habitat; fish spawning; marine habitat; and shellfish harvesting.

3.4.2.3.2.2.1 Municipal and Domestic Supply Beneficial Use

Inland surface waters, enclosed bays, and estuaries with the municipal and domestic supply (MUN) beneficial use assigned to them must also comply with the following five water quality objectives for: pH; organic chemicals; inorganic chemicals; phenol; and radioactivity.

3.4.2.3.2.2.1.1 pH Water Quality Objective

The pH water quality objective for inland surface waters, enclosed bays, and estuaries, with the MUN beneficial use, states that the pH value shall neither be depressed below 6.5 nor raised above 8.3 (CCRWQCB, 2019a).

3.4.2.3.2.2.1.2 Organic Chemicals Water Quality Objective

The organic chemicals water quality objective for inland surface waters, enclosed bays, and estuaries, with the MUN beneficial use, states that inland surface waters, enclosed bays, and estuaries shall not contain concentrations of organic chemicals in excess of the maximum contaminant levels for primary drinking water standards specified in California Code of Regulations, Title 22, Division 4, Chapter 15, Article 5.5, Section 64444, Table 64444-A

(CCRWQCB, 2019a). This incorporation-by-reference is prospective, including future changes to the incorporated provisions as the changes take effect.

3.4.2.3.2.2.1.3 Inorganic Chemicals Water Quality Objective

The inorganic chemicals water quality objective for inland surface waters, enclosed bays, and estuaries, with the MUN beneficial use, states that waters shall not contain concentrations of inorganic chemicals in excess of the maximum contaminant levels for primary drinking water standards specified in California Code of Regulations, Title 22, Division 4, Chapter 15, Sections 64431 and 64433.2 (CCRWQCB, 2019a). This incorporation-by-reference is prospective, including future changes to the incorporated provisions as the changes take effect.

3.4.2.3.2.2.1.4 Phenol Water Quality Objective

The inorganic chemicals water quality objective for inland surface waters, enclosed bays, and estuaries, with the MUN beneficial use, states that waters shall not contain phenol concentrations in excess of 1.0 μg/L (CCRWQCB, 2019a).

3.4.2.3.2.2.1.5 Radioactivity Water Quality Objective

The radioactivity water quality objective for inland surface waters, enclosed bays, and estuaries, with the MUN beneficial use, states that waters shall not contain concentrations of radionuclides in excess of the limits specified in California Code of Regulations, Title 22, Division 4, Chapter 15, Article 5, Sections 64442 and 64443 (CCRWQCB, 2019a). This incorporation-by-reference is prospective, including future changes to the incorporated provisions as the changes take effect.

3.4.2.3.2.2.2 Agricultural Supply Beneficial Use

Inland surface waters, enclosed bays, and estuaries with the agricultural supply (AGR) beneficial use assigned to them must also comply with the following three water quality objectives for: pH; dissolved oxygen; and chemical constituents.

3.4.2.3.2.2.2.1 pH Water Quality Objective

The pH water quality objective for inland surface waters, enclosed bays, and estuaries, with the AGR beneficial use, states that the pH value shall neither be depressed below 6.5 nor raised above 8.3 (CCRWQCB, 2019a).

3.4.2.3.2.2.2.2 Dissolved Oxygen Water Quality Objective

The dissolved oxygen water quality objective for inland surface waters, enclosed bays, and estuaries, with the AGR beneficial use, states that the dissolved oxygen concentration shall not be reduced below 2.0 mg/L at any time (CCRWQCB, 2019a).

3.4.2.3.2.2.2.3 Chemical Constituents Water Quality Objective

The chemical constituents water quality objective for inland surface waters, enclosed bays, and estuaries, with the AGR beneficial use, states that waters shall not contain concentrations of chemical constituents in amounts which adversely affect the agricultural beneficial use (CCRWQCB, 2019a). Interpretation of adverse effect shall be as derived from the University of California Agricultural Extension Service guidelines provided in Figure 3.10 (CCRWQCB, 2019a). In addition, waters used for irrigation and livestock watering shall not exceed concentrations for those chemicals listed in Figure 3.11 (CCRWQCB, 2019a). Salt concentrations for irrigation waters shall be controlled through implementation of the antidegradation policy to the effect that mineral constituents of currently or potentially usable

Guidelines for Interpretation of Quality of Water for Irrigation[a]

Problem and Related Constituent	No Problem	Water Quality Guidelines Increasing Problems	Severe
Salinity[b]			
EC of irrigation water, mmho/cm	<0.75	0.75 - 3.0	>3.0
Permeability			
EC of irrigation water, mmho/cm	>0.5	<0.5	<0.2
SAR, adjusted[c]	<6.0	6.0 - 9.0	>9.0
Specific ion toxicity[d] from root absorption			
Sodium (evaluate by adjusted SAR)	<3	3.0 - 9.0	>9.0
Chloride			
me/L	<4	4.0 - 10	>10
mg/L	<142	142 - 355	>355
Boron, mg/L	<0.5	0.5 - 2.0	2.0 - 10.0
Specific ion toxicity[d] from foliar absorption[e] (sprinklers)			
Sodium			
me/L	<3.0	>3.0	--
mg/L	<69	>69	--
Chloride			
me/L	<3.0	>3.0	--
mg/L	<106	>106	--
Miscellaneous[f]			
NH4 - N, mg/L for sensitive crops	<5	5 - 30	>30
NO3 - N, mg/L for sensitive crops	<5	5 - 30	>30
HCO3 (only with overhead sprinklers)			
me/L	<1.5	1.5 - 8.5	>8.5
mg/L	<90	90 - 520	>520
pH	Normal range	6.5 - 8.4	--

a. Interpretations are based on possible effects of constituents on crops and/or soils. Guidelines are flexible and should be modified when warranted by local experience or special conditions of crop, soil, and method of irrigation.

b. Assumes water for crop plus needed water for leaching requirement (LR) will be applied. Crops vary in tolerance to salinity. Refer to tables for crop tolerance and LR. The mmho/cm x 640 = approximate total dissolved solids (TDS) in mg/L or ppm; mmho x 1,000 = micromhos.

c. Adjusted SAR (sodium adsorption ratio) is calculated from a modified equation developed by U.S. Salinity Laboratory to include added effects of precipitation and dissolution of calcium in soils and related to $CO_3 + HCO_3$ concentrations.

To evaluate sodium (permeability) hazard: Adjusted SAR = Na/[1/2 (Ca + Mg)] $^{1/2}$[1+ (8.4 - pHc)].
Refer to Appendix A-26 for calculation assistance.

SAR can be reduced if necessary by adding gypsum. Amount of gypsum required (GR) to reduce a hazardous SAR to any desired SAR (SAR desired) can be calculated as follows:

$$GR = \left[\frac{2(Na)^2}{SAR^2 desired} - (Ca + Mg)\right]234$$

Note: Na and Ca + Mg should be in me/L. GR will be in lbs. of 100 percent gypsum per acre foot of applied water.

d. Most tree crops and woody ornamentals are sensitive to sodium and chloride (use values shown). Most annual crops are not sensitive (use salinity tolerance tables). For boron sensitivity, refer to boron tolerance tables. A source of tolerance tables is "Agricultural Salinity and Drainage," University of California Water Management Series publication 3375, revised 2006.

e. Leaf areas wet by sprinklers (rotating heads) may show a leaf burn due to sodium or chloride absorption under low humidity/high evaporation conditions. (Evaporation increases ion concentration in water films on leaves between rotations of sprinkler heads.)

f. Excess N may affect production or quality of certain crops; e.g., sugar beets, citrus, avocados, apricots, etc. (1 mg/L NO_3 - N = 2.72 lbs. N/acre foot of applied water.) HCO_3 with overhead sprinkler irrigation may cause a white carbonate deposit to form on fruit and leaves.

Figure 3.10. Guidelines for Interpretation of Quality of Water for Irrigation as depicted in the Basin Plan (CCRWQCB, 2019a, Table 3-1).

Water Quality Objectives for Agricultural Water Use

Element	Maximum Concentration (mg/L)[a]	
	Irrigation supply[b]	Livestock watering
Aluminum	5.0	5.0
Arsenic	0.1	0.2
Beryllium	0.1	--
Boron	0.75	5.0
Cadmium	0.01	0.05
Chromium	0.10	1.0
Cobalt	0.05	1.0
Copper	0.2	0.5
Fluoride	1.0	2.0
Iron	5.0	--
Lead	5.0	0.1[c]
Lithium	2.5[d]	--
Manganese	0.2	--
Mercury	–	0.01
Molybdenum	0.01	0.5
Nickel	0.2	--
Nitrate + Nitrite	–	100
Nitrite	–	10
Selenium	0.02	0.05
Vanadium	0.1	0.10
Zinc	2.0	25

a. Values based primarily on "Water Quality Criteria 1972" National Academy of Sciences-National Academy of Engineers, Environmental Study Board, ad hoc Committee on Water Quality Criteria furnished as recommended guidelines by University of California Agriculture Extension Service, January 7, 1974; maximum values are to be considered as 90 percentile values not to be exceeded.

b. Values provided will normally not adversely affect plants or soils; no data available for mercury, silver, tin, titanium, and tungsten.

c. Lead is accumulative and problems may begin at threshold value (0.05 mg/L).

d. Recommended maximum concentration for irrigating citrus is 0.075 mg/L.

Figure 3.11. Water Quality Objectives for Agricultural Water Use as depicted in the Basin Plan (CCRWQCB, 2019a, Table 3-2).

waters shall not be increased (CCRWQCB, 2019a). It is emphasised that no controllable water quality factor shall degrade the quality of any groundwater resource or adversely affect long-term soil productivity (CCRWQCB, 2019a). Where wastewater effluents are returned to land for irrigation uses, regulatory controls shall be consistent with Title 22 of the California Code of Regulations and with relevant controls for local irrigation sources (CCRWQCB, 2019a).

3.4.2.3.2.2.3 Water Contact Recreation Beneficial Use

Inland surface waters, enclosed bays, and estuaries with the water contact recreation (REC-1) beneficial use assigned to them must also comply with the following two water quality objectives for: pH; and bacteria.

3.4.2.3.2.2.3.1 pH Water Quality Objective

The pH water quality objective for inland surface waters, enclosed bays, and estuaries, with the REC-1 beneficial use, states that the pH value shall neither be depressed below 6.5 nor raised above 8.3 (CCRWQCB, 2019a).

3.4.2.3.2.2.3.2 Bacteria Water Quality Objective

The bacteria water quality objective for inland surface waters, enclosed bays, and estuaries, with the REC-1 beneficial use, states that the faecal coliform concentration, based on a minimum of not less than five samples for any 30-day period, shall not exceed a log mean of 200/100 mL, nor shall more than ten percent of total samples during any 30-day period exceed 400/100 mL (CCRWQCB, 2019a).

3.4.2.3.2.2.4 Non-Contact Water Recreation Beneficial Use

Inland surface waters, enclosed bays, and estuaries with the non-contact water recreation (REC-2) beneficial use assigned to them must also comply with the following two water quality objectives, described below, for: pH; and bacteria.

3.4.2.3.2.2.4.1 pH Water Quality Objective

The pH water quality objective for inland surface waters, enclosed bays, and estuaries, with the REC-2 beneficial use, states that the pH value shall neither be depressed below 6.5 nor raised above 8.3 (CCRWQCB, 2019a).

3.4.2.3.2.2.4.2 Bacteria Water Quality Objective

The bacteria water quality objective for inland surface waters, enclosed bays, and estuaries, with the REC-2 beneficial use, states that faecal coliform concentration, based on a minimum of not less than five samples for any 30-day period, shall not exceed a log mean of 2000/100 mL, nor shall more than ten percent of samples collected during any 30-day period exceed 4000/100 mL (CCRWQCB, 2019a).

3.4.2.3.2.2.5 Cold Freshwater Habitat Beneficial Use

Inland surface waters, enclosed bays, and estuaries with the cold freshwater habitat (COLD) beneficial use assigned to them must also comply with the following four water quality objectives, described below, for: pH; dissolved oxygen; temperature; and bacteria.

3.4.2.3.2.2.5.1 pH Water Quality Objective

The pH water quality objective for inland surface waters, enclosed bays, and estuaries, with the COLD beneficial use, states that the pH value shall not be depressed below 7.0 nor raised above 8.5 (CCRWQCB, 2019a). Changes in normal ambient pH levels shall not exceed 0.5 in fresh waters (CCRWQCB, 2019a).

3.4.2.3.2.2.5.2 Dissolved Oxygen Water Quality Objective

The dissolved oxygen water quality objective for inland surface waters, enclosed bays, and estuaries, with the COLD beneficial use, states that the dissolved oxygen concentration shall not be reduced below 7.0 mg/L at any time (CCRWQCB, 2019a).

3.4.2.3.2.2.5.3 Temperature Water Quality Objective

The temperature water quality objective for inland surface waters, enclosed bays, and estuaries, with the COLD beneficial use, states that at no time or place shall the temperature be increased by more than five degrees Fahrenheit above natural receiving water temperature (CCRWQCB, 2019a).

3.4.2.3.2.2.5.3 Chemical Constituents Water Quality Objective

The chemical constituents water quality objective for inland surface waters, enclosed bays, and estuaries, with the COLD beneficial use, states that waters shall not contain concentrations of chemical constituents known to be deleterious to fish or wildlife in excess of the limits listed in Figure 3.12 (CCRWQCB, 2019a).

3.4.2.3.2.2.6 Warm Freshwater Habitat Beneficial Use

Inland surface waters, enclosed bays, and estuaries with the warm freshwater habitat (WARM) beneficial use assigned to them must also comply with the following four water quality objectives, as described below, for: pH; dissolved oxygen; temperature; and bacteria.

Toxic Metal Concentrations not to be Exceeded in Aquatic Life Habitats, mg/L[a]

Metal	Fresh Water (COLD, WARM) Hard (> 100 mg/L CaCO3)	Soft (< 100 mg/L CaCO3)
Cadmium[b]	0.03	0.004
Chromium	0.05	0.05
Copper	0.03	0.01
Lead	0.03	0.03
Mercury[c]	0.0002	0.0002
Nickel[d]	0.4	0.1
Zinc	0.2	0.004

a. Based on limiting values recommended in the National Academy of Sciences-National Academy of Engineers "Water Quality Criteria 1972." Values are 90 percentile values except as noted in qualifying note "c."

b. Lower cadmium values not to be exceeded for crustaceans and waters designated SPWN are 0.003 mg/L in hard water and 0.0004 mg/L in soft water.

c. Total mercury values should not exceed 0.05 µg/L as an average value; maximum acceptable concentration of total mercury in any aquatic organism is a total body burden of 0.5 µg/g wet weight.

d. Value cited as objective pertains to nickel salts (not pure metallic nickel).

Toxic Metal Concentrations Not to be Exceeded in Marine Habitats, mg/L[a]

Metal	Marine (MAR)
Cadmium	0.0002
Chromium	0.05
Copper	0.01
Lead	0.01
Mercury[b]	0.0001
Nickel[c]	0.002
Zinc	0.02

a. Based on limiting values recommended in the National Academy of Sciences-National Academy of Engineers "Water Quality Criteria 1972." Values are 90 percentile values except as noted in qualifying note "b."

b. Total mercury values should not exceed 0.05 µg/L as an average value; maximum acceptable concentration of total mercury in any aquatic organism is a total body burden of 0.5 µg/g wet weight.

c. Value cited as objective pertains to nickel salts (not pure metallic nickel).

Figure 3.12. Toxic Metal Concentrations not to be Exceeded in Aquatic Life or Marine Habitats in mg/L as depicted in the Basin Plan (CCRWQCB, 2019a, Table 3-3 & 3-4).

3.4.2.3.2.2.6.1 pH Water Quality Objective

The pH water quality objective for inland surface waters, enclosed bays, and estuaries, with the WARM beneficial use, states that the pH value shall not be depressed below 7.0 nor raised above 8.5. Changes in normal ambient pH levels shall not exceed 0.5 in fresh waters (CCRWQCB, 2019a).

3.4.2.3.2.2.6.2 Dissolved Oxygen Water Quality Objective

The dissolved oxygen water quality objective for inland surface waters, enclosed bays, and estuaries, with the WARM beneficial use, states that the dissolved oxygen concentration shall not be reduced below 5.0 mg/L at any time (CCRWQCB, 2019a).

3.4.2.3.2.2.6.3 Temperature Water Quality Objective

The temperature water quality objective for inland surface waters, enclosed bays, and estuaries, with the WARM beneficial use, states that at no time or place shall the temperature of any water be increased by more than five degrees Fahrenheit above natural receiving temperature (CCRWQCB, 2019a).

3.4.2.3.2.2.6.4 Chemical Constituents Water Quality Objective

The chemical constituents water quality objective for inland surface waters, enclosed bays, and estuaries, with the WARM beneficial use, states that waters shall not contain concentrations of chemical constituents known to be deleterious to fish or wildlife in excess of the limits listed in Figure 3.12 (CCRWQCB, 2019a).

3.4.2.3.2.2.7 Fish Spawning Habitat Beneficial Use

Inland surface waters, enclosed bays, and estuaries with the fish spawning (SPWN) beneficial use assigned to them must also comply with the following two water quality objectives, as described below, for: cadmium; and dissolved oxygen.

3.4.2.3.2.2.7.1 Cadmium Water Quality Objective

The cadmium water quality objective for inland surface waters, enclosed bays, and estuaries, with the SPWN beneficial use, states that cadmium shall not exceed 0.003 mg/L in hard water or 0.0004 mg/L in soft water at any time (CCRWQCB, 2019a). Hard water is defined as water exceeding 100 mg/L $CaCO_3$.

3.4.2.3.2.2.7.2 Dissolved Oxygen Water Quality Objective

The dissolved oxygen water quality objective for inland surface waters, enclosed bays, and estuaries, with the SPWN beneficial use, states that the dissolved oxygen concentration shall not be reduced below 7.0 mg/L at any time (CCRWQCB, 2019a).

3.4.2.3.2.2.8 Marine Habitat Beneficial Use

Inland surface waters, enclosed bays, and estuaries with the marine habitat (MAR) beneficial use assigned to them must also comply with the following three water quality objectives, described below, for: pH; dissolved oxygen; and chemical constituents.

3.4.2.3.2.2.8.1 pH Water Quality Objective

The pH water quality objective for inland surface waters, enclosed bays, and estuaries, with the MAR beneficial use, states that the pH value shall not be depressed below 7.0 nor raised above 8.5. Changes in normal ambient pH levels shall not exceed 0.2 units (CCRWQCB, 2019a).

3.4.2.3.2.2.8.2 Dissolved Oxygen Water Quality Objective

The dissolved oxygen water quality objective for inland surface waters, enclosed bays, and estuaries, with the MAR beneficial use, states that the dissolved oxygen concentration shall not be reduced below 7.0 mg/L at any time (CCRWQCB, 2019a).

3.4.2.3.2.2.8.3 Chemical Constituents Water Quality Objective

The chemical constituents water quality objective for inland surface waters, enclosed bays, and estuaries, with the MAR beneficial use, states that waters shall not contain concentrations of chemical constituents known to be deleterious to fish or wildlife in excess of limits listed in Figure 3.12 (CCRWQCB, 2019a).

3.4.2.3.2.2.9 Shellfish Harvesting (SHELL)

Inland surface waters, enclosed bays, and estuaries with the shellfish harvesting (SHELL) beneficial use assigned to them must also comply with the following two water quality objectives, described below, for: chromium; and bacteria.

3.4.2.3.2.2.9.1 Chromium Water Quality Objective

The chromium water quality objective for inland surface waters, enclosed bays, and estuaries, with the SHELL beneficial use, states that the maximum permissible value for waters shall be 0.01 mg/L (CCRWQCB, 2019a).

3.4.2.3.2.2.9.2 Bacteria Water Quality Objective

The bacteria water quality objective for inland surface waters, enclosed bays, and estuaries, with the SHELL beneficial use, states that in all areas where shellfish may be harvested for human consumption, the median total coliform concentration throughout the water column for any 30-day period shall not exceed 70/100 mL, nor shall more than ten percent of the samples collected during any 30-day period exceed 230/100 mL for a five-tube decimal dilution test or 330/100 mL when a three-tube decimal dilution test is used (CCRWQCB, 2019a).

3.4.2.3.2.3 Water Quality Objectives for Specific Inland Surface Waters, Enclosed Bays and Estuaries in the Central Coastal Basin of California

Water quality objectives have been established for selected surface waters; these objectives are intended to serve as a water quality baseline for evaluating water quality management in the basin (CCRWQCB, 2019a). Mean values, shown in Figure 3.13 for surface waters, are based on available data (CCRWQCB, 2019a). Therefore, application of these objectives must be based upon consideration of the surface water and groundwater quality naturally present, the existing quality of receiving waters, and water quality objectives (CCRWQCB, 2019a). Consideration of beneficial uses includes: a specific enumeration of all beneficial uses potentially to be affected by the waste discharge; a determination of the relative importance of competing beneficial uses; and the impact of the discharge on existing beneficial uses (CCRWQCB, 2019a). The Regional Board makes a judgment as to the priority of dominant use and minimises the impact on competing uses while not allowing the discharge to violate receiving water quality objectives (CCRWQCB, 2019a).

Mean Surface Water Quality Objectives, mg/L[a]

Hydrologic Unit/Sub-Area	TDS	Cl	SO4	B	Na
Big Basin (304)					
Boulder Creek	150	10	10	0.2	20
Zayante Creek	500	50	100	0.2	40
San Lorenzo River					
Above Bear Creek	400	60	80	0.2	50
At Tait Street Check Dam	250	30	60	0.2	25
Pajaro River (305)					
at Chittenden	1000	250	250	1.0	200
San Benito River	1400	200	350	1.0	250
Llagas Creek	200	10	20	0.2	20
Carmel River (307)	200	20	50	0.2	20
Santa Lucia (308)					
Big Sur River	200	20	20	0.2	20
Salinas River (309)					
Salinas River					
Above Bradley	250	20	100	0.2	20
Above Spreckles	600	80	125	0.2	70
Gabilan Tributary	300	50	50	0.2	50
Diablo Tributary	1200	80	700	0.5	150
Nacimiento River	200	20	50	0.2	20
San Antonio River	250	20	80	0.2	20
Estero Bay (310)					
Santa Rosa Creek	500	50	80	0.2	50
Chorro Creek	500	50	50	0.2	50
San Luis Obispo Creek	650	100	100	0.2	50
Arroyo Grande Creek	800	50	200	0.2	50
Santa Maria (312)					
Cuyama River (Near Garey)	900	50	400	0.3	70
Sisquoc River (Near Garey)	600	20	250	0.2	50
Santa Ynez (314)					
Cachuma Reservoir	600	20	220	0.4	50
Solvang	700	50	250	0.4	60
Lompoc	1000	100	350	0.4	100

a. Objectives shown are annual mean values. Objectives are based on preservation of existing quality or water quality enhancement believed attainable following control of point sources.

Figure 3.13. Surface Water Quality Objectives, in mg/L, as depicted in the Basin Plan (CCRWQCB, 2019a, Table 3-5).

3.4.2.3.3 Water Quality Objectives for Groundwater in the Central Coastal Basin of California

Three separate sets of water quality objectives, described in the following three sections, apply to groundwater in the Central Coastal Basin: general objectives; objectives for specific beneficial uses; and objectives for specific subbasins.

3.4.2.3.3.1 General Water Quality Objectives for Groundwater in the Central Coastal Basin of California

The following two water quality objectives, described below, apply to all groundwater subbasins of the Central Coastal Basin, including: tastes and odours; and radioactivity.

3.4.2.3.3.1.1 Tastes and Odours Water Quality Objective

The tastes and odours water quality objective for all groundwater subbasins states that groundwater shall not contain taste or odour producing substances in concentrations that adversely affect beneficial uses (CCRWQCB, 2019a).

3.4.2.3.3.1.2 Radioactivity Water Quality Objective

The radioactivity water quality objective for all groundwater subbasins states that radionuclides shall not be present in concentrations that are deleterious to human, plant, animal, or aquatic life; or result in the accumulation of radionuclides in the food web to an extent which presents a hazard to human, plant, animal, or aquatic life (CCRWQCB, 2019a).

3.4.2.3.3.2 Water Quality Objectives for Specific Beneficial Uses of Groundwater in the Central Coastal Basin of California

In addition to the general water quality objectives that apply to all groundwater subbasins, there are also two beneficial uses, described below, with specific water quality objectives that also apply to groundwater subbasins: municipal and domestic supply; and agricultural supply.

3.4.2.3.3.2.1 Municipal and Domestic Supply Beneficial Use

Groundwater subbasins with the municipal and domestic supply (MUN) beneficial use assigned to them must also comply with the following four water quality objectives, described below, for: bacteria; organic chemicals; inorganic chemicals; and radioactivity.

3.4.2.3.3.2.1.1 Bacteria Water Quality Objective

The bacteria water quality objective for groundwater subbasins with the MUN beneficial use states that the median concentration of coliform organisms over any seven-day period shall be less than 2.2/100 mL (CCRWQCB, 2019a).

3.4.2.3.3.2.1.2 Organic Chemicals Water Quality Objective

The organic chemicals water quality objective for groundwater subbasins with the MUN beneficial use states that groundwater shall not contain concentrations of organic chemicals in excess of the maximum contaminant levels for primary drinking water standards specified in California Code of Regulations, Title 22, Division 4, Chapter 15, Article 5.5, Section 64444, Table 64444-A, depicted in Figure 3.14 (CCRWQCB, 2019a).

22 CCR § 64444

§ 64444. Maximum Contaminant Levels - Organic Chemicals.

The MCLs for the primary drinking water chemicals shown in table 64444-A shall not be exceeded in the water supplied to the public.

Table 64444-A Maximum Contaminant Levels Organic Chemicals

Chemical	Maximum Contaminant Level, mg/L
(a) Volatile Organic Chemicals (VOCs)	
Benzene	0.001
Carbon Tetrachloride	0.0005
1,2-Dichlorobenzene	0.6
1,4-Dichlorobenzene	0.005
1,1-Dichloroethane	0.005
1,2-Dichloroethane	0.0005
1,1-Dichloroethylene	0.006
cis-1,2-Dichloroethylene	0.006
trans-1,2-Dichloroethylene	0.01
Dichloromethane	0.005
1,2-Dichloropropane	0.005
1,3-Dichloropropene	0.0005
Ethylbenzene	0.3
Methyl- *tert* -butyl ether	0.013
Monochlorobenzene	0.07
Styrene	0.1
1,1,2,2-Tetrachloroethane	0.001
Tetrachloroethylene	0.005
Toluene	0.15
1,2,4-Trichlorobenzene	0.005
1,1,1-Trichloroethane	0.200
1,1,2-Trichloroethane	0.005

Figure 3.14. Format of California's Primary Drinking Water Standards for Organic Chemicals, in mg/L, table as depicted in the Code of Regulations (22 CCR §64444). The table includes twenty-seven Volatile Organic Compounds (VOCs), of which the first twenty-two are depicted here, and thirty-four Synthetic Organic Chemicals (SOCs).

3.4.2.3.3.2.1.3 Inorganic Chemicals Water Quality Objective

The inorganic chemicals water quality objective for groundwater subbasins with the MUN beneficial use states that groundwater shall not contain concentrations of inorganic chemicals in excess of the maximum contaminant levels for primary drinking water standards specified in California Code of Regulations, Title 22, Division 4, Chapter 15, Article 4, Section 64431 and Article 4.1, Section 64433.2, depicted in Figures 3.15 and 3.16, respectively (CCRWQCB, 2019a).

3.4.2.3.3.2.1.4 Radioactivity Water Quality Objective

The radioactivity water quality objective for groundwater subbasins with the MUN beneficial use states that groundwater shall not contain concentrations of radionuclides in excess of the limits specified in California Code of Regulations, Title 22, Division 4, Chapter 15, Article 5, Section 64443, depicted in Figure 3.17 (CCRWQCB, 2019a).

3.4.2.3.3.2.2 Agricultural Supply Beneficial Use

Groundwater subbasins with the agricultural supply (AGR) beneficial use assigned to them shall not contain concentrations of chemical constituents in amounts that adversely affect such beneficial use. Interpretation of adverse effect shall be as derived from the University of California Agricultural Extension Service guidelines provided in Figure 3.10 (CCRWQCB, 2019a). In addition, water used for irrigation and livestock watering shall not exceed the concentrations for those chemicals listed in Figure 3.11. No controllable water quality factor shall degrade the quality of any groundwater resource or adversely affect long-term soil productivity (CCRWQCB, 2019a). The salinity control aspects of groundwater management will account for effects from all sources (CCRWQCB, 2019a).

22 CCR § 64431

§ 64431. Maximum Contaminant Levels - Inorganic Chemicals.

Public water systems shall comply with the primary MCLs in table 64431-A as specified in this article.

Table 64431-A

Maximum Contaminant Levels

Inorganic Chemicals

Maximum Contaminant	
Chemical	*Level, mg/L*
Aluminum	1.
Antimony	0.006
Arsenic	0.010
Asbestos	7 MFL*
Barium	1.
Beryllium	0.004
Cadmium	0.005
Chromium	0.05
Cyanide	0.15
Fluoride	2.0
Mercury	0.002
Nickel	0.1
Nitrate (as nitrogen)	10.
Nitrate+Nitrite (sum as nitrogen)	10.
Nitrite (as nitrogen)	1.
Perchlorate	0.006
Selenium	0.05
Thallium	0.002

* MFL=million fibers per liter; MCL for fibers exceeding 10μm in length.

Figure 3.15. California's Primary Drinking Water Standards for Inorganic Chemicals, in mg/L, table as depicted in the Code of Regulations (22 CCR §64431).

22 CCR § 64433.2

§ 64433.2. Optimal Fluoride Levels.

Any public water system that is fluoridating shall comply with the temperature-appropriate fluoride levels in Table 64433.2-A. The system shall determine, and submit to the State Board, its annual average of maximum daily air temperatures based on the five calendar years immediately preceding the current calendar year.

Table 64433.2-A

Optimal Fluoride Levels

Annual average of maximum daily air temperatures, degrees		*Optimal fluoride level, mg/L*	*Control Range, mg/L*	
Fahrenheit	*Celsius*		*Low*	*High*
50.0 to 53.7	10.0 to 12.0	1.2	1.1	1.7
53.8 to 58.3	12.1 to 14.6	1.1	1.0	1.6
58.4 to 63.8	14.7 to 17.7	1.0	0.9	1.5
63.9 to 70.6	17.8 to 21.4	0.9	0.8	1.4
70.7 to 79.2	21.5 to 26.2	0.8	0.7	1.3
79.3 to 90.5	26.3 to 32.5	0.7	0.6	1.2

Figure 3.16. California's Primary Drinking Water Standards for Fluoride, in mg/L, table as depicted in the Code of Regulations (22 CCR §64433.2).

22 CCR § 64443

§ 64443. MCLs and Monitoring - Beta Particle and Photon Radioactivity.

(a) Each community and nontransient-noncommunity water system (system) shall comply with the primary MCLs in table 64443 and use the DLRs for reporting monitoring results:

Table 64443

Radionuclide Maximum Contaminant Levels (MCLs) and Detection Levels for Purposes of Reporting (DLRs)

Radionuclide	**MCL**	**DLR**
Beta/photon emitters	4 millirem/year annual dose equivalent to the total body or any internal organ	Gross Beta particle activity: 4 pCi/L
Strontium-90	8 pCi/L	2 pCi/L
	(= 4 millirem/yr dose to bone marrow)	
Tritium	20,000 pCi/L	1,000 pCi/L
	(= 4 millirem/yr dose to total body)	

Figure 3.17. Radioactivity Groundwater Quality Objectives, as depicted in the California Code of Regulations, Title 22, Division 4, Chapter 15, Article 5, Section 64443 (22 CCR 64443).

3.4.2.3.3.3 Water Quality Objectives for Specific Groundwater Subbasins in the Central Coastal Basin of California

Water quality objectives have been established for selected groundwater subbasins; these objectives are intended to serve as a water quality baseline for evaluating water quality management in the Central Coastal Basin (CCRWQCB, 2019a). The median values for groundwater subbasins are shown in Figure 3.18 (CCRWQCB, 2019a). The Regional Board must afford full consideration to: present and probable future beneficial uses affected by the waste discharge; competing beneficial uses; degree of impact on existing beneficial uses; receiving water quality; and water quality objectives, before adjudging priority of dominant use and promulgating waste discharge requirements (CCRWQCB, 2019a). As part of the state's continuing planning process, water quality data will be collected and numerical water quality objectives will be developed for mineral constituents that are without sufficient information presently available for the establishment of such objectives (CCRWQCB, 2019a).

3.4.3 Defining Wastewater Quality in the Central Coastal Basin of California

The Regional Board implements the Basin Plan by issuing and enforcing waste discharge requirements to individuals, communities, or businesses with waste discharges that affect water quality (CCRWQCB, 2019a). These requirements can be either state waste discharge requirements for discharges to land, or federally delegated National Pollutant Discharge Elimination System (NPDES) permits for discharges to surface water, as described in the US wastewater quality section of the chapter (CCRWQCB, 2019a). Effluent limitations for disposal of wastes are based on water quality objectives for the area of effluent disposal and applicable state and federal policies and effluent limits. Water quality objectives and policies are based on beneficial uses established for receiving waters (CCRWQCB, 2019a). Water

Median Groundwater Objectives, mg/L[a]

Basin/Sub-Area	TDS	Cl	SO_4	B	Na	N[b]
Big Basin						
Near Felton	100	20	10	0.2	10	1
Near Boulder Creek	250	30	50	0.2	20	5
Pajaro Valley						
Hollister	1200	150	250	1.0	200	5
Tres Pinos	1000	150	250	1.0	150	5
Llagas	300	20	50	0.2	20	5
Salinas Valley						
Upper Valley[f]	600	150	150	0.5	70	5
Upper Forebay[f]	800	100	250	0.5	100	5
Lower Forebay[f]	1500	250	850	0.5	150	8
180 foot Aquifer[f]	1500	250	600	0.5	250	1
400 foot Aquifer[f]	400	50	100	0.2	50	1
Paso Robles Area[g]						
Central Basin[f]	400	60	45	0.3	80	3.4
San Miguel[f]	750	100	175	0.5	105	4.5
Paso Robles[f]	1050	270	200	2.0	225	2.3
Templeton[f]	730	100	120	0.3	75	2.7
Atascadero[f]	550	70	85	0.3	65	2.3
Estrella[f]	925	130	240	0.75	170	3.2
Shandon	1390	430	1025[h]	2.8	730	2.3
Estero Bay						
Santa Rosa	700	100	80	0.2	50	5
Chorro	1000	250	100	0.2	50	5
San Luis Obispo	900	200	100	0.2	50	5
Arroyo Grande	800	100	200	0.2	50	10
Carrizo Plain	[e]	[e]	[e]	[e]	[e]	[e]
Santa Maria River Valley[c]						
Upper Guadalupe[f]	1000[d]	165	500[d]	0.5	230	1.4[e]
Lower Guadalupe[f]	1000[d]	85	500[d]	0.2	90	2.0[e]
Lower Nipomo Mesa[f]	710	95	250	0.15	90	5.7[e]
Orcutt[f]	740	65	300	0.1	65	2.3[e]
Santa Maria[f]	1000[d]	90	510	0.2	105	8.0[e]
Cuyama Valley	1500	80	--	0.4	--	5
San Antonio Creek Valley	600	150	150	0.2	100	5
Santa Ynez River Valley						
Santa Ynez	600	50	10	0.5	20	1
Santa Rita	1500	150	700	0.5	100	1
Lompoc Plain[f]	1250	250	500	0.5	250	2
Lompoc Upland[f]	600	150	100	0.5	100	2
Lompoc Terrace[f]	750	210	100	0.3	130	1
South Coast						
Goleta	1000	150	250	0.2	150	5
Santa Barbara	700	50	150	0.2	100	5
Carpinteria	700	100	150	0.2	100	7

a. Objectives shown are median values based on data averages; objectives are based on preservation of existing quality or water quality enhancement believed attainable following control of point sources.
b. Measured as Nitrogen
c. Basis for objectives is in the "Water Quality Objectives for the Santa Maria Ground Water Basin Revised Staff Report, May 1985" and February 1986, Staff Report.
d. These are maximum objectives in accordance with Title 22 of the Code of Regulations.
e. Groundwater basin currently exceeds usable mineral quality.
f. Groundwater basin boundary maps available in the Appendix: Salinas (Appendix A-32), Paso Robles (Appendix A-33), Santa Maria (Appendix A-34), and Lompoc (Appendix A-35).
g. Basis for objectives is in the report "A Study of the Paso Robles Ground Water Basin to Establish Best Management Practices and Establish Salt Objectives", Coastal Resources Institute, June 1993.
h. Standard exceeds California Secondary Drinking Water Standards contained in Title 22 of the Code of Regulations. Water quality standard is based upon existing water quality. If water quality degradation occurs, the Regional Board may consider salt limits on appropriate discharges.

Figure 3.18. Groundwater Quality Objectives, in mg/L, as depicted in the Basin Plan (CCRWQCB, 2019a, Table 3-6).

quality is controlled when such discharges are managed so that: they meet these requirements; water quality objectives are met; and beneficial uses are protected (CCRWQCB, 2019a).

3.4.4 Defining Industrial Wastewater Quality in the Central Coastal Basin of California

The five options for industrial wastewater discharges are: ocean discharge and compliance with the *State Ocean Plan*, the *State Thermal Plan*, and *Public Law 92-500*; containment of non-saline and non-toxic wastes on land; reinjection of oil and gas production brines; inland surface water discharge, if other alternatives are proved infeasible; and, abandonment of the treatment facility and connection to a publicly owned treatment works. In most cases, alternatives are limited by standards of performance and pretreatment standards developed by US EPA (CCRWQCB, 2019a). It should also be noted that federal guidelines are subject to regional considerations such as important fishery resources or wildlife areas which could necessitate making regional industrial discharge requirements more stringent than national performance standards (CCRWQCB, 2019a).

Specific effluent limitations are promulgated by US EPA for existing industrial waste discharges together with standards of performance and pretreatment standards of performance for new sources (CCRWQCB, 2019a). Waste source categories of particular interest in the Central Coastal Basin include: meat product and rendering processing; dairy product processing; canned and preserved fruit and vegetable processing; canned and preserved seafood processing; cement manufacturing; feedlots; electroplating; beet sugar processing; petroleum production and refining; steam electric power plants; and leather tanning and finishing (CCRWQCB, 2019a).

3.4.5 Defining Stormwater Quality in the Central Coastal Basin of California

The US EPA estimates that at least thirty-three percent of all contamination in lakes and estuaries and ten percent of all river contamination are caused by stormwater runoff (CCRWQCB, 2019a). Sources of pollution include runoff from industrial facilities, construction sites, and urban municipalities (CCRWQCB, 2019a). The US Code of Federal Regulations requires certain industrial facility operators to obtain stormwater discharge permits (CCRWQCB, 2019a). The specific type of facility that needs coverage is dependent upon the facility's standard industrial classification code (CCRWQCB, 2019a). The program is primarily directed at manufacturing facilities, oil and gas extraction, transportation maintenance facilities, and construction sites. In addition, municipalities with populations greater than one hundred thousand people must participate in a municipal stormwater permitting program (CCRWQCB, 2019a).

The State Board adopted a statewide General Construction Activity Stormwater Permit and General Industrial Activities Stormwater Permit (CCRWQCB, 2019a). The stormwater program objectives include identification and elimination of pollutant contact with stormwater by implementation of best management practices (CCRWQCB, 2019a). General industrial permit requirements include the development of a stormwater pollution prevention plan (SWPPP) and stormwater runoff monitoring. The SWPPP is a facility-specific document which includes: a site description; facility processes; pollutant sources; stormwater management system; employee education and training program; and measures proposed to eliminate non-stormwater discharges (CCRWQCB, 2019a). Minimum monitoring and reporting requirements include: sampling and analysis of four pollutant indicator parameters; wet and dry weather stormwater conveyance system inspections; and annual reporting. The Regional Board can recommend additional monitoring parameters based on the presence of specific pollutant sources (CCRWQCB, 2019a). The construction permit has similar requirements regarding development of an SWPPP focused on reducing pollutant sources associated with erosion and sediment transfer and chemicals used at construction sites (CCRWQCB, 2019a). Annual monitoring reports required by the industrial permit are submitted to the Regional Board each year (CCRWQCB, 2019a).

3.4.6 Defining Water Reuse Quality in the Central Coastal Basin of California

The Basin Plan is also implemented by encouraging water users to improve the quality of their water supplies, particularly where the wastewater they discharge is likely to be reused. Water shortages in California are resulting in increased demand for reclamation. Reclamation and reuse is encouraged where feasible and beneficial. Treatment process selection for reclamation of wastewater is dependent upon the intended reuse. Where irrigation reuse or groundwater recharge is intended, treatment requirements depend on conditions described under land disposal. The nature of the crop to be irrigated, soil percolation, and water characteristics are important considerations.

Title 22 of the California Code of Regulations provides wastewater reclamation criteria to regulate specific uses of reclaimed water (CCRWQCB, 2019a). Secondary treatment with coagulation, filtration, and disinfection is required for water reuse intended for water contact recreation (CCRWQCB, 2019a). Where golf course irrigation is practiced, this level of treatment minus coagulation and filtration may be adequate (CCRWQCB, 2019a). More stringent measures may be necessary with increased risk of public exposure. However, where more complete reclamation is envisioned, such as creation of recreational lakes for fishing, swimming, and water-skiing, nutrient removal may also be required to minimise algae growths and to encourage fish propagation (CCRWQCB, 2019a). Comparable treatment may also be needed for industrial water supplies used for cooling and uses where algae growth in transfer channels or cooling towers is of concern. Nitrogen removal and demineralisation processes may also be necessary for selected reclamation projects as discussed under land disposal (CCRWQCB, 2019a). To meet the increased demand for reclamation, existing regulations contained in the California Code of Regulations, Title 22 are being expanded (CCRWQCB, 2019a).

3.4.7 Academic Literature Related to Gaps in Defining California Water Quality

In addition to the water quality definitions established by the agencies responsible for water quality in California, there is discussion of the gaps related to defining water quality in the academic literature. This section aims to capture the barriers caused by unclear definitions and the shift in focus from surface water to groundwater.

Two decades ago, the discussion of water quality definitions in the academic literature related to California was focused on water bodies listed by the state as impaired due to the presence of contaminants. For example, Hall *et al.* (2006) aim to characterise physical habitat and benthic communities (*i.e.*, macroinvertebrates) in the Stanislaus, Tuolumne, and Merced Rivers in California's San Joaquin Valley in 2003. These rivers are listed as impaired water bodies by the State of California due to the presence of: organophosphate insecticides chlorpyrifos and diazinon; organochlorine pesticides; and mercury (Hall *et al.*, 2006). Hall *et al.* found that channel flow, an instream metric, and bank stability, a riparian metric, were the most important physical habitat metrics influencing the various benthic metrics for all three rivers. Abundance measures of benthic macroinvertebrates were similar among the three rivers in the San Joaquin watershed (Hall *et al.*, 2006). Hall *et al.* concluded that the presence of one hundred and seventeen taxa in the Stanislaus River, one hundred and fourteen taxa in the Tuolumne River and ninety-six taxa in the Merced River imply that the benthic communities in these streams are fairly diverse, but without a clear definition of benthic community expectations it is unknown if these water bodies are actually impaired.

More recently, discussion in the academic literature related to defining water quality in California has focused on groundwater. For example, Rudestam *et al.* (2015) note that groundwater, a critical resource in many parts of the world, is often characterised as a common pool resource. Multiple individuals utilise groundwater from a basin, and each person has the capacity to reduce the quantity or quality available to others (Rudestam *et al.*, 2015). Rudestam *et al.* turn to a case study of the Pajaro Groundwater Basin in Central California to re-envision the characterisation of commons. While providing a useful frame from which to analyse groundwater depletion in the Pajaro, Rudestam *et al.* find Common Pool Resource (CPR) theory to be imprecise in its approach to a geographic scale. The notion of the commons is central to CPR studies, however there is wide divergence in what the commons constitutes, both spatially and socially. Rather than propose a normative definition for the commons, Rudestam *et al.* suggest that the commons as a geographic category is socially constructed and dynamically active over time, akin to the analytics of scale as developed within the fields of political ecology and geography. Rudestam *et al.* (2015) believe this move from situating the commons as a fixed and discrete geographic area to that which is constantly changing and relational improves understanding of the ways in which water users collaborate and communicate around shared groundwater sources.

Kang *et al.* (2019) believe groundwater demands are growing in many arid regions, and the use of non-traditional water resources, especially during extreme droughts, is increasingly common. One non-traditional resource is deep groundwater, which Kang *et al.* define as one hundred and fifty metres to several kilometres or more below the surface. They analyse 41,081 data points from seventeen basins in the southwestern US to estimate the distribution of fresh and usable deep groundwater for potential human consumption and irrigation. Kang *et al.* find seven out of the seventeen southwestern basins indicate the presence of substantial quantities of usable deep groundwater. They find that thirty-six percent of the Central Valley of California has deep groundwater with sufficiently low toxic and trace element concentrations for irrigation use without treatment, with greater percentages available for more tolerant crops. However, Kang *et al.* (2019) caution that given the potentially large deep fresh and usable groundwater volumes across the southwestern US, it is important to characterise the resource and protect it for potential use in decades and centuries to come.

Kang *et al.* (2020) acknowledge that the depth at which groundwaters transition from fresh to more saline, the base of freshwater, is frequently used to determine the stringency and types of measures put in place to manage groundwater and protect it from contamination. Therefore, it is important to understand salinity distributions and compare defined bases of freshwater with salinity distributions and groundwater well depths (Kang *et al.*, 2020). Kang *et al.* find that nineteen to fifty-six percent of the groundwater TDS measurements made at depths deeper than defined bases of freshwater pump fresh groundwater (*i.e.*, with TDS concentrations less than 2,000 mg/L). Because fresh groundwater is found at depths deeper than the base of freshwater, current policies informed by base of freshwater assessments may not be managing and protecting large volumes of deep fresh groundwater (Kang *et al.*, 2020). Furthermore, Kang *et al.* find that nearly four percent of existing groundwater wells penetrate defined bases of freshwater, and nearly sixteen percent of wells overlie it by no more than one hundred metres, evidencing widespread encroachment on the base of freshwater by groundwater users. Kang *et al.*'s (2020) analysis suggests that groundwater sustainability in California may be poorly safeguarded in some places and that the base of freshwater concept needs to be reconsidered as a means to define and manage groundwater.

3.4.8 Section Summary: Defining Categories of Water Quality for the State of California

In summary, unlike the waters of the US definition, which omits groundwater, the waters of the state definition for California includes groundwater. Rather than defining water quality at the state level, California defines water quality at the hydrologic region (*i.e.*, watershed basin) level to account for regional variation. Water quality definitions are updated, peer reviewed, and approved by the US EPA every three years. Both federal and state regulations acknowledge regional considerations and local requirements. The organisation responsible for establishing water quality definitions remains involved in implementation, monitoring, and assessment. The academic literature defines deep groundwater, and reports on the quality of that water as appropriate for use, and identifies risk for abuse of groundwater commons, as reviewed in the following seven sections.

3.4.8.1 Waters of the State Definition Includes Groundwater in California

While the federal CWA focuses on waters of the United States, navigable surface waters and their tributaries, the term waters of the state under the California Water Code is broader (SWRCB, 2022). Waters of the state means any surface water or groundwater, including saline waters, within the boundaries of the state (SWRCB, 2022). Also included are surface waters that are not tributary to navigable waters. California has water quality standards that apply to all of these waters (SWRCB, 2022).

3.4.8.2 The State of California Defines Water Quality at the Hydrologic Region Level

The CWA defines water quality standards as provisions of state or federal law which consist of designated uses and water quality criteria (SWRCB, 2022). For California, the designated uses of water are called beneficial uses and the water quality criteria based on those uses are called water quality objectives (SWRCB, 2022). California's water quality standards are found in the *Water Quality Control Plans* adopted by the California Water Boards. Because the plans cover one water basin, they are often referred to as Basin Plans (SWRCB, 2022). The quality requirements for irrigation are different from those for domestic use, and the plan recognises such variations (CCRWQCB, 2019a).

3.4.8.3 Water Quality Definitions Updated, Peer Reviewed, and Approved by the US EPA Every Three Years

The California Water Code specifies that each Regional Water Quality Control Board shall establish water quality objectives which, in the Regional Board's judgment, are necessary for the reasonable protection of beneficial uses and for the prevention of nuisance. As new information becomes available, the Regional Board reviews the appropriateness of the existing objectives. These objectives are subject to public hearing at least once during each three-year period following adoption of the plan for the purpose of review and modification as appropriate. Basin Plan amendment hearings are advertised in the public notice section of a newspaper circulated in areas affected by the amendment. Persons interested in a particular issue (*e.g.*, university professors, PhD students, scientists, environmental professionals), can also notify the Regional Board staff of their interest in being notified of hearings on the topic. Basin Plan amendments do not become effective until approved by the State Board. Surface water standards also require the approval of the US EPA to become effective.

3.4.8.4 Regional Considerations and Local Control

It should also be noted that federal guidelines are subject to regional considerations such as important fishery resources or wildlife areas which could necessitate making, for example, regional industrial discharge requirements more stringent than national performance standards (CCRWQCB, 2019a). In addition, the chemical constituents water quality objective for all inland surface waters, enclosed bays, and estuaries states that where wastewater effluents are returned to land for irrigation uses, regulatory controls shall be consistent with Title 22 of the California Code of Regulations and other relevant local controls.

3.4.8.5 Regional Board Involvement

Examples of Regional Board involvement include that the natural receiving water temperature of intrastate waters can not be altered unless it can be demonstrated to the satisfaction of the Regional Board that such alteration does not adversely affect beneficial uses (CCRWQCB, 2019a). The toxicity water quality objective for all inland surface waters, enclosed bays, and estuaries states that all waters shall be maintained free of toxic substances in concentrations which are toxic to, or which produce detrimental physiological responses in, human, plant, animal, or aquatic life (CCRWQCB, 2019a). Compliance with this objective is determined by use of indicator organisms, analyses of species diversity, population density, growth anomalies, toxicity bioassays of appropriate duration, or other appropriate methods as specified by the Regional Board (CCRWQCB, 2019a). For waters where existing concentrations are presently nondetectable or where beneficial uses would be impaired by concentrations in excess of nondetectable levels, total identifiable chlorinated hydrocarbon pesticides shall not be present at concentrations detectable within the accuracy of analytical methods prescribed in the Standard Methods for the Examination of Water and Wastewater or other equivalent methods approved by the Executive Officer of the Regional Board

(CCRWQCB, 2019a). Consideration of beneficial uses includes: a specific enumeration of all beneficial uses potentially to be affected by the waste discharge; a determination of the relative importance of competing beneficial uses; and impact of the discharge on existing beneficial uses (CCRWQCB, 2019a). The Regional Board makes a judgment as to the priority of dominant use and minimises the impact on competing uses while not allowing the discharge to violate receiving water quality objectives (CCRWQCB, 2019a).

3.4.8.6 Available Data and Additional Monitoring

Water quality objectives have been established for selected surface waters; these objectives are intended to serve as a water quality baseline for evaluating water quality management in the basin (CCRWQCB, 2019a). Mean values for surface waters are based on available data. As part of the state's continuing planning process, water quality data will be collected and numerical water quality objectives will be developed for mineral constituents that are without sufficient information presently available for the establishment of such objectives (CCRWQCB, 2019a). The State Board adopted a statewide General Construction Activity Stormwater Permit and General Industrial Activities Stormwater Permit (CCRWQCB, 2019a). The Regional Board can recommend additional monitoring parameters based on the presence of specific pollutant sources (CCRWQCB, 2019a). Annual monitoring reports required by the industrial permit are submitted to the Regional Board each year (CCRWQCB, 2019a).

3.4.8.7 Deep Groundwater Quality and the Risk for Abuse of Groundwater Commons

Perhaps as a result of the adoption of the Sustainable Groundwater Management Act in 2014, the discussion in the academic literature related to defining water quality has focused on groundwater. Rather than propose a normative definition for the groundwater commons, Rudestam *et al.* suggest that the commons as a geographic category is socially constructed and dynamically active over time, akin to the analytics of scale as developed within the fields of political ecology and geography. Kang *et al.* define deep groundwater as one hundred and fifty metres or more below the surface and find that thirty-six percent of the Central Valley of California has deep groundwater with sufficient water quality for irrigation use, with greater percentages available for more tolerant crops. However, Kang *et al.* (2019) caution that given the potentially large deep fresh and usable groundwater volumes across the southwestern US, it is important to characterise the resource and protect it. Kang *et al.* (2020) find that nearly four percent of existing groundwater wells penetrate defined bases of freshwater, and nearly sixteen percent of wells overlie it by no more than one hundred metres, evidencing widespread encroachment on the base of freshwater by groundwater users. Kang *et al.*'s (2020) analysis suggests that groundwater sustainability in California may be poorly safeguarded in some places and that the base of freshwater concept needs to be reconsidered as a means to define and manage groundwater.

3.5 Defining Categories of Water Quality at the City Level using the City of El Paso de Robles, California

This section investigates the drinking water, groundwater, ambient water, wastewater, industrial wastewater, water reuse, and stormwater quality definitions established for the City of El Paso de Robles (hereafter Paso Robles), and the methods used to develop them. The section ends with a summary of the findings. The city has established the following water resource goals for its water system: improve water quality; increase and diversify water resources; increase reliability of water supplies; reduce salt loading into the basin and thereby comply with regulatory mandates; and anticipate regulatory requirements (Paso Robles, 2021a).

3.5.1. Defining Drinking Water Quality for Paso Robles

The water sources for the City of Paso Robles include nineteen groundwater wells and water from Lake Nacimiento, located outside the city limits (Paso Robles, 2020e). The water extracted from these sources is combined and treated at the city's water treatment plant. The City of Paso Robles states in its *Annual Water Quality Report* (Paso Robles, 2020e) that the water treatment plant delivers 'safe, high-quality drinking water that meets or exceeds state and federal drinking water standards'.

Paso Robles monitors its water for many different substances on a strict sampling schedule to ensure the water they deliver to their residents and businesses meets each of the specific health standards (Paso Robles, 2020e). Figure 3.19 shows only those substances that were detected and compares them to their respective maximum allowed levels (Paso Robles, 2020e). Figure 3.20 depicts the quality of water compared to the optional secondary standards (Paso Robles, 2020e).

Paso Robles participates in the US EPA's Unregulated Contaminant Monitoring Rule (UCMR4) program by performing additional tests on its drinking water (Paso Robles, 2020e). UCMR4 sampling provides the US EPA with data regarding the occurrence of contaminants suspected to be in drinking water, in order to determine if US EPA needs to introduce new regulatory standards to improve drinking water quality (Paso Robles, 2020e). Unregulated contaminant monitoring results are depicted in Figure 3.21 (Paso Robles, 2020e).

REGULATED SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	MCL [MRDL]	PHG (MCLG) [MRDLG]	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Arsenic (ppb)	2020	10	0.004	1.37	ND–7.9	No	Erosion of natural deposits; runoff from orchards; glass and electronics production wastes
Barium (ppm)	2020	1	2	0.02678	ND–0.33	No	Discharges of oil drilling wastes and from metal refineries; erosion of natural deposits
Chlorine (ppm)	2020	[4.0 (as Cl2)]	[4 (as Cl2)]	1.2	0.7–1.7	No	Drinking water disinfectant added for treatment
Fluoride (ppm)	2020	2.0	1	0.18	ND–0.35	No	Erosion of natural deposits; water additive that promotes strong teeth; discharge from fertilizer and aluminum factories
Gross Alpha Particle Activity (pCi/L)	2020	15	(0)	1.73	ND–11	No	Erosion of natural deposits
Haloacetic Acids (ppb)	2020	60	NA	11.11	2.6–22.4	No	By-product of drinking water disinfection
Nitrate [as nitrogen] (ppm)	2020	10	10	1.18	ND–7.2	No	Runoff and leaching from fertilizer use; leaching from septic tanks and sewage; erosion of natural deposits
Nitrate + Nitrite [as N] (ppb)	2020	10,000	10,000	1,310	ND–4,900	No	Runoff and leaching from fertilizer use; leaching from septic tanks sewage; erosion of natural deposits
Selenium (ppb)	2020	50	30	12.04	ND–29	No	Discharge from petroleum, glass, and metal refineries; erosion of natural deposits; discharge from mines and chemical manufacturers; runoff from livestock lots (feed additive)
TTHMs [Total Trihalomethanes] (ppb)	2020	80	NA	25.23	10.5–44.10	No	By-product of drinking water disinfection
Turbidity (NTU)	2020	TT	NA	0.088	0.004–0.088	No	Soil runoff
Turbidity [lowest monthly percent of samples meeting limit]	2020	TT = 95% of samples meet the limit	NA	100	NA	No	Soil runoff
Uranium (pCi/L)	2020	20	0.43	1.53	ND–4.5	No	Erosion of natural deposits

Definitions

MCL (Maximum Contaminant Level): The highest level of a contaminant that is allowed in drinking water. Primary MCLs are set as close to the PHGs (or MCLGs) as is economically and technologically feasible. Secondary MCLs (SMCLs) are set to protect the odor, taste, and appearance of drinking water.

MCLG (Maximum Contaminant Level Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs are set by the U.S. EPA.

MRDL (Maximum Residual Disinfectant Level): The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.

MRDLG (Maximum Residual Disinfectant Level Goal): The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.

NA: Not applicable

ND (Not detected): Indicates that the substance was not found by laboratory analysis.

NS: No standard

NTU (Nephelometric Turbidity Units): Measurement of the clarity, or turbidity, of water. Turbidity in excess of 5 NTU is just noticeable to the average person.

pCi/L (picocuries per liter): A measure of radioactivity.

PDWS (Primary Drinking Water Standard): MCLs and MRDLs for contaminants that affect health, along with their monitoring and reporting requirements and water treatment requirements.

PHG (Public Health Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. PHGs are set by the California EPA.

ppb (parts per billion): One part substance per billion parts water (or micrograms per liter).

ppm (parts per million): One part substance per million parts water (or milligrams per liter).

TT (Treatment Technique): A required process intended to reduce the level of a contaminant in drinking water.

Figure 3.19. Substances Detected in Water Produced by Paso Robles Water Treatment Plant Compared to Maximum Allowed Levels, as Depicted in the Paso Robles Drinking Water Annual Report for 2020 (Paso Robles, 2020e).

SECONDARY SUBSTANCES

SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	SMCL	PHG (MCLG)	AMOUNT DETECTED	RANGE LOW-HIGH	VIOLATION	TYPICAL SOURCE
Aluminum (ppb)	2020	200	NS	0.04	ND–51	No	Erosion of natural deposits; residual from some surface water treatment processes
Chloride (ppm)	2020	500	NS	30.45	9.3–120	No	Runoff/leaching from natural deposits; seawater influence
Iron (ppb)	2020	300	NS	36.27	ND–650	No	Leaching from natural deposits; industrial wastes
Manganese (ppb)	2020	50	NS	3.48	ND–29	No	Leaching from natural deposits
Odor–Threshold (units)	2020	3	NS	1.45	1–3	No	Naturally occurring organic materials
Specific Conductance (µS/cm)	2020	1,600	NS	589.89	230–890	No	Substances that form ions when in water; seawater influence
Sulfate (ppm)	2020	500	NS	89.31	18–160	No	Runoff/leaching from natural deposits; industrial wastes
Total Dissolved Solids (ppm)	2020	1,000	NS	364.46	120–660	No	Runoff/leaching from natural deposits
Turbidity (units)	2020	5	NS	0.14	0.10–0.60	No	Soil runoff

Figure 3.20. Substances Detected in Water Produced by Paso Robles Water Treatment Plant Compared to Optional Secondary Standards, as Depicted in the Paso Robles Drinking Water Annual Report for 2020 (Paso Robles, 2020e).

Definitions

MCL (Maximum Contaminant Level): The highest level of a contaminant that is allowed in drinking water. Primary MCLs are set as close to the PHGs (or MCLGs) as is economically and technologically feasible. Secondary MCLs (SMCLs) are set to protect the odor, taste, and appearance of drinking water.

MCLG (Maximum Contaminant Level Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs are set by the U.S. EPA.

ND (Not detected): Indicates that the substance was not found by laboratory analysis.

NS: No standard

NTU (Nephelometric Turbidity Units): Measurement of the clarity, or turbidity, of water. Turbidity in excess of 5 NTU is just noticeable to the average person.

PHG (Public Health Goal): The level of a contaminant in drinking water below which there is no known or expected risk to health. PHGs are set by the California EPA.

ppb (parts per billion): One part substance per billion parts water (or micrograms per liter).

ppm (parts per million): One part substance per million parts water (or milligrams per liter).

TT (Treatment Technique): A required process intended to reduce the level of a contaminant in drinking water.

µS/cm (microsiemens per centimeter): A unit expressing the amount of electrical conductivity of a solution.

UNREGULATED AND OTHER SUBSTANCES [1]			
SUBSTANCE (UNIT OF MEASURE)	YEAR SAMPLED	AMOUNT DETECTED	RANGE LOW-HIGH
Bicarbonate (ppm)	2020	222.31	ND–440
Boron (ppb)	2020	91.94	ND–800
Calcium (ppm)	2020	58.55	21–100
Chromium-6 (ppb)	2020	0.17	ND–2.6
Hardness, Total [as CaCO3] (grains/gal)	2020	13.51	5.2–18.7
pH (units)	2020	7.7	7.2–8.2
Potassium (ppm)	2020	1.44	1.2–2.8
Sodium (ppm)	2020	31.82	10–130
Total Alkalinity (ppm)	2020	183.26	76–360
Vanadium (ppb)	2020	9.09	ND–64

[1] Unregulated contaminant monitoring helps U.S. EPA and the State Water Resources Control Board determine where certain contaminants occur and whether the contaminants need to be regulated.

Definitions

grains/gal (grains per gallon): Grains of compound per gallon of water.

ND (Not detected): Indicates that the substance was not found by laboratory analysis.

Figure 3.21. Unregulated Contaminant Monitoring Results Reported in the 2020 Drinking Water Paso Robles Annual Report (Paso Robles, 2020e).

Groundwater and surface water are the sources of the city's drinking water, so the following two sections address how Paso Robles defines groundwater and ambient water quality.

3.5.2 Defining Groundwater Quality for Paso Robles

The *Paso Robles Subbasin Groundwater Sustainability Plan* (GSP) (Paso Robles, 2019c) states that groundwater quality in the subbasin is generally suitable for both municipal and agricultural uses. The most common drinking water quality standard exceedance in the subbasin is TDS (Paso Robles, 2019c). The second most common drinking water quality standard exceedance in the subbasin is nitrate (Paso Robles, 2019c). Some historical groundwater samples from the subbasin indicate slight to moderate restriction on irrigation use due to sodium or chloride toxicity (Paso Robles, 2019c).

3.5.2.1 Definition of Groundwater Quality in Paso Robles

Groundwater quality is monitored in the following ways: municipal and community water purveyors collect water quality samples on a regular basis for compliance monitoring and reporting to the California Division of Drinking Water; the USGS collects water quality data on a regular basis under the Groundwater Ambient Monitoring and Assessment (GAMA) program and the data are stored in the state's GAMA Geotracker system; multiple sites monitor groundwater quality as part of compliance monitoring programs through the Central Coast Regional Water Quality Control Board (Paso Robles, 2019c). Water quality is monitored in the forty-one public water supply wells in the subbasin and twenty-eight agricultural supply wells (Paso Robles, 2021a). The results, depicted in Figure 3.22, define the quality of groundwater in Paso Robles.

Measured and Average Water Quality Constituent Concentrations for Study Areas

Study Area	TDS Concentration Range of Measurements (mg/L)	TDS Concentration Area Average (mg/L)	TDS Groundwater Objective Range (mg/L)	Nitrate (as N) Concentration Range of Measurements (mg/L)	Nitrate (as N) Concentration Area Average (mg/L)	Nitrate (as N) Groundwater Objective Range (mg/L)	Chloride Concentration Range of Measurements (mg/L)	Chloride Concentration Area Average (mg/L)	Chloride Groundwater Objective Range (mg/L)
Atascadero	330-828	573	550-730	0.1-6.7	1.8	2.3-2.7	19-208	77.5	70-100
Creston	186-590	388	400	0.8-9.2	3.2	3.4	25-175	69.4	60
San Juan	160-1700	425	--	0.1-5.8	2.8	--	13-390	64.2	--
Estrella	310-1920	552	400-1050	0.0-16.2	2.5	2.3-4.5	28-614	94.2	60-270
Shandon	270-3160	563	400-1390	1.2-12.1	4.6	2.3-3.4	31-451	80.0	60-430
North Gabilan	371-1320	856	--	5.0-9.8	8.4	--	35-209	112.9	--
South Gabilan	634	451	--	15.8	6.3	--	38	37.2	--
Bradley	234-1343	751	--	0.0-5.8	2.7	--	27.5-400	84.4	--

Figure 3.22. Groundwater Quality in the Paso Robles Groundwater Subbasin (Paso Robles, 2015, Table 3-12).

3.5.2.2 Method for Defining Groundwater Quality in Paso Robles

The method Paso Robles uses to establish groundwater quality definitions, as described in the *Salt/Nutrient Management Plan for the Paso Robles Groundwater Basin* (Paso Robles, 2015), is to identify the applicable water quality objectives published in the Central Coastal Basin Plan (Paso Robles, 2015). Figure 3.23 depicts the median water quality objectives for TDS, nitrate (as N), and chloride in groundwater including the subareas that intersect the Paso Robles subarea (Paso Robles, 2015). The water quality objectives for nitrate (as N) in municipal and domestic water supplies and for agricultural water use (*i.e.*, irrigation supply and livestock watering) are listed in Figure 3.24 (Paso Robles, 2015). Primary and secondary drinking water standards for TDS, nitrate (as N), and chloride as established by the California Department of Health Services, Code of Regulations, Title 22, Sections 64435 and 64473, are also presented in Figure 3.24 (Paso Robles, 2015).

3.5.2.3 Method for Defining Significant and Unreasonable Groundwater Conditions for Paso Robles

The GSP establishes sustainable management criteria and management actions to avoid significant and unreasonable undesirable results related to chronic lowering of groundwater levels, reduction of groundwater storage, degradation of groundwater quality, land subsidence affecting land use, and depletion of interconnected surface waters affecting beneficial use (Paso Robles, 2021a). The GSP focuses only on constituents that might be impacted by groundwater management activities (Paso Robles, 2019c). The constituents of concern are chosen because: the constituent has either a drinking water standard or a known effect on crops; and concentrations have been observed above either the drinking water standard or the level that affects crops (Paso Robles, 2019c). Locally defined significant and unreasonable conditions were assessed based on federal and state mandated drinking water

Median Groundwater Quality Objectives

Basin Plan Subarea	Associated Study Areas	Total Dissolved Solids (mg/L)	Chloride (mg/L)	Nitrate (as N) (mg/L)
Central Basin	Estrella/Shandon/Creston	400	60	3.4
San Miguel	Estrella	750	100	4.5
Paso Robles	Estrella	1,050	270	2.3
Templeton	Atascadero Subbasin	730	100	2.7
Atascadero	Atascadero Subbasin	550	70	2.3
Estrella	Estrella/Shandon	925	130	3.2
Shandon	Shandon	1,390	430	2.3

Figure 3.23. Median Groundwater Quality Objectives for the Paso Robles Groundwater Subbasin (Paso Robles, 2015, Table 3-9).

Nitrate (as N) Water Quality Objectives for Municipal and Domestic Supply, and Agricultural Water Use

Constituent	Municipal and Domestic Supply Maximum Contaminant Level (MCL) (mg/L)	Agricultural Water Use Irrigation Supply Maximum Concentration (mg/L)	Agricultural Water Use Livestock Watering Maximum Concentration (mg/L)
Nitrate (as N)	10	--	90

Title 22 Drinking Water Standards for TDS, Nitrate (as N), and Chloride

Water Quality Constituent	Primary Drinking Water Standard Recommended MCL (mg/L)	Secondary Drinking Water Standard Recommended MCL (mg/L)	Secondary Drinking Water Standard Upper Limit (mg/L)	Secondary Drinking Water Standard Short Term (mg/L)
Total Dissolved Solids	–	500	1,000	1,500
Nitrate (as N)	10	--	–	--
Chloride	–	250	500	600

Figure 3.24. Water Quality Objectives for Municipal and Domestic Supply, and Agricultural Water Use, and Drinking Water Applicable to Groundwater in Paso Robles (Paso Robles, 2015, Tables 3-10 and 3-11).

and groundwater quality regulations, the sustainable management criteria survey, public meetings, and discussions with GSA staff (Paso Robles, 2019c).

3.5.2.4 Definition of Significant and Unreasonable Groundwater Conditions for Paso Robles

Significant and unreasonable changes in groundwater quality in the subbasin are increases in a chemical constituent that either: result in groundwater concentrations in a public supply well above an established primary or secondary MCL; or lead to reduced crop production (Paso Robles, 2019c).

Undesirable result means one or more of the following effects caused by groundwater conditions occurring throughout the basin: chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon; significant and unreasonable reduction of groundwater storage; significant and unreasonable seawater intrusion; significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies; significant and unreasonable land subsidence that substantially interferes with surface land uses; or depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water (California Water Code, Definitions, Sec. 10721).

Two mapped geologic formations constitute the primary water bearing formations in the subbasin: the Quaternary Alluvium bordering streams and rivers, and the Plio-Pleistocene Paso

Robles Formation (Paso Robles, 2019c). The Alluvium is typically no more than 100 feet thick. The Paso Robles Formation constitutes most of the subbasin, with depths up to 3,000 feet thick in some places (Paso Robles, 2019c). The bases for establishing minimum thresholds for each constituent of concern in the Paso Robles Formation Aquifer and Alluvial Aquifer are listed in Figure 3.25 (Paso Robles, 2019c). Based on the number of agricultural and municipal supply wells in the existing water quality monitoring network, the number of existing exceedances plus the ten percent for each constituent is shown in Figure 3.26 (Paso Robles, 2019c). The exceedance numbers in the tables are the minimum thresholds. The tables additionally include the percentage of existing wells that exceed the minimum thresholds for each constituent (Paso Robles, 2019c). The percentage defines the upper bound of wells that can exceed the minimum thresholds as additional wells are added to the monitoring program. Based on the existing monitoring network, the measurable objectives for degraded groundwater quality in the Paso Robles Formation and Alluvial Aquifers are shown in Figure 3.27 (Paso Robles, 2019c).

3.5.3 Defining Ambient Water Quality for Paso Robles

The Basin Plan lists beneficial uses, describes the water quality which must be maintained to allow those uses, provides an implementation plan, details plans and policies to protect water quality and a statewide surveillance and monitoring program as well as regional surveillance and monitoring programs (Paso Robles, 2019c). Present and potential future beneficial uses for inland waters in the basin that apply to Paso Robles include: surface water and groundwater as municipal supply; agricultural; groundwater recharge; recreational water contact and non-contact; sport fishing; warm freshwater habitat; wildlife habitat; rare, threatened or endangered species; and, spawning of fish (Paso Robles, 2019c).

Groundwater Quality Minimum Thresholds Bases

Constituent of Concern	Minimum Threshold Based on Number of Production Wells
Agricultural Wells in Monitoring Program	
Chloride	Fewer than 10% of additional agricultural production wells that are in the GSP monitoring program shall exceed 350 milligrams per liter (mg/L).
Boron	Fewer than 10% of additional agricultural production wells that are in the GSP monitoring program shall exceed 0.5 mg/L.
Municipal Wells in Monitoring Program	
Total Dissolved Solids	Fewer than 10% of additional municipal or domestic production wells that are in the GSP monitoring program shall exceed the TDS secondary MCL of 500 mg/L.
Chloride	Fewer than 10% of additional municipal or domestic production wells that are in the GSP monitoring program shall exceed the chloride secondary MCL of 250 mg/L.
Sulfate	Fewer than 10% of additional municipal or domestic production wells that are in the GSP monitoring program shall exceed the sulfate secondary MCL of 250 mg/L.
Nitrate	Fewer than 10% of additional municipal or domestic production wells that are in the GSP monitoring program shall exceed the nitrate MCL of 45 mg/L, measured as nitrate.
Gross Alpha Radiation	Fewer than 10% of additional municipal or domestic production wells that are in the GSP monitoring program shall exceed the gross alpha radiation MCL of 15 pCi/L.

Figure 3.25. Locally Defined Significant and Unreasonable Groundwater Conditions for Paso Robles Subbasin. Establishing Minimum Threshold Bases (Paso Robles, 2019c, Table 8-4).

. Minimum Thresholds for Degraded Groundwater Quality in Paso Robles Formation Aquifer Supply Wells Under the Current Monitoring Network [1]

Constituent of Concern	Number of Existing Supply Wells in Monitoring Network	Minimum Threshold Based on Existing Monitoring Network	Percentage of Wells with Exceedances
Agricultural Wells			
Chloride	28	4	14%
Boron	28	10	36%
Municipal Wells			
Total Dissolved Solids	34	12	35%
Chloride	34	2	6%
Sulfate	34	2	6%
Nitrate	34	2	6%
Gross Alpha Radiation	32	0	0%

Minimum Thresholds for Degraded Groundwater Quality in Alluvial Aquifer Supply Wells Under the Current Monitoring Network [1]

Constituent of Concern	Number of Existing Supply Wells in Monitoring Network	Minimum Threshold Based on Existing Monitoring Network	Percentage of Wells with Exceedances
Public Supply Wells			
Total Dissolved Solids	8	5	63%
Chloride	8	3	38%
Sulfate	8	3	38%
Nitrate	9	0	0%
Gross Alpha Radiation	7	0	0%

Figure 3.26. Minimum Thresholds for Degraded Groundwater Quality in Paso Robles (Paso Robles, 2019c, Tables 8-5 & 8-6).

Measurable Objectives for Degraded Groundwater Quality in Paso Robles Formation Aquifer Supply Wells Under the Current Monitoring Network

Constituent of Concern	Number of Existing Supply Wells in Monitoring Network	Measurable Objective Based on Existing Monitoring Network	Percentage of Wells with Exceedances
Agricultural Wells			
Chloride	28	3	14%
Boron	28	9	36%
Municipal Wells			
Total Dissolved Solids	34	10	35%
Chloride	34	1	6%
Sulfate	34	1	6%
Nitrate	34	1	6%
Gross Alpha Radiation	32	0	0%

. Measurable Objectives for Degraded Groundwater Quality in Alluvial Aquifer Supply Wells Under the Current Monitoring Network

Constituent of Concern	Number of Existing Supply Wells in Monitoring Network	Measurable Objective Based on Existing Monitoring Network	Percentage of Wells with Exceedances
Public Supply Wells			
Total Dissolved Solids	8	4	63%
Chloride	8	2	38%
Sulfate	8	2	38%
Nitrate	9	0	0%
Gross Alpha Radiation	7	0	0%

Figure 3.27. Measurable Objectives for Degraded Groundwater Quality in Paso Robles (Paso Robles, 2019c, Tables 8-7 & 8-8).

Paso Robles adheres to the water quality objectives for both groundwater and surface water as provided in the Basin Plan (Paso Robles, 2019c). The only surface water body in the city of Paso Robles is the Salinas River, and a Total Maximum Daily Load (TMDL) for the Upper Salinas River has not been developed (Paso Robles, 2019c). The Basin Plan identifies actions to be implemented in the basin that relate to Paso Robles including: dischargers along the Salinas River should remain as separate treatment facilities with land disposal to evaporation or percolation systems and land application systems where possible, and disposal should be managed to provide maximum nitrogen reduction (*e.g*., through crop irrigation or wet and dry cycle percolation); and the City of Paso Robles operates a wastewater treatment plant that discharges to the Salinas River, beneficial use of reclaimed water should be investigated and implemented, if feasible (Paso Robles, 2019c). The median water quality objectives for TDS and chloride in surface water associated with the Salinas River and major tributaries to the Salinas River (*e.g*., San Antonio River, Nacimiento River) are presented in Figure 3.28 (Paso Robles, 2015).

The following three sections address wastewater, industrial wastewater, and water reuse.

3.5.4 Defining Wastewater Quality for Paso Robles

In 2019, the city completed construction of its new tertiary treatment project which added flow equalisation, cloth media filtration, and ultraviolet (UV) light disinfection facilities to the existing wastewater treatment process (Paso Robles, 2021b). In 2020, the average dry weather flow treated at the wastewater treatment plant (WWTP) was 9,592 cubic metres (2.11 million gallons) per day (Paso Robles, 2021b). The treatment plant processes include preliminary screening and grit removal, primary clarification, three stage biological nutrient removal process with internal recycle, secondary clarification with return activated sludge,

Median Surface Water Quality Objectives

Measurement Point/Tributary	Total Dissolved Solids (mg/L)	Chloride (mg/L)
Salinas River Above Bradley	250	20
Salinas River Above Spreckles	600	80
Gabilan Tributary	300	50
Diablo Tributary	1,200	80
Nacimiento River	200	20
San Antonio River	250	20

Figure 3.28. Median Surface Water Quality Objectives for TDS and Chloride in Water Associated with the Salinas River and Tributaries (Paso Robles, 2015, Table 3-8).

tertiary treatment utilising ten-micron cloth media filtration, and UV light disinfection (Paso Robles, 2021b). Solids handling includes dissolved air flotation sludge thickening, anaerobic sludge digestion, combined heat and power cogeneration generators, solids dewatering using a belt filter press, and a nutrient harvesting system (Paso Robles, 2021b). Treated effluent is currently discharged via a polishing channel into the Salinas River (Paso Robles, 2021b). The new facilities will continue to produce tertiary quality water that, in the future, will be distributed via the recycled water distribution system that is in the design phase, awaiting financing from the state's revolving fund loan program (Paso Robles, 2021b). Upon completion, the recycled water distribution system will deliver the recycled water to the east side of Paso Robles, where it will be used to irrigate golf courses, parks, and vineyards, and help passively recharge the Paso Robles Groundwater Basin (Paso Robles, 2021b).

3.5.4.1 Method for Defining Paso Robles Wastewater Quality

The method for defining wastewater quality is the NPDES permitting process, described earlier in this chapter. As a result of the tertiary treatment project completion, the State Water Resources Control Board reclassified the City of Paso Robles WWTP as a Class IV Tertiary Treatment wastewater treatment facility (Paso Robles, 2021b). The facility operates under an NPDES permit (*i.e.*, Order No. R3-2011-0002) issued by the Central Coast Regional Water Quality Control Board (Paso Robles, 2021b). Figure 3.29 depicts the table of constituent effluent limits which describes the quality of the discharge permitted to the Salinas River.

3.5.4.2 Definition of Paso Robles Wastewater Quality

The *2020 Paso Robles Wastewater Treatment Facility Annual Report* (Paso Robles, 2021b) states: the average influent Biochemical Oxygen Demand (BOD) was 339mg/L while the final effluent BOD averaged 3.45 mg/L (*i.e.*, a yearly average removal rate of 98.9 percent of

NPDES Water Quality Requirements

Constituent	Units	Effluent Limits		
		Average monthly	Average Weekly	Maximum Daily
BOD_5	mg/L	25	35	50 [3]
	lb/day[1]	1,022	1,430	2,043 [3]
	kg.day[1]	463	649	927 [3]
TSS	mg/L	30	45	90 [3]
	lb/day[1]	1,226	1,839	3,678 [3]
	kg.day[1]	556	834	1,668 [3]
Oil and Grease	mg/L	10	18	20 [3]
Settleable Solids	ml/L/hr	0.1	0.3	0.3 [3]
pH	s.u.	6.5-8.3 at all times		
Dissolved Oxygen	mg/L	2.0 minimum		---
Nitrogen, Total (as N)	mg/L	10	---	---
Salt [2]				
Total Dissolved Solids	mg/L	1,115	---	---
Sodium	mg/L	255	---	---
Chloride	mg/L	355	---	---
Sulfate	mg/L	200	---	---
Metals & Organic Compounds				
Copper	µg/L	21	---	39
Selenium	µg/L	4.0	---	8.6
Cyanide	µg/L	---	---	8.6 [3]
Bromoform	µg/L	---	---	8.6 [3]
Chlorodibromomethane	µg/L	0.40	---	0.80
Dichlorobromomethane	µg/L	0.56	---	1.6
Bis(2ethylhexyl)phthalate	µg/L	1.8	---	5.4
Acute Toxicity	TUa	Pass/Fail		---
Chronic Toxicity	TUc	1.0		---

Notes:

1 Mass emission limitations apply when flows are equal to or less than 4.9 mgd.

2 The limits may be increased if evidence presented and approved by RWQCB.

3 Historic Effluent Limitations

4 Shaded parameters are of particular significance for some irrigation uses.

Figure 3.29. Paso Robles Wastewater Treatment Plant NPDES Permit Effluent Limits (Paso Robles, 2014, Table 4-3).

influent BOD loadings); the average influent Total Suspended Solids (TSS) was 253 mg/L while the final effluent TSS averaged 3.32 mg/L (*i.e.*, a yearly average removal rate of 98.70 percent of influent TSS loadings) (Paso Robles, 2021b). A summary of key final effluent parameters for 2020 are shown in Figures 3.30 and 3.31 (Paso Robles, 2021b).

3.5.5 Defining Industrial Wastewater Quality for Paso Robles

Paso Robles implements an industrial waste program to reduce pollutants discharged into the city sewer by issuing permits to facilities with certain types of industrial discharges including: restaurants; small wineries and small breweries; and hauled waste dump stations (Paso Robles, 2021c). Industrial Wastewater Discharge Permits are issued to facilities which fall under the requirements of Title 40, CFR, Part 403 or discharge pollutants that may be harmful to the wastewater system (Paso Robles, 2021c). Permitted facilities may be required to monitor their discharge to ensure compliance with the city's discharge limits listed in Section 14.10.070(B) of the City of Paso Robles Sewer Use Ordinance (Paso Robles, 2021d), depicted in Figure 3.32.

3.5.6 Defining Water Reuse Quality for Paso Robles

The city's wastewater treatment plant produces tertiary quality water that will be distributed using the recycled water distribution system once design and construction are complete (Paso Robles, 2021a). The recycled water distribution system will deliver recycled water to the east side of the city for golf course, park, and vineyard irrigation, while surplus water may be used to recharge the groundwater basin (Paso Robles, 2021a). Because very few non-irrigation needs were identified by the city, the *Recycled Water Master Plan* (Paso Robles, 2014) focuses on serving large irrigation demands, including golf course, agricultural, and other irrigation (Paso Robles, 2021a).

Key Final Effluent Parameters 2020

Quarterly	Q1	Q2	Q3	Q4
Ammonia (mg/L as N)	0.109	0.706	0.119	ND
Unionized Ammonia (mg/L as N)	0.0018	0.0145	0.003	ND
Nitrate (mg/L as N)	5.39	5.66	6.16	5.50
Copper (µg/L)	7.94	11.2	6.92	8.71
Dichlorobromomethane (µg/L)	ND	ND	ND	ND
Dibromochloromethane (µg/L)	ND	ND	ND	ND
pH	7.67	7.59	7.69	7.66
Total Nitrogen (mg/L as N)	9.4	8.97	8.39	7.00
Selenium (µg/L)	6.50	2.20	1.08	3.61
Bis(2-Ethlhexyl)phthalate (µg/L)	1.05	1.03	ND	ND
Total Hardness CaCO3 (mg/L)	324	260	206	254

Figure 3.30. Paso Robles Wastewater Effluent Parameters as Depicted in their 2020 Annual Report (Paso Robles, 2021b, Table 4).

Key Treatment Parameters 2020

Effluent Flow, MGD

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	2.3	2.35	2.53	2.42	2.3	2.38	2.43	2.6	2.5	2.48	2.41	2.37
Mean	2.14	2.15	2.18	2.09	2.15	2.22	2.26	2.25	2.28	2.32	2.3	2.19
Total (MG)	66.3	62.4	67.6	62.7	66.7	66.7	69.9	69.7	68.5	72.0	69.1	68.0

Effluent BOD, mg/L

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	6.76	5.81	2.98	3.1	7.6	9.78	5.0	3.04	4.90	9.2	9.6	7.8
Mean	3.45	4.32	2.15	1.95	4.0	4.45	2.13	2.18	3.45	4.13	5.14	5.17
Average lbs./day	61.6	77.5	39.1	34.0	71.7	82.4	40.1	40.9	65.6	79.9	98.6	94.4

Effluent TSS, mg/L

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	6.5	2.9	3.40	3.80	7.40	3.40	5.10	3.00	<2.0	<2.0	2.20	<2.0
Mean	3.32	2.03	2.26	2.29	2.88	2.13	2.20	2.11	<2.0	<2.0	2.01	<2.0
Average lbs./day	59.3	36.4	41.1	39.9	51.6	39.4	41.5	39.6	<38.0	<38.0	38.6	<36.5

Effluent pH

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	7.79	7.91	7.87	7.97	7.70	7.84	7.93	7.82	7.77	7.80	7.77	7.80
Min	7.58	7.54	7.54	7.50	7.40	7.00	7.62	7.55	7.44	7.50	7.47	7.54
Mean	7.68	7.70	7.68	7.62	7.56	7.63	7.73	7.69	7.59	6.63	7.62	7.63

Effluent Settleable Solids mL/L

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Min	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Effluent Chlorine Residual, mg/L (*Caused by maintenance procedure)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max	ND	ND	ND	ND	ND	ND	ND	ND	0.05*	ND	ND	ND
Min	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Figure 3.31. Paso Robles Wastewater Treatment Parameters as Depicted in their 2020 Annual Report (Paso Robles, 2021b, Table 5).

Constituent	Concentration limit
Ammonia	35 mg/L
Boron	0.7 mg/L
Cadmium	2.7 mg/L
Chromium	3.5 mg/L
Copper	0.38 mg/L
Cyanide	1.4 mg/L
Nickel	4.5 mg/L
Arsenic	0.54 mg/L
Selenium	0.11 mg/L
Zinc	0.49 mg/L
Sulfate	322 mg/L
Total dissolved solids (TDS)	1,770 mg/L

Constituent	Concentration limit
Lead	12 mg/L
Mercury	1.1 mg/L
Molybdenum	610 mg/L
pH	6—9
Sodium	452 mg/L
Chloride	262 mg/L
Biochemical oxygen demand (BOD)	360 mg/L
Total suspended solids (TSS)	360 mg/L
Oil and grease	100 mg/L
Silver	1.8 mg/L

Figure 3.32. Paso Robles Industrial Wastewater Discharge Limits as Depicted in Section 14.10.070(B) of the City of Paso Robles Sewer Use Ordinance (Paso Robles, 2021d).

3.5.6.1 Method for Defining Water Reuse Quality for Paso Robles

As stated in the city's *Urban Water Management Plan* (Paso Robles, 2021a), Paso Robles adheres to the regulatory requirements and criteria for the production, distribution, and use of recycled water that have been established by the California Department of Public Health in Title 22, Division 4, Chapter 3 of the California Code of Regulations. These regulations, commonly known as Title 22 or California Water Recycling Criteria, prescribe treatment and recycled water quality requirements for allowed uses of recycled water, reliability features for treatment facilities producing recycled water, and use area requirements (Paso Robles, 2021a).

3.5.6.2 Definition of Water Reuse Quality for Paso Robles

Paso Robles states in its *Recycled Water Master Plan* (Paso Robles, 2014) that the city adheres to the California Water Code Section 13050(n) definition of recycled water as water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur, and is therefore considered a valuable resource (Paso Robles, 2021a). Title 22 establishes four standards of recycled water suitable for various uses and defined by the level of treatment and water quality (Paso Robles, 2014). General treatment and water quality requirements for these four recycled water standards are summarised in Figure 3.33, along with allowable irrigation uses for each standard (Paso Robles, 2014).

Lastly, the following section focuses on how Paso Robles defines stormwater quality.

Treatment level and total coliform requirements for irrigation uses

Treatment Level	Allowable Landscaping and Agriculture Irrigation Uses	Water Quality (TC) Requirements *
Disinfected Tertiary (Planned level of treatment for Paso Robles Recycled Water System)	Unrestricted access golf courses Parks, playgrounds, school yards Food crops (w/ edible portion contact) Residential landscaping Commercial and industrial landscaping Roadway landscaping All irrigation uses listed below with less stringent requirements	7-day median TC: 2.2 MPN/ 100 mL 30-day max TC: 23 MPN/ 100 mL Maximum TC: 240 MPN/ 100 mL
Disinfected Secondary-2.2	Food crops (w/o edible portion contact) All irrigation uses listed below with less stringent requirements	7-day median TC: 2.2 MPN/ 100 mL 30-day max TC: 23 MPN/ 100 mL
Disinfected Secondary-23	Cemeteries Freeway landscaping Restricted access golf courses Nursery stock and sod, unrestricted Pasture for animals producing milk for consumption Non-edible vegetation areas (non-recreation) All irrigation uses listed below with less stringent requirements	7-day median TC: 23 MPN/ 100 mL 30-day max TC: 240 MPN/ 100 mL
Undisinfected Secondary	Orchards and vineyards (w/o edible portion contact) Non-food-bearing trees ** Fodder, fiber crops, pasture for animals not producing milk for consumption Seed crops not for human consumption Food crops (with commercial pathogen-destroying process) Ornamental nursery stock, sod farms **	No TC requirements

* TC = total coliform. Additional requirements for turbidity, chlorine contact time, and/ or virus inactivation apply to disinfected tertiary recycled water.

** Irrigation with recycled water prohibited 14 days prior to harvest for some crops.

Figure 3.33. Four Categories of Water Reuse Quality as Depicted in the City of Paso Robles Recycled Water Master Plan (Paso Robles, 2014, Table 3-1).

3.5.7 Defining Stormwater Quality for Paso Robles

In 1987, Congress amended the CWA to mandate controls on discharges from municipal separate storm sewer systems (Paso Robles, 2016b). Acting under the federal mandate and the California Water Code, California Water Boards issue NPDES permits that require cities, towns, and counties to regulate activities that can result in pollutants entering their storm drains (Paso Robles, 2016b). Municipal staff use best management practices when maintaining streets, storm drains, and municipal buildings (Paso Robles, 2016b). They inspect businesses and construction sites, educate the public, and monitor the storm drain system and receiving waters (Paso Robles, 2016b).

3.5.7.1 Method for Defining Stormwater Quality in Paso Robles

As a condition of municipal approvals and permits, construction projects must control pollutant sources and reduce, detain, retain, and treat specified amounts of runoff (Paso Robles, 2016b). In 2013, the Central Coast Water Board adopted Order R3-2013-0032 with new, more stringent post-construction requirements (PCRs). Construction projects are subject to the PCRs if they create or replace 2,500 square feet or more of impervious area (Paso Robles, 2016b). The PCRs mandate that development projects use low impact development (LID) to detain, retain, and treat runoff. LID incorporates and conserves on-site natural features, together with constructed hydrologic controls to more closely mimic pre-development hydrology and watershed processes (Paso Robles, 2016b).

3.5.7.2 Defining Stormwater Quality in Paso Robles

Stormwater quality in Paso Robles is not defined by water quality parameters, but instead through the use of best management practices. Paso Robles has published its own *Stormwater Technical Guide* (Paso Robles, 2016b), a sizing calculator, templates, and other associated tools, as well as outreach and training for land development professionals (Paso Robles, 2016b). Figure 3.34 depicts the four tiers of post-construction best management practices, using an LID approach, that are required in Paso Robles (Paso Robles, 2016b).

3.5.8 Section Summary: of Defining Categories of Water Quality for the City of Paso Robles

In summary, the City of Paso Robles has a stated goal of improving water quality and increasing and diversifying water reliability and supply. In addition, Paso Robles has a regulatory incentive to reduce discharge to the Salinas River. The city has the capacity to perform additional monitoring and an intention to meet or exceed state and federal water quality standards. Paso Robles establishes and enforces city-level water quality requirements and permits, as summarised in the following sections. The academic literature review for defining water quality in Paso Robles, a very narrow focus, produced only one paper (Bitting and Cullen, 2021). This paper is the entirety of the next chapter, so it is not reviewed here.

3.5.8.1 Goal of Improving Water Quality and Increasing and Diversifying Water Reliability and Supply

The city has established water resource goals for its water system to: improve water quality; increase and diversify water resources; increase reliability of water supplies; reduce salt loading into the basin and thereby comply with regulatory mandates; and anticipate regulatory requirements (Paso Robles, 2021a).

3.5.8.2 Regulatory Incentive to Reduce Discharge to the Salinas River

The Basin Plan identifies actions to be implemented in the basin that relate to Paso Robles including: dischargers along the Salinas River should remain as separate treatment facilities

Type of Project	Requirements
Tier 1 Projects, including single-family homes, that: • create or replace 2,500 square feet or more of impervious surface.	**Implement LID Measures:** • Limit disturbance of natural drainage features. • Limit clearing, grading, and soil compaction. • Minimize impervious surfaces. • Minimize runoff by dispersing runoff to landscape or using permeable pavements **Application completeness:** • Submit a Stormwater Control Plan for Small (Tier 1) Projects (Single Family Residence Site Plan).
Tier 2 Projects, other than single-family homes, that: • create or replace 5,000 SF or more of net impervious surface*. Detached single-family homes that; • create or replace 15,000 SF of or more net impervious surface*.	**Tier 1 requirements, plus:** • Treat runoff with an approved and appropriately sized LID treatment system prior to discharge from the site. **Application completeness:** • Submit a Stormwater Control Plan that addresses Site Design (Tier 1), runoff treatment and source control measures (Tier 2).
Tier 3 Projects including single-family homes that: • create or replace 15,000 SF or more of impervious surface.	**Tier 2 requirements, plus:** • Prevent offsite discharge from events up to the 95th percentile rainfall event using Stormwater Control Measures. **Application completeness:** • Submit a Stormwater Control Plan that addresses Site Design (Tier 1, runoff treatment and source control measures (Tier 2), and stormwater retention (Tier 3).
Tier 4 Projects that: • create or replace 22,500 SF or more of impervious surface (collectively over the entire project site).	**Tier 3 requirements, plus:** • Post-development peak flows discharged from the site must not exceed pre-project peak flows for 2-year through 10-year storm events. • **This requirement is not applicable in Watershed Management Zone 4 (on the west side of Paso Robles).**
* Net impervious surface equals new and replaced impervious area minus the total pre-project-to-post-project reduction in impervious area (if any).	

Figure 3.34. Tiers of Post-Construction Best Management Practices to Reduce Pollutant Discharge Taken from the Paso Robles Storm Water Technical Guide (Paso Robles, 2016b, Table 1-1).

with land disposal to evaporation or percolation systems and land application systems where possible, and disposal should be managed to provide maximum nitrogen reduction (*e.g.*, through crop irrigation or wet and dry cycle percolation); and the City of Paso Robles operates a wastewater treatment plant that discharges to the Salinas River, beneficial use of reclaimed water should be investigated and implemented, if feasible (Paso Robles, 2019c).

3.5.8.3 Have the Capacity to Perform Additional Monitoring

Paso Robles participates in the US EPA's unregulated contaminant monitoring program by performing additional tests on its drinking water (Paso Robles, 2020e).

3.5.8.4 Meet or Exceed State and Federal Water Quality Standards

The City of Paso Robles states that the water treatment plant delivers drinking water that meets or exceeds state and federal drinking water standards (Paso Robles, 2020c). Paso Robles adheres to the water quality objectives for both groundwater and surface water as provided in the Basin Plan (Paso Robles, 2019c). The method the city uses to establish groundwater quality definitions is to identify the applicable water quality objectives published in the Central Coastal Basin Plan (Paso Robles, 2015). The method for defining wastewater quality is the NPDES permitting process. The City of Paso Robles WWTP, a Class IV Tertiary Treatment wastewater treatment facility, operates under an NPDES permit issued by the Central Coast Regional Water Quality Control Board (Paso Robles, 2021b). As stated in the city's *Urban Water Management Plan* (Paso Robles, 2021a), Paso Robles adheres to the regulatory requirements and criteria for the production, distribution, and use of recycled water have been established by the California Department of Public Health in Title 22, Division 4, Chapter 3 of the California Code of Regulations.

3.5.8.5 Establish and Enforce City-Level Water Quality Requirements and Permits

Paso Robles issues industrial wastewater discharge permits to facilities that may discharge pollutants harmful to the wastewater system (Paso Robles, 2021c). Permitted facilities may be required to take water quality samples of their discharge to ensure compliance with the city's discharge limits listed in the City of Paso Robles Sewer Use Ordinance (Paso Robles, 2021d). A condition of city permit approval for construction projects is that they must control pollutant sources and reduce, detain, retain, and treat specified amounts of runoff (Paso Robles, 2016b).

Paso Robles has published its own *Stormwater Technical Guide* (Paso Robles, 2016b), a sizing calculator, templates, and other associated tools, as well as outreach and training for land development professionals (Paso Robles, 2016b).

3.6 Chapter Summary

The first research question asks how water quality is defined, by the entities identified in the second chapter, and what method is used to establish these definitions. To add water quality to a water budget, a set of water quality definitions is needed for the types of water in the water budget (*i.e.*, water in the natural and built environments). In response to the first research question, the aim of this chapter is to identify water quality definitions, and the methods used to establish them, for different types of water (*e.g.*, drinking water, ambient water, groundwater, wastewater) at the global, national, state, and city levels.

A review of global water quality definitions and methods reveals: that international drinking water standards are intended for nation-specific adaptation; ambient water quality and wastewater quality are classified using site-specific targets; refining treatment facilities outflow quality to match use requirements is recommended; global water quality index limitations; and the use of, and need for, water quality scales.

A review of nationwide US water quality definitions reveals a robust method for regular review of the definitions. Groundwater is not included in the definition of waters of the US; however, states can adopt more stringent water quality requirements that reflect site-specific conditions. Water quality definitions must be scientifically defensible and are subject to external peer and public review. In addition, the CWA allows for the state and federal governments to be sued for failure to adequately carry out the scientific and public process of developing water quality standards (*e.g.*, third-party lawsuits). The academic literature identifies examples of: an inflexible methodology for establishing water quality definitions potentially limiting water quality protection; a relevant water quality definition that includes specific criteria for different water uses and circumstances; and a recommendation for mass flow–based definitions that include water quality.

Unlike the waters of the US definition, which omits groundwater, the waters of the state definition for California includes groundwater. Rather than defining water quality at the state level, California defines water quality at the hydrologic region (*i.e.*, watershed basin) level to account for regional variation. Water quality definitions are updated, peer reviewed, and approved by the US EPA every three years. Both federal and state regulations acknowledge the importance of regional considerations and local requirements. The organisation responsible for establishing water quality definitions remains involved in implementation, monitoring, and assessment. The more recent academic literature focuses on groundwater;

defining deep groundwater; reporting on the quality of deep groundwater as appropriate for use; and discussing the potential risk for abuse of groundwater commons.

The City of Paso Robles has a stated goal of improving water quality and increasing and diversifying water reliability and supply. In addition, the city has a regulatory incentive to reduce or eliminate waste discharge to the Salinas River. Paso Robles has the capacity to perform additional monitoring as needed, and an intention to meet or exceed state and federal water quality standards. Paso Robles establishes and enforces city-level water quality requirements and permits.

The review of water quality definitions and methods identifies the use of, and need for, water quality scales, and recommends mass flow-based definitions that include water quality. The second research question, the focus of the following chapter, asks: can a method be established for creating a scale of water quality using the applicable water quality definitions for the types of water in a water budget in California? The findings from this chapter suggest the use of a flexible method with locality-specific and locality-appropriate water quality definitions.

Chapter 4

Developing a Method for Creating a Water Quality Scale

4.1. Introduction

The previous chapter explored ways to define water quality and found a scale of water quality to be an appropriate tool for organising categories of quality for the purpose of adding water quality to a water budget. This chapter addresses the second research question, which asks: can a method be established for creating a scale of water quality using the applicable water quality definitions for the types of water in a water budget in California? Therefore, in response to the second research question, the aim of this chapter is to develop a method to create a scale of water quality specific to California. The six-step method is demonstrated by creating a descending scale of water quality categories that includes water found in both the natural and built environments in California. The results section presents, first, the scale of water quality for California created by applying the method and, second, the scale tailored to a specific location within California, using the City of Paso Robles as an example.

The discussion section first identifies challenges related to creating the method such as selecting the scope of the water quality scale, comparing different types of water quality definitions, and comparing many water quality parameter values at once. Then, using the resulting scale to compare the quality of different categories of water in the natural and built environments of California, and depicting the quantity and quality of water in the natural and built environments of California simultaneously, is discussed. The resulting scale is used in the following chapter to add water quality to a water budget.

4.2. Method for Creating a Water Quality Scale

The following new method has been devised to address the lack of a comprehensive set of water quality definitions, in the literature or in practice, appropriate for use in California. This six-step method is demonstrated by creating a descending scale of water quality categories that includes water found in both the natural and built environments in California. The method is described below and summarised in Figure 4.1.

4.2.1. Step 1: Select a Geographical Context

Water quality, as discussed in the third chapter, can vary by location, so the first step in creating a water quality scale is to select the geographical context (*e.g.*, state, watershed basin, city) for which the scale is intended. The scale will have more credibility and applicability when the scale is specific to, and appropriate for, the location intended for use, as discussed in the third chapter. To demonstrate this method for creating a water quality scale, the state of California is selected for the reasons described in the second chapter, and briefly summarised here. Since the state experiences drought, water resources in California are monitored closely. Water quantity and quality data are available for most streams, rivers, lakes, and groundwater basins in the state. While sampling and measurements are usually conducted locally, the results are deposited into statewide databases that are accessible to the public. Water is transported throughout the state using aqueducts and pipelines, so for California a statewide scale of water quality that can be made specific to a particular city, the level at which water is sourced and treated, was selected. Once a geographical context is chosen, the next step involves collecting water quality data.

Step 1: Select a Geographical Context
Since water quality varies by location, the first step in creating a water quality scale is to select the geographical context (*e.g.*, state, watershed basin, city) for which the scale is intended.

Step 2: Collect Water Quality Data Applicable to the Selected Location
Two sets of water quality data are collected in this step: the expected quality of the water found in the natural and urban environments, and the water quality standards required for water use. Identify the types of water found in the natural and urban environments of the location for which the scale is intended, and collect applicable water quality parameter datasets reported in the academic literature or applicable water quality standards that describe the quality of water required for a particular use.

See **Tables 4.1 & 4.2** for an example.

Step 3: Compile Water Quality Parameter Data
Create a matrix listing the types of water found in the natural and urban environments of the location for which the scale is intended in a column on the left, and the names of the water quality parameters for which data were collected in a row across the top. Populate the centre of the matrix with the corresponding water quality parameter values collected. Apply a colour-coding system to allow the values to be identified as maximum, average, or minimum concentration levels.

See **Figures 4.2 & 4.3** for examples.

Step 4: Organise Water Quality Parameters
The water quality parameters, collected in Step 2 and compiled in Step 3, can be listed on the matrix in any preferred order (*e.g.*, alphabetically, grouped by characteristics). Figure 4.4 demonstrates grouping the water quality parameters by characteristics that are pertinent to California.

See **Figure 4.4** for an example.

Step 5: Order Rows of Water Quality Parameter Data Values to Form Categories of Water Quality
To transform the matrix of water quality parameter data into a descending scale of water quality, the rows of water quality parameter data values are ordered from lowest concentration of pollutants at the top of the table, in descending order, to highest level of contamination at the bottom. An explanation of how each category was ordered on the scale is provided in Table 4.3. Once the rows are ordered, types of water with identical water quality parameter data values are grouped together to form a single water quality category. Types of water with unique water quality parameter data vales are shown on the scale as individual categories of water quality. To allow the scale to be tailored to a specific location within California, categories such as surface water, groundwater, precipitation, and stored or other water supply are added to the bottom of the scale with the data values left blank as placeholders for local water quality data to be added, to allow customisation of the scale.

See **Table 4.3** for an example.

Step 6: Document Data Sources and Notes
Document the data sources and notes in a separate, but identical, table to the one completed in Step 5, with the names of the water types listed in a column on the left and water quality parameter names listed in a row across the top. Instead of populating the centre of the matrix with the water quality parameter values, insert the data source references for the values in the table, along with any notes (*e.g.*, 7-day median).

See **Figures 4.5 & 4.6** for an example.

Figure 4.1. Summary of the New Method for Creating a Scale of Water Quality.

4.2.2. Step 2: Collect Water Quality Data Applicable to Selected Location

Two sets of water quality data are collected in this step: the quality of the water found in the natural and urban environments, and the water quality standards required for water use. The collection of both sets of data is outlined in the following two sections.

4.2.2.1. Natural and Urban Environment Water Quality Data

Identify the types of water found in the natural and urban environments of the location for which the scale is intended. For California, these types of water are listed in Table 4.1.

Water quality parameter datasets reported in the academic literature are collected in this step to identify values or ranges of contaminants in urban storm water, raw sewage, greywater, primary treated wastewater, secondary treated wastewater, and tertiary treated wastewater.

4.2.2.2. Water Quality Standards Required for Water Use

Water quality standards describe the quality of water required for a particular use (*e.g.*, drinking, landscape irrigation, food crop irrigation) using a set of pertinent water quality parameters, discussed in the third chapter. Regulatory organisations set water quality parameter limits for pollutants to protect living organisms (*e.g.*, people, plants, animals, ecosystems). Consequently, the allowable levels of pollutants vary by water use and location. Therefore, the applicable standards most local to the selected geographic context are collected in this step. For California, state-specific standards are sought first, for each type of water. Federal standards are collected when no state standard exists. If no federal standard is found, international standards are collected. As discussed in the third chapter, standards take precedence over guidelines in California, so standards are collected first and if standards are not available, guidelines are used. For California, the documents that provide water quality

Table 4.1. Types of Water in the Natural and Urban Environments of California.

WATER TYPES	CATEGORIES OF WATER QUALITY	DEFINITIONS
Potable Water	Potable Drinking Water	Water that meets California Regulations and US EPA drinking water standards.
	Potable Surfacewater & Groundwater Augmentation	Augmentation of a drinking water source (surface or groundwater) with reclaimed water followed by an environmental buffer that precedes normal drinking water treatment (US EPA, 2012b).
Reclaimed Water	Public Park Irrigation Water & Recreational Impoundments	The use of reclaimed water for non-potable applications in municipal settings where public access is not restricted (US EPA, 2012b). The use of reclaimed water in an impoundment in which no limitations are imposed on body-contact water recreation activities (US EPA, 2012b).
	Restricted Contact Impoundments	The use of reclaimed water in an impoundment where body contact is restricted (US EPA, 2012b).
	Restricted Contact Municipal Reuse	The use of reclaimed water for non-potable applications in municipal settings where public access is controlled or restricted by physical or institutional barriers, such as fencing, advisory signage, or temporal access restriction (US EPA, 2012b).
	Environmental Reuse	The use of reclaimed water to create, enhance, sustain, or augment water bodies, including wetlands, aquatic habitats, or stream flow (US EPA 2012b).
Stormwater	Captured Rainwater for Indoor Use	Captured rainwater used for urinal/toilet flushing, clothes washing, trap priming, cooling tower make up water, large-scale spray irrigation, ornamental fountains, and other water features (CPC, 2016).
	Captured Rainwater for Outdoor Use	Captured rainwater used for car washing, surface, subsurface or drip irrigation, and small-scale spray irrigation (CPC, 2016).
	Urban Stormwater	Untreated rainwater runoff that has come in contact with the urban environment.
Agricultural Water	Livestock Drinking Water	Meets 2012 Guidelines for Water Reuse for concentrations of substances in livestock drinking water (US EPA, 2012b).
	Food Crop Irrigation Water	The use of reclaimed water to irrigate food crops that are intended for human consumption (US EPA, 2012b).
	Non-food Crop Irrigation Water	The use of reclaimed water to irrigate crops that are not consumed by humans (US EPA 2012b).
	Processed Food Crop Irrigation Water	The use of reclaimed water to irrigate crops that are processed before human consumption (US EPA, 2012b).
	Agricultural Irrigation Water	Meets the United Nations Food and Agriculture Organization's Guidelines for Interpretations of Water Quality for Irrigation (Ayers and Westcot, 1985).
Greywater	Commercial Greywater Reuse	Treated greywater for multi-family or commercial restricted indoor and unrestricted outdoor use (US EPA, 2012b).
	Residential Greywater Reuse	Treated greywater for residential restricted indoor and unrestricted outdoor use (US EPA, 2012b).
	Greywater from Clothes Washing	Untreated laundry wash water.
	Greywater from Bathroom Sink & Shower	Untreated wastewater from a bathroom sink and/or shower/bathtub.
Industrial Water	Industrial Reuse	The use of reclaimed water for industrial applications and facilities, power production, and extraction of fossil fuels (US EPA, 2012b).
	Conventional Oil Produced Water	Water transferred from geologic formations to the surface during fossil fuel production (Meng *et. al*., 2016).
Wastewater	Tertiary Treated Wastewater	Secondary treated wastewater that has been through some type of physicochemical treatment, such as coagulation, filtration, reverse osmosis, and additional disinfection (Pepper *et. al*., 2015).
	Secondary Treated Wastewater	Primary treated wastewater that has been through biological treatment, such as a trickling filter bed, an aeration tank, or a sewage lagoon and a disinfection step (Maier *et. al*., 2009).
	Primary Treated Wastewater	Wastewater that has gone through a settling process to separate floating material and heavy solids from liquid waste.
	Raw Sewage	Untreated refuse liquids or waste matter usually carried off by sewers.
Saltwater	Brackish Water	Water that has a higher salinity than freshwater and a lower salinity than seawater.
	Seawater	Salt water in or from the sea.
Local Water	Raw Precipitation	Local untreated precipitation (rain or snow).
	Raw Surface Water	Existing local untreated surface water.
	Raw Groundwater	Existing local untreated groundwater.
	Stored or Other Water Supply	Water stored in tanks or other supplies of water such as piped or transported water from outside the area.

standards applicable to potable water, reclaimed water, irrigation water, livestock drinking water, harvested rainwater, greywater, brackish water, and seawater are listed in Table 4.2.

4.2.3. Step 3: Compile Water Quality Parameter Data

Using a table, spreadsheet, or database, create a matrix listing the types of water found in the natural and urban environments of the location for which the scale is intended in a column on the left, and the names of the water quality parameters for which data were collected in a row across the top, as depicted in Figure 4.2. Populate the centre of the matrix with the corresponding water quality parameter values collected in Step 2.

Some of the values collected and inserted into the matrix may represent maximum levels of contamination, others may represent average concentration levels, and some, as in the case of disinfectants, may represent minimum concentration levels. Applying a colour-coding system allows the values to be easily identified as a maximum, average, or minimum concentration. For the California-specific data collected, red highlighting is used to indicate values representing Maximum Contaminant Levels (MCLs). MCLs are enforceable standards set by the US EPA or the California Water Boards. Orange highlighting indicates values representing averages. Yellow highlighting indicates that a value is a minimum concentration level. Single values that are not highlighted are non-enforceable maximum levels of contamination. A range of values means the level of concentration of the given contaminant is expected to fall within the range listed. Figure 4.3 summarises this data format and colour-coding system.

Table 4.2. Applicable Water Quality Standards Required for Water Use in California

		Bibliography Reference	Water Types Addressed by the Document
Standards Authored by California State Government Agencies	Water Quality Control Plan for the Central Coast Basin, June 2019 Edition	CCRWQCB 2019a	Agricultural Irrigation Water, Livestock Drinking Water
	California Regulations Related to Drinking Water, April 16, 2019	SWRCB 2019a	Potable Drinking Water
	Maximum Contaminant Levels and Regulatory Dates for Drinking Water, U.S. EPA vs California, October 2018	SWRCB 2018a	Potable Drinking Water
	Regulations Related to Recycled Water, October 2018	SWRCB 2018b	Potable Surface Water and Groundwater Augmentation
	2016 California Plumbing Code, Chapter 16	CPC 2016	Captured Rainwater for Indoor Use and Outdoor Use
	California Ocean Plan, 2015	SWRCB 2015	Seawater
Standards Authored by U.S. Federal Government Agencies	National Primary Drinking Water Regulations	US EPA 2009	Potable Drinking Water
Guidelines Authored by U.S. Federal Government Agencies	National Secondary Drinking Water Regulations	US EPA 2019	Potable Drinking Water
	2017 Potable Reuse Compendium	US EPA 2017	Potable Surface Water and Groundwater Augmentation
	2012 Guidelines for Water Reuse	US EPA 2012b	Potable Surface Water and Groundwater Augmentation, Graywater Reuse, Industrial Reuse, Municipal Reuse, Environmental Reuse, Crop Irrigation Water
	Desalting Handbook for Planners, 3rd Edition, July 2003	USDI 2003	Brackish Water, Seawater
Guidelines Authored by International Organizations	Water Quality for Agriculture	Ayers and Westcot 1985	Agricultural Irrigation Water

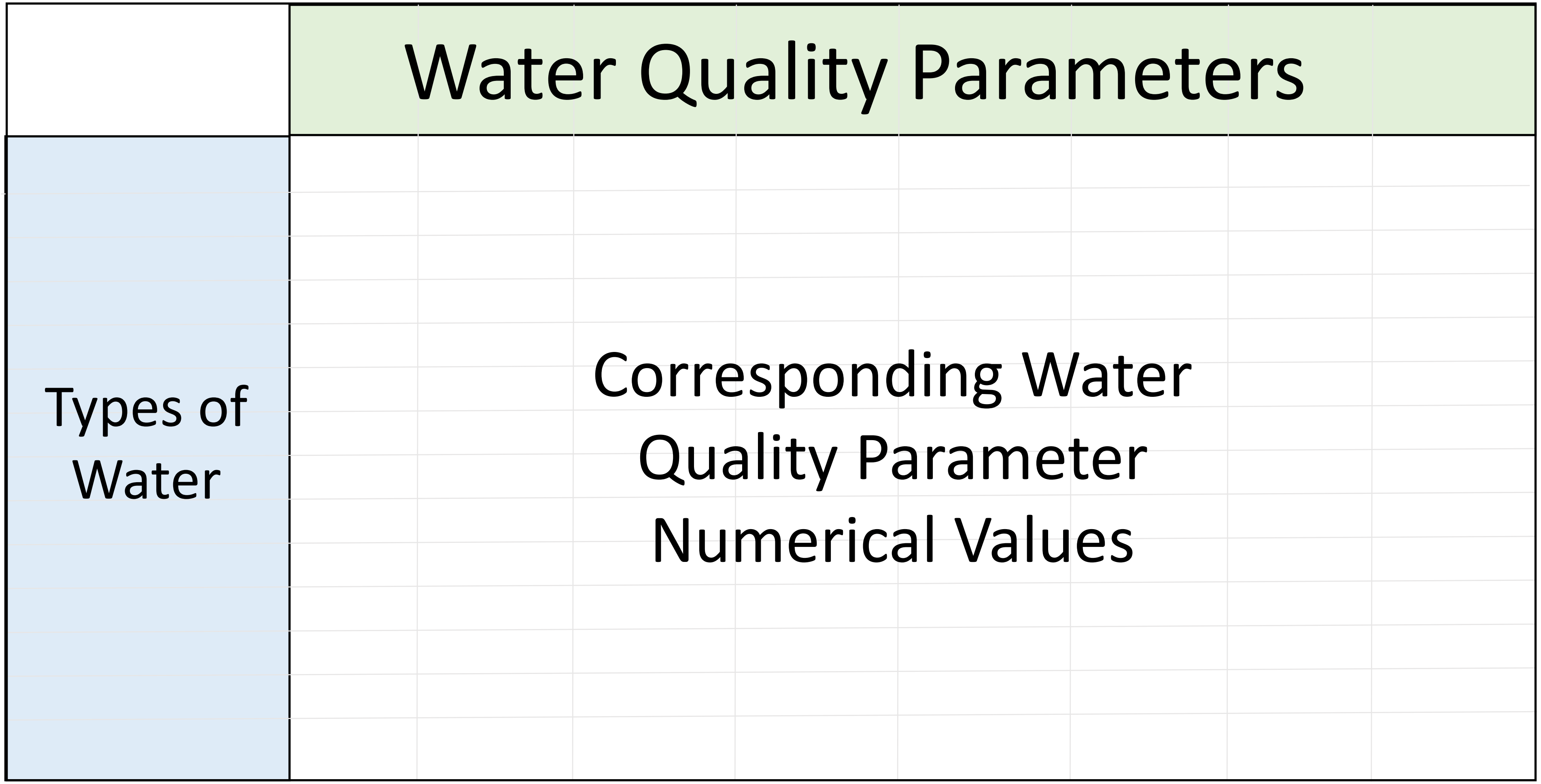


Figure 4.2. Conceptual Depiction of Matrix Listing Types of Water, Water Quality Parameters, and Corresponding Numerical Values.

Data Format	Example	Definition
Single value	30	Value represents a maximum level of contamination, unless highlighted orange or yellow.
Range of values	50–300	Level of concentration varies within the range of values listed.
Red highlighting	15	Enforceable maximum set by a regulatory agency, referred to as a Maximum Contaminant Level (MCL).
Orange highlighting	200	Value represents an average, rather than a maximum or minimum.
Yellow highlighting	1	Value represents the required minimum concentration level.

Figure 4.3. Water Quality Parameter Data Format and Colour Code.

4.2.4. Step 4: Organise Water Quality Parameters

The water quality parameters, collected in Step 2 and compiled in Step 3, can be listed on the matrix in any preferred order (*e.g.*, alphabetically, grouped by characteristics). Figure 4.4 demonstrates grouping the water quality parameters by characteristics that are pertinent to California. As discussed in the third chapter, at the simplest level, water quality can be described and measured by its bacteriological, physical, chemical and radiological characteristics, so the water quality parameters are first grouped into those basic categories. Disinfectants are grouped separately since these include the only water quality parameter with a minimum concentration threshold. Other types of parameters are grouped together such as salinity and measures of wastewater treatment effectiveness (*e.g.*, oxygen demand). The eight most common contaminants detected in community drinking water wells in California at levels above the maximum contaminant level (SWRCB, 2013) are grouped into organic and inorganic chemicals, two of which are also radiological water quality parameters.

4.2.5 Step 5: Order Rows of Water Quality Parameter Data Values to Form Categories of Water Quality

To transform the matrix of water quality parameter data into a descending scale of water quality, the rows of water quality parameter data values are ordered from lowest concentration of pollutants at the top of the table, in descending order, to highest level of contamination at the bottom. In comparing each row of water quality parameter values to another, if all of the water quality parameter data values are higher than the other, the row with the highest levels of contamination are placed lower on the scale than the row with lower concentrations of pollutants. If all of the water quality parameter data values are lower than the other row, the row with the lowest levels of contamination are placed higher on the scale than the row with higher concentrations of pollutants. In the case of two rows of water

The water quality parameters are initially organized by grouping bacteriological, physical, chemical, and disinfectants separately.

	Water Quality Parameters																						
	Bacteriological			Physical			Chemical															Disinfectants	
						Salinity		Oxygen Demand					Principal Contaminants in California										
													Inorganic Chemicals						Organic Chemicals				
													Radiological										
Full Name	**Faecal Coliform**	**Total Coliform**	***Escherichia coli***	**Turbidity**	**Total Suspended Solids**	**Total Dissolved Solids**	**Sodium**	**Total Organic Carbon**	**Biochemical Oxygen Demand**	**Carbonaceous Biochemical Oxygen Demand**	**Oil & Grease**	**pH**	**Gross Alpha Particle Activity**	**Uranium**	**Total Nitrogen**	**Nitrate as Nitrogen**	**Arsenic**	**Perchlorate**	**Tetrachloro ethylene**	**Trichloro ethylene**	**1,2-Dibromo-3-chloropropane**	**Chlorine Residual**	**Total Chlorine**
Abreviation			*E. coli*		TSS	TDS		TOC	BOD	CBOD									PCE	TCE	DBCP		
Units	(CFU/100 ml)	(CFU/100ml)	(CFU/100ml)	(NTU)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)		(pCi/L)	(pCi/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)

Next, other parameters are grouped together such as salinity and measures of wastewater treatment effectiveness (*i.e.*, oxygen demand).

The eight most common contaminants detected in community drinking water wells in California at levels above the maximum contaminant level (SWRCB, 2013) are grouped together and divided into organic and inorganic chemicals, two of which are also radiological water quality parameters.

Figure 4.4. Demonstration of Step 4, Water Quality Parameter Organization, by Characteristics Pertinent to California.

quality parameter data with some water quality parameter data values higher than the other, and some lower than the other, a selection criteria is applied to determine which row should be ordered before the other, depending on the water quality priorities of the selected geographic context. This is demonstrated using California as an example; an explanation of how each category was ordered on the scale is provided in Table 4.3.

Once the rows are ordered, types of water with identical water quality parameter data values are grouped together to form a single water quality category. Types of water with unique water quality parameter data vales are shown on the scale as individual categories of water quality.

The geographical context selected to demonstrate this method (*i.e.*, the whole state of California), is an appropriate level to create a scale of water quality since water is transported throughout the state using pipelines and aqueducts that transcend the natural boundaries of the watersheds. However, the water quality of surface water bodies and groundwater basins varies throughout the state. To allow the scale to be tailored to a specific location within California, categories such as surface water, groundwater, precipitation, and stored or other water supply are added to the bottom of the scale with the data values left blank as placeholders for local water quality data to be added, for customisation of the scale.

4.2.6. Step 6: Document Data Sources and Notes

Now that the water quality parameters are organised on the matrix in the preferred order, the source for each water quality value, and specific notes, are documented in a separate, but identical, table to the one completed in Step 5, with the names of the water types listed in a column on the left and water quality parameter names listed in a row across the top.

Table 4.3. Explanation for the Order of the California Water Quality Scale Categories.

	Categories of Water Quality	Explanation for Position on Scale
1	Potable Drinking Water	Category 1 water has the lowest level of contamination for each water quality parameter on the scale compared to all of the other categories.
2	Potable Surface Water & Groundwater Augmentation	Category 2 water can have higher turbidity levels (2 NTU) than category 1 (1 NTU).
3	Tertiary Treated Wastewater	Category 3 water can have higher TOC levels (3 - 3.1 mg/L) than category 2 (0.5 mg/L).
4	Food Crop Irrigation Water	Category 4 water can have higher BOD levels (10 mg/L) than category 3 (2.2 - 2.6 mg/L).
5	Public Park Irrigation Water & Recreational Impoundments	Categories 4 and 5 have similar levels of water quality, except that category 4 water cannot have more than 0.1 mg/L of arsenic in it, and category 5 has no arsenic restrictions. Consequently, category 5 is placed after category 4.
6	Commercial Greywater Reuse	Categories 6 and 7 both have lower TSS concentrations that category 8, so they are ordered before category 8. Category 7 water can have higher *E. coli* levels (14 CFU/100ml) than category 6 (2.2 CFU/100ml) and higher turbidity levels (5 NTU) than category 6 (2 NTU), so category 6 is ordered before category 7.
7	Residential Greywater Reuse	
8	Industrial Reuse	Category 8 water can have higher TSS (30 mg/L) than category 7 (10 mg/L).
9	Restricted Contact Impoundments	Categories 8 and 9 are almost identical, except that category 8 has a turbidity maximum of 2 NTU, and category 9 has no turbidity restrictions. Since category 8 is more restrictive than category 9, category 9 is ordered after category 8.
10	Non-food Crop Irrigation Water	Category 10 water can have higher total coliform levels (23 CFU/100 ml) than category 9 (2.2 CFU/100 ml).
11	Restricted Contact Municipal Reuse	Categories 10 and 11 have similar levels of water quality, except that category 10 water cannot have more than 0.1 mg/L of arsenic in it, and category 11 has no arsenic restrictions. Consequently, category 11 is placed after category 10.
12	Processed Food Crop Irrigation Water	Categories 11 and 12 are similar, except that category 11 has a total coliform average of 23 CFU/100 ml, and category 12 has no total coliform restrictions.
13	Environmental Reuse	Category 13 is similar to category 12, but does not have a pH range or arsenic limit, so it is ordered below category 12.
14	Secondary Treated Wastewater	Category 14 water has a 0.5 mg/L chlorine residual level, which is a lower level of water quality than all of the categories above.
15	Agricultural Irrigation Water	Category 15 is the first category without a chlorine level requirement, so it was placed after categories 1-14.
16	Livestock Drinking Water	Category 16 does not have a chorine requirement either but has higher levels of contaminants allowed for all parameters compared to category 15, so it is ordered after category 15.
17	Captured Rainwater for Indoor Use	Category 17 has fewer water quality requirements than category 16, so it is ordered after category 15.
18	Captured Rainwater for Outdoor Use	Category 18 has the same source as category 17, but no water quality parameter requirements, as specified in the standard, so it is ordered after category 17.
19	Greywater from Clothes Washing	Categories 19 through 22 are ordered by the upper end of the range for each of the three bacteriological water quality parameters, *E. coli*, fecal coliform, and total coliform.
20	Greywater from Bathroom Sink & Shower	
21	Primary Treated Wastewater	
22	Raw Sewage	
23	Brackish Water	Categories 23 through 25 are ordered by the level of TDS.
24	Seawater	
25	Conventional Oil Produced Water	
26	Urban Stormwater	Category 26 has the highest upper range of TSS, oil & grease, and pH, so it is ordered last on the scale.
A	Raw Groundwater	Categories A through D were placed at the bottom of the scale as placeholders for local water quality.
B	Raw Surface Water	
C	Raw Precipitation	
D	Stored or Other Water Supply	

However, instead of populating the centre of the matrix with the water quality parameter values, the data source references for the values are inserted in the table, along with notes regarding the numerical values (*e.g.*, 7-day median). Figures 4.5 and 4.6 demonstrate this step of the method by documenting the data source(s) for each water quality parameter value collected, and any notes on these values, for California.

4.3 Result of Applying the Method

This results section presents, first, the scale of water quality created by applying the method above and, second, the scale tailored to a specific location within California, the City of Paso Robles, by adding local water quality data to the placeholder categories at the bottom of the scale.

4.3.1 Natural and Built Environments Water Quality Categories Scale for California

The result of applying the method is a scale of twenty-six defined water quality categories, including water found in both the natural and built environments of California, as shown in Figure 4.7. Each category on the scale is identified by a number and title to describe the type of water it represents. Table 4.1 lists the definitions, and their sources, for each category of water quality included in the scale. The levels of water quality are represented by twenty-three water quality parameters. Figures 4.5 and 4.6 document the data source(s) for each water quality parameter value associated with each category of water in the scale. The categories of water quality listed in the scale are ordered from highest to lowest quality, with an explanation of the order given in Table 4.3. The values on the scale that are MCLs are highlighted in red, average values are highlighted in orange, and minimum allowable levels are highlighted in yellow (Figure 4.3). Alpha categories (*e.g.*, A, B, C) act as placeholders for

	Categories of Water Quality	Fecal Coliform	Total Coliform	*E. coli*	Turbidity	TSS	TDS
1	Potable Drinking Water	(SWRCB, 2019a)		(SWRCB, 2019a)	(SWRCB, 2019a)		(US EPA, 2019) & (SWRCB, 2019a)
2	Potable Surface Water & Groundwater Augmentation		7-day med, 240 max (SWRCB, 2018b) & (US EPA, 2012b, table 4-16)		avg for media filters, 10 NTU max (US EPA, 2017, table 7-1; US EPA, 2012b, table 4.4)		
3	Tertiary Treated Wastewater					(Bulloch et al, 2015)	
4	Food Crop Irrigation Water	non- detect 7-day median, 14 max (US EPA 2012b, table 4.4)	7-day med, 240 max (US EPA, 2012b, table 4.9)		avg for media filters, 10 NTU max (US EPA, 2012b, tables 4.4 & 4.9)		
5	Public Park Irrigation Water & Recreational Impoundments		7-day med, 240 max (US EPA, 2012b, table 4.7)		avg for media filters, 10 NTU max (US EPA, 2012b, tables 4.4 & 4.7)		
6	Commercial Greywater Reuse			test average, single sample max 200 (US EPA, 2012b, table 2.5)	test average, single sample max 5 (US EPA, 2012b, table 2.5)	test average, single sample max 30 (US EPA, 2012b, table 2.5)	
7	Residential Greywater Reuse			test average, single sample max 240 (US EPA, 2012b, table 2.5)	test average, single sample max 10 (US EPA 2012b, table 2.5)		
8	Industrial Reuse	7 day median, 800 max (US EPA, 2012b, table 4.4)	7-day med, 240 max (US EPA, 2012b, table 4.14)		avg for media filters, 10 NTU max (US EPA, 2012b, table 4.14)	(US EPA, 2012b, table 4.4)	
9	Restricted Contact Impoundments		7-day med (US EPA 2012b, table 4.12)				
10	Non-food Crop Irrigation Water		(US EPA 2012b, table 3.6)				
11	Restricted Contact Municipal Reuse		7-day med, 240 max (US EPA, 2012b, table 4-8)				
12	Processed Food Crop Irrigation Water						
13	Environmental Reuse						
14	Secondary Treated Wastewater					(Bulloch et al., 2015)	
15	Agricultural Irrigation Water						(US EPA, 2012b, table 3.4) & (Ayers and Westcot 1985)
17	Captured Rainwater for Indoor Use			(CPC, 2016)			
18	Captured Rainwater for Outdoor Use				Minimum Treatment Requirement: Debris excluder or other approved means in compliance with Section 1602.9.10 or 100 micron in compliance with Section 1602.9.11. (CPC, 2016)		
19	Greywater from Clothes Washing	(De Gisi et al., 2016)			(De Gisi et al., 2016)		
20	Greywater from Bathroom Sink & Shower						
21	Primary Treated Wastewater	(Boczek et al., 2010)		(Boczek et al., 2010)			
22	Raw Sewage	(Lowe et al. 2009)		(Lowe et al., 2009)		(Lowe et al., 2009)	
23	Brackish Water						(USDI 2003)
24	Seawater						(USDI 2003)
25	Conventional Oil Produced Water						(Echchelh et al. 2018)
26	Urban Stormwater					(Pitt et al. 2018)	

Figure 4.5. Data Sources and Notes for the Bacteriological and Physical Water Quality Parameter Data Collected and Compiled for California.

	Categories of Water Quality	Sodium	TOC	BOD	CBOD	Oil & Grease	pH	Gross Alpha Particle Activity	Uranium	Total Nitrogen	Nitrate as Nitrogen	Arsenic	Perchlorate	PCE	TCE	DBCP	Chlorine Residual	Total Chlorine
1	Potable Drinking Water						(US EPA 2019)	(SWRCB 2019a) & (SWRCB 2018a)	(SWRCB 2018a)		(SWRCB 2019a)	(SWRCB 2019a) & (SWRCB 2018a)		(SWRCB 2018a)		(US EPA 2009)	(US EPA 2019) & (SWRCB 2019a)	
2	Potable Surface Water & Groundwater Augmentation		(SWRCB 2018b) & (US EPA 2012b, table 4-16)				(US EPA 2017, table 7-1) & (US EPA 2012b, table 4.4)			avg of 4 consecutive samples (SWRCB 2018b) & (US EPA 2017, table 3-2) & (US EPA 2012b, table 4-16)							(US EPA 2017, table 7-1) & (US EPA 2012b, table 4.4)	
3	Tertiary Treated Wastewater		(Bulloch et al. 2015)				(Bulloch et al. 2015)										(Bulloch et al. 2015)	
4	Food Crop Irrigation Water			5 day BOD test (US EPA 2012b, table 4.4)			(US EPA 2012b, table 4.4)					(US EPA 2012b, table 3.5)					(US EPA 2012b, table 4.4)	
5	Public Park Irrigation Water & Recreational Impoundments																	
6	Commercial Greywater Reuse				test average, single sample max 25 (US EPA 2012, table 2.5)		(US EPA 2012b, table 2.5)											(US EPA 2012b, table 2.5)
7	Residential Greywater Reuse																	
8	Industrial Reuse			5 day BOD test (US EPA 2012b, table 4.4)			(US EPA 2012b, table 4.4)										(US EPA 2012b, table 4.4)	
9	Restricted Contact Impoundments																	
10	Non-food Crop Irrigation Water						(US EPA 2012b, table 4.4)					(US EPA 2012b, table 3.5)						
11	Restricted Contact Municipal Reuse																	
12	Processed Food Crop Irrigation Water											(US EPA 2012b, table 3.5)						
13	Environmental Reuse																	
14	Secondary Treated Wastewater		(Bulloch et al. 2015)				(Bulloch et al. 2015)										(Bulloch et al. 2015)	
15	Agricultural Irrigation Water	(CCRWQB 2019a)					(US EPA 2012b, table 3.4) & (Ayers and Westcot 1985)				(US EPA 2012b, table 3.4) & (Ayers and Westcot 1985)	(CCRWQB 2019a)						
16	Livestock Drinking Water	short-term exposure max 4000 (US EPA 2012b, table 3.7)									(CCRWQCB 2017)	(US EPA 2012b, table 3.7) & (CCRWQB 2019a)						
19	Greywater from Clothes Washing			(De Gisi et al. 2016)			(De Gisi et al. 2016)			(De Gisi et al. 2016)								
20	Greywater from Bathroom Sink & Shower																	
21	Primary Treated Wastewater		(Boczek et al. 2010)				(Boczek et al. 2010)											
22	Raw Sewage		(Lowe et al. 2009)		(Lowe et al. 2009)					(Lowe et al. 2009)								
24	Seawater	(Duxbury et al. 2019)					(Marion et al. 2011)					(SWRCB 2015)						
25	Conventional Oil Produced Water	(Echchelh et al. 2018)				(Echchelh et al. 2018)												
26	Urban Stormwater					(Pitt et al. 2018)												

Figure 4.6. Data Sources and Notes for the Disinfectants and Chemical Water Quality Parameter Data Collected and Compiled for California.

		Water Quality Parameters																						
		Bacteriological			Physical			Chemical															Disinfectants	
							Salinity							Principal Contaminants in California										
									Oxyen Demand					Radiological		Inorganic Chemicals				Organic Chemicals				
	Categories of Water Quality	**Fecal Coliform (CFU/100ml)**	**Total Coliform (CFU/100ml)**	***E. coli* (CFU/100 ml)**	**Turbidity (NTU)**	**TSS (mg/L)**	**TDS (mg/L)**	**Sodium (mg/L)**	**TOC (mg/L)**	**BOD (mg/L)**	**CBOD (mg/L)**	**Oil & Grease (mg/L)**	**pH**	**Gross Alpha Particle Activity (pCi/L)**	**Uranium (pCi/L)**	**Total Nitrogen (mg/L)**	**Nitrate as Nitrogen (mg/L)**	**Arsenic (mg/L)**	**Perchlorate (mg/L)**	**PCE (mg/L)**	**TCE (mg/L)**	**DBCP (mg/L)**	**Chlorine Residual (mg/L)**	**Total Chlorine (mg/L)**
1	Potable Drinking Water	0		0	1		$1x10^3$						6.5-8.5	15	20		10	0.01	0.006	0.005	0.005	0.0002	0.2 4	
2	Potable Surface Water & Groundwater Augmentation		2.2		2				0.5				6.5-8.5			10							1	
3	Tertiary Treated Wastewater					0.9			3-3.1	2.2-2.6			7.1-7.4										2.7-3.4	
4	Food Crop Irrigation Water	0	2.2		2					10			6-9					0.1					1	
5	Public Park Irrigation Water & Recreational Impoundments	0	2.2		2					10			6-9										1	
6	Commercial Greywater Reuse			2.2	2	10					10		6-9											0.5- 2.5
7	Residential Greywater Reuse			14	5	10					10		6-9											0.5- 2.5
8	Industrial Reuse	200	2.2		2	30				30			6-9										1	
9	Restricted Contact Impoundments	200	2.2			30				30													1	
10	Non-food Crop Irrigation Water	200	23			30				30			6-9					0.1					1	
11	Restricted Contact Municipal Reuse	200	23			30				30			6-9										1	
12	Processed Food Crop Irrigation Water	200				30				30			6-9					0.1					1	
13	Environmental Reuse	200				30				30													1	
14	Secondary Treated Wastewater					6.9-13			1.2	5.1-5.7			7.2-7.9										1	
15	Agricultural Irrigation Water						$2x10^3$	9					6.5-8.4				5-30	0.1						
16	Livestock Drinking Water							$1x10^3$									100	0.2						
17	Captured Rainwater for Indoor Use			100	10																			
18	Captured Rainwater for Outdoor Use																							
19	Greywater from Clothes Washing	$50–1.4×10^3$	$200.5–7×10^5$		50–444	68–465				48–472	$231\text{-}2.9x10^3$		7.1–10			1–40								
20	Greywater from Bathroom Sink & Shower	$0–3.4×10^5$	$10–2.4×10^7$		44–375	7–505				50–300	100-633		6.4–8.1			3–19						**MCL**		
21	Primary Treated Wastewater	$7.14x10^6 - 1.58x10^7$		$2.18x10^6 - 7.90x10^6$	26-55	43-75			16-37				6.3-7.2									**Avg.**		
22	Raw Sewage	$1x10^4\text{-}1.73x10^8$		$1.0x10^4\text{-}8.16x10^7$		$22\text{-}1.69x10^3$			35-738		$112\text{-}1.1x10^3$	10-109	6.4-10.1			20-85	0.2-8.5					**Min.**		
23	Brackish Water						$1x10^3\text{-}3.5x10^4$																	
24	Seawater						$3.5x10^4$	$1.1x10^4$					7.4-9.6					0.003						
25	Conventional Oil Produced Water						$80\text{-}4.72x10^5$	$1.2x10^5$				0.565	4.3-10											
26	Urban Stormwater					$0.11\text{-}4.8x10^3$						$0.060\text{-}2.9x10^3$	3.4-10.7											
A	Raw Groundwater																							
B	Raw Surface Water																							
C	Raw Precipitation																							
D	Stored or Other Water Supply																							

Figure 4.7. Natural and Built Environments Descending Scale of Water Quality Categories for California.
The values on the scale that are Maximum Contaminant Levels (MCL) are highlighted in red,
average values are highlighted in orange, and minimum allowable levels are highlighted in yellow.

water quality parameter data values for the local supply of water (*e.g.*, groundwater, surface water, precipitation) allowing the scale to be tailored to a specific location within California.

4.3.2 Scale of Water Quality Tailored to a Specific Location within California: City of Paso Robles

Tailoring the scale to a specific location within California is demonstrated by collecting and inserting water quality parameter data values for the City of Paso Robles' local supply of water into the alpha category placeholders using the same method (Figure 4.8). The alpha categories are ordered amongst the numeric categories and the result is depicted in Figure 4.9. The details of this application of the scale are discussed in the section that follows.

4.3.2.1. Demonstration: Tailoring the California Scale to the City of Paso Robles

To demonstrate tailoring the scale to a city within California, water quality parameter data for the City of Paso Robles are inserted into the placeholder categories of the scale. Paso Robles is located on the central coast of California in San Luis Obispo County. It has a population of over thirty thousand people and an area of almost twenty square miles (fifty-two square kilometres) (Paso Robles, 2019a).

For Paso Robles, water in the local environment includes:

1. *Groundwater* from one groundwater basin only: the Paso Robles Groundwater Basin, numbered by the California Department of Water Resources as Basin No. 3-4.06 (Paso Robles, 2016a). USGS water quality parameter data for that basin was inserted into category A in Figure 4.8 (USGS, 2019b).

		Water Quality Parameters																						
		Bacteriological			Physical				Chemical														Disinfectants	
							Salinity			Oxyen Demand				Principal Contaminants in California										
														Inorganic Chemicals						Organic Chemicals				
														Radiological										
	Categories of Water Quality	Fecal Coliform (CFU/100ml)	Total Coliform (CFU/100ml)	*E. coli* (CFU/100 ml)	Turbidity (NTU)	TSS (mg/L)	TDS (mg/L)	Sodium (mg/L)	TOC (mg/L)	BOD (mg/L)	CBOD (mg/L)	Oil & Grease (mg/L)	pH	Gross Alpha Particle Activity (pCi/L)	Uranium (pCi/L)	Total Nitrogen (mg/L)	Nitrate as Nitrogen (mg/L)	Arsenic (mg/L)	Perchlorate (mg/L)	PCE (mg/L)	TCE (mg/L)	DBCP (mg/L)	Chlorine Residual (mg/L)	Total Chlorine (mg/L)
1	Potable Drinking Water	0		0	1		$1x10^3$						6.5-8.5	15	20		10	0.01	0.006	0.005	0.005	0.0002	0.2 4	
2	Potable Surface Water & Groundwater Augmentation		2.2		2				0.5				6.5-8.5			10							1	
3	Tertiary Treated Wastewater					0.9			3-3.1	2.2-2.6			7.1-7.4										2.7-3.4	
4	Food Crop Irrigation Water	0	2.2		2					10			6-9					0.1					1	
5	Public Park Irrigation Water & Recreational Impoundments	0	2.2		2					10			6-9										1	
6	Commercial Greywater Reuse			2.2	2	10					10		6-9											0.5- 2.5
7	Residential Greywater Reuse			14	5	10					10		6-9											0.5- 2.5
8	Industrial Reuse	200	2.2		2	30				30			6-9										1	
9	Restricted Contact Impoundments	200	2.2			30				30													1	
10	Non-food Crop Irrigation Water	200	23			30				30			6-9					0.1					1	
11	Restricted Contact Municipal Reuse	200	23			30				30			6-9										1	
12	Processed Food Crop Irrigation Water	200				30				30			6-9					0.1					1	
13	Environmental Reuse	200				30				30													1	
14	Secondary Treated Wastewater					6.9-13			1.2	5.1-5.7			7.2-7.9										0.5	
15	Agricultural Irrigation Water						$2x10^3$	9					6.5-8.4				5-30	0.1						
16	Livestock Drinking Water							$1x10^3$									100	0.2						
17	Captured Rainwater for Indoor Use			100	10																			
18	Captured Rainwater for Outdoor Use																							
19	Greywater from Clothes Washing	$50–1.4×10^3$	$200.5–7×10^5$		50–444	68–465				48–472	$231-2.9x10^3$		7.1–10			1–40								
20	Greywater from Bathroom Sink & Shower	$0–3.4×10^5$	$10–2.4×10^7$		44–375	7–505				50–300	100-633		6.4–8.1			3–19						MCL		
21	Primary Treated Wastewater	$7.14x10^6$ - $1.58x10^7$		$2.18x10^6$ - $7.90x10^6$	26-55	43-75			16-37				6.3-7.2									Avg.		
22	Raw Sewage	$1x10^4$-$1.73x10^8$		$1.0x10^4$-$8.16x10^7$		$22-1.69x10^3$			35-738		$112-1.1x10^3$	10-109	6.4-10.1			20-85	0.2-8.5					Min.		
23	Brackish Water						$1x10^3$-$3.5x10^4$																	
24	Seawater						$3.5x10^4$	$1.1x10^4$					7.4-9.6					0.003						
25	Conventional Oil Produced Water						$80-4.72x10^5$	$1.2x10^5$				0.565	4.3-10											
26	Urban Stormwater					$0.11-4.8x10^3$						$0.060-2.9x10^3$	3.4-10.7											
A	Raw Groundwater - Paso Robles Groundwater Basin						344-762					7-8.2		2.8-18	1.4-8		0.04-3.9	1.4-17.7	0.1-1.3					
B	Raw Surface Water - Salinas River	$7-5x10^3$	$21-8x10^3$	10-460	0-359	0.8-64	290-980					7.3-8.5				0.13-2.12	0.02-0.56							
C	Raw Precipitation																							
D	Water Storage Tanks/Facilities				0–0.12		120-660	10-150				7.2-8.1		0-11	0-4.5		0-3.9	0-0.0064						0.5-2.4
E	Groundwater Wells Pumping Salinas River Underflow				1.2		540	87				7		0	0.9		0	0	0	0	0			
F	Lake Nacimiento (untreated lake water)		370-400	1	2-14		160	7.8	3.9-4.8			7-8.6					0.4	0.001	0.0005					
G	Nacimiento Water Project Water (delivered)		$25-2.4x10^4$	0-1	3.1-45		100-380	7.4-10	3.0-4.3			7.4-8.6		0			0-0.146	0-5.9						
H	Raw Untreated Sewage					$58-1x10^3$	$888-1.1x10^3$	151-199		185-530		3-8.7												
I	Reclaimed Water		1.8-110			1-14.3	$737-1.5x10^3$	145-221		2.13-8.9		7.0-8.0	2.17-8.9			0.5-877	3.8-4.7						0.01-0.31	
J	Urban Stormwater Runoff																							

Figure 4.8. Natural and Built Environments Water Quality Categories Scale is Tailored to a Specific Location within California, City of Paso Robles, by First Inserting Local Water Quality Data into Categories A-J. Next, categories A-J are ordered amongst categories 1-26, depicted in Figure 4.9. Table 4.4 includes an explanation of the order.

The values on the scale that are Maximum Contaminant Levels (MCL) are highlighted in red,
average values are highlighted in orange, and minimum allowable levels are highlighted in yellow.

		Water Quality Parameters																						
		Bacteriological			Physical				Chemical														Disinfectants	
														Principal Contaminants in California										
							Salinity		Oxyen Demand					Radiological		Inorganic Chemicals				Organic Chemicals				
	Categories of Water Quality	**Fecal Coliform (CFU/100ml)**	**Total Coliform (CFU/100ml)**	***E. coli* (CFU/100 ml)**	**Turbidity (NTU)**	**TSS (mg/L)**	**TDS (mg/L)**	**Sodium (mg/L)**	**TOC (mg/L)**	**BOD (mg/L)**	**CBOD (mg/L)**	**Oil & Grease (mg/L)**	**pH**	**Gross Alpha Particle Activity (pCi/L)**	**Uranium (pCi/L)**	**Total Nitrogen (mg/L)**	**Nitrate as Nitrogen (mg/L)**	**Arsenic (mg/L)**	**Perchlorate (mg/L)**	**PCE (mg/L)**	**TCE (mg/L)**	**DBCP (mg/L)**	**Chlorine Residual (mg/L)**	**Total Chlorine (mg/L)**
D	Water Storage Tanks/Facilities				0–0.12		120-660	10-150				7.2-8.1		0-11	0-4.5		0-3.9	0-0.0064						0.5-2.4
1	Potable Drinking Water	0		0	1		1x10^{3}						6.5-8.5	15	20		10	0.01	0.006	0.005	0.005	0.0002	0.2 4	
E	Groundwater Wells Pumping Salinas River Underflow				1.2		540	87				7		0	0.9		0	0	0	0	0			
2	Potable Surface Water & Groundwater Augmentation		2.2		2				0.5				6.5-8.5			10							1	
3	Tertiary Treated Wastewater					0.9			3-3.1	2.2-2.6			7.1-7.4										2.7-3.4	
4	Food Crop Irrigation Water	0	2.2		2					10			6-9					0.1					1	
5	Public Park Irrigation Water & Recreational Impoundments	0	2.2		2					10			6-9										1	
6	Commercial Greywater Reuse			2.2	2	10					10		6-9											0.5- 2.5
7	Residential Greywater Reuse			14	5	10					10		6-9											0.5- 2.5
8	Industrial Reuse	200	2.2		2	30				30			6-9										1	
9	Restricted Contact Impoundments	200	2.2			30				30													1	
10	Non-food Crop Irrigation Water	200	23			30				30			6-9					0.1					1	
11	Restricted Contact Municipal Reuse	200	23			30				30			6-9										1	
12	Processed Food Crop Irrigation Water	200				30				30			6-9					0.1					1	
13	Environmental Reuse	200				30				30													1	
14	Secondary Treated Wastewater					6.9-13			1.2	5.1-5.7			7.2-7.9										0.5	
I	Reclaimed Water		1.8-110			1-14.3	737-1.5x10^{3}	145-221		2.13-8.9		7.0-8.0	2.17-8.9			0.5-877	3.8-4.7						0.01-0.31	
F	Lake Nacimiento (untreated lake water)		370-400	1	2-14		160	7.8	3.9-4.8			7-8.6					0.4	0.001	0.0005					
15	Agricultural Irrigation Water						2x10^{3}	9					6.5-8.4				5-30	0.1						
16	Livestock Drinking Water							1x10^{3}									100	0.2						
17	Captured Rainwater for Indoor Use			100	10																			
C	Raw Precipitation																							
18	Captured Rainwater for Outdoor Use																							
G	Nacimiento Water Project Water (delivered)		25-2.4x10^{4}	0-1	3.1-45		100-380	7.4-10	3.0-4.3			7.4-8.6		0			0-0.146	0-5.9						
B	Raw Surface Water - Salinas River	7-5x10^{3}	21-8x10^{3}	10-460	0-359	0.8-64	290-980					7.3-8.5				0.13-2.12	0.02-0.56							
A	Raw Groundwater - Paso Robles Groundwater Basin						344-762					7-8.2		2.8-18	1.4-8		0.04-3.9	1.4-17.7	0.1-1.3					
19	Greywater from Clothes Washing	50–1.4×10^{3}	200.5–7×10^{5}		50–444	68–465				48–472	231-2.9x10^{3}		7.1–10			1–40								
20	Greywater from Bathroom Sink & Shower	0–3.4×10^{5}	10–2.4×10^{7}		44–375	7–505				50–300	100-633		6.4–8.1			3–19								
21	Primary Treated Wastewater	7.14x10^{6} - 1.58x10^{7}		2.18x10^{6} - 7.90x10^{6}	26-55	43-75			16-37				6.3-7.2											
H	Raw Untreated Sewage					58-1x10^{3}	888-1.1x10^{3}	151-199		185-530		3-8.7												
22	Raw Sewage	1x10^{4}-1.73x10^{8}		1.0x10^{4}-8.16x10^{7}		22-1.69x10^{3}			35-738		112-1.1x10^{3}	10-109	6.4-10.1			20-85	0.2-8.5							
23	Brackish Water						1x10^{3}-3.5x10^{4}																	
24	Seawater						3.5x10^{4}	1.1x10^{4}					7.4-9.6					0.003						
25	Conventional Oil Produced Water						80-4.72x10^{5}	1.2x10^{5}				0.565	4.3-10											
26	Urban Stormwater					0.11-4.8x10^{3}						0.060-2.9x10^{3}	3.4-10.7											
J	Urban Stormwater Runoff																							

MCL
Avg.
Min.

Figure 4.9. Natural and Built Environments Water Quality Categories Scale Tailored to the City of Paso Robles by Ordering Categories A through J (Figure 4.8) Amongst Categories 1 through 26 (Figure 4.7).

The values on the scale that are Maximum Contaminant Levels (MCL) are highlighted in red, average values are highlighted in orange, and minimum allowable levels are highlighted in yellow.

2. One *surface water* body, namely, the Salinas River (Paso Robles, 2016a). Central Coast Ambient Monitoring Program water quality parameter data for the Salinas River was inserted in category B in Figure 4.8 (CCRWQCB, 2019b).
3. *Raw precipitation.* The average annual rainfall in Paso Robles is about fourteen inches (thirty-six centimetres) (Paso Robles, 2019b). The rainwater that infiltrates into the ground before coming in contact with urban areas is accounted for in category C. Since water quality parameter data is not available, category C in Figure 4.8 remains blank, and acts as a placeholder for the quantity of precipitation when it is compared to other categories of water in Figure 4.9.

Additional sources of water for Paso Robles include:

1. *Four water storage tanks* that augment the water supply when needed (Paso Robles, 2016a). Water quality parameter data published by the City of Paso Robles was inserted into category D in Figure 4.8 (Paso Robles, 2018).
2. *Wells that extract Salinas River underflow*. The city has surface water rights to water in the Salinas River. That water is extracted from the Salinas River through the use of wells. The water quality parameter data for this water was inserted into category E (SWRCB, 2019b).
3. *Water from Lake Nacimiento*. The City of Paso Robles holds a delivery entitlement for Lake Nacimiento water. For comparison purposes, water quality parameter data for both the untreated surface water (San Luis Obispo County, 2019) and the treated, delivered Nacimiento Water Project water (San Luis Obispo County, 2018) were inserted into categories F and G, respectively, in Figure 4.8.
4. *Reclaimed water.* The city built a new tertiary treatment facility that treats wastewater for the purpose of water reuse. The distribution system is not yet complete. Until the

distribution system is ready to be used, the tertiary treated water is being discharged into the Salinas River. For comparison purposes, water quality parameter data for both the raw untreated sewage entering the wastewater treatment facility (obtained by request from the City of Paso Robles) and the reclaimed water leaving the wastewater and tertiary treatment plant (SWRCB, 2019c) were inserted into categories H and I, respectively, in Figure 4.8.

5. *Urban stormwater runoff.* The rainwater that infiltrates into the ground after coming in contact with urban areas is accounted for in category J of Figure 4.8. The City of Paso Robles has constructed facilities that infiltrate rainwater into the ground; however, the city does not collect water quality data. Since water quality parameter data is not available, category J remains blank and acts as a placeholder to draw attention to the need for data (*i.e.*, data gap).

At the bottom of the scale, Figure 4.8 lists, in categories A through J, the types of water found in the local environment, as well as other sources of water available to the City of Paso Robles and their associated water quality parameter data.

In order to evaluate how the quality of the available water compares with use requirements, categories A through J are reordered among the numbered categories in such a manner that the water quality parameter values of the categories above these insertions represent higher levels of water quality and the categories below these insertions include lower levels of water quality, as explained in Table 4.4.

Figure 4.9 shows the resulting scale for Paso Robles' water resources capturing in one image the quality of water available compared to the standards for use.

Table 4.4. Explanation for the Scale Order of the Paso Robles Water Quality Categories.

	Water in Paso Robles	Explanation for Position on Scale
D	Water Storage Tanks/Facilities	Category D is placed above category 1 because the water quality parameter values available for comparison meet the potable drinking water standards listed in category 1.
E	Groundwater Wells Pumping Salinas River Underflow	Category E is placed below category 1 because Turbidity (1.2 NTU) exceeds the max of 1 NTU for potable drinking water.
I	Reclaimed Water	Category I is placed below category 14 because the expected chlorine residual (0.01-0.31 mg/L) is lower than 0.5mg/L. The categories that follow would not be expected to include chlorine residual.
F	Lake Nacimiento (untreated lake water)	Category F follows category I because Total Coliform (370-400 CFU/100ml) is higher than 1.8-110 CFU/100ml and because there is no chlorine residual expected in lake water.
C	Raw Precipitation	Since Paso Robles does not currently measure rainwater quality, there are no water quality values to compare to those of other categories. Category C is placed between categories 17 and 18 (Captures Rainwater) as a placeholder for when values are available.
G	Nacimiento Water Project Water (delivered)	While category G has higher Total Coliform than category B, category B has higher *E. coli* by a higher order of magnitude, so category G is ordered before category B.
B	Raw Surface Water - Salinas River	
A	Raw Groundwater - Paso Robles Groundwater Basin	Category A does not have bacteriological parameter values for comparison, but the Arsenic levels are higher for it than for category G, and the Nitrate as Nitrogen levels are higher than they are for both G and B, so category A is placed after B.
H	Raw Untreated Sewage	There are no bacteriological parameter values available for comparison, so Category H is placed above category 22 because the upper end of the range of the TSS concentration (1,001 mg/L) is less than that for category 22 (1,690mg/L).
J	Urban Stormwater Runoff	Paso Robles does not currently measure urban storm water runoff quality. Since there are no water quality values to compare to those of other categories, category J is placed below category 26 as a placeholder until Paso Robles has water quality data for this category.

4.4 Discussion

This section first discusses the challenges related to creating the method such as selecting the scope of the water quality scale, comparing different types of water quality definitions, and comparing many water quality parameter values at once. Then, using the resulting scale to compare the quality of different categories of water in the natural and built environments of California, and depicting the quantity and quality of water in the natural and built environments of California simultaneously, is discussed.

4.4.1 No Existing Applicable Water Quality Scale for Adding Water Quality to a Water Budget in California, nor a Method for Creating Such a Scale

To add water quality to a water budget, water quality definitions for all of the types of water in the mass balance are required. When no applicable set of water quality definitions was found for particular types of water in a California water budget, in the literature or in practice, that could be used to add water quality to a California water budget, the method in this chapter was used to create the scales found in Figures 4.7 through 4.9. When the scales were submitted to the American Society of Civil Engineering (ASCE) *Journal of Sustainable Water in the Built Environment* for publication, the reviewers responded that while the water quality scale was of interest, there was no published method for creating such a scale. However, if the method used to create the scale was submitted for publication, it would be accepted. Consequently, the focus of this chapter shifted from creating a scale of water quality, to developing a method for creating a scale of water quality. This six-step method, demonstrated by creating a descending scale of water quality categories that includes water found in both the natural and built environments in California, was submitted in May 2020, and published in January 2021, in the *Journal of Sustainable Water in the Built Environment* (Bitting and Cullen, 2021). This journal was selected for publication of this chapter since it is listed on the Cambridge University Engineering Department library's electronic resources webpage which has six tabs; databases; ebooks; journals and proceedings; patents; standards; and institutions and societies. The journals and proceedings tab lists six journals: American Institute of Aeronautics and Astronautics Meeting Papers; ASCE Journals; American Society of Mechanical Engineers Proceedings; Design Society Papers; NASA Technical Reports; Professional Society for Optics and Photonics Technology Conference Proceedings (CUED, 2022). Of those six journals and proceedings, the ASCE journals subject area focus aligns with this research.

4.4.2 Optimal Scope of the Water Quality Scale

In California, water quality is defined at the hydrologic region-level (*i.e.*, watershed basin) by state agencies (*i.e.*, California Water Boards). Water is transported throughout the state by a state agency (*i.e.*, DWR) using a network of pipelines and aquifers. However, water is treated and distributed to the end-user at the local level (*i.e.*, city, town), consequently the level for funding and decision-making. This presents a problem when selecting the appropriate scope for the scale: state level; hydrologic region level; or the city level. The ideal scale would incorporate all three levels of specificity and include: the water quality definitions made at the state level; for a specific hydrologic region; and also include water quality data specific to a particular city or town. The state of California is selected to demonstrate this method for creating a water quality scale for the reasons described in the second chapter and summarised here. Water quantity and quality data are available for most streams, rivers, lakes, and groundwater basins in the state. While water quality sampling and water quantity measurements are usually conducted locally, the results are deposited into statewide databases that are accessible to the public. Water is transported between watershed basins, so for California the optimal scope for the scale is a statewide scale of water quality that can be made specific to a particular city, the level at which water is sourced and treated.

4.4.3 Comparing Different Types of Water Quality Definitions

Water quality standards (*e.g.*, mandatory maximum contaminant levels (MCLs)) are not available for every type of water in the natural and built environments. For the types of water without water quality standards, guideline values are available for some, and measured values of water quality sampled in the natural environment or at outflow discharge locations are available for others. In collecting water quality parameter data and values for different types of water, some are water quality standards that are mandatory, some are optional guidance values, and others are measured values, which presents the problem of making it difficult to compare values with different levels of priority. Ideally, each water quality parameter value in the matrix would be identified as either a requirement, guidance, or a measured value. Applying a colour-coding system allows the values to be easily identified as a maximum, average, or minimum concentration. For the California-specific data collected, red highlighting is used to indicate values representing MCLs. MCLs are enforceable standards set by the US EPA or the California Water Boards. Orange highlighting indicates values representing averages. Yellow highlighting indicates that a value is a minimum concentration level. Single values that are not highlighted are non-enforceable maximum levels of contamination. A range of values means the level of concentration of the given contaminant is expected to fall within the range listed.

4.4.4 Comparing Many Water Quality Parameter Values at Once in a Transparent Format

Creating a scale of water quality categories, for the purpose of adding water quality to a water budget, that may be used in city- or state-level decision-making will come under scientific and public scrutiny as part of the public government decision-making process. A ‘black box’ approach where values used, or calculations performed, are not visible or apparent to the reader offers little credibility. Displaying the values allows errors to be identified and corrections made based on scientifically credible information and input during the peer review phase of the state or city public process. The result of applying the method is a scale of twenty-six defined water quality categories, including water found in both the natural and built environments of California. Each category on the scale is identified by a number and title to describe the type of water it represents. The levels of water quality are represented by twenty-three water quality parameters. The categories of water quality listed in the scale are ordered from highest to lowest quality, with an explanation of the order given in Table 4.3. The values on the scale that are MCLs are highlighted in red, average values are highlighted in orange, and minimum allowable levels are highlighted in yellow. Alpha categories act as placeholders for water quality parameter data values for the local supply of water, allowing the scale to be tailored to a specific location within California.

4.4.5 California Scale Can be Tailored to Any Municipality in the Central Coastal Hydrologic Region

Tailoring the scale to a specific location within California is demonstrated by collecting and inserting water quality parameter data values for the City of Paso Robles’ local supply of water into the alpha category placeholders (Figure 4.8). The alpha categories are ordered amongst the numeric categories, and Figure 4.9 shows the resulting scale for Paso Robles’ water resources, capturing in one image the quality of water available compared to the standards for use. However, the California scale could be tailored to any municipality (*e.g.*, town, city, university, military base) within the Central Coastal Basin, by inserting the water quality parameter data into the placeholder categories and carrying out the same process described in the method, detailed earlier in the chapter.

4.4.6 Identifying Data Gaps

Water quality parameter data is not available for all of the types of water in Paso Robles. For example, the City of Paso Robles does not collect stormwater quality parameter data. This makes comparing the quality of all of the different types of water in the city difficult. However,

the city of Paso Robles conducts potable water and wastewater quality sampling, as discussed in the third chapter, and therefore may have the capacity to conduct, or arrange for, stormwater quality sampling. If the city identifies a gap, it can allocate funds. Since that water quality parameter data is not available, category J remains blank on the scale, to draw attention to the need for that data (*i.e*., data gap).

4.4.7 Comparing the Quality of Different Categories of Water in the Natural and Built Environments of California

The resulting scale brings together water quality requirements for use, with the quality of water in the natural and built environments. As discussed in the second chapter, existing scales of water quality include either one water quality parameter (*e.g*., E. coli) across multiple types of water, or multiple water quality parameters for the use of one type of water (*e.g*., reclaimed wastewater for water reuse). The scale in Figure 4.7 intermixes for the first time supply-side and demand-side water quality, in the form of ordered descending categories, allowing the numerous types of water found in California and the various types of uses to all be compared together.

4.4.8 Depicting the Quantity and Quality of Water in the Natural and Built Environments of California Simultaneously

Establishing a water quality scale is an initial step toward adding water quality to a water budget. As discussed in the third chapter, to add water quality to a water budget, definitions of water quality are required, such as a scale of water quality. In this chapter a method for creating a water quality scale is introduced. The resulting scale is used in the next chapter to add water quality to a California water budget. Since the scale intermixes for the first time supply-side and demand-side water quality in the form of defined categories, it includes the definitions necessary for the unprecedented pairing of water quantity and water quality together in a California water budget. The following chapter is dedicated to this concept.

4.5 Summary

Not only did the literature review reveal no scale appropriate for adding water quality to a water budget, there was also no method for creating such a scale; therefore, this chapter developed a method to create a scale of water quality specific to California. The method brings together water quality requirements for use, with the quality of water in the natural and built environments, in the form of ordered descending categories, allowing the numerous types of water found in California and the various types of uses to all be compared together. Since the scale intermixes for the first time supply-side and demand-side water quality in the form of defined categories, it includes the definitions necessary for the unprecedented pairing of water quantity and water quality together in a California water budget, which is the focus of the following chapter.

Chapter 5

Developing a Method for Adding Water Quality to a Water Budget in California

5.1 Introduction

Whether there is enough water to meet the needs of residents, businesses, agriculture, and the natural environment, is important to Californians. One of the tools used to assess water availability in California is the water budget. While this tool is useful for tracking quantity, it does not include water quality.

This chapter addresses the third research question, which asks: can a method be established for defining the quality of the water in a water budget in California? The third chapter explored ways to define water quality and selects a scale of water quality as an appropriate tool for adding quality to a water budget. The fourth chapter developed a method to create a scale of water quality specific to California. The resulting scale is used in this chapter to add water quality to a water budget.

The literature review in the second chapter reveals helpful examples of MFA used to depict water flows in California as Sankey diagrams (Curmi *et. al*., 2013). However, no method for adding water quality to a water budget is identified, so in response to the third research question, the aim of this chapter is to develop a method for adding water quality to a water budget in California.

This chapter introduces a seven-step method for creating a water budget, in the form of a modified mass flow diagram, that depicts the quality of each quantity of water. The method is applicable at any level of regional scale within California (*e.g.*, state, watershed basin, city) for which water quantity and water quality data are available.

The first four steps of the method involve converting water budget tables to a mass diagram. These steps are demonstrated at two levels, state and city, to demonstrate the process for both an already balanced water budget and a water budget that is compiled manually. The last three steps of the method involve adding water quality to the water budget. These steps are demonstrated at the city level, because while water quality data is available for most of the more than three thousand lakes in California, 304,896 km (189,454 miles) of river (NWSRS, 2020), and five hundred and fifteen groundwater basins and subbasins (CNRA, 2020), the whole state does not represent the best level of complexity for the 'proof of concept' of this method.

The result of the method applied to the City of Paso Robles is a water budget that includes water quality. Three different options for visualising the water budget are provided, as well as a description of how the diagram could be drawn using a graphic software tool, or a programming software tool.

This depiction of the water budget in diagram form provides new insights unavailable in a traditional water budget. Some of these insights are revealed just by transforming water budget tables to a diagram. Other insights come from depicting the quality, in addition to the quantity, of water in the modified mass flow diagram. These are explored in the discussion section of this chapter.

5.2 Method for Adding Water Quality to a Water Budget in California

The following new seven-step method has been devised for adding water quality data into a water budget. Each step of the method is illustrated using the City of Paso Robles as an example. The method is described in detail below and summarised in Figure 5.1.

5.2.1 Step 1: Delineate the System Boundary for the Water Balance

A mass balance accounts for all of the material entering and leaving a system. Therefore, the first step in creating a mass balance is to identify the system to be analysed and delineate a clear boundary. A watershed boundary, or a political boundary such as a city limit line, can be used.

This step is demonstrated using two scales of application: the whole state; and a single city. The boundary for the statewide level of application is the state boundary line of California. The Paso Robles city limit line is the boundary for the city-level application of the method. The City of Paso Robles is representative of many cities in California as it does not share a boundary with any other city. This non-contiguous nature simplifies demonstrating the method and drawing a system boundary.

5.2.2 Step 2: Select the Water Budget Time Period to be Used for the Analysis

In addition to establishing a physical boundary for the mass balance, a time boundary must also be delineated. Water budgets often cover a twelve-month period to account for seasonal

Step 1: Delineate the System Boundary for the Water Balance
The first step in creating a mass balance is to identify the system to be analysed and establish a clear boundary. A watershed boundary, or a political boundary such as a city limit line, can be used.

Step 2: Select the Water Budget Time Period to be Used for the Analysis
The second step involves constraining the mass balance to a specific period of time. Water budgets often cover a 12-month period to account for seasonal variation in precipitation, streamflow, water storage, and water use. When those 12 months do not line up with the calendar year, they are referred to as a *water year*. Either a calendar year or water year can be used.

Step 3: Collect Water Quantity Data Applicable to the Selected System Boundary and Time Period
Water quantity data is needed for each type of water entering, leaving, used, or stored within the boundary. Water quantity data can be obtained by either using an already balanced and published water budget, or by compiling the data needed for a water budget from multiple sources.

See **Figure 5.2 & Table 5.1** for an example of each.

Step 4: Draw a Modified Mass Flow Diagram
Create a diagram of the quantities of water stacked on a line, with a baseline at zero, and over-extraction shown below the line. Water entering the boundary is shown on the left, water leaving the boundary is depicted on the right, and how the water was used or stored is depicted in between. The diagram can be drawn using any software tool such as Excel or Inkscape.

See **Figures 5.4 through 5.8** for examples.

Step 5: Select and Assign a Colour Code to the Selected Water Quality Scale
Select a preferred colour code, such as a continuous colour scale that ranges from dark blue as the highest water quality, to light blue, then light brown, and finally to dark brown as the lowest quality. Assign the colour code to the scale of water quality that is appropriate for use within the designated boundary.

See **Figure 5.9** for an example.

Step 6: Apply the Colour Code Representing Water Quality to the Modified Mass Flow Diagram
Next, colour each quantity of water depicted on the diagram with the colour that corresponds with the appropriate category of water quality on the scale.

See **Figures 5.10 & 5.11** for examples.

Step 7: Order Diagram Slices by Quality
Finally, order the quantities in each slice of the mass flow diagram by quality, with the highest quality at the top and the lowest quality at the bottom.

See **Figures 5.10 & 5.11** for examples.

Figure 5.1. Overview of the New Method for Creating a Water Budget that Includes Water Quality.

variation in precipitation, streamflow, water storage, and water use. When those twelve months do not match the calendar year, they are referred to as a water year.

Since most of the rain on the central coast of California falls in the winter and spring months across the calendar year divide, Paso Robles measures its water year from the first day of July to the last day of June (City of Paso Robles, 2020a) to make measurement of the ‘rainy season’ more meaningful.

Within the last decade, California experienced both a significantly ‘wet’ year with high levels of rainfall and a significantly ‘dry’ year with low levels of rainfall. In 2011, California’s total precipitation was one hundred and thirty-four percent of the average rainfall for the state, whereas in 2014 only fifty-six percent of the state’s usual precipitation fell within the state boundary.

The average annual rainfall in Paso Robles is fourteen inches (thirty-six centimetres) (City of Paso Robles, 2020a). In water year 2011, 21.97 inches (55.8 cm) of precipitation fell in Paso Robles, one hundred and fifty-five percent of the average annual rainfall; just three years later, in water year 2014, 6.13 inches (15.57 cm) of precipitation fell in Paso Robles, representing forty-three percent of the average annual rainfall (City of Paso Robles, 2020a).

Water years 2011 and 2014 are selected to demonstrate this method for two reasons: if the method can be applied at both extremes, high and low annual precipitation, it is reasonable to assume the method can be used for the ranges of annual rainfall between the two extremes:

applying the method for both ends of the annual precipitation spectrum provides an opportunity to compare the results and investigate how the outcomes vary.

5.2.3 Step 3: Collect Water Quantity Data Applicable to the Selected System Boundary and Time Period

Water quantity data is needed for each type of water entering, leaving, used, or stored within the boundary. Water quantity data can be obtained two ways; either by using an already balanced and published water budget, or by compiling the data needed for a water budget from multiple sources. Both approaches for acquiring water quantity data are demonstrated below.

5.2.3.1 Using Water Quantity Data from a Published Water Budget

An example of an already balanced and published water budget is presented in Figure 1.1, which shows the two tables that make up the water budget for the State of California (State of California, 2019a). The table on the left lists the quantities of water that entered and left the state, including changes in stored ground and surface water, for 2011 through 2015. The table on the right lists the uses of that water (*i.e.,* urban, irrigated agriculture, environment) and the sources of that water (*i.e.,* reuse and recycled water, groundwater extraction, Colorado River water). The water quantity data collected for this step of the method is taken from the 2011 and 2014 columns of these two tables.

5.2.3.2 Using Water Quantity Data Compiled from Multiple Sources

The data needed to create a water budget may be collected and compiled from reports and data tables that are published for other purposes when a balanced water budget is not available. The City of Paso Robles publishes some of the data needed for a water budget in its *Urban Water Management Plan* (City of Paso Robles, 2016a). Other data needed for a water budget is published on the city's webpage and in the *Paso Robles Subbasin Groundwater Sustainability Plan* (PRSGSA, 2019).

Table 5.1 details the data, and its sources, used for the quantities of water within, entering, and leaving the city limits of Paso Robles for the water years 2011 and 2014. The water quantity data collected for this step of the method is taken from the 2011 and 2014 columns of this table.

5.2.4 Step 4: Draw a Modified Mass Flow Diagram

Once the water budget data has been collected, it is used to create a modified mass flow diagram. In a mass flow diagram, imbalances can indicate storage or losses of water in the system, or data errors. A process of data reconciliation is implemented to correct for imbalances. In this case, however, whenever data are not available, no guess is made as to what happens to the water, resulting in a modified mass flow diagram. The quantities of water with unknown use are collected and depicted in the 'water available, but not used' column.

Table 5.1. Water Entering, Leaving, and Found in the City of Paso Robles, California. Units in Acre-feet per Year (AFY) unless otherwise noted.

	Type	Name	Quantity Data (AFY) 2011	Quantity Data (AFY) 2014	Data Sources and Notes
Water Available or Allocated	Precipitation		21.97 in. (55.8 cm)	6.13 in. (15.57 cm)	In measured depth of annual rainfall (Paso Robles, 2020a).
	Precipitation		23,323	6,508	In volumetric units. Calculated using rainfall depth in inches, converted to feet, and multiplied by 12,740 acres, the size of the City of Paso Robles (Paso Robles, 2020b).
	Surface Water	Salinas River	4,600	4,600	Page ES-3 (Paso Robles, 2016a).
	Groundwater	Paso Robles Groundwater Basin No. 3-4.06	~2,000	~2,000	Past use of groundwater by all users of the sub-basin has been unsustainable. Over a 31-year period, the annual average groundwater storage loss was ~12,600 AF, page 6-31 (PRSGSA, 2019). There is no sustainable yield calculated for the City of Paso Robles, so 2,000 AFY is an estimated sustainable yield since it is assumed that some reduction in use is required.
	Imported Water	Nacimiento Water Project	4,000	4,000	Allocation increased to 6,488 AFY in April 2016, but was 4,000 AFY in 2011 and 2014 (Paso Robles, 2016a, Table 6-8).
Water Extracted	Surface Water	Salinas River Underflow Extraction Wells	4,069	2,772	(Paso Robles 2016a, Table 6-1)
	Groundwater	Paso Robles Groundwater Basin No. 3-4.06	2,327	3,497	
Water Treated	Potable Water		6,396	6,269	(Paso Robles, 2016a, Table 4-1)
Water Uses	Domestic		3,998	3,790	Calculated by adding single family and multi-family water use together (Paso Robles, 2016a, Table 4-1).
	Industrial		159	209	(Paso Robles, 2016a, Table 4-1)
	Commercial		779	799	
	Parks, Irrigation Water, Other		865	1,031	
	System Losses		595	440	
Wastewater Collection	Sewage		~3,332	~3,266	Wastewater treatment quantities are estimated using 2010 and 2015 data (Paso Robles 2016a, page 32 and Tables 6-2 & 6-3). In both 2010 and 2015, the wastewater quantity treated was 52% of the potable water treated. 2011 and 2014 wastewater amounts were estimated to be 52% of the amounts of potable water treated those years.
Wastewater Treatment	Secondary Effluent		~3,332	~3,266	
Disposal	Percolation Ponds to the Salinas River		~3,332	~3,266	

The diagram may be created using a graphic software tool (*e.g*., Excel, Inkscape), or a programming software tool (*e.g.*, Python). Excel is used to demonstrate the method, since the software is widely available. However, the use of programming software is demonstrated in the stacked quantities diagrams drawn using a programming software tool in the discussion section of this chapter.

5.2.4.1 Drawing a Diagram for California

To demonstrate this step at the statewide level, California's balanced water budget data is translated from table form to diagram form, as shown in Figures 5.2 and 5.3. The quantities of water are drawn to scale, stacked on a line, with a baseline at zero and over-extractions below the line.

Figure 5.2 shows how data describing water entering California in 2011 is taken from the portion of the water budget table outlined with a green box and stacked in a bar chart with the largest quantities at the top of the column, and the smallest quantities at the bottom. In the same manner, a column for water leaving California for 2011 is created using the data highlighted by an orange box. The data in the red box includes the changes in surface water and groundwater storage. Positive numbers are depicted above the baseline in the water entering California column, and negative numbers, which indicate over-extraction, are depicted below the baseline of zero.

Figure 5.3 shows how the published water budget table that includes water supply and use quantity data are added to the diagram between the water entering California column and the

California Hydrologic Summary (in million acre-feet)

	Water Year (Percent of Average Precipitation)					Average 1998–2015
	2011 (134%)	2012 (75%)	2013 (77%)	2014 (56%)	2015 (78%)	
Water Entering California						
Precipitation	249.4	138.9	142.0	102.6	143.3	182.2
Inflow from Oregon/Mexico	1.3	1.0	0.8	0.8	0.7	1.3
Inflow from Colorado River	4.2	4.7	5.3	5.8	5.0	4.9
Imports from Other Regions	NA	NA	NA	NA	NA	NA
Total	**254.9**	**144.6**	**148.1**	**109.2**	**149.0**	**188.4**
Water Leaving California						
Consumptive Use[a] of Applied Water (Agricultural, Municipal and Industrial, Wetlands)	26.5	30.6	30.9	30.8	29.4	27.3
Outflow to Oregon/Nevada/Mexico	2.1	0.9	0.9	0.6	0.4	1.1
Exports to Other Regions	NA	NA	NA	NA	NA	NA
Statutory Required Outflow to Salt Sink	32.6	22.6	18.8	13.1	16.6	25.3
Additional Outflow to Salt Sink	28.8	8.0	9.8	3.8	7.2	19.2
Evaporation, Evapotranspiration of Native Vegetation, Groundwater Subsurface Outflows, Natural/Incidental Runoff, Agricultural Effective Precipitation, and Other Outflows	164.7	102.7	107.4	84.4	115.2	126.8
Total	**254.6**	**164.8**	**167.8**	**132.7**	**168.8**	**199.6**
Storage Changes in the Region						
[+] Water added to storage [–] Water removed from storage						
Change in Supply — Surface Reservoir	6.2	-7.4	-4.1	-5.1	-0.8	-0.6
Change in Supply — Groundwater Storage	-5.9	-12.8	-15.8	-18.4	-19.0	-10.6
Total	**0.3**	**-20.2**	**-19.9**	**-23.5**	**-19.8**	**-11.2**

Note: NA = not applicable

[a] Consumptive use is the amount of applied water used and no longer available as a source of supply. Applied water is greater than consumptive use because it includes consumptive use, reuse, and outflows.

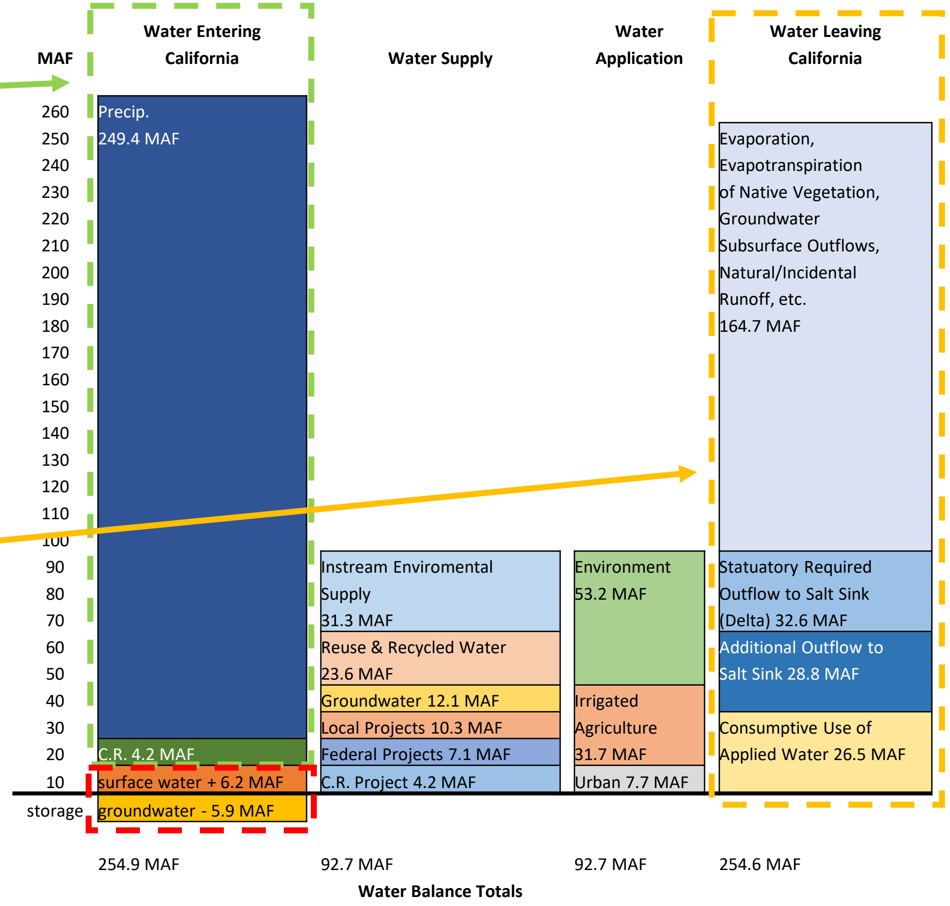


Figure 5.2. Translating the California Water Budget 2011 Data (State of California, 2019b, Table 2) for Water Entering and Leaving California, as well as Changes in Supply, from a Table to a Diagram.

California Water: How It Was Used and Where It Came From, 2011–2015

Water Year % Average Rainfall *Precipitation in millions of acre feet (MAF)*	2011 134% *248.1*	2012 75% *138.9*	2013 77% *142.0*	2014 56% *102.6*	2015 77% *143.3*
Applied Water Use - how water was used ...					millions of acre feet
Urban	7.7	8.3	8.3	8.1	7.0
Large Landscape	0.6	0.8	0.7	0.8	0.7
Commercial	1.1	1.1	1.2	1.1	1.0
Industrial	0.4	0.4	0.4	0.3	0.3
Energy Production	0.1	0.1	0.1	0.1	0.1
Residential - Interior	2.4	2.7	2.7	2.9	2.4
Residential - Exterior	2.3	2.4	2.5	2.4	1.9
Conveyance Applied Water	0.4	0.4	0.4	0.4	0.3
Groundwater Recharge Applied Water	0.5	0.5	0.2	0.1	0.2
Irrigated Agriculture	31.7	35.0	35.7	35.0	32.4
Applied Water - Crop Production	26.9	31.6	32.6	32.5	30.5
Conveyance Applied Water	3.4	3.0	2.9	2.3	1.8
Groundwater Recharge Applied Water	1.4	0.3	0.2	0.2	0.1
Environmental Water	53.2	33.9	29.8	21.7	24.7
Managed Wetlands	1.5	1.6	1.6	1.6	1.5
Minimum Req'd Delta Outflow	7.4	5.3	4.5	4.0	3.7
Instream Flow Requirements	7.9	6.8	6.6	5.6	5.3
Wild & Scenic Rivers	36.5	20.2	17.1	10.5	14.2
Total Uses	92.7	77.2	73.7	64.7	64.1
Dedicated and Developed Water Supply - where it came from ...					millions of acre feet
Instream Enviro. Supply	31.3	21.6	18.0	12.4	16.2
Local Projects	10.3	8.2	6.8	6.3	4.9
Local Imported Deliveries	1.0	0.8	0.7	0.5	0.4
Colorado River Project	4.2	4.7	5.3	5.8	5.0
Federal Projects	7.1	6.4	5.7	3.9	3.3
State Project	2.9	2.8	2.0	1.3	0.9
Groundwater Extraction	12.1	18.1	20.8	23.0	22.9
Inflow & Return Flow for Carryover Storage	0.1	0.1	0.1	0.1	0.1
Reuse and Recycled Water	23.6	14.4	14.2	11.4	10.4
Total Supplies	92.7	77.2	73.7	64.7	64.1

Source: *California Water Plan Update 2018*, Figure 1-1

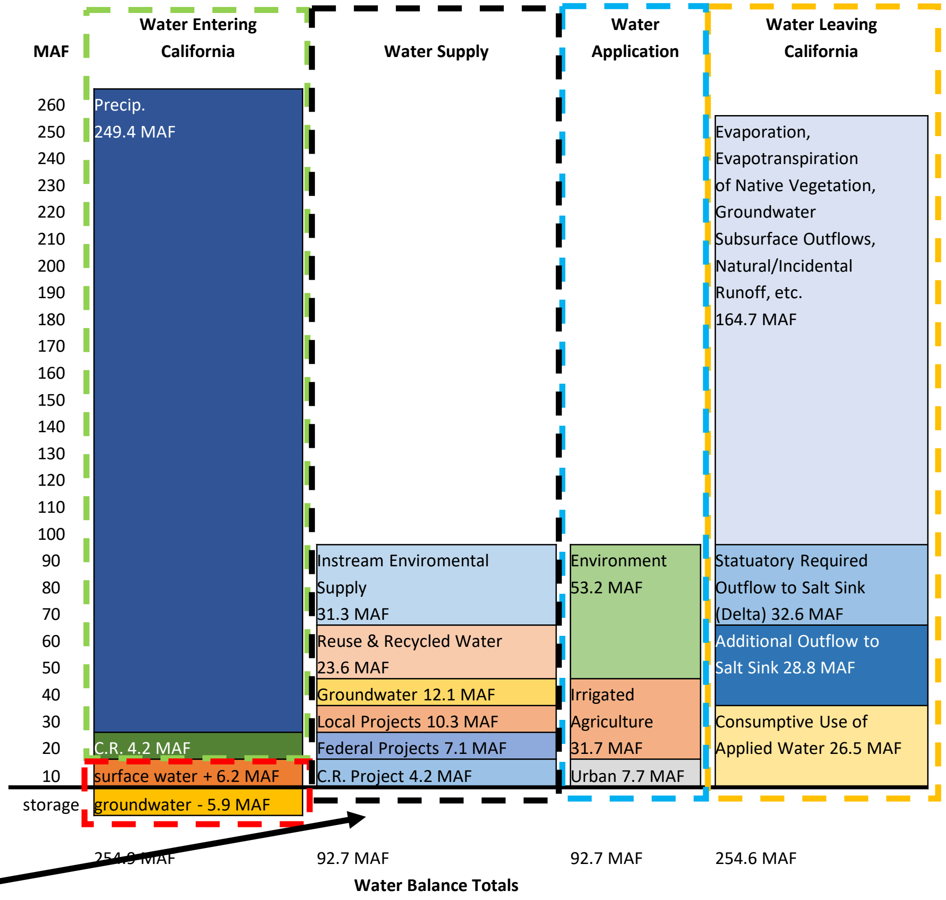


Figure 5.3. Translating the California Water Budget 2011 Data (State of California, 2019b, Fig. 1) for Applied Water Use and Dedicated and Developed Water Supply from a Table to a Diagram.

water leaving California column. Since the data in the black box describes the sources of the water used, the quantities listed in it are stacked in a water supply column and placed next to the water entering California column. The blue box highlights the data that detail how the water was used in 2011. The three water categories urban, irrigated agriculture, and environmental water are stacked in a column called water application and placed between the water supply and water leaving California columns. These columns are also ordered from largest quantity to smallest quantity. The two inside columns balance, as shown in Figure 5.3; however, the two external columns show an imbalance due to over-extraction. The same method is used to create a diagram for 2014, the dry year, which is placed beside the diagram for 2011 in Figure 5.4 for comparison.

The colours applied to the quantities depicted in the diagrams in Figures 5.2 through 5.4 do not represent anything beyond making it easier to see the different quantities more clearly. The diagrams could be created in a black and white format without colour. For demonstration purposes, quantities of water less than three million acre-feet (*i.e*., less than one percent of the mass balance) in the water budget are not included to prevent small slivers on the diagram that are difficult to see and labels that don't fit. However, small flows can be included in water budget diagrams, and are included in Figures 5.5 through 5.13 where water quality is added to a city-level water budget diagram.

While water quality data is available for most of the more than three thousand lakes in California, 304,896 km (189,454 miles) of river (NWSRS, 2020), and five hundred and fifteen groundwater basins and subbasins (CNRA, 2020), the whole state does not represent the best level of complexity for the ‘proof of concept’ of this method.

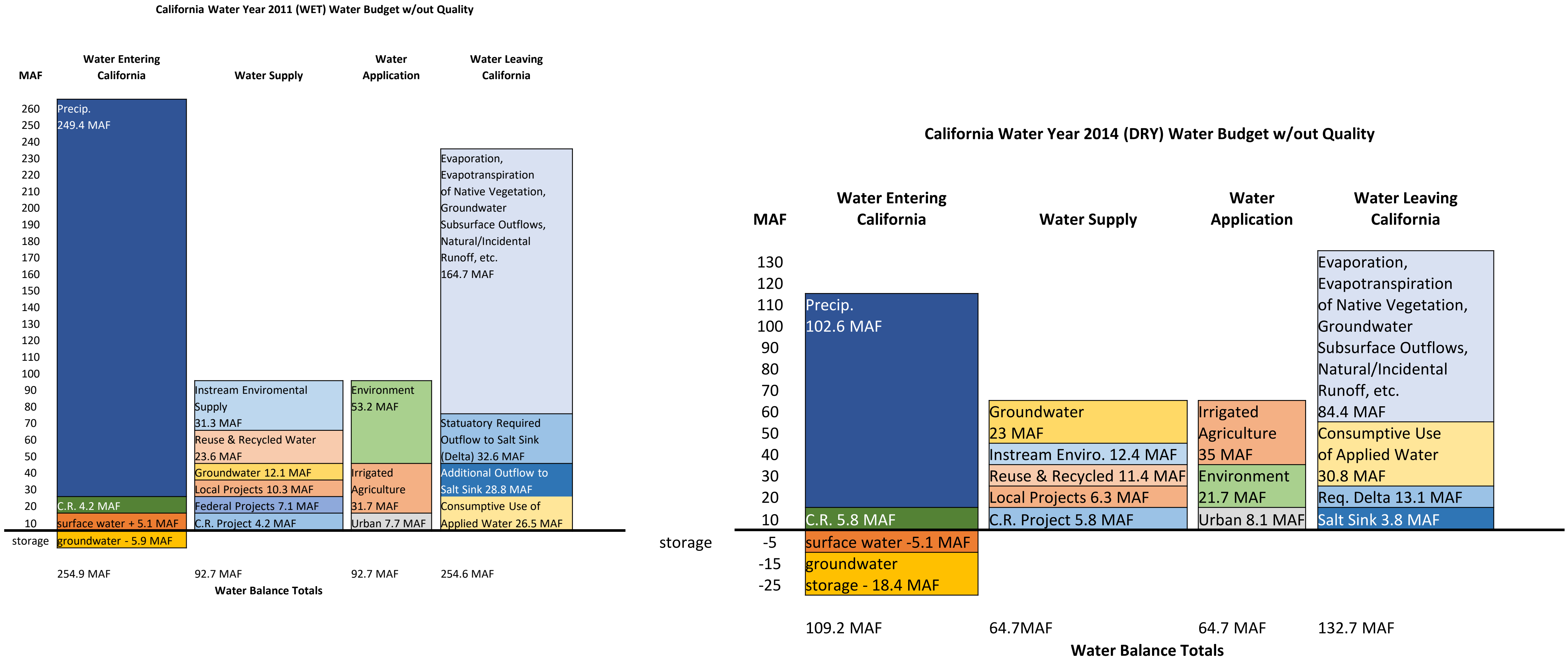


Figure 5.4. Stacked Quantities Diagrams of the Water Budgets for California Water Years 2011 (wet year) and 2014 (dry year).

Since the remaining steps of the method include adding water quality to the water budget, they are demonstrated at the city level, using City of Paso Robles water quantity and quality data.

5.2.4.2 Drawing a Modified Mass Flow Diagram for Paso Robles

Paso Robles' water budget data for water years 2011 and 2014 are translated from Table 5.1 into diagram form and depicted in Figures 5.5 and 5.6, respectively.

The diagrams depict the quantities of water either within or entering the boundary, as well as the amount extracted from each source, then treated, used, collected as raw sewage, treated to secondary effluent, and discharged into the Salinas River. The quantities are 'flowing' through the connections established between the columns of stacked quantities. The diagram has a baseline at zero, with over-extraction depicted below the line. In addition, the amount of water not used is depicted in the last column. Totals are listed at the bottom of the internal columns to show that supply and use balance, as in the statewide example.

A column is created for each change in water quality in the mass flow, in preparation for adding quality in Step 6. For example, rather than showing wastewater collection, wastewater treatment, and disposal as one column of approximately three thousand two hundred acre-feet per year, three separate columns are created since raw sewage, secondary effluent, and the Salinas River represent different levels of water quality.

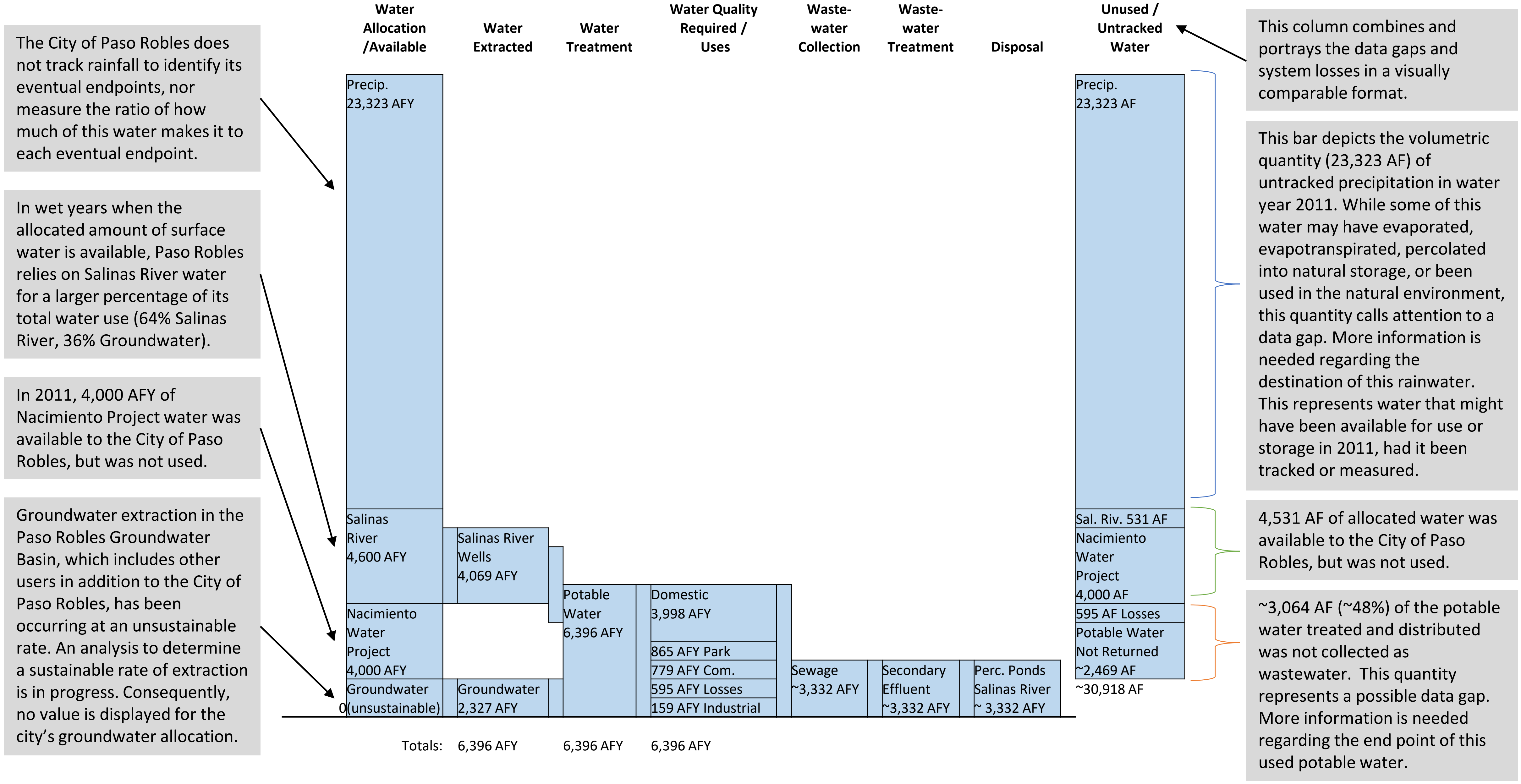


Figure 5.5. Stacked Quantities Diagram of the Water Budget for the City of Paso Robles, California for Water Year 2011, a Year with More Precipitation than Usual.

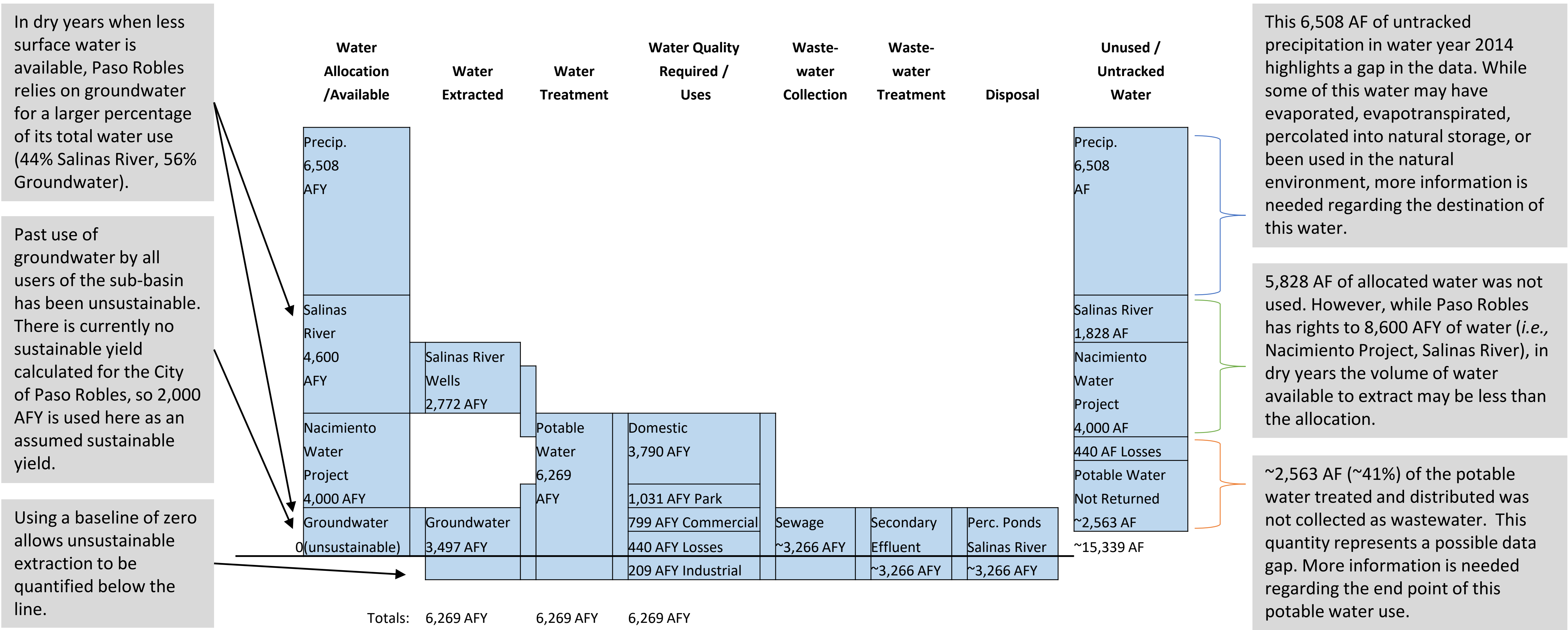


Figure 5.6. Stacked Quantities Diagram of the Water Budget for the City of Paso Robles, California for Water Year 2014, a Year with Less Precipitation than Usual.

The ‘water allocation/available’ column depicts the four types of water entering, or already within, the boundary established for this mass balance, described in the fourth chapter, and listed in Table 5.1. The precipitation quantity shown is the annual rainfall depth multiplied by the total area of the city. The Salinas River is the only surface water body in Paso Robles. The city has a right to four thousand six hundred acre-feet per year of that water, therefore that amount is depicted in this column. Water from the Nacimiento Water Project originates outside the boundary, but Paso Robles had a right to four thousand acre-feet per year in 2011 and 2014, and that allocation is added to this column accordingly. The mass balance boundary line is within one groundwater subbasin (*i.e.,* Groundwater Basin No. 3-4.06). There is currently no sustainable yield allocation calculated for Paso Robles. The city has a right to use groundwater, and the *Paso Robles Subbasin Groundwater Sustainability Plan* (PRSGSA, 2019) indicates some use of the groundwater is sustainable, but not the levels of extraction that occurred in the past. An amount between zero and four thousand acre-feet per year is needed, so two thousand acre-feet per year is used as a reasonable assumption and depicted in this column.

The ‘water extracted’ column depicts the quantities of Salinas River water and groundwater that were extracted, but because Nacimiento water was not used in 2011 or 2014, it is not depicted in this column. Paso Robles did not track what happened to the quantity of water that fell in the form of precipitation within their city limits. No assumption was made regarding the use or destination of that water. Consequently, it is not depicted in this column.

The ‘water treatment’ column shows the extracted ground and surface water is combined and treated to potable water standards. The ‘water quality required/uses’ column depicts how much potable water was used for domestic, commercial, industrial, parks and irrigation water, and system losses, as detailed in Table 5.1.

The ‘wastewater collection’ column shows the amount of used potable water that is collected at the city’s wastewater treatment plant. The city’s reports do not indicate where the potable water that is not collected and treated at the wastewater treatment plant goes, so that quantity is depicted in Figures 5.5 and 5.6 in the ‘untracked water’ column.

The ‘wastewater treatment’ column is added to the diagram because while the quantity of water may not change as it is treated from raw sewage to secondary effluent, the quality of the water changes. This column is added in preparation for Step 6 of this method when water quality is added to the water budget diagram. The ‘disposal’ column shows what happens to the water after

it is treated.

The ‘unused/untracked water’ column depicts the water that did not ‘flow’ across the diagram either because it was not used by Paso Robles, or because it is not tracked, therefore the use and destination, including quantities for each, are not known. Precipitation is included in this column, because while some of this water may have evaporated, evapotranspirated, percolated into natural storage, or been used in the natural environment, more information is needed regarding the uses and destination, including quantities for each, of this water. Paso Robles has surface water rights to eight thousand six hundred acre-feet per year of water (*i.e.,* Nacimiento Project, Salinas River). The allocated water that was not used is added to this column. Around forty-five percent of the potable water treated and distributed was not collected as wastewater. This quantity of water is added to this untracked water column because more information is needed regarding the end point of this potable water use. This column does not sit on the baseline, but instead extends down from the top of the diagram. It is a collection of unused or untracked water with the total at the bottom.

5.2.5 Step 5: Select and Assign a Colour Code to the Selected Water Quality Scale

A water quality scale is required, and used, to define categories of water quality that are applicable in the geographical context. Bitting and Cullen (2021) developed a method for creating a water quality scale for use in a California water budget. The resulting scale, made specific to Paso Robles (Figure 4.9), is selected for use here.

In this step, a colour code is selected and applied to the scale. A continuous colour scale that ranges from dark blue as the highest quality, to light blue, then light brown, and finally to dark brown as the lowest quality is preferred. Python is used to generate the continuous colour scale, and corresponding HEX Codes, and the result is the colour-coded scale shown in Figure 5.7.

5.2.6 Step 6: Apply the Colour Code Representing Water Quality to the Modified Mass Flow Diagram

Next, the colour-coded scale of water quality categories is applied to the diagram by colouring each quantity of water depicted in the diagram with the colour that corresponds to the appropriate category of water quality on the scale.

	Categories of Water Quality	Hex-Codes
D	Water Storage Tanks/Facilities	#083d7f
1	Potable Drinking Water	#084b93
E	Groundwater Wells Pumping Salinas River Underflow	#0e59a2
2	Potable Surface Water & Groundwater Augmentation	#1966ad
3	Tertiary Treated Wastewater	#2474b7
4	Food Crop Irrigation Water	#3282be
5	Public Park Irrigation Water & Recreational Impoundments	#4090c5
6	Commercial Greywater Reuse	#519ccc
7	Residential Greywater Reuse	#63a8d3
8	Industrial Reuse	#75b4d8
9	Restricted Contact Impoundments	#8cc0dd
10	Non-food Crop Irrigation Water	#a0cbe2
11	Restricted Contact Municipal Reuse	#b2d2e8
12	Processed Food Crop Irrigation Water	#c2d9ee
13	Environmental Reuse	#cee0f2
14	Secondary Treated Wastewater	#d8e7f5
I	Reclaimed Water	#e3eef8
F	Lake Nacimiento (untreated lake water)	#edf4fc
15	Agricultural Irrigation Water	#f5f3ee
16	Livestock Drinking Water	#f5f0e0
17	Captured Rainwater for Indoor Use	#f6ecd3
C	Raw Precipitation	#f6e9c5
18	Captured Rainwater for Outdoor Use	#f1dfb3
G	Nacimiento Water Project Water (delivered)	#ead59f
B	Raw Surface Water - Salinas River	#e5cc8f
A	Raw Groundwater - Paso Robles Groundwater Basin	#dec17b
19	Greywater from Clothes Washing	#d6af65
20	Greywater from Bathroom Sink & Shower	#cd9d50
21	Primary Treated Wastewater	#c48b3a
H	Raw Untreated Sewage	#b97b29
22	Raw Sewage	#ab6e1f
23	Brackish Water	#9d6116
24	Seawater	#8f540c
25	Conventional Oil Produced Water	#804a09
26	Urban Stormwater	#714108
J	Urban Stormwater Runoff	#613806

Figure 5.7. Colour-Code Applied to the Paso Robles-Specific Water Quality Scale.

5.2.7 Step 7: Order Diagram Slices by Level of Water Quality

Finally, the quantities in each slice of the mass flow diagram are ordered by water quality, with the highest quality at the top and the lowest quality at the bottom.

5.3 Result of Applying this New Method and Discussion

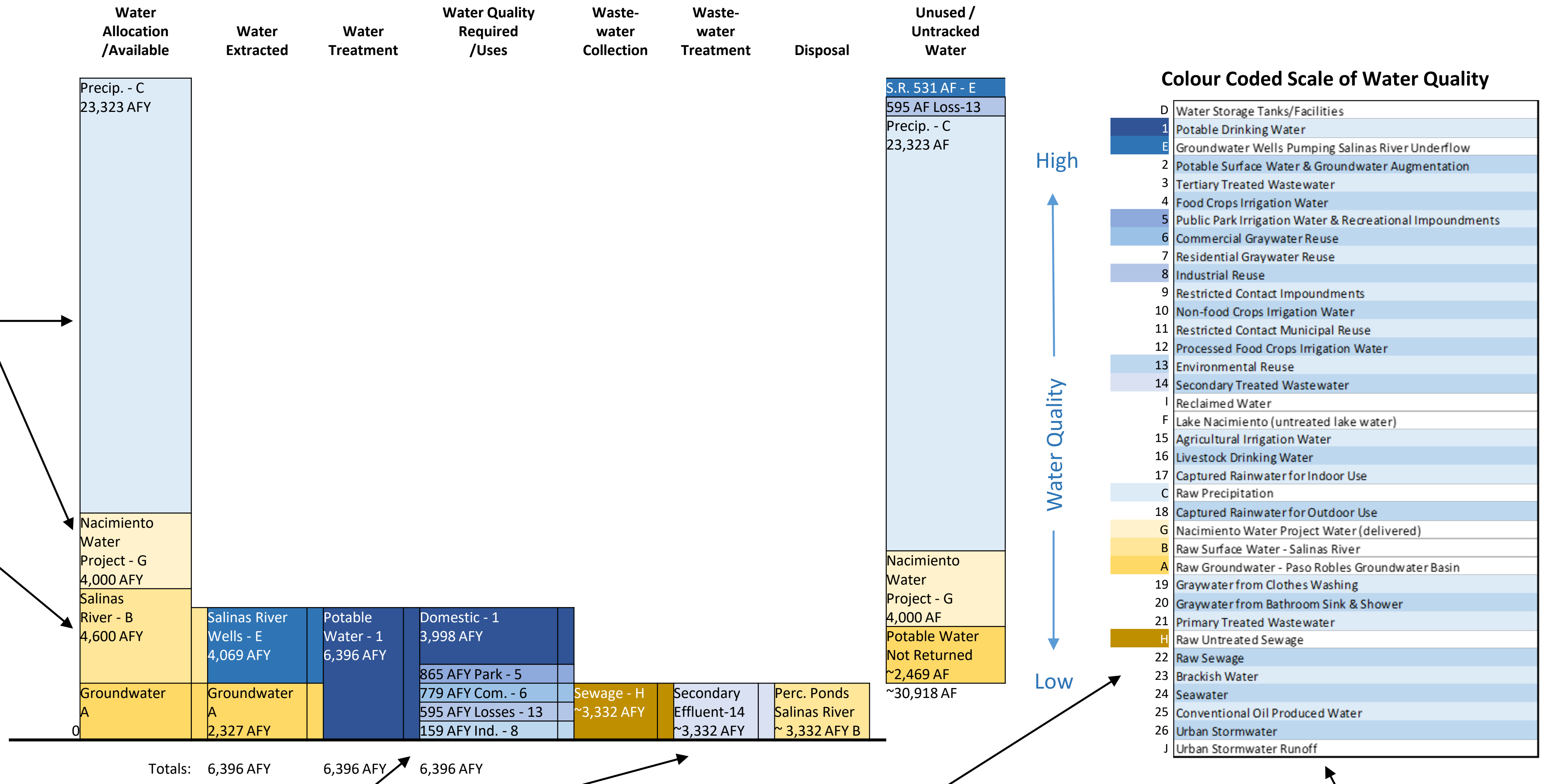
The result is a water budget depicted as a mass flow diagram that is colour-coded and ordered by quality. Figures 5.8 and 5.9 depict the result of applying the new method to the City of Paso Robles. Figures 5.8 and 5.9 include the water budget diagrams for Paso Robles water years 2011 and 2014, respectively, and the colour-coded water quality scale that was used. The quantities of water are coloured according to the corresponding category of water quality on the scale. Each column in the diagram is ordered along the vertical axis from high to low water quality.

This depiction of the water budget in diagram form provides new insights unavailable in a traditional water budget. Some of these insights are revealed just by transforming water budget tables to a diagram. Other insights come from adding water quality to a water budget. These insights are discussed in the following sections. While a stacked format is used to demonstrate the method, two alternative diagram formats are also presented in this section for comparison.

This configuration shows each slice of the mass diagram ordered by quality, with higher water quality on top, and lower water quality on the bottom.

The cleanest categories of water are not being utilized.

Paso Robles extracts their surface water right to Salinas River water using groundwater wells adjacent to the river. The river water is filtered through the soil, resulting in a higher quality of water extracted through the wells.



All of the water extracted is treated to potable water quality. Including a column depicting water quality requirements (*i.e.*, for the eventual water use) highlights that potable water quality may not be necessary for all of the water uses (*e.g.*, park irrigation).

The high quality of secondary effluent highlights an opportunity for water reuse in a use category with a similar shade of colour/quality, such as park irrigation.

The colour code applied to the water quality scale in Figure 5.7 is shown here only for the categories of water quality found in the Paso Robles Water Budget for easy identification.

This water quality scale (Bitting and Cullen 2021), shows lettered categories specific to Paso Robles in white among blue-numbered categories of water in California in descending order of quality.

Figure 5.8. Stacked Quantities Diagram of Water Budget for Paso Robles Water Year 2011 (wet year) with Water Quality Depicted Using Colour-Coded Scale.

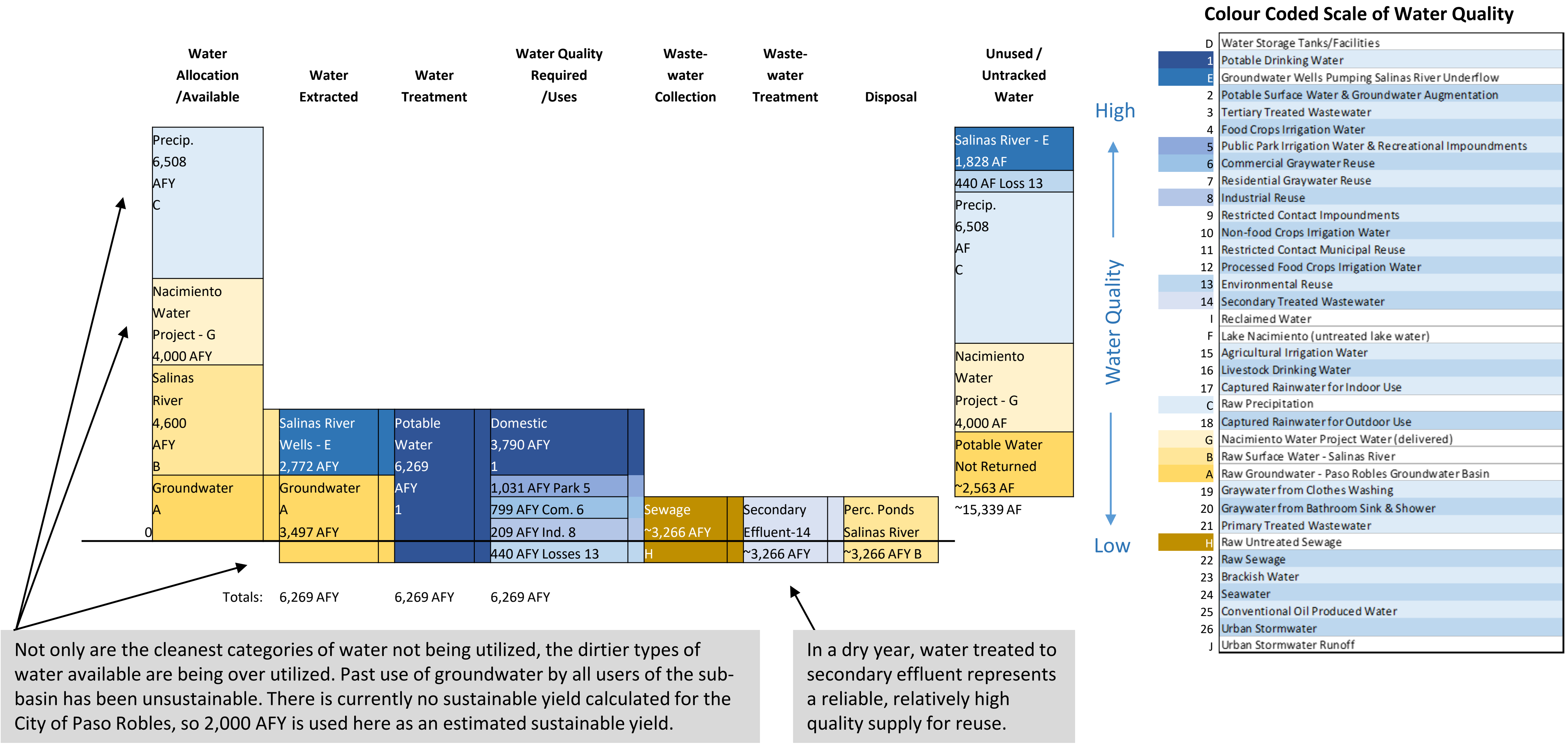


Figure 5.9. Stacked Quantities Diagram of Water Budget for Paso Robles Water Year 2014 (dry year) with Water Quality Depicted Using a Colour-Coded Scale.

5.3.1 Depicting Water Budgets as Diagrams

The conversion of water budget data tables, typically organised as shown in Figure 1.1, to a graphical representation of the data (*i.e*., Figures 5.5 and 5.6), makes imbalances, losses, and unused water more evident and easier to compare. These are discussed in the following three sections.

5.3.1.1 Identifying Imbalances, Data Gaps and System Losses

While some of the water shown in the 'unused/untracked water' column may have evaporated, evapotranspirated, percolated into natural storage, or been used in the natural environment, the diagram highlights the following two data gaps. First, the City of Paso Robles does not track rainfall to identify its eventual endpoints, nor measure the ratio of how much of this water makes it to each eventual endpoint. In diagram form, it is more evident that additional information is needed regarding the destination of this rainwater. Second, the graphical representation (*i.e.*, Figures 5.5 and 5.6) also highlights that around forty-five percent of the water treated to potable water quality was not collected as wastewater. This quantity represents a possible data gap. More information is needed regarding the end point of this used potable water.

5.3.1.2 Identifying Unused Water

The City of Paso Robles has legal surface water rights to eight thousand six hundred acre-feet per year of water: four thousand six hundred acre-feet per year from the Nacimiento Water Project, and four thousand acre-feet per year from the Salinas River, as depicted in Figures 5.5 and 5.6. However, 4,531 acre-feet of allocated surface water in 2011 (Figure 5.5) and 5,828 acre-feet of allocated surface water in 2014 (Figure 5.6) was not used. When the water budget quantities are drawn to scale, it makes it easier to compare the quantities visually and see that the amount of unused water is about eighty percent of the amount of water the city used in a year (*e.g.*, 6,269 acre-feet in 2014, 6,396 acre-feet in 2011).

5.3.1.3 Comparing Water Years

Figures 5.5 and 5.6 illustrate how a graphical representation of the data makes it easier to compare the differences between the two ends of the spectrum: higher rainfall than usual in 2011 (Figure 5.5), and less rainfall than usual in 2014 (Figure 5.6). For example, in the wet year of 2011, more surface water was used than groundwater (*i.e.*, sixty-four percent taken from the Salinas River and thirty-six percent taken from groundwater) to make up the total potable water supply for the year. Conversely, in the dry year of 2014, when less surface water was flowing in the Salinas River, more groundwater was used than surface water (*i.e.*, forty-four percent taken from the Salinas River and fifty-six percent taken from groundwater) to make up the total potable water supply that year.

5.3.2 Adding Water Quality to Water Budgets Depicted as Mass Flow Diagrams

By adding water quality to the diagrams and ordering the columns by quality rather than quantity, as illustrated in Figures 5.8 and 5.9, additional insights are gained. These are described in the following four sections.

5.3.2.1 Higher Quality Water Not Being Used

The two quantities of allocated or available water that are being used (*i.e.*, Salinas River and groundwater) are the water sources with lower water quality. Salinas River water is extracted under the city's surface water right but taken from underflow extraction wells that provide water at a higher quality (*i.e.*, category E) than the river water (*i.e.,* category B), since the water is filtered through soil. Salinas River water is combined with groundwater (*i.e.*, category A), the lowest level of water quality of the sources available, and treated at some effort and expense to potable water standards (*i.e.*, category 1). By adding water quality to the diagram and ordering the columns by level of water quality, as depicted in Figures 5.8 and 5.9, it becomes evident that the two categories of the highest quality water allocated or available are not being used (*i.e.*, Nacimiento Water Project water) or tracked by the city (*i.e.*, precipitation). These water sources could potentially be made available for use or stored in a wet year for use in dryer years.

5.3.2.2 Identify Opportunities for More Efficient Use

Viewing the quantities and qualities depicted together on the same graphic allows like quantities and qualities to be matched, revealing opportunities for meeting demand using different water sources, often at lower qualities. For example, the column depicting the water quality required, in Figure 5.8, shows that while sixty-three percent of the potable water produced is used for domestic purposes, a further twenty-eight percent is used for park irrigation, commercial, and industrial water demands. Non-potable water demand could potentially be met by using lower-quality water sources without treatment or reclaimed water. Fifty-two percent of all potable water is collected as raw sewage and treated at the city's wastewater treatment plant to a secondary effluent level of quality. This treated water is discharged back into the Salinas River, but could instead be used directly as reclaimed water to meet the demands for park irrigation, as well as commercial and industrial uses, and avoiding the additional energy and cost burden associated with re-extraction from the Salinas River wells.

5.3.2.3 Identify Alternatives to Over-Extraction of Lower Quality Water

The added benefit of depicting water quality in a water budget is evident in a scarce water year (*i.e*., 2014), as shown in Figure 5.9. Not only are the cleanest quantities of water underutilised (*i.e*., precipitation and the Nacimiento Water Project), but the lowest quality water is being extracted at an unsustainable rate (*i.e*., groundwater), leading to higher costs associated with extraction and treatment, and the corresponding negative impacts on the environment. The City of Paso Robles is not the only user of the groundwater basin. Over a thirty-one-year period, the average annual groundwater storage loss for the whole groundwater basin was approximately twelve thousand six hundred acre-feet per year (PRSGSA, 2019). The projected future groundwater budget shows a long-term imbalance between inflows and outflows and indicates an average annual decrease in stored groundwater of thirteen thousand seven hundred acre-feet per year (PRSGSA, 2019), meaning that the groundwater basin, as a whole, is in overdraft. However, the city's extraction could potentially be reduced or avoided, since cleaner water is available to Paso Robles even in a dry year.

5.3.2.4 Opportunities for Reuse

Figure 5.9 shows that there could have been as much as 15,339 acre-feet of unused or untracked water available in 2014. That amount is more than the potable water supply of 6,269 acre-feet that year. In addition, in a dry year, when the unpredictability of precipitation is evident, water treated to secondary effluent is a reliable supply for reuse. Adding water quality to water budgets may not only show areas where there is room for improvement but also depict areas where there are resources and opportunities that might not have been visually obvious from a table of numbers.

5.3.3 Diagram Options for Depicting Water Budgets with Water Quality Included

Water budget diagrams can be depicted using different formats. Three options are provided below, namely: stacked quantities; scale movement; and Sankey diagrams.

5.3.3.1 Stacked Quantities Diagrams

Stacked quantities diagrams can be drawn using a drawing tool software or using a programming software tool, as described in the following two sections.

5.3.3.1.1 Stacked Quantities Diagrams Drawn Using a Drawing Tool Software

Figures 5.8 and 5.9 are examples of stacked quantities diagrams. The advantage of this format is that no special software is required to draw the diagrams. They can be drawn using a drawing tool software such as Excel or Inkscape. Quantities are easy to compare since they are drawn to scale and baselined at zero. Water quality can be indicated using colour, and changes in water quality can be tracked by observing the changes in colour from left to right. This style of diagram makes side-by-side comparisons of water budgets, for more than one water year, easier by matching the baselines, as shown in Figure 5.10, which compares the Paso Robles water budget diagrams for 2011 and 2014.

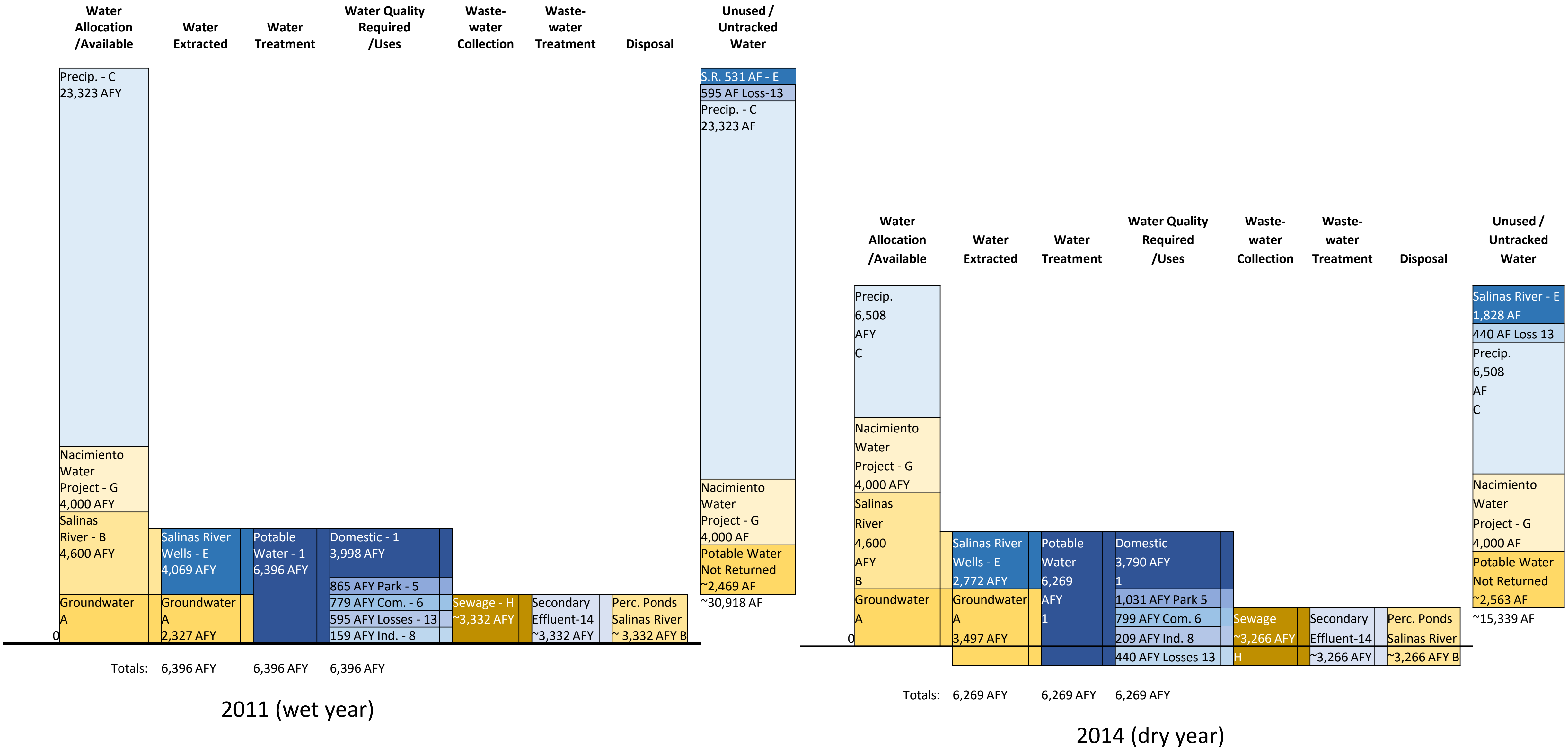


Figure 5.10. Stacked Quantities Diagram of Water Budget for Paso Robles Water Years 2011 (wet year) and 2014 (dry year) with Water Quality Depicted Using Colour.

5.3.3.1.2 Stacked Quantities Diagrams Drawn Using a Programming Software Tool

Stacked quantities diagrams can also be drawn using a programming software tool. Figure 5.11 provides an example of using the open-source programming tool Plotly to visualise the water budget data for water year 2014. The advantage of using Plotly, a Python package, is the automated generation of the figure from the data input such that the size of the stacked boxes representing the water quantities is proportional, allowing even the smallest flows to be depicted. In addition, the water quality colour scale can be automatically applied to each quantity of water. The disadvantage of using Plotly is that it requires a familiarity with Python. So far, Python tools are not commonly used for visualising water budgets. However, this may change in the future, and could be an area to be explored in further research.

5.3.3.2 Scale Movement Diagram

Figure 5.12 shows an alternative approach in which the quantity flows are positioned vertically on the water quality scale to more clearly show the changes in water quality across the water budget. This figure is drawn using Excel. Water quantities are shown in thousand acre-feet per year on a horizontal scale. In this configuration, the water quality changes are more obvious; however, the quantities are difficult to compare and the available unused water is not as evident.

5.3.3.3 Sankey Diagrams

A conventional Sankey diagram depicts mass flow quantities with the proportional thicknesses of the lines. The Sankey diagram in Figure 5.13 uses thickness to convey quantity but adds placement on the page, and colour, to convey water quality. Here, quality is

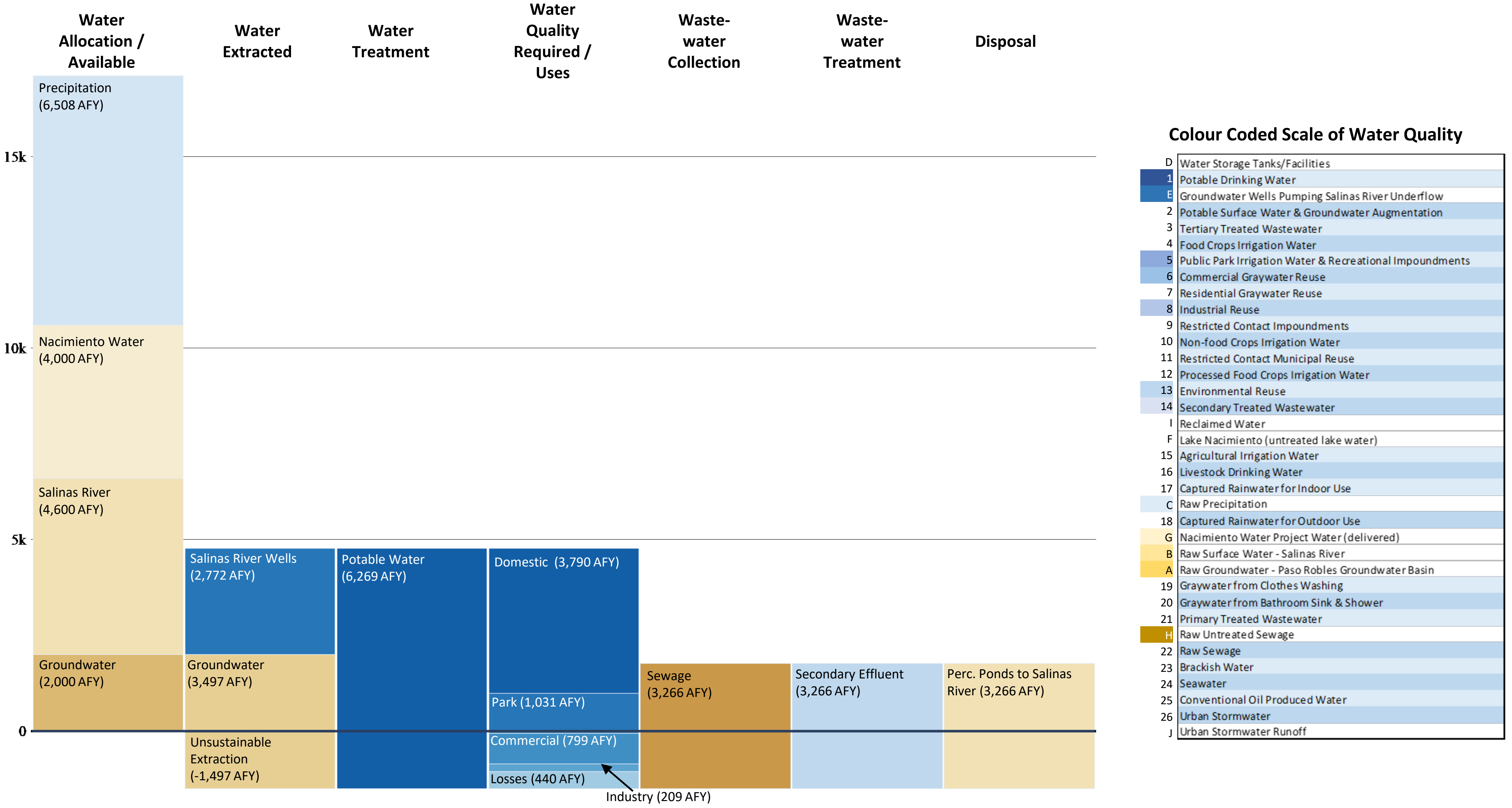


Figure 5.11. Plotly Used to Draw Stacked Quantities Diagram of Paso Robles Water Budget for Water Year 2014 (dry year) with Water Quality Depicted Using Colour.

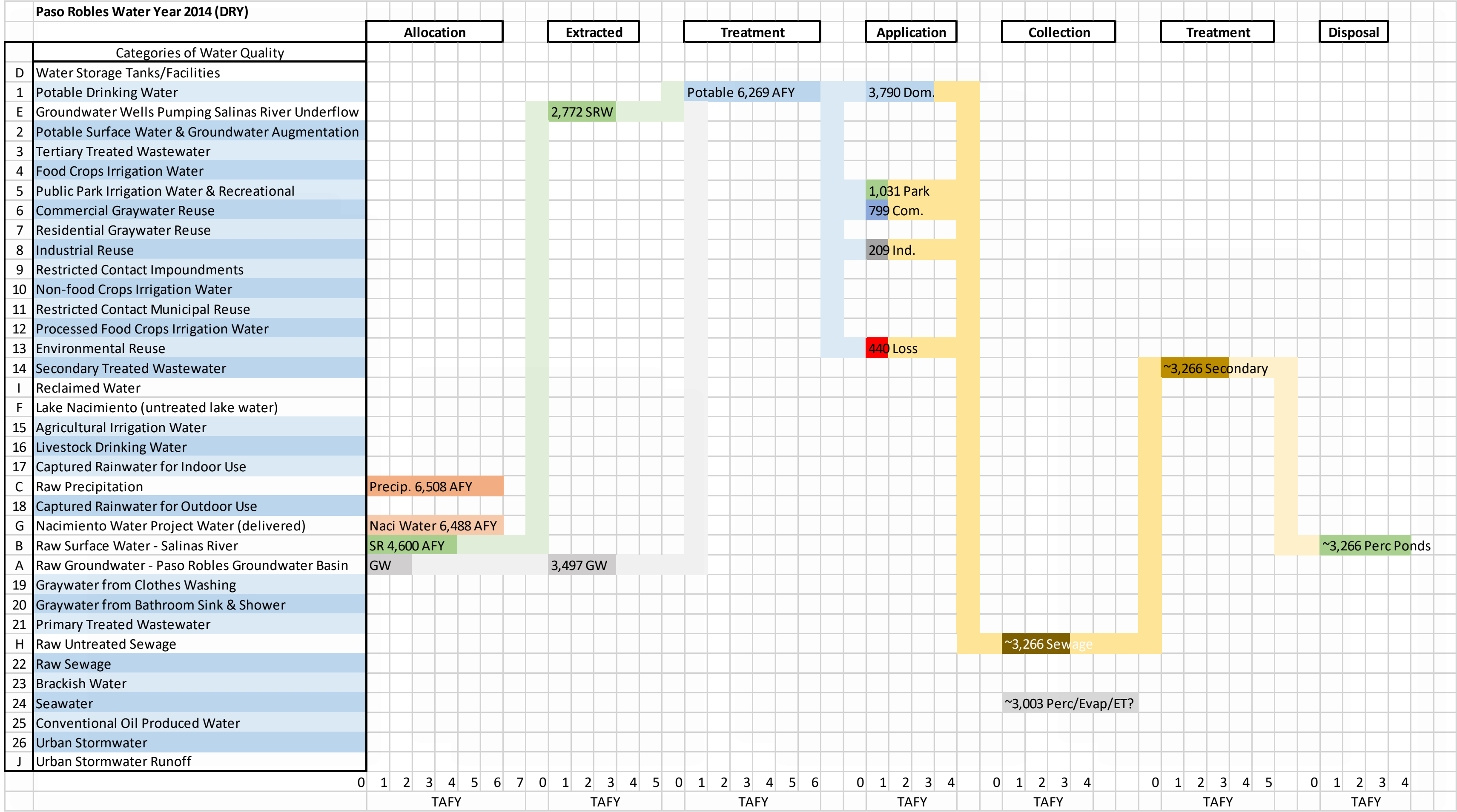


Figure 5.12. Modified Mass Flow Diagram of Water Budget for Paso Robles Water Year 2014 with Water Quality Changes Depicted via Movement on the Water Quality Scale.

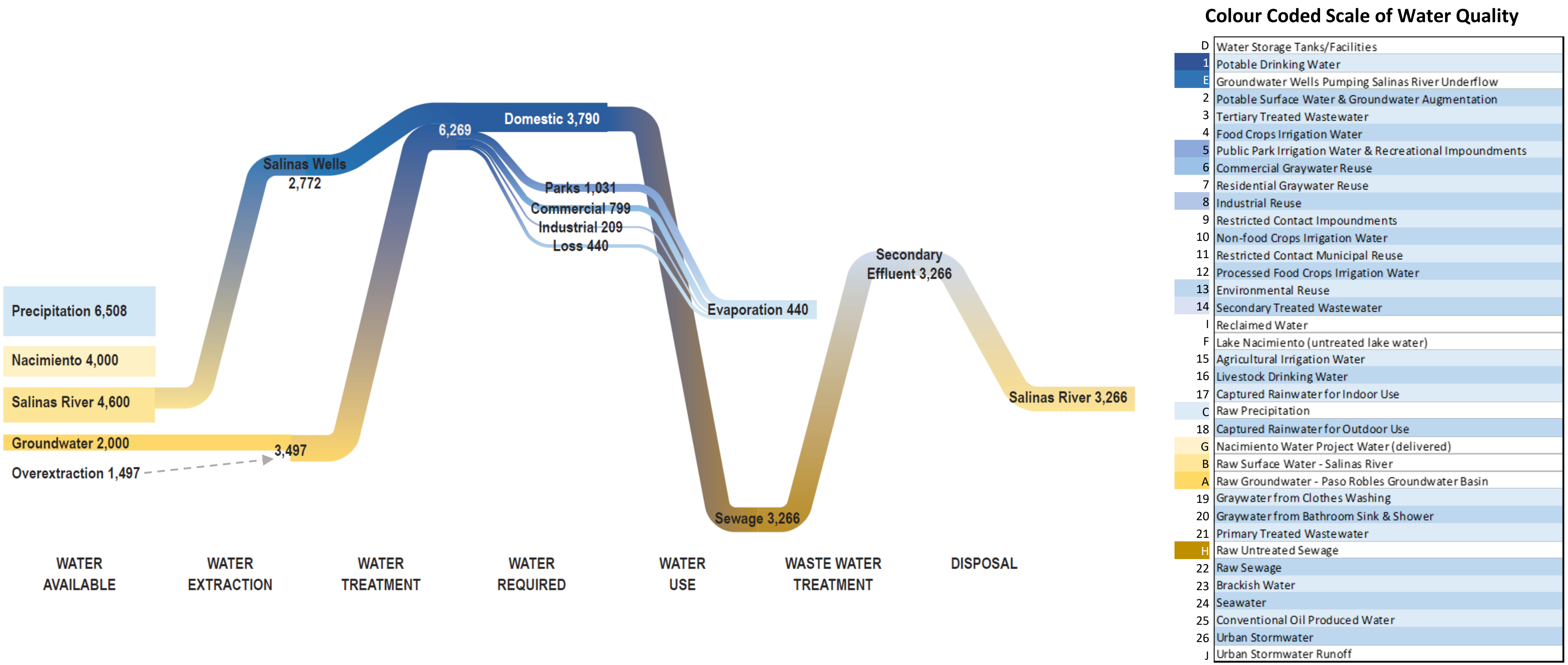


Figure 5.13. Sankey Diagram of Water Budget for Paso Robles Water Year 2014 with Water Quality Changes Depicted Using both Colour and Placement on Page.

represented by changing the vertical height of the water flows in the diagram, with flows at the top representing higher quality categories. In addition, the same colour code from the water quality scale (Figure 5.7) is used to visually represent the change in quality as the water is used or treated. In this configuration, the water quality changes are more obvious; however, the quantities are difficult to compare and the available unused water is not as evident. Different software tools can be used for visualising data in Sankey diagrams. There are commercial solutions such as e!Sankey, simple online tools including SankeyMatic, or the Python tool floWeaver. The diagrams can also be created by hand using software such as Inkscape or Adobe Illustrator.

5.4 Summary

The literature review in the second chapter reveals helpful examples of MFA used to depict water flows in California as Sankey diagrams (Curmi *et. al*., 2013). However, no method for adding water quality to a water budget is identified, so in response to the third research question, the aim of this chapter is to develop a method for adding water quality to a water budget in California.

This chapter introduces a seven-step method for creating a water budget in the form of a modified mass flow diagram that depicts the quality of each quantity of water. The method is applicable at any level of regional scale within California (*e.g.*, state, watershed basin, city) for which water quantity and water quality data are available. Water quantity data is needed for each type of water entering, leaving, used, or stored within the boundary. Water quantity data can be obtained in two ways; either by using an already balanced and published water budget, or by compiling the data needed for a water budget from multiple sources. Both approaches for acquiring water quantity data are demonstrated.

The method is demonstrated using water year 2011 (*i.e.*, above average rainfall) and 2014 (*i.e.*, below average rainfall) data for the City of Paso Robles. Applying the method for both ends of the annual precipitation spectrum provides an opportunity to compare the results and investigate how the outcomes vary. The result of the method applied to the City of Paso Robles is a water budget that includes water quality. The water budget is depicted as a mass flow diagram that is colour-coded and ordered by the quality of the water. Figure 5.8 depicts the result of applying the new method to the City of Paso Robles for water year 2011. Figure 5.9 includes the water budget diagrams for Paso Robles water year 2014. The quantities of water are coloured according to the corresponding category of water quality on the scale (Figure 5.7). Each column in the diagram is ordered along the vertical axis from high to low water quality. Three different options for visualising the water budget are provided, as well as a description of how the diagrams could be drawn either using a graphic software tool or using a programming software tool.

This depiction of the water budget in diagram form provides new insights unavailable in a traditional water budget. Some of these insights are revealed just by transforming water budget tables to a diagram. Other insights come from depicting the quality, in addition to the quantity, of water in the modified mass flow diagram. The conversion of water budget data to a graphical representation of the data, such as in Figures 5.5 and 5.6, makes identifying imbalances, data gaps, system losses, and unused water more evident. In addition, the graphical representation of the water budget data makes it easier to compare the differences between water years including the two ends of the spectrum (*i.e.,* higher rainfall than usual, and less rainfall than usual). Other insights come from adding water quality to a water budget. Adding quality to the modified mass flow diagrams and ordering the columns by quality rather than quantity, as illustrated in Figures 5.8 and 5.9, allows for the opportunity to identify areas for more efficient use, alternatives to over-extraction, and opportunities for reuse. In addition, insights regarding the inefficient use of water can be gained, such as lower quality water being over-extracted while higher quality water is not being used. The method's results and practical application, as well as the applicability to California at a statewide level and usefulness to other geographical locations, are explored further in the next chapter.

Chapter 6

Discussion

6.1 Introduction

This chapter discusses the findings of the previous chapters including: global, national, state, and local definitions of water quality, and the methods for establishing them; the method for creating a scale to add water quality to a California water budget, and the resulting scale of water quality categories; and the method for adding water quality to a water budget in California, and the resulting water budget diagram that includes water quality. The conclusions of this discussion chapter, and the thesis, are presented in the following and last chapter.

Whether there is enough water is important to Californians. One of the tools used to assess water availability in California is the water budget. It quantifies how much water enters and leaves the state, and how it is used or stored each year. This information is useful for tracking quantity; however, it does not provide any information regarding the quality of the water. To add water quality to a water budget, a set of applicable water quality definitions is required. Scales of water quality are a useful format for organising water quality definitions. Neither in the academic literature nor in practice is there a scale of water quality that contains all of the types of water found in a water mass balance in California. Material Flow Analysis is used to track water flows, including water budgets. Curmi *et al.* (2013) develop an approach for analysing water supply and demand in California and use Sankey diagrams to present the results. While water MFAs and Sankey diagrams are being used effectively to depict changes to the quantity of water as it moves through a system, water quality is not defined. The *2014 California Water Action Plan* (CNRA, 2014) identifies the need for better tools that address water quality and quantity objectives and aid communication by stating that natural resources and water quality agencies will, through a transparent process, make water delivery decisions and propose options to address water quality and supply objectives in extreme conditions. The plan states that millions of Californians rely, at least in part, on contaminated groundwater for their drinking water, and while most water purveyors blend or treat water to meet public health standards, many disadvantaged communities cannot afford to do so. Better tools are needed to address California's water quantity and quality objectives. MFA and Sankey diagrams have proven useful for mapping use, however, have not defined the quality of the water.

In response to the knowledge gaps identified above, this thesis focused on the following research questions:

1. How is water quality defined, by the entities identified in the literature review, and what method do they use to establish these definitions?
2. Can a method be established for creating a scale of water quality using the applicable water quality definitions for the types of water in a water budget in California?
3. Can a method be established for defining the quality of the water in a water budget in California?

6.2 Global, National, State, and Local Definitions of Water Quality

The organisations that establish global water quality standards (*e.g.*, WHO, UN) expect different sets of those standards to be adopted in each country, allowing for modification as appropriate to the local context. In the US and California, the US EPA and California Water Boards both use water quality standards to define water quality. Water quality standards include beneficial uses of water to be defined and allocated to each water body, and water quality criteria to be established to protect those beneficial uses. In California, groundwater is included in the definition of a water body. At the city level, for the City of Paso Robles, the water quality standards that apply to the location of Paso Robles within the state, in the central coastal watershed basin, define water quality for the city, although the city can establish more protective water quality definitions if it chooses. In summary, global, national, state, and city water quality definitions all indicate a preference for location-specific water quality definitions.

6.2.1 Methods for Establishing Global, National, State, and Local Definitions of Water Quality

The methods used to develop water quality definitions range from prescribing a specific method of analysis to using available data, as appropriate for the water type or use. Regardless of how initial water quality parameter data is collected and analysed, experts are used to either develop the definitions initially or refine them in the peer review process. In the US, and in California, the public review process involves everyone from concerned citizens to university professors, includes public meetings where input is heard and discussed, and all documents and records are made available to the public (*e.g.*, online and in public libraries). In summary, the water quality definitions established in California have been thoroughly reviewed, and therefore there is no need to develop a different set of definitions. Any new definitions proposed, if intended for use in California, would require the same public peer review process that has already occurred for the existing definitions. If a water quality definition did not exist for a particular water quality parameter and there is reason to believe it should, or if there is new evidence to suggest modifying an existing water quality definition such as cancer risk (*e.g.*, human or wildlife), there would be reason for proposing new or different water quality definitions.

6.3 Method for Creating a Scale to Add Water Quality to a California Water Budget

To add water quality to a water budget, water quality definitions for all types of water in the mass balance are required. When no applicable set of water quality definitions was found for all of the types of water in a California water budget, in the literature or in practice, that could be used to add water quality to a California water budget, this method was used to create the scales found in Figures 4.7 through 4.9. When the scales were submitted for publication, the reviewers responded that there was no published method for creating such a scale. Consequently, the focus of this research shifted from the scale of water quality to developing a method for creating the scale of water quality. This six-step method for creating a scale of water quality categories that includes water found in both the natural and built environments in California was published in the *Journal of Sustainable Water in the Built Environment* (Bitting and Cullen, 2021).

In California, water quality is defined at the hydrologic region-level by state agencies. However, water is treated and distributed to the end-user at the local level, which is consequently the level for funding and decision-making. The scale incorporates all three levels of specificity and includes the water quality definitions made at the state level (*i.e.*, for a specific hydrologic region) and water quality data specific to a particular city. Since water is transported between watershed basins, for California the optimal scope for the scale is a state scale that can be made specific to a particular city, the level at which water is sourced and treated.

In collecting water quality parameter data and values for different types of water, some are water quality standards that are mandatory, some are optional guidance values, and others are measured values requiring the comparison of values with differing levels of priority. Using this method, each water quality parameter value in the matrix is identified as either a requirement, guidance, or a measured value by applying a colour-coding system that allows the values to be easily identified as a maximum (*i.e.*, highlighted red), average (*i.e.*, highlighted orange), or minimum (*i.e.*, highlighted yellow) concentration. Single values that are not highlighted are non-enforceable maximum levels of contamination. A range of values means the level of concentration of the given contaminant is expected to fall within the range listed. Displaying the water quality parameter values allows errors to be identified and corrections made based on scientifically credible information and input during the peer review phase of the state or city public process.

In summary, the resulting scale brings together water quality requirements for use, with the quality of water in the natural and built environments. As discussed in the second chapter, existing scales of water quality include either one water quality parameter across multiple types of water, or multiple water quality parameters for the use of one type of water. The scale in Figure 4.7 intermixes for the first time supply-side and demand-side water quality, in the form of ordered descending categories, allowing the numerous types of water found in California and the various types of uses to all be compared together.

6.3.1 Resulting Scale of Water Quality Categories

The result of applying the method is a scale of twenty-six defined water quality categories for water found in both the natural and built environments of California. Each category on the scale is identified by a number and title to describe the type of water it represents. The levels of water quality are represented by twenty-three water quality parameters. The categories of water quality listed in the scale are ordered from highest to lowest quality, with an explanation of the order given in Table 4.3. The values on the scale that are maximum contaminant levels are highlighted in red, average values are highlighted in orange, and minimum allowable levels are highlighted in yellow. Alpha categories act as placeholders for water quality parameter data values for the local supply of water, allowing the scale to be tailored to a specific location within California.

The California scale can be tailored to any municipality (*e.g.*, town, city, university, military base) within the Central Coastal Basin. Therefore, tailoring the scale to a specific location within California is demonstrated by collecting and inserting water quality parameter data values for the City of Paso Robles' local supply of water into the alpha category placeholders (Figure 4.8). However, water quality parameter data is not available for all of the types of water in Paso Robles; the city does not collect stormwater quality parameter data.

The City of Paso Robles conducts potable water and wastewater quality sampling, and therefore may have the capacity to conduct, or arrange for, stormwater quality sampling. If the city identifies a gap, it can allocate funds. Since that water quality parameter data is not available, category J remains blank on the scale, to draw attention to the need to fill that data gap. The alpha categories for the rest of the water types are ordered amongst the numeric categories, and Figure 4.9 shows the resulting scale for Paso Robles' water resources and captures in one image the quality of water available compared to the standards for use.

In summary, establishing a water quality scale is an initial step toward adding water quality to a water budget. As discussed in the third chapter, to add water quality to a water budget, definitions of water quality are required, such as a scale of water quality. In the fourth chapter the method for creating a water quality scale is introduced. The resulting scale is used in the fifth chapter to add water quality to a California water budget. Since the scale intermixes for the first time supply-side and demand-side water quality in the form of defined categories, it includes the definitions necessary for the pairing of water quantity and water quality together in a California water budget. The following section is dedicated to this concept.

6.4 Method for Adding Water Quality to a Water Budget in California

The literature review in the second chapter reveals no method for adding water quality to a water budget. Consequently, this thesis introduces a seven-step method for creating a water budget, in the form of a modified mass flow diagram, that depicts the quality of each quantity of water. The method is applicable at any level of regional scale within California (*e.g.*, state, watershed basin, city) for which water quantity and water quality data are available. Water quantity data is needed for each type of water entering, leaving, used, or stored within the boundary, which can be obtained either by using an already balanced and published water budget or by compiling the data needed for a water budget from multiple sources. It is used to create a modified mass flow diagram that depicts the quantities of water either within or entering the boundary, as well as the amount extracted from each source, treated, used, collected, and discharged. A column is created for each change in water quality in the mass flow, in preparation for adding quality. The diagram has a baseline at zero, with over-extraction depicted below the line. In addition, the amount of water not used is depicted in the last column. Totals are listed at the bottom of the columns that balance.

In a mass flow diagram, imbalances may indicate storage, losses, or data errors. A process of data reconciliation is implemented to correct for imbalances. In this case, however, whenever data are not available, no guess is made as to what happens to the water, resulting in a modified mass flow diagram. The quantities of water with an end use not tracked in the water budget are collected and depicted in the 'water available, but not used' column to draw attention to the data gap. There is no evidence to confirm that this water is available for use; however, there is no evidence to confirm that it is not available for use.

A water quality scale is required to define categories of water quality that are applicable in the geographical context. The scale discussed in the previous section is colour-coded with a continuous colour scale. The colour-coded scale of water quality categories is applied to the diagram by colouring each quantity of water depicted in the diagram with the colour that corresponds to the appropriate category of water quality on the scale. This makes it easier to order the quantities in each slice of the mass flow diagram by level of water quality, with the highest quality at the top and the lowest quality at the bottom.

The order of the information in California water budget tables (Figure 1.1) and the City of Paso Robles water budget tables (Figure 2.4) is not immediately apparent; they do not appear to be ordered by quantity or alphabetically. This method orders the diagrams of water quantity by level of water quality.

Water budget diagrams can be depicted in different formats, including stacked quantities, scale movement, and Sankey diagrams. In the stacked quantities diagrams, quantities are easy to compare since they are drawn to scale and baselined at zero. Water quality is indicated using colour, and changes in water quality can be tracked by observing the changes in colour from left to right. This style of diagram makes side-by-side comparisons of water budgets easier by matching the baselines. In the scale movement diagram, quantity flows are positioned vertically on the water quality scale to more clearly show the changes in water quality across the water budget. In this configuration, the water quality changes are more obvious; however, the quantities are difficult to compare and the available unused water is not as evident. The Sankey diagram uses thickness to convey quantity but adds placement on the page, and colour, to convey water quality. Water quality is represented by changing the vertical height of the water flows in the diagram, with flows at the top representing higher quality categories. In addition, the same colour code from the water quality scale is used to visually represent the change in quality as the water is used or treated. In this configuration, the water quality changes are more obvious; however, the quantities are difficult to compare and the available unused water is not as evident.

The method is demonstrated using water years 2011 (*i.e.*, above average rainfall) and 2014 (*i.e.*, below average rainfall) data for the City of Paso Robles. Applying the method at both ends of the annual precipitation spectrum provides an opportunity to compare the results and investigate how the outcomes vary.

6.4.1 Resulting Water Budget Diagram that Includes Water Quality

The result of the method applied to the City of Paso Robles is a water budget that includes water quality. The water budget is depicted as a mass flow diagram that is colour-coded and ordered by the quality of the water. The quantities of water are coloured according to the corresponding category of water quality on the scale. Each column in the diagram is ordered along the vertical axis from high to low water quality.

This depiction of the water budget in diagram form provides new insights. Some of these insights are revealed just by transforming water budget tables to diagram form. Other insights come from depicting the quality, in addition to the quantity, of water.

The conversion of water budget data from a tabular form to a graphical representation of the data, such as in Figures 5.5 and 5.6, makes identifying imbalances, data gaps, system losses, and unused water more evident. The diagram form of the water budget makes it evident that additional information is needed regarding the destination of rainwater in the City of Paso Robles, since the city does not track rainfall to identify its eventual endpoints, nor measure the ratio of how much of this water makes it to each eventual endpoint. The graphical representation also highlights a possible data gap regarding the destination of forty-five percent of potable water that is not collected as wastewater. When the water budget quantities are drawn to scale, it makes it easier to compare the quantities visually and see that the amount of unused water is about eighty percent of the amount of water the city used in a year. In addition, the graphical representation of the water budget data makes it easier to compare the differences between water years including the two ends of the spectrum (*i.e.,* higher rainfall than usual, and less rainfall than usual).

By adding quality to the modified mass flow diagrams and ordering the columns by quality rather than quantity, insights regarding the inefficient use of water can be gained such as lower quality water being over-extracted while higher quality water is not being used. By adding water quality to the diagram and ordering the columns by level of water quality, as depicted in Figures 5.8 and 5.9, it becomes evident that the two categories of the highest quality water allocated or available are not being used (*i.e.*, Nacimiento Water Project water) or not being tracked by the city (*i.e.*, precipitation). These water sources could potentially be made available for use or stored in a wet year for use in dryer years.

In summary, adding quality to the water budget diagrams allows for the opportunity to identify areas for more efficient use, alternatives to over-extraction, and opportunities for reuse. Viewing the quantities and qualities depicted together on the same graphic allows like quantities and qualities to be matched, revealing opportunities for meeting demand using different water sources, often at lower qualities. Adding water quality to water budgets may not only show areas where there is room for improvement, but also depict areas where there are resources and opportunities that might not have been visually obvious from a table of numbers.

Chapter 7

Conclusions

The objective of this thesis is to determine whether a method can be established for defining the quality of the water in a water budget in California. To do so requires determining whether a method can be established for creating a scale of water quality using the applicable water quality definitions for the types of water in a water budget in California. That requires determining how water quality is defined. The following three sections review the three research questions and identify how this thesis has addressed each objective.

7.1 How is water quality defined, by the entities identified in the literature review, and what method do they use to establish these definitions?

Global, national, state, and city water quality definitions all indicate a preference for location-specific definitions. The methods used to develop water quality definitions range from prescribing a specific method of analysis to using available data, as appropriate for the water type or use. Regardless of how initial water quality parameter data is collected and analysed, experts are used to either develop the definitions initially or refine them in the peer review process. In the US, and in California, the public review process is robust. The water quality definitions established in California have been thoroughly reviewed, and therefore there is no need to develop a different set of definitions.

7.2 Can a method be established for creating a scale of water quality using the applicable water quality definitions for the types of water in a water budget in California?

The fourth chapter introduces a new six-step method for creating a scale of water quality categories that includes water found in both the natural and built environments in California. The method involves: selecting a geographical context; collecting water quality data applicable to the selected location; compiling water quality parameter data; organising water quality parameters in a matrix; ordering the rows of water quality parameter data values to form categories of water quality; and documenting data sources and notes.

Using this method, each water quality parameter value in the matrix is identified as either a requirement, guidance, or a measured value by applying a colour-coding system allowing the values to be easily identified as a maximum (*i.e.*, highlighted red), average (*i.e.*, highlighted orange), or minimum (*i.e.*, highlighted yellow) concentration. Single values that are not highlighted are non-enforceable maximum levels of contamination. A range of values means the level of concentration of the given contaminant is expected to fall within the range listed. Displaying the water quality parameter values allows errors to be identified and corrections made based on scientifically credible information and input during the peer review phase of the state or city public process.

The result of applying the method is a scale of twenty-six defined water quality categories for water found in both the natural and built environments of California. Each category on the scale is identified by a number and title to describe the type of water it represents. The levels of water quality are represented by twenty-three water quality parameters. The categories of water quality listed in the scale are ordered from highest to lowest quality. Alpha categories act as placeholders for water quality parameter data values for the local supply of water, allowing the scale to be tailored to a specific location within California. The California scale can be tailored to any municipality within the Central Coastal Basin. However, tailoring the scale to a specific location within California is demonstrated by collecting and inserting water quality parameter data values for the City of Paso Robles' local supply of water into the alpha category placeholders (Figure 4.8). The alpha categories are ordered amongst the numeric categories, and Figure 4.9 shows the resulting scale for Paso Robles' water resources, capturing in one image the quality of water available compared to the standards for use.

The method brings together water quality requirements for use, with the quality of water in the natural and built environments, in the form of ordered descending categories, allowing the numerous types of water found in California and the various types of uses to all be compared together. Since the scale intermixes supply-side and demand-side water quality in the form of defined categories, it includes the definitions necessary for the pairing of water quantity and water quality together in a California water budget, which is the focus of the following section.

7.3 Can a method be established for defining the quality of the water in a water budget in California?

The fifth chapter introduces a seven-step method for creating a water budget, in the form of a modified mass flow diagram, that depicts the quality of each quantity of water. The method involves: delineating the system boundary for the water balance: selecting the water budget time period to be used for analysis; collecting water quantity data applicable to the selected system boundary and time period; drawing a modified mass flow diagram; selecting and assigning a colour code to the selected water quality scale; applying the colour code representing water quality to the modified mass flow diagram; and ordering diagram slices by level of water quality.

The method is applicable at any level of regional scale within California for which water quantity and water quality data are available. Water quantity data is needed for each type of water entering, leaving, used, or stored within the boundary, which can be obtained either by using an already balanced water budget or by compiling the data needed from multiple sources.

The data are used to create a modified mass flow diagram that depicts the quantities of water either within or entering the boundary, as well as the amount extracted from each source, treated, used, collected, and discharged. A column is created for each change in water quality in the mass flow. The diagram has a baseline at zero, with over-extraction depicted below the line. The amount of water not used or tracked is depicted in the last column. Totals are listed at the bottom of the columns that balance. No guess is made regarding the fate of water when information is not available. The quantities of water not tracked in the water budget are collected and depicted in the 'water available, but not used' column to draw attention to the data gap. There is no evidence to confirm that this water is available for use, however, there is no evidence to confirm the contrary. The scale created in the fourth chapter is colour-coded with a continuous colour scale and applied to the diagram by colouring each quantity of water depicted in the diagram with the colour that corresponds to the appropriate category of water quality on the scale. The quantities in each slice of the mass flow diagram are ordered by level of water quality, with the highest quality at the top and the lowest at the bottom. Three format options are provided for depicting the water budget diagrams: stacked quantities, scale movement, and Sankey diagrams. The diagrams can be drawn using a drawing tool software or using a programming software tool.

The method is demonstrated using water years 2011 and 2014 data for the City of Paso Robles. Applying the method for opposite ends of the annual precipitation spectrum provides an opportunity to compare the results and investigate how the outcomes vary. The result of the method applied to the City of Paso Robles is a water budget that includes water quality, depicted as a mass flow diagram that is colour-coded and ordered by the quality of the water.

Water budget data presented as a diagram, rather than a table (Figures 5.5 and 5.6), provides an opportunity for imbalances, data gaps, system losses, and unused water to become more apparent. The diagram form of the water budget makes it visually evident that additional information is needed to identify eventual endpoints and the ratio of how much water makes it to each eventual endpoint. The graphical representation also highlights a possible data gap regarding the destination of potable water that is not collected as wastewater. When the water budget quantities are drawn to scale, it is easier to compare the quantities visually and see the amount of unused water relative to the amount of water used in a year. The graphical representation of the water budget data makes it easier to compare the differences between water years, including the two ends of the annual rainfall spectrum.

By adding water quality to the diagram and ordering the columns by level of water quality (Figures 5.8 and 5.9), insights regarding the inefficient use of water can be gained such as lower quality water being over-extracted while higher quality water is not being used. The two categories of the highest quality water allocated or available are either not being used or not being tracked or measured. These water sources could potentially be made available for use or stored in a wet year for use in dryer years.

A water budget that includes water quality allows for areas of more efficient use, alternatives to over-extraction, and opportunities for reuse to be identified. Viewing the quantities and qualities depicted together on the same graphic allows like quantities and qualities to be matched, revealing opportunities for meeting demand using different water sources, often at lower qualities. Adding water quality to water budgets may not only show areas where there is room for improvement, but also depict areas where there are resources and opportunities that might not have been visually obvious from a table of numbers.

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