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PROJECT NO.
4956

Addressing Impediments and Incentives for Agricultural Reuse

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Addressing Impediments and Incentives for Agricultural Reuse

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Abstract and Benefits

Abstract:

Water systems across the United States are facing unprecedented levels of stress arising from challenges such as a changing climate, aging infrastructure, and shifting patterns of water supply and demand. Agricultural water reuse has the potential to increase the resilience of water and agricultural systems through benefits such as supply diversification, access to an additional water supply, nutrient management, and compliance with water quality permits. However, realization of these benefits and scaling reuse are hindered by broad ranging, but surmountable barriers and tradeoffs. Part 1 of this report (Literature Review) provides a synthesis of the health and agronomic risks of agricultural water reuse in the context of current regulatory frameworks. Part 2 of this report (Guidebook) highlights specific strategies for addressing barriers to agricultural water reuse and includes thirteen profiles of projects and programs advancing agricultural water reuse. This work (WRF 4956) directly builds on the lessons learned in WRF 4775, Agricultural Use of Recycled Water: Impediments and Incentives, (Sheikh et al. 2019) and WRF 4829, Economic and Environmental Benefits of Agricultural Water Reuse (Thebo 2021). While the specific drivers and challenges of agricultural water reuse projects vary widely across contexts, several common themes emerged in this work. The most successful agricultural water reuse projects invariably address multiple objectives and deliver co-benefits to diverse stakeholders. They do this through early, ongoing, and strategic stakeholder engagement and partnerships. State and federal agencies can support advancement of agricultural water reuse through robust capacity building programs and integration of co-benefits into funding programs. Science-based regulatory programs that are aligned with the needs of both water agencies and the agricultural sector can streamline permitting processes while remaining protective of human, agronomic, and environmental health. In combination, the research products developed in WRF 4956 aim to support water managers, regulators, and the agricultural sector in identifying and overcoming barriers to agricultural water reuse across diverse geographic and agricultural contexts in the United States.

Benefits:

- Synthesize the current scientific understanding and knowledge gaps on the health and agronomic risks of agricultural water reuse and discussion of risk in the context of current regulatory frameworks.
- Identify the common characteristics of successful agricultural water reuse projects and programs.
- Equip stakeholders with additional resources on strategies for evaluating, incentivizing, and overcoming common barriers to agricultural water reuse projects across diverse geographic and agricultural contexts.
- Provide thirteen illustrative profiles of policies, programs, and projects advancing agricultural water reuse in the United States.

Keywords: Recycled water regulations; Irrigated agriculture; Co-benefits; Benefits and tradeoffs; Overcoming barriers; Stakeholder engagement; Capacity building; Funding; Scaling

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Acronyms and Abbreviations

AFY	Acre-feet per year
AOP	Advanced oxidation process
ARB	Antibiotic resistant bacteria
ARG	Antibiotic resistance genes
ASR	Aquifer storage and recharge
AZLGMA	Arizona Leafy Greens Marketing Agreement
BOD	Biochemical oxygen demand
BOM	Biodegradable organic matter
CEC	Constituents of emerging concern
CBOD	Carbonaceous biochemical oxygen demand
CALGMA	California Leafy Greens Marketing Agreement
COD	Chemical oxygen demand
CWA	Clean Water Act
CWNS	Clean Watersheds Needs Survey
DBP	Disinfection byproducts
DOM	Dissolved organic matter
EC	Electroconductivity
EDC	Endocrine disrupting chemicals
EPA	Environmental Protection Agency
FDA	Food and Drug Administration
FSMA	Food Safety Modernization Act
FSMA-PSR	Food Safety Modernization Act – Produce Safety Rule
HAA	Haloacetic acids
HIA	Health Impact Assessment
LGMA	Leafy Greens Marketing Agreement
MF	Microfiltration
NDMA	N-Nitrosodimethylamine
NPDES	National Pollutant Discharge System
NRCS	Natural Resources Conservation Service
NTU	Nephelometric turbidity units
O&G	Oil and gas
PAA	Peroxyacetic acid
PFAS	Per- and polyfluoroalkyl substances
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonates
POTW	Publicly owned treatment works
QMRA	Quantitative microbial risk assessment

REUSExplorer	Regulations and End-Use Specifications Explorer
RO	Reverse osmosis
SAR	Sodium adsorption ratio
SBIR	Small Business Innovation Research
STTR	Small Business Technology Transfer
SWRCB	State Water Resources Control Board
TAFY	Thousand acre-feet per year
TDS	Total dissolved solids
TMF	Technical, managerial, and financial
TSS	Total suspended solids
TWW	Treated wastewater
USDA	United States Department of Agriculture
UV	Ultraviolet
WRAP	Water Reuse Action Plan
WRF	The Water Research Foundation
WRF	Water Reclamation Facility
WWTP	Wastewater Treatment Plant

Executive Summary

ES.1 Key Findings

Key findings from WRF 4956 (Addressing Impediments and Incentives for Agricultural Water Reuse) include:

- Agricultural water reuse is an extremely heterogeneous practice with widely varying incentives and impediments and immense untapped potential.
- Despite this variability, common themes were observed across successful projects and programs. Successful projects fulfill the following criteria:
    - Address multiple objectives and provide multiple benefits
    - Have early and meaningful stakeholder engagement
    - Are backed by regulatory programs that support reuse while remaining protective of public health and the environment
    - Invest in innovation, capacity building, and partnerships
- Scientific advances make it possible to better understand which constituents are in recycled water, but differences in study context and approaches make contextualization of realized human health and agronomic risks difficult.
- Additional research on the fate and transport of contaminants of emerging concern (CECs) (especially per- and polyfluoroalkyl substances (PFAS)) in agricultural systems irrigating with recycled water could help provide fuller insights into exposure and potential health, agronomic, and ecosystem risks posed by CECs in recycled water.
- Science advisory panels, interagency working groups, and basic research can help align regulations with the current best available knowledge.
- Additional investments in practical, stakeholder-vetted tools are needed to better support decision making in the face of uncertainty.

ES.2 Background and Objectives

Water systems across the United States are operating under unprecedented levels of stress. Climate change, changes in water use patterns, and other stressors are driving the need for a paradigm shift in how the sector thinks about and manages water resources across the United States. Fortunately, there are many mature and emerging strategies, such as water reuse, that can help build water resilience and support water managers in addressing these challenges.

There is extensive but under-realized potential for expanding water reuse in the United States (Sheikh et al. 2019). Among the many types of water reuse possible, agricultural water reuse plays an important role and is often the most accessible type of reuse for small to medium communities. Agricultural water reuse has a long history of helping communities address challenging water quantity and quality issues, and additional opportunities are possible. However, research on agricultural water reuse is often confusing, conflicting, or fails to address foundational issues impeding reuse projects.

The primary aim of WRF 4956 is to develop practical, evidence-based guidance to help bridge the gap between the potential for agricultural water reuse and on-the-ground reality through the identification of proven strategies for advancing water reuse and overcoming barriers. This report focuses the use of municipal recycled water for agricultural irrigation, though some topics are also relevant for other forms of water reuse and even other sources of water.

ES.3 Project Approach

WRF 4956 employed multiple methods to identify and assess strategies for incentivizing and overcoming impediments to agricultural water reuse, including a literature review, synthesis research methods, and profiles. The literature review (Part 1) includes a survey and synthesis of current agricultural water reuse regulatory programs in the United States (Figure ES-1) and summarizes current research on potential health and agronomic risks associated with agricultural water reuse. The guidebook and profiles (Part 2) highlight specific strategies for incentivizing and overcoming barriers to agricultural water reuse. Findings from a geospatial analysis looking at several of these topics are also interspersed throughout the report document.

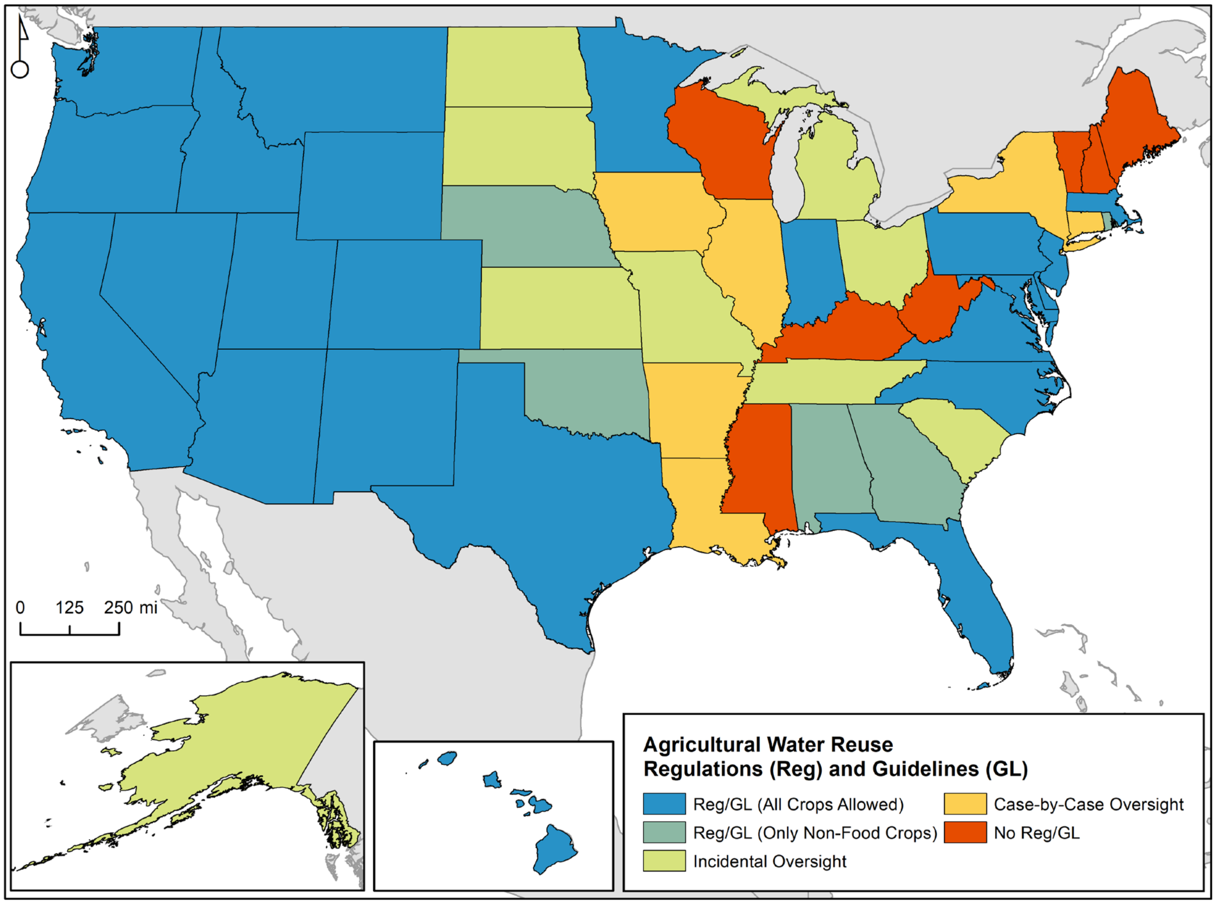


Figure ES-1. Status of State Regulations and Guidelines on Recycled Water Use in Agriculture.

ES.4 Results

The literature review (Part 1) focuses on understanding potential human health and agronomic risks associated with agricultural water reuse and how these risks intersect with current regulatory frameworks in the United States. Fit-for-purpose regulatory approaches are common and typically take a risk-based approach to set water quality criteria and monitoring requirements. Current regulations in the United States do not typically include traditional constituents of agronomic concern such as salinity, though information on these constituents is sometimes available in states with more stringent groundwater quality protection programs.

Current regulations focus on exposure to pathogens and have been shown to generally be adequately protective of public health, though there are growing concerns about CECs such as personal care products, PFAS, and other legacy chemicals. Research on the fate and transport of these chemicals in agricultural systems is convoluted and more work is needed in this area. Based on the current science as of 2018, a California State Water Resources Control Board Science Advisory Panel focused on CECs in recycled water recommended against additional monitoring or regulations on CECs in non-potable reuse. Current recommendations should be revisited periodically by the Science Advisory Panel as new scientific information becomes available. Efforts to harmonize research efforts to better understand the impact context of specific agronomic factors such as plant type, irrigation methods, and soil type are also needed. These efforts would help address concerns about both human health and agronomic risks of long-term use of recycled water.

The guidebook and profiles in Part 2 transition to a more practical examination of strategies that have proven effective in incentivizing or helping overcome barriers to agricultural water reuse (Figure ES-2).

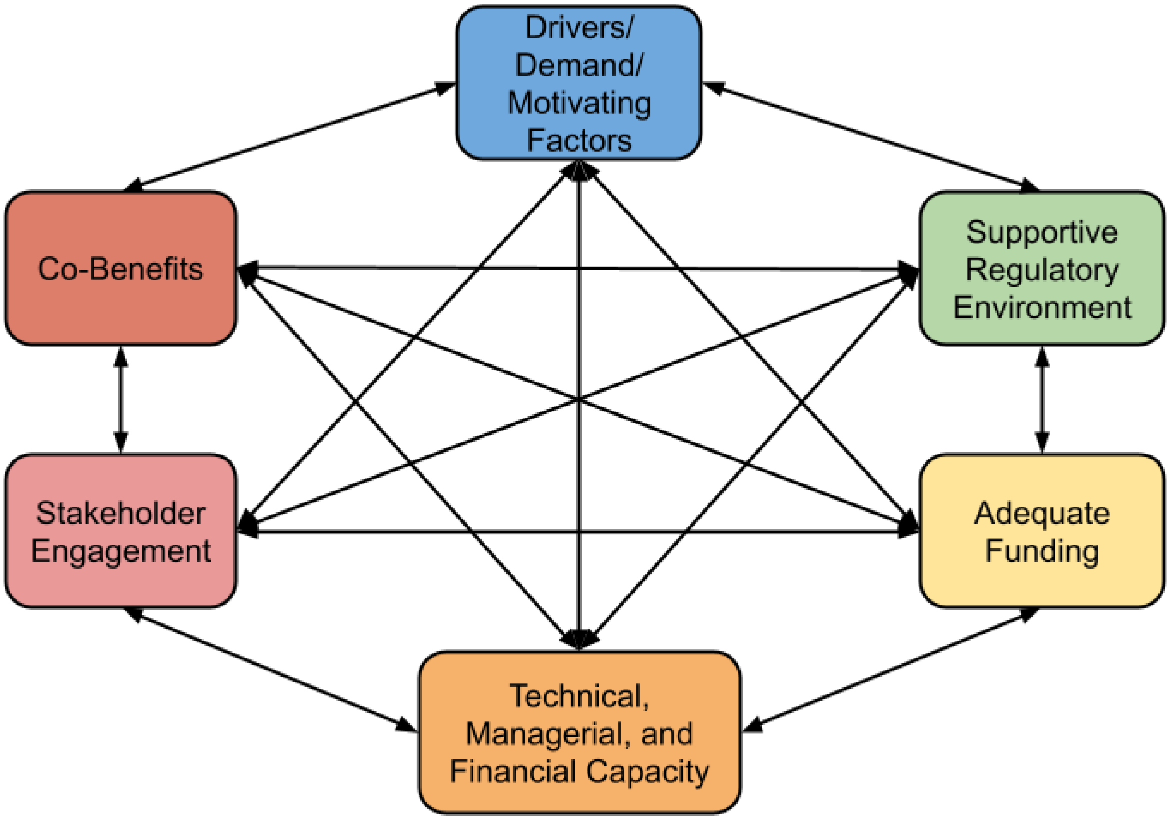


Figure ES-2. Common Characteristics of Successful Agricultural Water Reuse Programs.

Findings are organized into eight chapters, including thirteen profiles in Chapter 13. The purpose of Part 2 is to serve as a resource library for stakeholders considering pursuing an agricultural water reuse program. Topics covered in Part 2 include:

- Fit-for-purpose approaches to agricultural water reuse regulations (Chapter 7)
- Co-benefits of agricultural water reuse (Chapter 8)
- Strategies for overcoming human health and agronomic risks (Chapter 9)
- Stakeholder engagement strategies (Chapter 10)
- Addressing technical, managerial, and financial barriers (Chapter 11)
- Role of research, data, and information in scaling agricultural water reuse (Chapter 12)
- Thirteen U.S. profiles of projects and programs addressing barriers to agricultural water reuse (Chapter 13).

Chapter contents are written to stand alone though relationships between topics and relevant profiles are noted throughout the text.

The primary findings from Part 2 are that the most successful agricultural water reuse projects invariably address multiple objectives and deliver numerous co-benefits to diverse stakeholders. They do this through early and strategic stakeholder engagement and partnerships. State and federal agencies can help advance agricultural water reuse through robust capacity building programs and by integrating co-benefits into funding programs. Science-based regulatory programs that are aligned with the needs of both water agencies and the agricultural sector can streamline permitting processes while remaining protective of human, agronomic, and environmental health.

ES.5 Benefits

Agricultural water reuse has the potential to contribute to a multitude of benefits such as supply diversification and access to an additional water supply, nutrient management, climate resilience, and production of agricultural products (Thebo 2021), but realization of these benefits and the full potential for reuse is hindered by wide-ranging yet surmountable barriers (Sheikh et al. 2019). The outputs from Part 1 of WRF 4956 distill current scientific knowledge on human health and agronomic risks of agricultural water reuse, including acknowledgement of limitations in our current scientific understanding. Part 2 of this report provides concrete strategies and recommendations on how projects can incentivize and overcome barriers to agricultural water reuse. Thirteen profiles demonstrate how these strategies are being utilized within real-world regulatory programs and agricultural water reuse projects. In combination, these research products provide regulators, water managers, and the agricultural sector resources to help overcome barriers to agricultural water reuse and advance the practice across diverse U.S. geographies and agricultural contexts.

ES.6 Related WRF Research

- Economic and Environmental Benefits of Agricultural Water Reuse (4829)
- Agricultural Use of Recycled Water—Impediments and Incentives (4775)
- Groundwater Replenishment with Recycled Water on Agricultural Lands (4782)

- 2020 Update: Agricultural Best Management Practices Database (4847)
- Assessing the State of Knowledge and Research Needs for Stormwater Harvesting (4841)

About This Report

Overview

This report is comprised of a literature review, guidebook and profiles developed for WRF 4956 (Addressing Impediments and Incentives to Agricultural Water Reuse). The literature review (Part 1) includes a survey and synthesis of current agricultural water reuse regulatory programs in the United States and summarizes current research on potential health and agronomic risks associated with agricultural water reuse. The guidebook and profiles (Part 2) highlight specific strategies for incentivizing and overcoming barriers to agricultural water reuse. Findings from a geospatial analysis looking at several of these topics are also interspersed throughout the document.

Terminology and Scope

There is substantial variability across the United States in the terminology used to describe water reuse and the range of practices and water supplies that constitute reuse (Dery et al. 2016). Many sources of water such as municipal wastewater, oil and gas produced water, stormwater runoff, and tile drainage water are reused in the agricultural sector with varying levels of treatment and permitting. Water is reused in agricultural settings for multiple purposes including irrigation, dust control, and frost protection. The terms reclaimed water and recycled water are all commonly used to describe these sources of water and their use which can be a source of significant ambiguity and confusion. Many of the topics discussed in this literature review and guidebook are also relevant to the use of other alternative water sources and types of reuse. However, detailed consideration of those water sources and types of reuse were beyond the scope of this document.

WRF 4956 focuses specifically on the reuse of treated municipal wastewater for agricultural irrigation within the United States. This report refers to this practice as ***agricultural water reuse*** or water reuse (when the text is clearly referring to water reuse for agricultural irrigation). The terms recycled water and reclaimed water are considered synonymous in this document.

Previous WRF Studies on Agricultural Water Reuse

This project builds on the work of two prior WRF studies on agricultural water reuse. WRF 4775 (Agricultural Use of Recycled Water: Impediments and Incentives) provides a broad overview of agricultural water reuse and includes an assessment of the national potential for agricultural water reuse (Sheikh et al. 2019). WRF 4829 (Economic and Environmental Benefits of Agricultural Water Reuse) includes a deeper discussion of the benefits and tradeoffs of agricultural water reuse including frameworks for benefit identification and accounting (Thebo 2021). This project (WRF 4956) directly builds on these previous studies and readers are directed to preceding reports for additional rationale on the motivations for this study.

Addressing Impediments and Incentives for Agricultural Reuse (WRF 4956)

Part 1: Literature Review

CHAPTER 1

Literature Review

1.1 Introduction

Climate change, drought, and other changes in hydrologic systems are fundamentally shifting demand for water and the timing, distribution, and intensity of precipitation. Urban centers are rapidly growing in some locales while shrinking in others. Much of the water infrastructure in the United States is at or beyond the end of its useful design life. Agricultural systems are challenged by higher temperatures, prolonged, frequent droughts, and changes in historical precipitation patterns. What these changes mean practically is that the past is an insufficient predictor of future conditions in the water and agricultural sectors and additional strategies are needed to build resilience to these changes. Agricultural water reuse is one specific strategy that can help communities adapt to and build resilience to these stressors.

As with all water management strategies, agricultural water reuse has both benefits and tradeoffs. Recycled water can help communities diversify their water supply portfolio and build resilience to droughts and other supply shortages. Likewise, diverting effluent to reuse can help limit wastewater discharges to sensitive receiving waters and help water agencies comply with their NPDES permits. Water supply and water quality are two major drivers of agricultural water reuse projects. The stressors listed above are motivating interest in implementation of water reuse projects in both water scarce and water abundant regions of the United States.

However, there are also noteworthy knowledge gaps and practical barriers to safely and sustainably advancing agricultural water reuse. Regulations on agricultural water reuse have historically focused on limiting consumer's exposure to water and foodborne diseases. This focus has limited consideration of constituents of agronomic concern such as salinity, nutrients, and trace elements that are not typically removed via standard wastewater treatment processes. Scientific advances in risk assessment and measurement methods have also greatly expanded our ability to both measure and understand the fate and transport of a broad range of constituents of emerging concern (CECs). Many of which are also not removed via standard wastewater treatment processes. These advances in scientific knowledge raise many important questions around the safety and sustainability of agricultural water reuse.

- What water quality constituents should we be concerned about in water used for agricultural irrigation?
- What is the fate and transport of these constituents within plants and soil?
- How do potential human health and agronomic risk associated with these constituents vary across differing agronomic, environmental, and climate conditions?

Discussion of the risks associated with agricultural water reuse are complicated by the complex system agricultural water reuse exists within. Recycled water use is regulated at the state level while on-farm use of water is regulated at the federal level by FSMA. Different end uses of recycled water require different qualities (and quantities) of water to both sustain agricultural production and remain protective of public health and the environment. Once recycled water has been applied to crops, unique characteristics of crops, soils, climate, and a host of other contextual factors determine the extent to which potential risks are realized.

These are all big topics and the subject of significant ongoing research and discussion. A lack of scientific consensus and the very specific contexts of many studies make generalized recommendations inappropriate. With those caveats stated, this chapter begins with a discussion of the regulatory environment around agricultural water reuse in the United States – how we got to here, fit-for-purpose approaches, and recommendations for improving current regulatory approaches. This is followed by a short overview of typical wastewater treatment processes. The following two sections summarize current research on real and perceived health and agronomic risks related to the use of recycled water for agricultural irrigation. Specific strategies for managing and communicating about these potential risks are included in the companion guidebook (Part 2).

TREWAG Conference and White Paper

The TREWAG Conference was held in Israel in October 2022 and brought together international experts on agricultural water reuse. In conjunction with WRAP Action 1.6, the conference participants are producing a white paper on water quality and risks associated with agricultural water reuse that will likely address many of the same topics as this literature review from an international perspective. This will include discussion of water reuse regulations in Israel and other countries. When available, it will be posted on the WRAP Action Online Platform under Action 1.6. (US EPA 2023a)

CHAPTER 2

Agricultural Water Reuse Regulatory Environment

2.1 Overview

Amongst classes of reuse, agricultural water reuse is somewhat unique in the diverse range of sectors it involves, the complex regulatory environment it exists within, and the practice's long-standing and evolving history. This chapter begins with a short overview of guidelines, regulations, and standards relevant to agricultural water reuse. The remainder of the chapter focuses on the evolution, development, and tradeoffs of state-level fit-for-purpose regulations and guidelines on the use of municipal recycled water for agricultural irrigation.

2.2 Current Guidelines, Regulations, and Other Standards Relevant to Agricultural Water Reuse in the United States

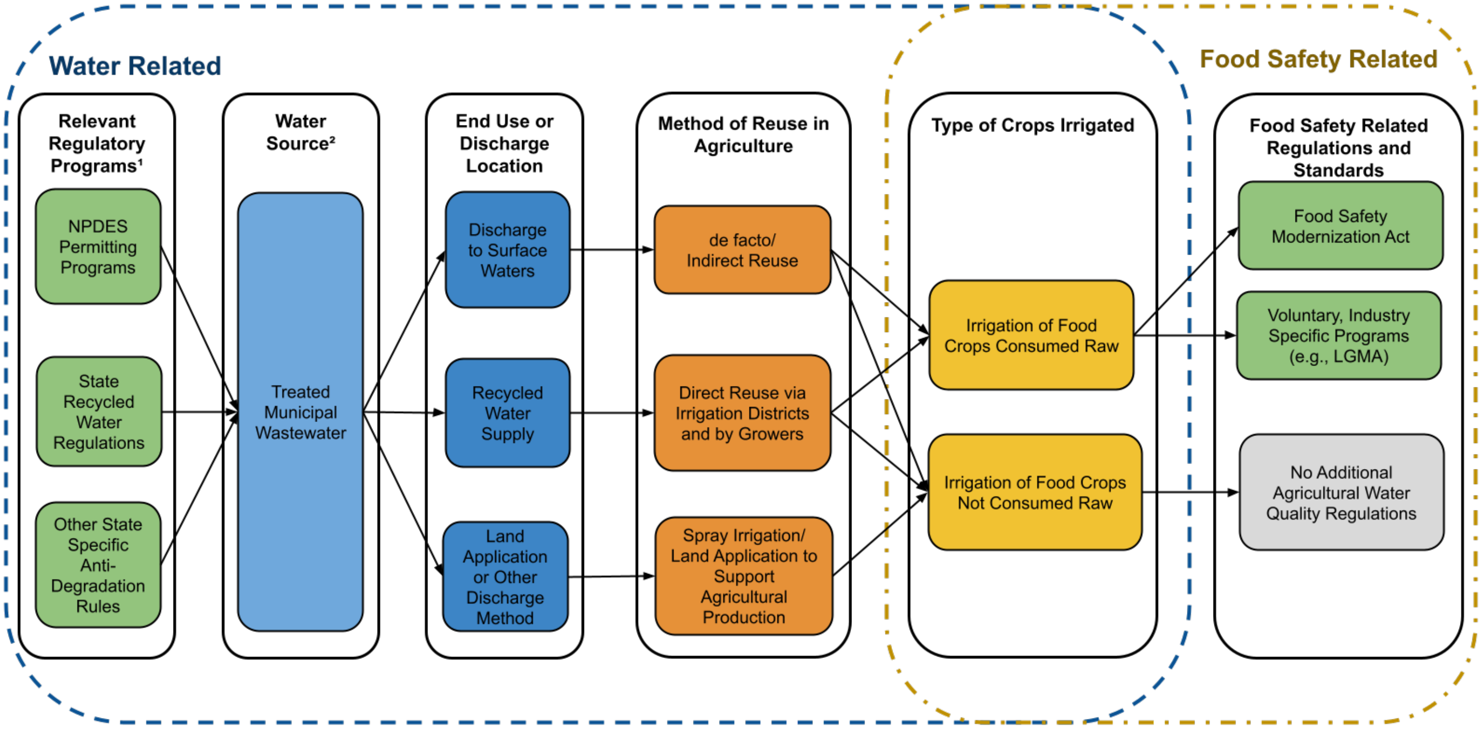
Agricultural water reuse programs are regulated directly and indirectly via a range of state and federal government programs and industry driven standards (Table 2-1). Which regulations, guidelines, and standards apply depends on the source of water being used, where effluent is discharged, how the water is reused, and the types of crops being produced (Figure 2-1). Using recycled water for organic farming is not prohibited under any certification programs in the United States. Currently, recycled water to irrigate organic crops occurs in California and in other regions in the U.S. (Sheikh 2015).

This project focuses on the reuse of treated municipal wastewater. Other sources of water are of course used (and reused) in agriculture for irrigation, dust control, washing produce, etc. Each source and use case exists within its own system of regulations. Given the focus of this project on the reuse of treated municipal wastewater for agricultural irrigation, Table 2-1 and Figure 2-1 focus on that specific water source and use case.

Table 2-1. Summary of Regulations, Guidelines, and Standards Relevant to Agricultural Water Reuse.

Regulation, Guideline, or Standard	What is it?	Developed by	Who it applies to?
2012 EPA Water Reuse Guidelines	Compendium of resources on water reuse, including best practice guidance on state regulations	USEPA and other stakeholders	N/A - General guidelines, for reference only
NPDES Permitting Programs	State-level implementation of federal Clean Water Act requirements	Federal and state environmental protection agencies	Facilities discharging to waters of the United States (includes many wastewater treatment facilities)
State Recycled Water Regulations/Guidelines	State regulations on recycled/reclaimed water quality and use	Typically, state environmental protection agencies	Water agencies treating and supplying recycled water
State anti-degradation policies impacting groundwater/ land application regulations	State regulations to limit degradation of surface and/or groundwater resources[1]	Typically, state environmental protection agencies	Land-based activities (such as the application of recycled water) that have the potential to impact surface and/or groundwater resources
Food Safety Modernization Act - Produce Safety Rule (FSMA - PSR)	2011 federal legislation creating/updating microbial water quality standards for all waters[2] used in agricultural production and processing	Federal legislation, rulemaking led by FDA	Agricultural producers and processors using water for the production of food crops consumed raw
Leafy Greens Marketing Agreement (LGMA)	Industry driven food safety standards and audits overseeing the production of leafy greens in CA and AZ	Industry consortium developed based on food safety best practices	Growers and processors of leafy greens in AZ and CA

1. Federal Clean Water Act anti-degradation policies typically do not generally apply to groundwater, but some states have supplemental regulations and permitting programs aimed at protecting groundwater quality. Some include requirements impacting the use of recycled water for irrigation.
2. FSMA-PSR regulations apply across all sources of water used in the production and processing of all food crops consumed raw. This includes recycled water, but also all other water sources used (e.g., surface water, canal water, groundwater).



1. Regulatory programs relevant to the management of municipal wastewater.
2. This figure focuses on the reuse of municipal wastewater. Other sources of water are commonly used for agricultural irrigation (see footnote).

Figure 2-1. Overview of Water Quality Related Regulations Impacting Agricultural Reuse of Treated Municipal Wastewater and the Contexts Where Different Regulations Apply.

Food Safety Modernization Act – Produce Safety Rule

While no current federal regulations exist on the use of recycled water, the FDA does recognize that some farms will be using recycled water as a source in their operations. Under the proposed FSMA PSR, current water quality and treatment requirements would apply to any water used as agricultural water, regardless of the source type, including recycled water (FDA 2021). In most cases, federal regulations (FSMA) for produce and sprouts are less stringent than the states that regulate recycled water for agricultural irrigation of crops intended to be eaten fresh, indicating that recycled water in agricultural irrigation is considered to pose lower risks to consumers (Sheikh 2020; Rock et al. 2019).

2.3 Evolution of Agricultural Water Reuse Regulations in the United States

Agricultural water reuse is a long-standing and growing practice both within the United States and around the world. Prior to the development of modern wastewater treatment in the United States, untreated wastewater from cities was used to irrigate a wide variety of crops and dispose of solids. California was one of the first U.S. states to develop guidance (1907) and regulations (1918) on the use of municipal wastewater for irrigation (Olivieri et al. 2020). Regulations in California and elsewhere have evolved significantly over the years as our understanding of health risks and the co-benefits of water reuse have evolved. Using the evolution of California’s regulations as an example, we summarize the evolution of recycled water regulations over the past century (Table 2-2) and discuss the role of agricultural reuse within this evolving regulatory framework. Many states have followed a similar regulatory pathway, starting with guidance and followed by evolving regulations tailored to the state’s needs and priorities surrounding water reuse.

At the outset, the primary objective of California’s recycled water regulations was protection of public health and reducing risks associated with the use of recycled water for agricultural irrigation and other beneficial uses. As water has become increasingly scarce and unreliable in the western U.S., California’s recycled water policy has evolved to recognize the important role recycled water plays in the State’s water management portfolio. This led to a recycled water policy with an overarching goal of motivating the safe reuse of municipal wastewater for a growing number of beneficial uses through the development of risk-based regulations and volumetric targets to encourage the expansion of recycled water use. Recycled water regulations in many western states have adopted elements of California’s recycled water policy and/or are informed by research the state has funded through organizations such as the Water Research Foundation and expert panels convened by state agencies (e.g., CECs, potable reuse criteria).

Table 2-2. Evolution of the Scope, Goals, and Aims of California's Recycled Water Regulations by Decade.

Decade(s) (Approximate)	Scope/Theme	Key Issues
1900-1930	Minimizing health risks by limiting reuse. Focus on agricultural reuse.	Growing awareness of health risks. Prohibitions on the use of raw sewage. Limited use of treated (primary) effluent for irrigation of non-food/cooked produce crops. Emphasis of on-farm management strategies (e.g., time between last irrigation and harvest).
1930-1960	Early development of science-based standards.	Developed early bacterial standards. Treatment standards expanded to allow irrigation of food crops consumed raw (provided that the effluent was "well oxidized, nonputrescible, and reliably disinfected or filtered" to meet a bacterial standard approximately equivalent to drinking water standards at that point in time. Reuse of sludge was prohibited.
1960s	Establishing the legal frameworks for managing and regulating reuse.	Porter-Cologne Water Quality Control Act. Development of state level legal authority for developing and enforcing reclaimed water standards.
1970s	Treatment reliability and expansion of beneficial uses.	Development of treatment reliability standards. Legal recognition of reuse as a priority in state water management, planning, and funding. Standards updated to allow groundwater recharge and landscape irrigation with reclaimed water. Passage of Federal Clean Water Act (1972).
1980 - 2000s	Fundamental research and demonstration of safety of recycled water.	Research, demonstration projects, advances in treatment, and consideration of a broader range of types of reuse.
1990s	Expanded recognition of reuse as a state water priority.	Development of first long-term recycled water goal (for CA) (1991).
2000s	Strategies for scaling recycled water use.	Major policy updates. Expansion of the types of reuse allowed. Updates to state goals. Shift from reclaimed to recycled water terminology. Creation of CA LGMA.
2010s	Science and data for decision making.	Expert panel reports on constituents of emerging concern (CECs). Further policy updates prioritizing reuse. Development of Volumetric Annual Reporting program. Policy and regulations on indirect potable reuse and onsite reuse. Passage of FSMA (federal).
2020s	Potable reuse. Continued update of policy and goals with new knowledge. Direct measurement methods.	Development of direct potable reuse regulations. Initial decade of results from volumetric annual reporting – better understanding of trends in reuse and wastewater availability. Scientific advances in measuring and monitoring a broader range of water quality constituents. Implementation of FSMA (federal).

Regulations on agricultural water reuse began as a means of prohibiting the irrigation of high-risk food crops with untreated or poorly treated wastewater. However, as our understanding of pathogens, health risk assessment, and exposure science have evolved, regulations in California and many other states have matured to allow for or encourage the use of recycled water for a broader range of crops and alternate beneficial uses. California and many other states take a ‘risk-based approach’ to setting water quality criteria for recycled water used for irrigation (Olivieri et al. 2014). This approach takes into account typical levels and types of exposure then uses risk assessment methods to set quantitative limits for certain water quality parameters (e.g., pathogen (indicators)) relevant to public health protection.

Fit-for Purpose Approaches

A currently recognized best practice approach to recycled water planning and regulations is via a ‘fit-for-purpose’ approach. Regulations and projects developed using a fit-for-purpose approach to water reuse match the quality of recycled water supplied with the needs of different recycled water customers while remaining protective of public health and the environment. A recognized limitation of ‘fit-for-purpose’ approaches is their focus on known threats to public health and the environment. However, there are processes for updating water quality criteria and monitoring within this framework as scientific knowledge advances.

Agricultural water reuse projects are diverse with recycled water used to irrigate everything from forest products and fodder crops through strawberries consumed raw. The health risk profile of crops irrigated with recycled water varies widely with crops consumed raw posing the highest potential health risk. Regulations adopting a fit-for-purpose approach typically use risk-based approaches to develop multiple classes of recycled water suitable for different types of agricultural water reuse. Agricultural water reuse projects employing this approach collaborate with local agricultural producers to understand the types of crops they produce, understand their water quality needs, and design treatment processes to meet these needs. Fit-for-purpose approaches can help create a win-win-win situation where public health and the environment are protected, treatment facilities are designed appropriately, and recycled water customers receive water that meets their water quality needs.

2.4 Characteristics of State Regulations and Guidelines on Agricultural Water Reuse

Recycled water use for agricultural irrigation is regulated at the state level. State priorities around reuse (or lack thereof), wastewater facilities’ interest in reuse, agricultural interests and types of production, irrigation demand, volume of wastewater available, and other factors all shape the scope and characteristics of how states approach the regulation of agricultural water reuse. Detailed guidance on the development of state water reuse regulations is included in the 2012 Guidelines for Water Reuse (US EPA 2012). The findings in this section are based on a review and update of data compiled in the 2012 Guidelines for Water Reuse and Sheikh et al. (2019) via review of state recycled water program documents, information in the USEPA REUSExplorer (US EPA 2021) and recent compilations by Shoushtarian and Negahban-Azar (2020), Ritter (2021), and Reimer and Bushman (2021). In our review, we identified seven primary elements present in most state regulations and guidelines (Table 2-3).

Table 2-3. Common Components of Agricultural Reuse Regulations.

Regulatory Component	Description
Regulatory Approach	The formality of 'regulations' governing agricultural reuse varies widely from formal regulations through guidelines, less formal guidance, incidental oversight, and case-by-case review of projects.
Crop Classes	Division into food and non-food/processed food crops is common, though many states develop more granular classes separating out orchard or fodder type crops (for example).
Classes of Recycled Water	Classes of water are linked to the types of crops that can be irrigated with a given class of water. Each class has an associated level of treatment, water quality requirements, etc.
Level of Treatment	Level of treatment required for a given class of water/type of crop.
Public Access	Whether public access to the site is restricted or unrestricted.
Water Quality Parameters	Pathogen indicators, oxidizable material (BOD, COD), and water clarity (TSS, turbidity). Specific limits and parameters selected vary widely.
Monitoring Requirements	Varies widely in terms of monitoring frequency (daily, weekly), measures of norms (median, not to exceed in n samples), and maximum values.
Engineering Report and Operator Requirements	Permitting typically requires a detailed engineering report. Operator certification and/or availability requirements.

2.4.1 Regulatory Approach

Regulatory approaches to agricultural water reuse vary widely across U.S. regions (Figure 2-2). Regulations typically develop explicit water quality and treatment specifications and are codified in law with enforcement mechanisms. Many western states have regulations where the intent is regulating the use of recycled water while, in other states, the use of recycled water is addressed incidentally via existing regulations such as NPDES and land application permits regulating the disposal of wastewater (US EPA 2012). State guidelines provide best-practice guidance on appropriate levels of treatment and water quality, but lack the legal underpinnings and enforceability of regulations. Guidelines often precede the development of regulations. Similar to regulations, guidelines can address reuse directly or provide incidental guidance. Case-by-case approval of reuse projects is the third approach states take towards regulating agricultural water reuse.

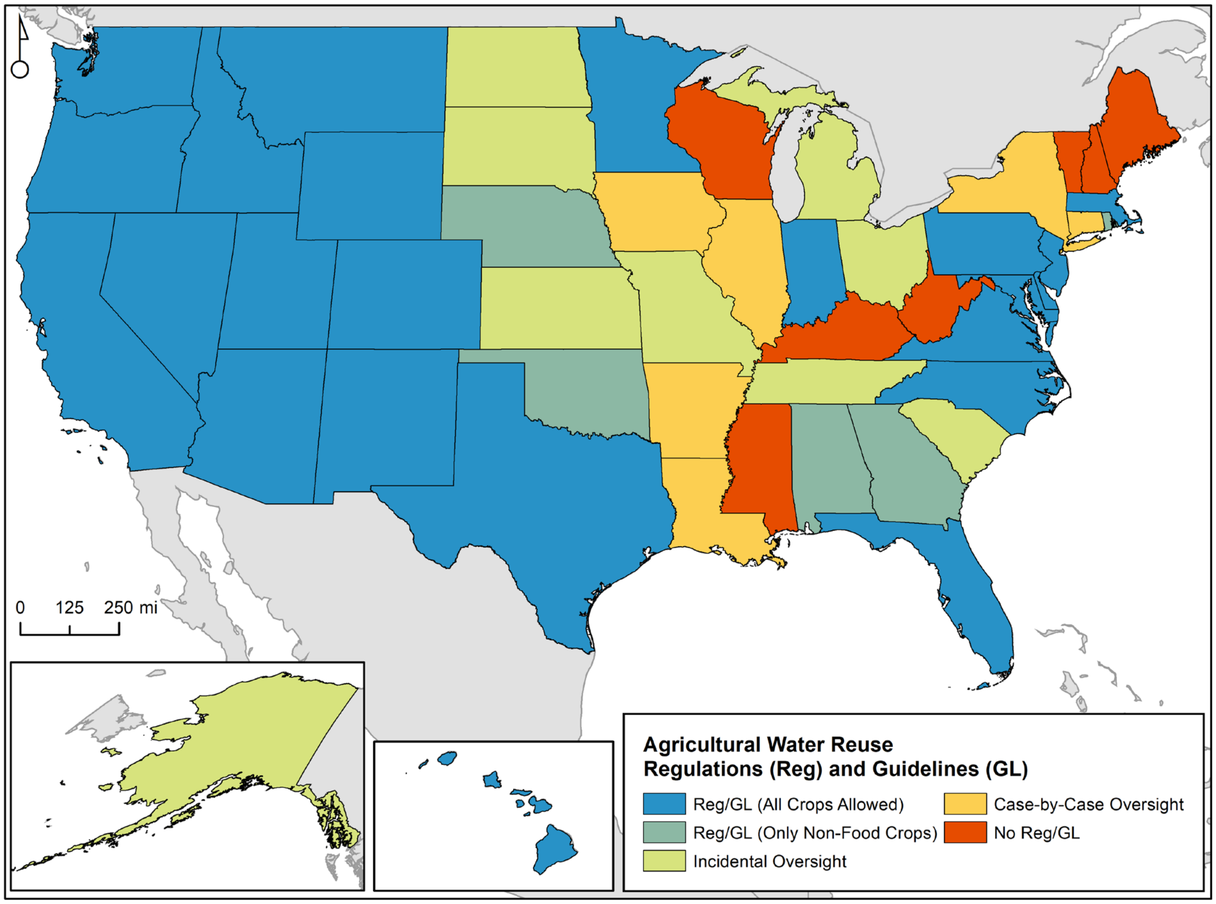


Figure 2-2. Status of State Regulations and Guidelines on Agricultural Water Reuse.

There were clear regional trends in the regulatory approaches adopted by states (Figure 2-2). Fifteen western states[1] (79%) have adopted formal regulations or guidelines on agricultural water reuse, the majority of which allow for irrigation of all crops (Table 2-4). In the eastern United States, regulation of agricultural water reuse is more heterogenous. Thirteen eastern states (42%), primarily densely populated, coastal states in the Mid-Atlantic, New England, and Southeast have developed formal regulations or guidelines. A greater proportion of eastern states (n=8, 26%) limit agricultural water reuse to irrigation of non-food crops than western states (n=3, 16%). Fifteen states take an incidental or case-by-case approach (see Box) while seven states have no regulations or guidelines on agricultural water reuse (Figure 2-2).

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[1] In this document we define 'western states' to include the seventeen western states defined by the Bureau of Reclamation plus Alaska and Hawai'i.

Incidental and Case-by-Case Oversight of the Use of Treated Wastewater in Agriculture

The agricultural and wastewater sectors have a long history of working together. Preceding any formal regulations or consideration of reuse, 'sewage farms' were a common means of disposing of wastewater and sludge (United States Geological Survey 1897; 1899). Section 2.3 talks at greater length about the evolution from a disposal to resource recovery mindset. This legacy continues to influence modern water reuse regulations and creates some ambiguity on what defines reuse of treated municipal wastewater. Land application (or spray irrigation) of wastewater is an important piece of many communities' wastewater management strategies. Particularly in the Great Plains and Midwest, land application and 'no-discharge' wastewater treatment programs are common (e.g., Ohio, South Carolina, South Dakota, Michigan, Missouri). Water from these programs is commonly used to irrigate non-food crops, particularly hay and alfalfa. Permitting typically occurs through an extension of existing NPDES permit programs and/or separate programs focused on protecting groundwater quality. Formal definitions of reuse such as those used in REUSExplorer, exclude this use of treated wastewater as a type of reuse. However, these projects are often locally significant (>130 projects in Kansas, for example (Kansas Water Office 2022)), motivated by the same drivers (Missouri Department of Natural Resources 2022), and provide the same range of benefits as formal agricultural water reuse programs. Interestingly, many of these same states (e.g., Ohio, Iowa, South Dakota, Wisconsin) do have formal regulations/guidelines on the use of recycled water for landscape irrigation suggesting land application or no-discharge programs are a distinct, locally tailored regulatory approach designed to meet local public health and environmental needs.

2.4.2 Crop Classes

In most cases, agricultural water reuse regulations and guidelines include specifics on the types of crops that can be irrigated with recycled water. At a high level, crops are commonly divided into food and non-food or processed crops. Definitions in state agricultural water reuse policies do not always align perfectly with the Food Safety Modernization Act's definition of food crops consumed raw. Food crops are considered to be higher risk because they are often consumed raw and/or recycled water makes direct contact with the edible portion of the crop.

Seventy-four percent of western states allow for the irrigation of both food and non-food crops with treated municipal wastewater/recycled water (versus 32 percent of eastern states) (Table 2-4). An additional sixteen percent of western states and 26 percent of eastern states allow agricultural water reuse for irrigation of non-food crops. These totals include uses associated with all regulatory approaches described in Section 2.4.1. Seven states did not have regulations or guidelines and an additional eight states provided unclear or non-specific guidance on the types of crops that could be irrigated via agricultural water reuse (Table 2-4). There is a lot of nuance in how states define food and non-food crops with many states developing more granular classes of crops to better reflect local agricultural production. Several examples of these classes and the specific types of crops that can be irrigated are discussed in the next section.

Table 2-4. Classes of Crops Allowed to be Irrigated with Recycled Water in the Eastern and Western United States.

Types of Crops Allowed[1]	Eastern States		Western States		TOTAL
	n	% in Region	n	% in Region	
All Crops Allowed	10	32	14	74	24
Only Non-Food Crops Allowed	8	26	3	16	11
No Reg/GL or Unclear[2]	13	42	2	11	15
TOTAL	**31**		**19**		**50**

1. Includes all regulatory approaches (Reg/GL, Incidental, and Case-by-Case)
2. Unclear includes incidental and case-by-case regulatory states where it was not clear what types of crops were allowed to be irrigated.

2.4.3 Classes of Recycled Water

States adopting a fit-for-purpose approach commonly adopt regulations that include multiple classes of recycled water. Classes are defined based on the level of treatment and measured water quality thresholds. Each class has specific types of crops that can be irrigated with a given class of water. Appendix A includes tables summarizing the classes of recycled water adopted by four states from multiple regions of the country. REUSExplorer[2] (US EPA 2021) provides direct links to current state regulations and guidelines for multiple types of water reuse, including agricultural water reuse.

California

Agricultural irrigation remains one of the most common beneficial use of recycled water in California (~190,000 of 728,000 AF in 2020) (California State Water Resources Control Board 2021). California is the nation's top producer of a diverse range of commodities including numerous fruit and nut crops while also producing large quantities of fodder crops such as alfalfa to support the state's dairy and cattle industries. The diversity of agricultural production in California is reflected in the state's tailored approach to regulating recycled water use in agriculture (Table A-1).

Florida

Florida is the nation's largest user of reclaimed (recycled)[3] water, reusing approximately 2 MAFY. However, most reclaimed water use in Florida supports urban irrigation with only about 60,000 AFY used for agricultural crops (FDEP 2021). Citrus is the most common edible crop irrigated with reclaimed water in Florida though the majority of agricultural irrigation (86%, 51,000 AFY) in Florida is for irrigation of non-food crops. Regional differences in the use of reclaimed water in Florida are reflected in Florida's regulatory approach (e.g., regulations oriented around public access vs, specific beneficial use classes) (Table A-2).

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[2] https://www.epa.gov/waterreuse/regulations-and-end-use-specifications-explorer-reusexplorer

[3] Florida uses the term reclaimed vs. recycled water in their state regulation. The two terms are synonymous in this context.

Idaho

Idaho is unique among states with robust reuse programs in that it has many long-standing examples of municipal reuse in smaller communities. Agricultural irrigation is the primary beneficial use of recycled water in Idaho. Many of these projects were motivated by a need to better manage nutrient discharges to surface or groundwater. What has evolved is a relatively unique set of regulations that are tailored to the state's unique reuse needs while adopting best practices from other western states (e.g., California's approved technologies list, log reduction approach) (IDEQ 2017a) (Table A-3).

Minnesota

Minnesota has a long-standing spray irrigation program using recycled water for irrigation of non-food crops. The primary driver for these programs is nutrient management. In recent years, the state has expanded their efforts around reuse to develop more formal regulations (Table A-4) modeled on those developed in California. Minnesota's reuse policies were developed by an inter-agency workgroup and also include guidance on the reuse of stormwater (Interagency Workgroup on Water Reuse 2018).

2.4.4 Level of Treatment

Standards commonly describe the level of treatment required to use the water for a specific purpose (e.g., irrigation of food crops consumed raw). Examples of typical treatment descriptors include oxidized, secondary treatment, filtration, and disinfection. Definitions of the specific technologies, processes, and treatment methods that meet these definitions vary state by state. Lists such as California's "Alternative Treatment Technology Report for Recycled Water" continue to evolve as the efficacy of novel treatment technologies is demonstrated(California State Water Resources Control Board 2014). The majority of states with regulations or guidelines on agricultural water reuse include treatment train specifications in their recycled water standards. Agricultural water reuse standards commonly require secondary treatment plus disinfection for non-food or processed crops while secondary treatment plus filtration and disinfection is required for food crops.

2.4.5 Water Quality Parameters

Three main classes of water quality parameters are relevant to agricultural reuse projects – human health, physicochemical, and agronomic parameters. Descriptions of the types of water quality parameters included in each class is summarized in Table 2-5 with additional discussion of agronomic and select physicochemical parameters in Chapter 5 (Evaluate and characterize long-term impact of agricultural water reuse for agricultural producers). Agricultural water reuse regulations have historically focused on the protection of human health and the environment and therefore tend to focus on parameters measuring treatment efficacy. Potential agronomic impacts of recycled water have not typically been a major factor in the development of recycled water criteria which has led to the underrepresentation of these parameters in current recycled water regulations in the U.S. though inclusion of agronomic parameters is more common in middle eastern countries (Shoushtarian and Negahban-Azar 2020; Sheikh et al. 2019).

Direct measurement of pathogens, CECs, and some other constituents in recycled water is an ongoing challenge and area of active research (e.g., Malayil et al. 2021; Drewes et al. 2018; Jiang et al. 2022) due to low concentrations (e.g., viruses), limitations in measurement methods, cost of direct measurement, and/or other factors. As such, current regulations typically utilize process indicators and/or fecal indicator bacteria such as turbidity, total coliform, and *E. coli* to assess treatment efficacy and removal of pathogens. Measurement methods for contaminants of emerging concern (CECs) is an area of ongoing research (Olivieri et al. 2016; Sutton et al. 2022; Drewes et al. 2022; 2018). Current agricultural reuse water quality criteria do not include standards on CECs though it is likely that these constituents will be monitored and regulated in the future, particularly in recycled water used for potable uses.

Table 2-5. Example Water Quality Parameters by Class.

Parameter Class	Example Parameters
Human health	Pathogen indicators (*E. coli*, Fecal coliform, Bacteriophage); Metals; CECs
Physicochemical	BOD_5, COD, TSS, TDS
Agronomic	Sodium adsorption ratio (SAR), Boron, Salinity

While regulations on recycled water use in agriculture vary by state, there are a few key classes of parameters states commonly include in their recycled water standards. A brief description of each of these topics is described below.

Oxygen Demand (of the recycled water) - Biochemical oxygen demand (BOD), chemical oxygen demand (COD), and carbonaceous BOD (CBOD) are common measures of different types of oxidizable substances in the recycled water. Wastewater discharge permits NPDES typically include limits on BOD, COD, and/or CBOD to limit oxygen depletion and degradation of receiving waters. In the case of recycled water, oxygen demand measures are used to monitor potential risks to aquatic ecosystems (from recycled water) and as a process indicator of treatment efficacy.

Total Suspended Solids (TSS) and Turbidity – Both TSS and turbidity measure the clarity of the recycled water, but do so via different measurement methods. TSS is a quantitative measure of the total amount of suspended solids present in the recycled water. Turbidity measures how well light passes through the sample. Both TSS and turbidity are process indicators measuring the efficacy of the treatment process. Since turbidity can be measured easily and in real time, it can be an early indicator of breakthrough in filtration systems.

Pathogen Indicators – Three commonly used pathogen indicators in recycled water standards are total coliform, fecal coliform, and *E. coli*.[4] Because of the challenges of directly measuring pathogens discussed earlier in this section, recycled water standards typically use indicator bacteria that are biologically similar to the actual pathogens that are the target of treatment processes. Total coliforms are extremely numerous in the environment and, as such, serve as a conservative process indicator (i.e., if concentrations of total coliform are low, it is likely that concentrations of all pathogenic bacteria are low). Process indicators such as total coliform provide insights into whether treatment plants supplying recycled water are operating

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[4] Enterococci is also an approved indicator in <5 states.

acceptably. Fecal coliforms are a more specific class of indicator bacteria and typically linked with fecal contamination. Fecal coliforms are a subset of total coliforms. *E. coli* is a more specific fecal indicator. Most *E. coli* are not pathogenic, but some specific strains are pathogenic (e.g., enteroaggregative *E. coli* (EAEC), enterotoxigenic *E. coli* (ETEC)). Shoushtarian and Negahban-Azar provide additional information on how different states and countries are using pathogen indicators in their agricultural reuse water quality criteria (Shoushtarian and Negahban-Azar 2020).

Other Water Quality Parameters – Pursuant to Federal anti-degradation policies in the federal Clean Water Act facilities are required to demonstrate that they will not adversely impact surface and groundwater quality. Implementation of this requirement varies state-by-state, but commonly requires an analysis demonstrating that the use of recycled water will not adversely impact surface or groundwater quality. Salts and nutrients are common water quality parameters at the center of these analyses. California, Florida, and other states require coordination with basin-level salt and nutrient management planning efforts. In the future, CECs may play a bigger role when there are potential impacts on sources of drinking water.

2.4.6 Monitoring Requirements

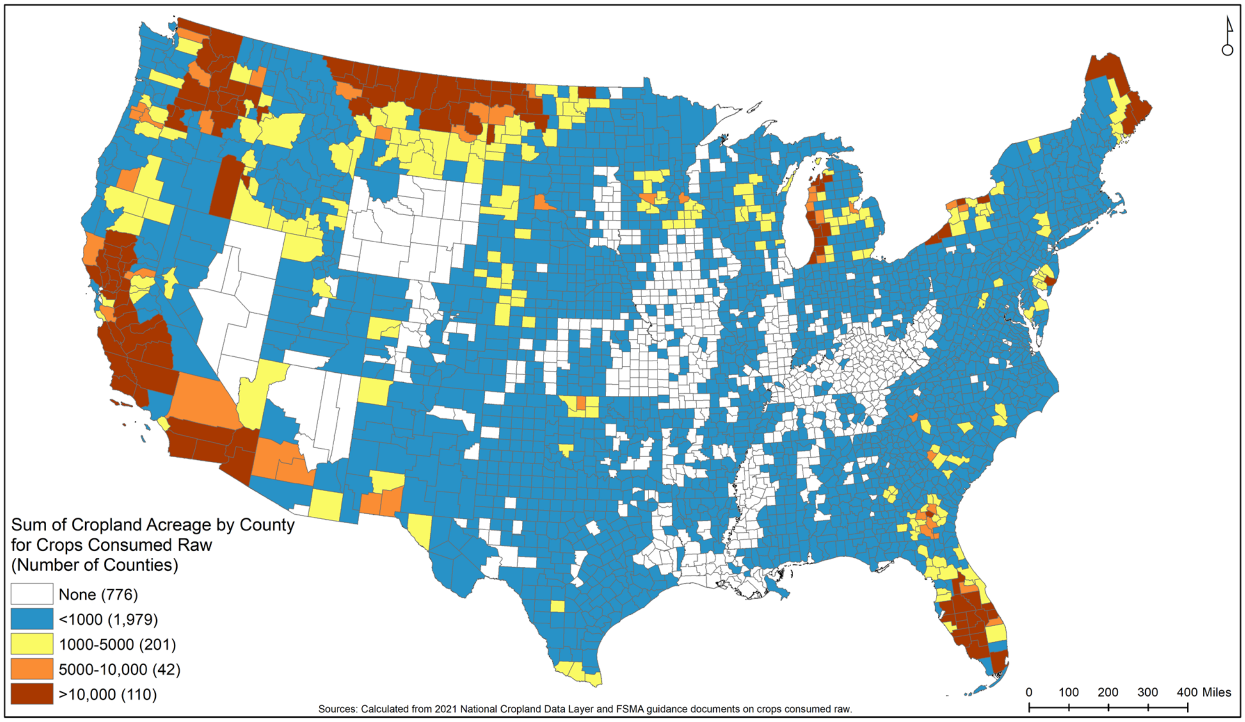
Recycled water standards typically specify different maximum allowable concentration limits over different time scales. Monitoring frequency varies state-by-state and with individual recycled water permits. While there is a lot of variation in the specifics, regulations typically include at least two values – an average or median value and an absolute maximum that no recycled water sample should exceed. For example, California's non-potable reuse standards specify maximum total coliform concentrations for a 7-day median, maximum for no more than one sample in a 30-day period, and an absolute maximum value that no sample should exceed. The wide variety of different metrics used to define regulatory limits makes quantitative comparison across state values challenging.

2.4.7 Engineering Reports and Operator Standards

State programs regulating agricultural water reuse commonly require a detailed engineering report. The specific contents of these reports vary but typically requires information on system design, where and how the recycled water will be used, a plan for monitoring, results from anti-degradation analyses, and other locally relevant information. In addition, many states require facilities to employ certified operator(s), set standards for operator availability, and develop contingency plans if systems malfunction.

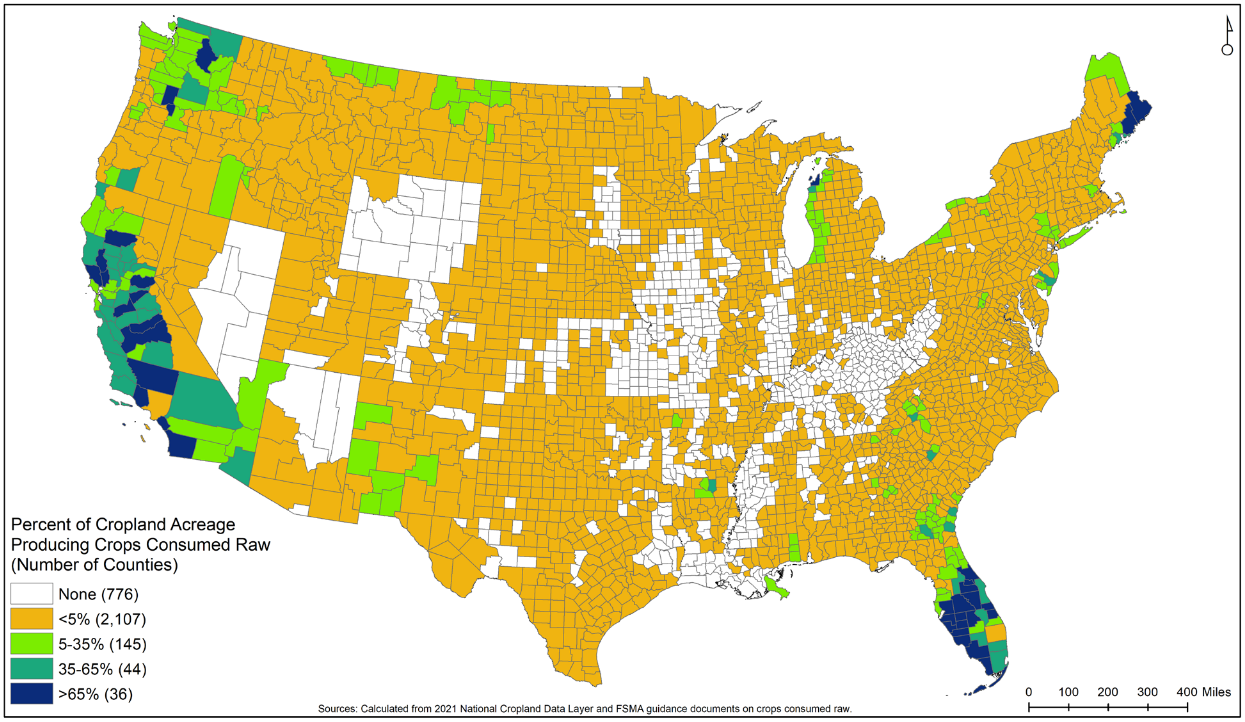
2.5 Production of Crops Consumed Raw

A key component of fit-for-purpose approaches is matching the quality of recycled water with the needs of a given end use. Typically, this approach focuses on minimizing risks to public health from food and waterborne pathogens. Factors such as whether a crop is consumed raw or cooked, processed, or used for non-food purposes (e.g., wood products) all impact the level of risk consumers are exposed to via agricultural water reuse. From a food and waterborne disease perspective, irrigation of food crops consumed raw poses the highest potential health risk. The vast majority of production of food crops consumed raw in the United States is concentrated in specific regions (Figure 2-3) and constitutes a small percentage of total agricultural production in the majority of counties (Figure 2-4). Most of the larger raw food crop producing regions (within CA, FL, AZ, WA) have mature regulations on agricultural water reuse. These findings have important practical implications when developing fit-for-purpose regulatory approaches in other regions. It is important to also adapt regulations to changing cropping patterns and advances in scientific knowledge. Our understanding of the fate and transport of CECs in agricultural environments is continually evolving and worth revisiting in future efforts. Likewise, the impacts of climate change on the agricultural sector are predicted to impact the scale, distribution, and economic viability of current agricultural activities (Hsiang et al. 2017) which may impact where raw foods crops are produced.



Sources: Calculated from 2021 National Cropland Data Layer and FSMA guidance documents on crops consumed raw.

Figure 2-3. Harvested Acreage of Crops Consumed Raw by County.



Sources: Calculated from 2021 National Cropland Data Layer and FSMA guidance documents on crops consumed raw.

Figure 2-4. Percentage of Total Harvested Acreage Comprised of Crops Consumed Raw.

Estimates of the acreage of croplands consumed raw and the percentage of harvested acreage of crops consumed raw were developed using the 2021 USDA National Cropland Data Layer (CDL) (USDA - National Agricultural Statistics Service- Research and Science 2021). Crop classes in the CDL were reclassified using the FSMA-PSR classification of crops typically consumed raw (Food and Drug Administration 2015) using ArcGIS. Cropland acreage was then summed by county and divided by total harvested acreage to calculate percentage of harvested acreage for each county. Agricultural lands used for pasture were excluded from this analysis.

2.6 Fit-for-Purpose Approach: Discussion and Recommendations

Agricultural water reuse has a long-history, predating any formal regulations on the use of municipal wastewater for agricultural irrigation. This long history coupled with a broad range of factors motivating current agricultural water reuse projects has led to a heterogeneous regulatory landscape. The heterogeneity of tailored fit-for-purpose approaches is both a strength and source of confusion. Chapter 7 of the companion guidebook discusses the benefits and tradeoffs of a fit-for-purpose approach. This section synthesizes this chapter’s findings on the state of agricultural water reuse regulations and makes recommendations for improving existing regulatory frameworks based on these findings.

Recommendations:

1) ***Consider local agricultural context when designing a fit-for-purpose regulatory approach for agricultural water reuse.***

A cornerstone of a fit-for-purpose approach is matching the quality of recycled water to the intended end use. Different types of agricultural products pose varying levels of risk, an idea codified in law via FSMA. Production of crops typically consumed raw is geographically concentrated in California, Florida, Arizona, and Washington, all states with robust agricultural water reuse regulatory programs. The regulatory programs in these states are grounded in science and often serve as a model for other states. While the agricultural production in these states is critical to the nation's food supply, it is not representative of agricultural production writ large across the United States. States such as Idaho and Minnesota are excellent examples of fit-for-purpose approaches that are tailored to state needs and agricultural systems focused on production of non-food crops. Profiles on both of these states are included in the companion guidebook.

2) ***Regularly revisit state water reuse policies for agricultural water reuse to ensure they continue to meet public health and environmental goals.***

The field of environmental risk assessment continues to advance and evolve rapidly. A limitation of most current fit-for-purpose approaches is their focus on known risks. The following two chapters in this literature review synthesize current scientific understanding on water quality constituents of concern to agricultural water reuse. The California State Water Resources Control Board's use of scientific advisory panels to help review and update the state recycled water policy is one such approach for integrating the best-available science into state policy. Research funded by The Water Research Foundation plays a similar role for many states and utilities. Research with robust findings that are applicable across multiple contexts is especially powerful and useful.

3) ***Consider opportunities for aligning regulatory frameworks for reuse of treated municipal wastewater and other alternative supplies commonly reused in agricultural systems.***

A common theme throughout this project and our work on WRAP Action 1.6[5] was widely varying perceptions on how to define and describe agricultural water reuse. This ambiguity makes interpretation of the already heterogeneous state regulations on agricultural water reuse more confusing. The scope and budget of this project necessitated limiting our focus to the reuse of treated municipal wastewater (recycled water). However, depending on geography, use of other alternative supplies such as oilfield produced water, stormwater, agricultural drainage water are all common and often more readily available supplies than treated wastewater in rural areas.

Some states, such as Minnesota, are taking steps to incorporate multiple sources of water in state water reuse policies (see companion guidebook for additional details). FSMA is an example of a federal, food safety focused regulatory approach to managing on-farm water quality in agricultural systems. FSMA requires annual agricultural water assessments, but is otherwise relatively agnostic to the source of water used for irrigation and instead focuses risk minimization (US Food and Drug Administration 2015). Off-farm, regulations on the supply of other alternative supplies varies widely state-by-state, though NPDES permits and anti-degradation policies often play some role. A recent WRF report, 'Potential of Oilfield Produced

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[5] WRAP Action 1.6 (Address Barriers to Water Reuse in Agriculture) https://www.epa.gov/waterreuse/national-water-reuse-action-plan-online-platform?action=1.6

Water for Irrigation in California’ (WRF 4993) (Thebo et al. 2023) discusses the opportunities and challenges in aligning California’s regulation of municipal recycled water and the use of oilfield produced water for agricultural irrigation. The scientific basis for our understanding of the composition of different alternative supplies and the relative health and environmental risks they pose varies widely. Nonetheless, if these hurdles and uncertainties can be managed, integrated regulation of all alternative supplies used in agriculture could streamline regulatory programs and help build the resilience of water systems.

CHAPTER 3

Recycled Water Treatment and Agricultural Water Reuse

3.1 Recycled Water from Municipal Supplies

3.1.1 Overview

The consistent quality and quantity of water produced from wastewater treatment plants (WWTP) makes irrigating with recycled water an attractive option. The majority of recycled water used for agricultural irrigation within the US is produced from publicly owned treatment works (POTWs)[6] or WWTP) (Sheikh et al. 2019). However, the quality of recycled water can vary depending on the volume and quality of the influent streams.

While secondary treatment is the typical minimum standard required for the treatment of wastewater at WWTP, some land and marine discharges are only treated to primary levels. The minimum water quality standards for discharges include limits for biochemical oxygen demand (BOD), pH, and total suspended solids (TSS). Other constituents present in recycled water may exist in higher concentrations than is suitable for the production of certain crops and may not currently be monitored. These include salts, nutrients, trace elements, heavy metals, and CECs. Additional monitoring may be needed to protect crop health from long-term use of municipal recycled water

Water discharged into sanitary, or municipal, sewer systems from domestic, commercial, and industrial users affect the quality of the water entering WWTPs. This in turn affects the efficacy of treatment methods utilized by WWTPs and the quality of recycled water discharged from the facility. To protect the quality of water entering these systems, and the integrity of the treatment trains employed by WWTPs, industrial discharges are federally regulated under the Clean Water Act (CWA) through pre-treatment programs[7] (EPA 2012).

Each agricultural water reuse project is site specific. This is in part due to the compatibility and complexities between the source water quality, environmental, and agronomic factors[8]. Suitability of recycled water for agricultural irrigation should be assessed according to several factors including crop and soil type, climate, and irrigation method and management (Lazarova

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[6] POTWs include municipal water reclamation facilities (WWTPs) and wastewater treatment plants (WWTP). These terms, POTW, WRF, and WWTP, are used interchangeably in this document.

[7] The National Pre-treatment Program was established under CWA to protect the environment and municipal treatment plants (EPA 2012). This program, along with the National Pollutant Discharge Elimination System (NPDES) Program, which sets water quality limits for discharges into any US waterway, are most relevant to water reuse and water treatment. Authorized state agencies (e.g., California State Water Resources Control Board (SWRCB) and the Arizona Department of Environmental Quality (AZDEQ)) may set more stringent standards to discharges and have the power to issue or deny permits.

[8] Other factors include location to sources, quantity, distribution and conveyance systems, and storage among others.

and Bahri 2008). A thorough evaluation is recommended to ensure current and future food supplies, and the soils and microorganisms that support their growth, are protected.

3.1.2 Treatment Technologies

There are three main treatment levels for wastewater at public WWTP - primary, secondary, and tertiary treatments (Table 3-1). During primary treatment, sediments and solids are removed using screening or sedimentation processes. Secondary treatments use biological methods to further remove biodegradable and residual organic matter and suspended solids.

Types of biological treatment technologies used during secondary treatment include biofiltration, fixed-film, membrane bioreactors, wetland ponds, activated sludge, biological aeration, and bio-electrochemical methods. These processes are able to remove between 85 and 95 percent of the biochemical oxygen demand (BOD_5) and total dissolved solids (TSS), and 99.9 percent of microorganisms (Pescod 1992; Wu et al. 2009; EPA 2012). A recent review by (Camarillo and Stringfellow 2018) shows that biological treatments are effective at reducing nutrients, metals, and trace contaminants as well.

Tertiary treatments include a variety of advanced methods used to remove nutrients (e.g., nitrogen and phosphorous), heavy metals, non-biodegradable organics, and dissolved minerals not removed during primary or secondary treatments. These technologies include chemical coagulation, membrane bioreactors, reverse osmosis (RO), filtration (e.g., sand filtration and activated charcoal), and disinfection.

Disinfection is used to inactivate remaining pathogens after secondary or tertiary treatment. The most common disinfection method used in water reclamation is chlorination, but other methods including peroxyacetic acid, UV, and ozone are also used. Because each process produces a higher level of quality, the allowable uses of recycled water, such as the irrigation of crops eaten fresh, increases with the higher levels of treatment.

Chlorination is the most commonly used disinfection method used to inactive human pathogens in WWTP. Other disinfection methods include ultraviolet radiation (UV), ozone, and peroxyacetic acid (PAA).

One concern related to treatment methods are disinfection by-products (DBPs) that may form during chlorination as organics in wastewater are oxidized. Chlorination produces more DBPs than other disinfectants, such as PAA - many of which are unknown. While they are considered as emerging trace compounds of concern, many are expected to degrade during storage or after application (Wu et al. 2009).

Table 3-1. Treatment Levels and Common Technologies Used by Municipal Wastewater Treatment Plants.

Data Sources: Pescod 1992; EPA 2012; Wu et al. 2009.

	Primary Treatment	Secondary (Biological) Treatment[1]	Tertiary/Advanced Treatment[2]
Substances removed	Organic and inorganic sediments, solid waste	Residual and BOM, suspended solids	Specialized treatment for removal of phosphates, nitrates, organics, heavy metals, dissolved solids and minerals, refractory organics, inactivation of pathogens
Efficacy	· 25-50% incoming BOD_5 · 50-70% TSS · > 65% O&G · 90% Microorganisms[3]	· 85-95% of BOD_5, TSS · 99.99% Microorganisms · Some heavy metals · Little removal of phosphorous, nitrogen, non-biodegradable organics, dissolved minerals	Individual treatments to remove: - Nitrogen - Phosphorous - Dissolved and suspended solids - Organics - Heavy metals
Processes	· Screening, sedimentation	· Biological treatments: · Biofiltration: sand, contact, trickling filters · Membrane bioreactors, aerobic biological treatments, oxidation, wetland ponds, activated sludge, bio-electrochemical methods	· Chemical coagulation · Membrane bioreactor, RO · Filtration: activated charcoal, sand filtration · Disinfection: chlorination, UV, ozone, ferrate
Ineffective at removing	· Heavy metals, phosphorous, nitrogen, non-biodegradable organic, dissolved minerals	· Some heavy metals	· Depends on specifics of treatment technology used

BOM = Biodegradable Organic Matter; BOD_5=Biochemical oxygen demand; TSS=Total Dissolved Solids; O&G=Oil and Grease; RO = Reverse Osmosis; UV = Ultraviolet; DOM = Dissolved Organic Matter.

[1] Often secondary treatment is followed by disinfection.

[2] Usually involves several treatment steps. Treatment train selected depend on the target contaminant(s).

[3] Removal of microorganisms may be up to 90% but a considerably large number are still present after primary treatment.

3.2 On-Farm or Decentralized Treatment

On-farm treatment is most commonly used when source waters used in the production of raw food crops face water quality challenges. Common on-farm water treatments include physical and chemical methods, such as filtration, chlorination, and peracetic acid products (FDA 2021). While on-farm treatment methods used by growers are often sufficient to meet water quality metrics specified by FSMA or industry standards such as the LGMA, treatments and validation tests can be costly, time consuming, and require detailed record keeping. In some cases, this may incentivize the use of municipal recycled water. If delivered directly to growers from a certified WWTP, the need for costly treatment, testing, and record keeping by producers may be eliminated if the water quality meets the requirements for the intended end-use. However, regrowth and proliferation of some microbes, including antibiotic resistant bacteria may occur in the distribution system from point of treatment to point of use. The efficacy of different on-farm treatment methods is a subject of ongoing research and outside of the scope of this project.

CHAPTER 4

Human Health Risks and Concerns Associated with Agricultural Water Reuse

4.1 Introduction

Agricultural fields, exposed to the natural environment, are subject to many external forces from microscopic organisms to violent storms that have the potential to disrupt landscapes and crops. Complex interplay between agriculture and environmental conditions (e.g., soil characteristics, UV intensity, and temperatures), weather events (e.g., heavy winds, rain, and hail), and water source type (e.g., groundwater, surface water, and municipal recycled water[9]) play a critical role in evaluating risks related to agricultural applications of water. Factors that have the potential to impact the realization of human health risks related to agricultural water reuse include crop type, means of consumption, level of water treatment, distribution systems, application and timing of watering events, soil characteristics, exposure pathways, and groundwater contamination.

While there are many benefits to using recycled water in agriculture, impacts on human health are an ongoing topic of discussion and central to all end uses and successful reuse policy (Paranychianakis et al. 2015; Drewes et al. 2018). Adverse health effects from using untreated or undertreated water sources, including surface water, groundwater, and wastewater, are well documented in the literature (Dickin et al. 2016; Keraita 2008). Rules, guidance, and treatment requirements for non-potable reuse are therefore concerned with protecting public health and tend to prioritize the acute effects of illness from microbiological and viral pathogens. However, illness from chemicals or constituents of emerging concern (CECs) and antibiotic resistance (AR) may have long-term effects that many not be immediately observable or recognized (EPA 2012).

Interest and concerns on both acute and long-term health risks associated with using recycled water for crop irrigation is a growing, and valid concern. Antibiotics, antibiotic resistant bacteria (ARBs), antibiotic resistance genes (ARGs), CECs, and other potentially harmful substances may be present in recycled water and have the potential to enter food supplies. In particular, there is growing cognizance of the ubiquity and persistence of Per- and polyfluoroalkyl Substances (PFAS) in the environment and a recognized need for additional research on the risks these substances pose in agricultural systems, particularly those using recycled water and/or biosolids (Thompson et al. 2022; Lenka et al. 2021). Additional research is needed to understand the fate and transformation of PFAS within conventional and advanced wastewater treatment processes. Understanding these topics remains a major knowledge gap and subject of ongoing research (e.g., “CONSERVE Research Overview” n.d.). An ongoing WRF study (4964 – Assessing the State of Knowledge and Impacts of Recycled Water Irrigation on Agricultural Crops)

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[9] While there are many types of water reuse in agricultural settings, this chapter focuses on the use of treated municipal wastewater (recycled water).

addresses these topics directly and is expected to be completed later in 2023 (Kisekka et al. In Process).[10]

Current research continues to show:

- There have been no known or documented cases of illnesses resulting from irrigating crops with recycled water when guidelines and regulations are followed (Olivieri et al. 2014; Crook 2005; Jjemba et al. 2015).
- Recent Quantitative Microbial Risk Assessment (QMRA) findings indicate that the risks of irrigating with conventional irrigation practices were greater or similar to that of irrigating with recycled water under current regulations (Olivieri et al. 2014; Rock et al. 2019).

The aim of this chapter is to summarize current research on real and perceived human health related concerns associated with agricultural reuse, including:

- Human health exposure pathways associated with agricultural water reuse;
- Factors impacting realization of potential health risks;
- Water quality constituents of public health significance; and
- Current data and knowledge gaps.

This chapter is intended as a synthesis of current research, acknowledging many remaining knowledge gaps. Context specific factors such as crop type, water quality, soils, and other characteristics will ultimately determine whether/how potential risks are realized and the magnitude of these risks. Additional information on specific, practical strategies for addressing human health risk related barriers to agricultural water reuse is included in the companion guidebook (Part 2 of this document).

4.2. Human Health Exposure Pathways Associated with Agricultural Water Reuse

Previous sections of this literature review focused on reducing health risks associated with agricultural water reuse via regulations and treatment. However, agricultural water reuse is perhaps somewhat unique in that it enters a complex set of secondary, potential exposure routes at its point of use. Among other things, constituents in recycled water can be taken up and transformed by plants and in the soil environment (Figure 4-1). This chapter focuses primarily on constituents potentially present in recycled water after treatment and what happens to those constituents after recycled water is applied to crops.

Irrigation with a contaminated water source has the potential to expose field workers, farmers, residents, and consumers via direct contact, inhalation, or unintended ingestion. These are the main potential exposure routes when using recycled water (Figure 4-1). Recycled water may be aerosolized directly from weathering events, irrigation methods, or accidentally. Recycled water can also mix with contaminated soil posing a threat to field workers. Exposure pathways can

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[10] Kisekka et al. In Process

also include the accumulation, leaching, and breakthrough of contaminants and pathogens into groundwater, drinking water, surface waters, and soils.

When pathogens and microcontaminants enter these environments, human exposure may occur. Plant uptake and accumulation of chemicals is complex and depends on a number of factors including analyte concentrations, chain length, and functional groups, studies indicate that organic content of the soil can also play a role. For example, bioaccumulation in lettuce grown in soils with lower organic content (<6%) showed a decrease in bioaccumulation of PFAAs over those grown in soils with lower organic content (0.4% and 2%) (Blaine et al. 2014). Figure 4-1 shows the main CECs of concern in municipal recycled water and summarizes the main exposure pathways, routes, and at-risk populations when used as an agricultural water source.

Pathogens and other contaminants have the potential to adhere to crop surfaces, migrate into exposed and damaged tissues, or become internalized into the edible portions of the crop, further exposing consumers. Rough, porous, and damaged areas are more susceptible to pathogen adherence. Studies have shown that damage to a plant surface tissue can help microbes to adhere, potentially allowing them to migrate into the nutrient rich tissue where they may become internalized, another area of great concern. Preharvest contamination via root uptake and internalization of pathogens has long been a topic of research and debate, with conflicting findings largely due to differences in experimental designs (Hirneisen et al. 2012).

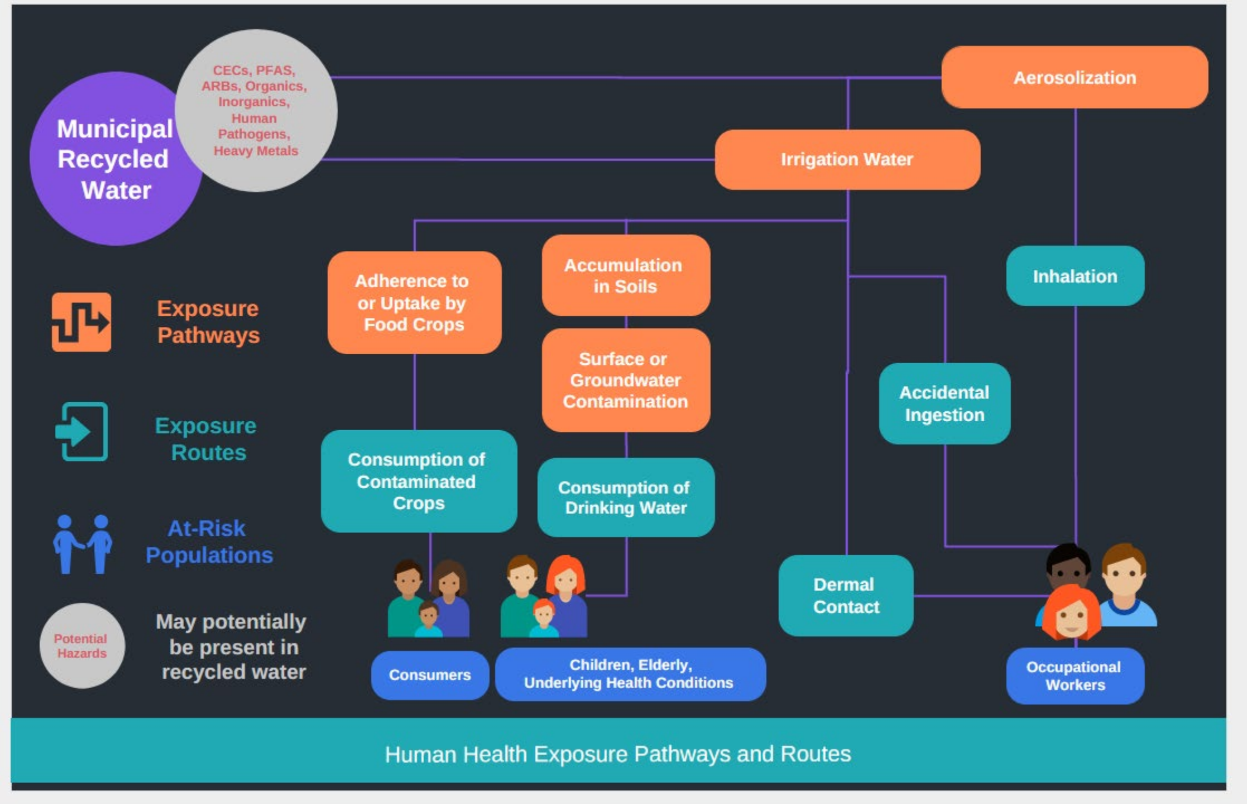

Figure 4-1. Potential Hazards in Recycled Water and Common Pathways and Routes of Exposure.

Source Water Quality

Different sources of irrigation water have different human health risk profiles. Surface waters are vulnerable to contamination from wildlife, septic systems, and sewer overflows. Outbreaks of gastrointestinal illnesses have occurred after irrigation water and/or agricultural soils were contaminated with feces from wild animals (Gelting et al. 2015; Waltenburg et al. 2022). Groundwater sources are less vulnerable to contamination with pathogens, but have an increased risk of contamination with salts and other water-soluble contaminants. Recycled water is typically treated to meet fit-for-purpose water quality standards, directly linked to the planned end use (See Chapters 2 and 3). While the quality of wastewater influent can vary, the quality of recycled water is generally consistent and can pose less of a risk than surface water or groundwater (Rock et al. 2019). The risk profiles of different sources of irrigation water are a key consideration of FSMA's agricultural water quality management, monitoring, and treatment requirements.

4.3 Factors Impacting Realization of Potential Health Risks

4.3.1 Overview

There are multiple factors impacting the realization health risks related to irrigation water, a known route of contamination (Barak and Schroeder 2012). Pairing water quality with site-specific needs is a key objective when designing irrigation management plans to minimize human health risks, and important for all agricultural water sources. Strategic monitoring can help evaluate potential fate and transport pathways and the role of the following factors in risk management. In some cases, the agronomic and environmental factors outlined in this section can be impediments or incentives for using municipal recycled water.

Producers using or considering municipal recycled water can develop management plans that both maximize crop yields and protect public health by considering these agricultural and environmental factors:

- Level of water treatment technology and intended uses
- Distribution system characteristics
- Water application activity, method, and timing
- Soil characteristics and soil amendments
- Crop type and characteristics
- Post-harvest processing and means of consumption
- Exposure pathways and routes
- At-risk populations
- Potential for surface and groundwater contamination

Some factors can be modified (irrigation timing, level of water treatment) based on more fixed factors (irrigation system, soil characteristics) to reduce human health risks while others cannot be so easily changed due to financial, technical, or other constraints. The following sections summarizes each of these factors that may impact human health.

4.3.2 Level of Treatment and Intended Uses

Recycled water is typically treated to meet fit-for-purpose water quality standards, directly linked to the planned end use (See Chapters 2 and 3). Standards outlined by the FDA for growing produce for human consumption require agricultural water to be of 'adequate quality for the intended use' and is subject to treatment and monitoring to meet microbial quality criterion (FDA 2021). Often, treatment trains using multiple methods are used to achieve a level of quality required for the end-uses. As the level of treatment increases, a higher quality of recycled water is produced, and will have more allowable end-uses. Food crops intended for human consumption require a higher quality of irrigation water than those produced for fodder, textiles, or biofuels.

This is especially important for produce eaten raw as there is no processing or kill-step prior to consumption that would eliminate potential hazards. Water source, level of control over the source, crop type, and means of consumption are important considerations for growers in determining the level of treatment required and the water source used. For example, the EPA 2012 guidelines for agricultural reuse recommend secondary treatment with disinfection for processed food crops and non-food crops to achieve a BOD and TSS of ≤ 30 mg/L and ≤ 200 fecal coliforms/100 mL, while secondary and tertiary treatments are recommended for food crops eaten raw (when irrigated with surface or overhead irrigation) to achieve a BOD of ≤ 10 mg/L, ≤ 2 NTU, and no detectable fecal coliforms/100 mL (EPA 2012).

While the EPA provides guidelines, states are responsible for developing regulations on agricultural reuse (see Chapter 2). At the federal level, the Food Safety Modernization Act Produce Safety Rule develops food safety standards that apply to all water (including recycled water) used for the irrigation and production of food crops consumed raw.

4.3.3 Distribution Systems

Distribution and conveyance systems, consisting of pipes, pumps, storage tanks, reservoirs, valves, sprinkler heads, and other components are required to carry water from its primary location to the points of use, including agricultural settings. While advanced treatments used in WWTPs produce high quality water, the unique properties of reclaimed water (e.g., high nutrient levels); corrosion and deterioration of structures; long retention times; and age can result in the quality becoming degraded as it moves through this distribution system (Jjemba et al. 2014; Garner et al. 2018). Mitigation strategies for WWTPs include managing operational and distribution system infrastructure, maintaining chlorine residuals, including booster disinfection stations in system design, and flushing service connections (Jjemba et al. 2014).

If microbiological regrowth does occur as it enters the in-field irrigation system, biofilms can form inside the pipes and other structures. These matrixes form when microorganisms, including pathogenic bacteria, adhere forming a complex and durable structure that can alter flow rates, corrode materials, and clog sprinkler heads. They are more resistant to disinfection and can lead to increased uptake of antibiotic resistant genes (ARGs) and antimicrobial resistant bacteria (ARB). Crop contamination may occur if contaminated water is used for agricultural activities, including irrigation, chemigation, or during harvesting operations.

To minimize contamination of human pathogens, in-field irrigation distribution systems, reservoirs, and delivery systems should be managed and maintained. Testing water at points of use and at the end of the delivery system (e.g., last sprinkler head) for microbial quality is important to ensure that microbial regrowth has not occurred after treatment and long retention times.

4.3.4 Water Application Method and Timing

Application method and timing used to deliver water to crops is an important consideration and each has a different level of risk for contamination. Overhead applications pose the greatest risk as the water comes into contact with the harvestable portion of the plant. Furrow (flood) methods pose a medium level of risk, while drip methods are the least risky (Steele and Odumeru 2004; California Leafy Greens Marketing Agreement (CALGMA) 2021; Gerba 2009; FDA 2021). While drip and subsurface irrigation reduce the potential for contamination, these methods are also more water efficient and decrease leaching and accumulation in soils.

As the time between application events and harvest becomes shorter, there is an increased risk of foodborne illness if the edible portion of the crop becomes contaminated. Microbial die-off rates on agricultural commodities in open fields depend on several factors. They include exposure to and intensity of UV, temperature, humidity, pH, nutrients, crop type, watering frequency, and competitors. Generally, during sunny months at higher temperatures and drier conditions, microorganisms will die-off at a faster rate than in lower temperatures, lower UV intensity, and higher humidity (Victor et al. 2008). Based on these factors, the EPA estimates microbial die-off at rates of 0.5 to 2.0 logs per day (FDA 2021). Recent updates to the CALGMA require certain agricultural waters to be treated if they are used in the overhead application of leafy greens within 21 days of harvest (California Leafy Greens Marketing Agreement (CALGMA) 2021).

4.3.5 Soil Characteristics and Soil Amendments

Soils are living, complex, and multidimensional ecosystems, filled with biotic and abiotic components. They are capable of breaking down and transforming chemicals and other contaminants and act as a filter to help purify water. Exposed to the environment, soils are susceptible to chemical and biological contamination from nonpoint (weather, runoff) and point sources (runoff from CAFOs).

Soil type affects the distribution, filtration, and decomposition of contaminants. For example, clay soils have smaller pore spaces, finer texture, and a greater ion exchange capacity than sandy soils. These properties help clay soils hold on to nutrients, water, and chemicals more effectively than coarse and grainy sandy soils which can help limit contaminant transport into groundwater. However, small pore spaces may protect cells from predation and competition which may contribute to increased susceptibility for pathogen adherence on crops grown in clay predominant soils (Natvig et al. 2002; Barak and Schroeder 2012). In soil environments, persistence and survival times of human enteric pathogens vary, but can range from less than thirty days to greater than twelve months depending on a variety of factors including soil type and structure (clay, sand), resident microflora, and environmental factors (temperature, humidity) (Barak and Schroeder 2012; FDA 2015a).

Organic farming in the US, where conventional synthetic fertilizers and pesticides are prohibited, often use biological soil amendments to improve soil health, including stabilized compost, manure, non-fecal animal byproducts, and agricultural tea among others (USDA 2011). However, if untreated amendments are used (such as raw manure), enteric pathogens frequently found in the intestines of livestock may enter the food supply or groundwater supplies (USDA 2011). Land application should therefore be managed to reduce human health risks, as contamination can occur either directly or indirectly. Weather or irrigation events can directly transfer pathogens directly from the soil to the crop through splashing, or indirectly by impacting groundwater supplies (FDA 2021).

4.3.6 Crop Characteristics

Physical and growth characteristics of crops can affect the susceptibility of pathogens to adhere to the surface of a crop or be taken up by plants, potentially increasing risk of contamination and illness. For example, highly textured and rough surface areas, such as the netted rind of cantaloupe and some leafy greens, are more likely to trap biotic and abiotic contaminants than crops with smooth surfaces, such as watermelon (Barak and Schroeder 2012; FDA 2021). Crop growth characteristics, including location of the edible portions (distance relative to the ground or water) are also important. For example, the closer to the ground the edible portion is, there is an increased risk of contamination as pathogens in soil can splash onto the crop during weather events or watering applications (Jung et al. 2014; EPA 2012).

Damage due to weather events (freezing, hail, rain, temperature, or sunburn) and biological damage (from plant pathogens) can leave the outer layer of the plant (epidermal layer) exposed and susceptible to the adherence or internalization/migration of microbiological hazards (FDA 2021). Studies have shown that *E. coli* O157:H7 preferentially attaches to cut and damaged edges than to intact tissue (Takeuchi et al. 2000; Patel et al. 2011). Other contaminants may also be able to stick to areas of tissue damage and may pose risks to human health.

Natural plant defenses may inhibit adherence, internalization, and persistence of pathogens, including plant-bacteria interactions and mechanisms activated by plant immune systems (e.g., hypersensitive response (HR) and systemic acquired resistance (SAR)). Plant-bacteria interactions include endophytic relationships, where a microorganism internal to a plant can enhance plant health and initiate or induce systemic resistance (ISR) mechanisms (Iniguez et al. 2004a). More research is needed in this area to fully understand natural plant defenses and responses to specific pathogens. While detail regarding these interactions is outside the scope of this literature review, plant internalization is further discussed in the section on exposure pathways.

4.3.7 Plant Uptake

Spinach, grown in soils inoculated with concentrations of *E. coli* not normally found in field settings (≥6 log/g of soil or 6 log/mL of irrigation water), has been shown to uptake the bacteria through the roots (Hirneisen et al. 2012; Erickson 2012). However, persistence was short-lived and the likelihood for pathogens to travel through the plant's interior structures into the edible portions is unlikely at concentrations normally found in field settings (Hirneisen et al. 2012; Erickson 2012). In contaminated soils, the normal flora are likely to predate on or out-compete human pathogens for nutrients and uptake by roots and would require concentrations greater than what would normally be found in contaminated field settings (van Elsas et al. 2011). Internalization via root systems is unlikely to occur in in-field conditions, and contamination will most likely occur post-harvest around damaged areas of the plant.

Pathogens may enter as opportunistic hitchhikers through the stomata, as moisture conditions allow for the quick exchange of gas (water vapor) and oxygen to enter and exit the leaf, indicating that leaf moisture may be an important factor in the migration of pathogens into leaves (Erickson 2012). Other studies show that stressors activate plant defenses that may target internalized enteric pathogens and prevent persistence (Iniguez et al. 2004a; Schikora et al. 2008). Because natural defenses, root systems, transport systems, and microflora are complex and vary between plants, more research on these mechanisms is warranted. A better understanding of commodity-specific defenses and risks may be valuable to develop best management practices (BMPs).

4.3.8 Groundwater and Surface Water Contamination

Exposure through drinking contaminated groundwater or surface water can occur if pathogens, salts, nutrients, trace elements, and chemicals enter a water supply source. To better understand the impacts irrigating with recycled water has on the quality of groundwater, routine monitoring and testing of salts and CECs is needed (FDA 2015b). In addition, potential fate and transport pathways should be evaluated through strategic monitoring. When contaminants in soil are water soluble (e.g., nitrates), risks to drinking water supplies are increased. While all waters used for irrigation contain salts to some degree, recycled water is known to contain higher levels of salts and nutrients (especially nitrogen). Groundwater in shallow wells can be under direct influence by surface water and land practices, including agricultural activities where recycled water is used to apply pesticides, fertilizers, soil amendments, leaching practices, or to for crop irrigation (Sheikh et al. 2019; FDA 2021).

Groundwater quality impacts when using recycled water to irrigate crops are an important consideration. In drier regions, an irrigation management practice called leaching is used to prevent the accumulation of dissolved solids, especially salts, in root zones of crops. Additional water is used to push these dissolved solids down past this zone, which can then enter groundwater. Human pathogens, such as *E. coli* and Campylobacter have also been found in groundwater near dairy pastures. Between 2007-2008, over half of the outbreaks associated to drinking water in the US were due to untreated groundwater (FDA 2015b; Close et al. 2008) (FDA 2015a).

Conflicting research on groundwater contamination indicates a need for further research and standardized methods. A study by Gu et al. (2019) showed that while long-term use of recycled water used for irrigation (>30 year) led to increased organic matter (OM) and may improve soil health, increased levels of potentially toxic elements (PTEs) (As, Cd, Cr, Hg, Zn, and Pb) in deep soil environments were also observed and may contaminate shallow groundwater. In contrast, another 30-year study where recycled water was used for irrigation found that no detectable steroid estrogens were detected in the groundwater samples taken below the irrigation sites (Sheikh et al. 2019). However, these risks can be mitigated with management strategies, such as treatment technologies employed at WWTP to remove many contaminants and reduce potential risks to groundwater (Sheikh et al. 2019).

To better understand the impacts irrigating with recycled water has on the quality of groundwater, routine monitoring and testing of salts and CECs is needed (FDA 2015b). Salt and nutrient issues are challenging to manage and cannot be addressed by reuse regulations alone; regional and subregional salt and nutrient management plans (SNMPs) can help to address these challenges.

4.4 Water Quality Constituents of Public Health Significance

4.4.1 Introduction

While there are no known disease outbreaks related to the use of recycled water, foodborne illness from biological pathogens continues to place a significant burden on the national economy, public health care systems, and food and agriculture industries (CDC 2018). Symptoms typically appear within 24 to 48 hours of consuming contaminated food, depending on the species, at-risk population, and other factors. Certain groups, including the young, the elderly, and the immunocompromised, are more vulnerable and impacted more severely by foodborne illnesses.

While microbiological pathogens (bacteria, viruses, and parasites) are generally the focus of regulatory guidelines, testing, and monitoring of agricultural waters, there is little oversight on contaminants of emerging concern (CECs) and antibiotic resistance (AR). In contrast to bacterial, viral, or parasitic symptoms, the effects of long-term exposure to low concentrations of CECs may not be realized for a long time, and could have significant affects, especially to those most vulnerable.

While many treatment methods are able to remove or inactivate pathogens and chemicals of concern, removal or inactivation may be treatment specific. Not all treatments will remove all types of chemicals. Having a more complete chemical profile of a water source will ensure that those of concern in agricultural settings can be removed. Table 4-1 provides a list of commonly used treatments and the constituents they are effective at removing or inactivating. Further discussion on treatment, detection, and monitoring of CECs are provided later in this section.

Table 4-1. Treatment Technology and Removal or Inactivation of Pathogens and Chemicals of Concern.

Specific Treatment	Removes or Inactivates	
Coagulation, Flocculation, & Filtration	• Colloidal particles ○ BOM	• Phosphorous • Nitrogen
Carbon Adsorption*	• Trace organics • Endocrine disruptors	• Metal ions ○ Cadmium, silver, selenium, hexavalent chromium
Membrane Filtration	• Metal ions • Viruses • Bacteria	• DOM • Pesticides
Chlorination, ozone, UV	• Bacteria • Viruses	• Protozoan cysts

*Carbon adsorption is an important process for recycled water to meet California's total organic carbon (TOC) rules for groundwater recharge (Wu et al. 2009).

The following sections summarize information on water quality constituents of potential concern to human health. In certain cases, constituents are relevant to both human and agronomic health.

4.4.2 Pathogens

The potential transmission of disease by pathogenic microorganisms (bacteria, viruses, and parasites) to humans is a principal concern when using recycled water for agricultural irrigation. Contamination of produce can occur at any point in the food production process, either directly, through ingestion or inhalation, or indirectly through the consumption of produce irrigated with contaminated irrigation water.

Treatment technologies, especially those used in public water systems, can reduce pathogens to limits below detection reducing the risks of illness. Studies using a quantitative microbial risk assessment (QMRA) by the California Department of Public Health (CDPH) found that the annual median risk of infection due to daily exposure to viruses (*Cryptosporidium parvum* and *Giardia lamblia*) and *Escherichia coli* O157:H7 in tertiary treated recycled water was between 10^{-8} to 10^{-4}. The CDPH determined that current agricultural water reuse regulations were sufficient to protect the public health.

Bacteria

A wide range of bacteria, from harmless coliforms to pathogenic ones, are found in high densities in untreated municipal wastewater. Enteric bacteria, including *Salmonella*, *Campylobacter jejuni*, Shigella, and pathogenic strains of *Escherichia coli* (*E. coli*) including *E. coli* O157:H7, are found in the guts of warm-blooded animals and are especially relevant to food safety. These are easy to remove through primary, secondary, and tertiary treatment.

Testing for pathogens directly can be quite challenging and expensive in laboratories, thus testing requirements instead use concentrations of *E. coli* or other organisms (total or fecal coliforms) as an indicator of fecal contamination. For example, the FSMA PSR is based on concentrations of *E. coli* while many states with regulations on recycled water use total or fecal coliforms. Studies indicate that the criteria for indicator organisms in recycled water used for crop irrigation are protective of public health (Olivieri et al. 2014; Rock et al. 2019).

Viruses

Viruses relevant to food safety include enteric norovirus, rotavirus, and hepatitis A, and are of concern in recycled water. Identification and enumeration of low viral counts is rather difficult to quantify in laboratory settings due to low cell recovery rates, cost of detection methods, and the length of time required to determine their presence. Little data exists on concentrations of norovirus and hepatitis A in tertiary-treated wastewater, both listed in the USEPA drinking water Contaminant Candidate List (4-CCL 4).

While viruses can be physically removed, sedimentation and filtration processes are less effective due to their small size. Disinfection is more effective at reducing or inactivating viruses than physical removal but does generally require higher doses or longer contact times than is required for bacteria or some parasites. Treatment with disinfection has been shown to reduce enteroviruses to low or non-detectable levels (EPA 2012). Title 22 (California) requires filtration, a 450-contact time (CT) for disinfection, and a minimum of a 5-log reduction of viruses, among others (Drewes et al. 2018). In addition some viruses, such as enterovirus, have exponential decay rates after application to crops (3.3 log reduction after seven days) (Olivieri et al. 2014).

The ongoing COVID-19 pandemic remains a major public health challenge and SARS-CoV-2 has been widely detected in wastewater influent. However, standard treatment and disinfection processes appear sufficient to remove or inactivate SARS-CoV-2 (Tran et al. 2021) and no changes to recycled water policies have been recommended at this time. Wastewater-based epidemiology is being used in numerous locations for passive surveillance of community COVID-19 infection dynamics (Kitajima et al. 2020).

Parasites

Parasites, including protozoa and helminths can be physically removed during sedimentation or filtration, due to their larger size (1um to 60 um or greater). Resistance to chemical disinfection, such as chlorination and UV, varies between species. For example, chlorination has been shown to be effective against Giardia but has limited effects against Cryptosporidium.

Improved Pathogen Detection Methods and Alternative Indicators

Monitoring for pathogens in a laboratory setting can be difficult and expensive, and current methods are unable to determine whether many pathogens are infective or not (EPA 2012). Fecal indicator organisms have been used as a surrogate for enteric pathogens and fecal contamination for decades, but the correlation between enteric pathogens and fecal indicators is complex and mixed (Teixeira et al. 2020; Wu et al. 2011). Major areas of current research include developing better methods for detecting actual pathogens, understanding more about the infectivity of pathogens detected, and developing better indicators of enteric pathogens. New research shows promise of using alternative indicators such as Bacteriophages (viruses that infect bacteria) for the presence of enteric viruses, including Norovirus genogroups I and II (GI and GII) (Teixeira et al. 2020) while scientific advances in DNA-labeling and sequencing methods are providing new insights into detecting viable-but-non-culturable (VBNC) pathogens in non-traditional irrigation waters, including recycled water (Malayil et al. 2021).

4.4.3 Constituents of Emerging Concern

Characterizing and understanding the relative risks posed by constituents of emerging concern (CECs) in recycled water is an active area of research. No strict definition exists for CECs, but these substances include a wide range of organic, inorganic, and trace chemical constituents including:

- Pharmaceuticals and personal care products (PPCP)
    - Caffeine
    - Medications (e.g., carbamazepine, ibuprofen, naproxen, and estrogens)
- Endocrine Disrupting Chemicals (EDC)
- Antimicrobials
- Microplastics and engineered nanomaterials
- Per- and polyfluoroalkyl substances (PFAS)
    - Perfluorooctanoic acid (PFOA)
    - Perfluorooctane sulfonates (PFOS)
- Trihalomethane (THM) compounds
- Haloacetic acids (HAA)
- N-nitrosodimethylamine (NDMA)

Unlike biological pathogens, these substances are not typically well-monitored and water quality standards nor regulatory thresholds exist for non-potable activities, including agricultural activities. The 2013 proposed rule by the FDA limited the PSR to biological hazards because the frequency and nature of non-biological hazards did not appear to be necessary at the time. The 2018 Science Advisory Panel, convened by the California State Water Resources Board also concluded that it is unnecessary to monitor for CECs in recycled water used for non-potable activities allowable under Title 22.

All water sources, including recycled water, contain some detectable levels of CECs due to their increased usage and persistence in the environment. The classes and concentrations found in surface and ground water will vary depending on the initial chemical concentration, chemical interactions, and environmental conditions. Factors contributing to the type and concentration in municipal recycled water include the inflow sources, treatment level, and collection system (Shi et al. 2022). Studies have shown that effective treatment options for the removal of certain endocrine disrupting chemicals (EDCs) and PPCPs include chlorinated compounds, UV, and ozonation with higher success rates when upstream technologies include long retention times, nanofiltrations, and reverse osmosis (RO) (Sheikh et al. 2019).

Some studies indicate that CECs in food crops are well below concentrations that would have adverse health effects when consumed (Blaine et al. 2014; Paltiel et al. 2016; Negreanu et al. 2012). However, conflicting research findings indicate that these chemicals may in fact pose health risks (Calderón-Preciado et al. 2013; Atamaleki et al. 2021; Piña et al. 2020). Data on the toxicological implications of CECs for human health including fate and transport in agricultural systems is inconsistent and little comprehensive data exists (State Water Resources Control Board 2018). For some CECs, such as Per- and polyfluoroalkyl substances (PFAS) there is significant data while others have very little. An ongoing project, WRF 4964, Assessing the State of Knowledge and Impacts of Recycled Water Irrigation in Agricultural Crops (Kisekka et al. In Process), is conducting in-field sampling of crops irrigated with recycled water. Results from this study will provide additional insights into fate and transport in crops irrigated with recycled water.

Concentrations of CECs in the edible portions of food crops irrigated with recycled water are typically low. As such, what may be of greater significance are the human health effects due to chronic exposure to low concentrations of CECs and the potential for recycled water containing CECs to reach groundwater and drinking water supplies. Given the exhaustive list of CECs, there is a need to develop a priority list of those most significant to impact human health. As methods for detecting low concentrations of CECs have improved, public health concerns related to the long-term exposure of these substances continue to grow. It is also important to distinguish CECs inputs arising from the use of biosolids versus recycled water. Many CECs, including PFAS, tend to accumulate in higher concentrations sludge (Lenka et al. 2021) versus liquid effluent. These differences are an important consideration in managing of CECs in agricultural systems. Substantial research on PFAS and biosolids (e.g., Johnson 2022; Pepper et al. 2023) has been conducted, but biosolids were outside the scope of this report.

The following sections briefly summarize the most common CECs found in recycled water and the current state of knowledge.

Organic and Inorganic Compounds

Organic components include natural (e.g., humic substances, fecal matter, detergents) and other substances (including per- and polyfluoroalkyl substances (PFAS)) that may contribute to irrigation system challenges including odors, clogging and microbial growth, depleted oxygen levels in irrigation water, and a decrease in disinfection efficacy. Negative human health effects may also arise if crops contaminated with toxic chemicals and compounds are consumed.

Many of these compounds have the potential to be transformed into disinfection byproducts (DBPs) in the presence of chlorinated compounds, including trihalomethane (THM) compounds, haloacetic acids (HAAs), and N-nitrosodimethylamine (NDMA), all of which are known carcinogens (Diana et al. 2019; Mazhar et al. 2020). Concerns related to PFAAs are growing, therefore the authors summarize the current state of knowledge in a section below.

Inorganic chemicals include salts, nutrients, metals, engineered nanomaterials, and oxyhalides. Treatment technologies are capable of reducing concentrations of trace elements to below requirements for drinking water and irrigation. However, recycled water is known to have increased levels of salts and nutrients that have the potential to impact groundwater. In some regions, including California, Netherlands, and China, groundwater with high salinity is a major public health concern that affects the drinking water of thousands of households a year. California has established salt and nutrient management plans (SNMPs) to prevent the exacerbation of ground water pollution.

Recycled water may also have concentrations of toxic heavy metals. And again, conflicting reports of plant uptake and potential human health risks make assessing risks difficult. Some research reports concentrations in the edible portions are below health guidelines (Njuguna et al. 2019) while others indicate negative health effects do occur through long-term consumption of foods contaminated by metals like Cu, Zn, Cr, Mn, Ni, Pb, and Cd (Cheshmazar et al. 2018; Harmanescu et al. 2011).

Perfluoroalkyl and Polyfluoroalkyl Substances

Per- and Polyfluoroalkyl Substances (PFAS) include perfluorooctanoic acid (PFOA) and perfluorooctane sulfonates (PFOS), the two most well-known PFAS substances. Derived from industrial and chemical products including textiles, paper, paint, and fire-extinguishing liquids to name a few, they are ubiquitous in water and the environment. The main route of exposure to PFAS is dietary, and thus they have become a significant topic in public health especially for drinking water supplies. Health risks to humans, animals, and environment from PFAS are well documented in the literature. These substances have been found in recycled water as well as in biosolids used for agricultural purposes.

Blaine et al. (2014) showed that plant uptake and bioaccumulation of PFAAs in edible crops (lettuce, tomatoes, and strawberries) in both greenhouse and field trials has occurred (Blaine et al. 2013; 2014). The results indicate that bioaccumulation depends on the functional group and chain length of the analyte (longer chain results in decreasing concentrations), the concentrations of PFAAs in the recycled water, and the organic content in the soil (lower bioaccumulation correlating with higher organic carbon loads in the soil) (Blaine et al. 2014).

Recently, in 2017, Domingo and Nadal compiled research on human health effects related to dietary intake of PFAS between 2011 and 2016. Their findings, based on available data, indicate that consuming produce irrigated with water containing PFAS would not pose a significant risk to human health for populations not occupationally exposed (Domingo and Nadal 2017). While this is in line with the 2008 German Federal institute for Risk Assessment that concluded health risks were not a concern from dietary exposure to foods containing PFOS and PFOAs, the research team recognized limited data exists (European Food Safety Authority 2012). Many countries, including the US, have limited data on dietary intake of PFOAs. and more data is needed to truly evaluate the human health risks to consuming food containing these substances (Domingo and Nadal 2017).

Pharmaceuticals, Personal Care Products, and Endocrine Disrupting Compounds

Pharmaceuticals and personal care products are defined by the EPA as 'any product used by individual for personal health, cosmetic, or used by agribusiness to enhance growth or health of livestock'. Common PPCPs include caffeine, over the counter or prescription medications (e.g., carbamazepine, ibuprofen, naproxen, and estrogens) among others.

Endocrine disrupting chemicals (EDCs) interfere with hormones or alter our bodies sensitivities to different hormones. They do this by mimicking natural hormones, blocking hormones, or by increasing or decreasing hormone levels in the blood by changing how they are made, broken down, or stored.

Studies have shown that plants are able to take up these compounds, through roots, leaves, and fruit (Shi et al. 2022). Research by Paltiel et al. (2016) indicates that produce irrigated with recycled water in Israel can take up carbamazepine, an antiseizure medication commonly found in recycled water, at levels between 0.1 ng/g to 100 ng/g. Uptake, however, depends on the crop type, chemical characteristics, and other environmental factors. The results indicate levels present in recycled water, along with other similar CECs, and do not pose a significant health risk to humans. Further risk assessments from Sheikh (2017) concluded that it would take between 200 to 8000 years of consuming produce to reach one typical daily dose of carbamazepine. However, more research is needed to fully understand the effects when chronically exposed to low doses.

Potential for Plant Uptake and Accumulation

The fate of these chemicals in recycled water and agricultural settings is complex and depends on a number of factors. Characteristics of the compound, crop, soil, and environment will determine movement, uptake, distribution, and accumulation within soils and crops and is often chemical and crop specific. Chemical concentration, solubility, and biodegradability under differing environmental conditions (e.g., temperature, pH, climate, moisture, and soil characteristics) impact persistence of these chemicals within the environment and how available they are for plants to take up. Plant defense mechanisms further influence how substances are taken up, sequestered, and degraded. Distribution and accumulation of compounds in roots, shoots, and leaves is often plant specific.

Further research that is crop and chemical specific would be valuable for assessing risks and developing best management practices protective of public health. This could provide guidance on pairing quality of recycled water with specific crops to minimize introduction of hazardous compounds into food systems. This information could also be used to develop site-specific management approaches to reduce contaminants in soils through bioremediation

Monitoring & Detection Methods

Detection methods for CECs include targeted chemistry and bioanalytical screening tools. Targeted chemistry is chemical specific while bioanalytical assays are intended to capture a wide range of CECs. Bioassays can be used to monitor and identify unknown CECs down to the type and assess potential physiological effects. However, because these methods can be costly and time consuming, bioassays are not routinely performed, and more information is needed to understand to what extent these chemicals are present in municipal recycled water.

Current water quality requirements for wastewater discharges (and drinking water) do not account for all chemicals that may be present. To assess how effective a treatment is at removing organic chemicals, concentrations of total organic carbon (TOC) can be used as a surrogate parameter (NWRI 2012). However, there are downsides to using TOC especially in the presence of high inorganic carbon, and removal of specific organic chemicals relevant to human health cannot necessarily be determined (NWRI 2012).

As an alternative, composite measures may better assess treatment performance and risks to public health. One approach measures the change in biodegradable dissolved organic carbon (BDOC) alongside indicator CECs and TOC. Measuring BDOC in conjunction with indicator chemicals (those with similar behaviors to target chemicals) may better represent removal of unregulated wastewater-derived organic compounds that may present a health risk. While this approach can provide information on removal of biodegradable organics, it does not provide information on removal of recalcitrant organics (NWRI 2012). However, the concentration at which organic compounds not readily biodegradable exist in recycled water is not well understood, and using BDOC in concert with indicator CECs and TOC is thought to be a superior approach to TOC alone.

Findings of the California SWRCB Science Advisory Panel on CECs in Recycled Water – Recommendations for Non-Potable Reuse

In 2017-2018, the Science Advisory Panel (convened by the California State Water Resources Control Board) reviewed the current state of knowledge and evaluated the potential health risks associated to the exposure of CECs in non-potable reuse activities, excluding ingestion of crops irrigated with recycled water. The Panel also evaluated human health risks associated with exposure to antibiotic resistant bacteria (ARB) and antibiotic resistant genes (ARGs).

The findings showed the most likely exposure routes for CECs were through accidental ingestion or skin contact. All scenarios indicated that accidental ingestion exposures with recycled water used for non-potable activities would be more than three orders of magnitude lower than potable use scenarios (<0.1% of potable water consumption) and that total exposure scenarios (ingestion, inhalation, and skin contact) are less than 10% than that of intentionally consumed potable exposures (State Water Resources Control Board 2018). Therefore, the Panel did not recommend CEC monitoring for non-potable reuse applications approved under Title 22 (Drewes et al. 2018).

To address gaps in knowledge regarding unknown CECs, the Panel added two bioanalytical screening tools that can be used to monitor and identify ten additional in vitro bioassays that may be appropriate for screening recycled water to identify different types of CECs (e.g., estrogenic or carcinogenic CECs) in water samples (State Water Resources Control Board) 2018). Continued research is needed to understand temporal variability in the occurrence and concentrations of CECs and to establish a formal monitoring and assessment program that is responsive to the rapidly incoming data.

4.4.4 Antibiotic Resistance

Antibiotic resistance (AR) has become a top global health concern as death rates rise from infections caused by antibiotic resistant bacteria (ARB) (Friedman et al. 2016; Victor et al. 2008). Resistance to antibiotics is thought to spread amongst microorganisms through natural selection and horizontal gene transfer. While AR can be driven by anthropogenic impacts, such as antibiotic residuals commonly found in treated wastewater (TWW), AR occurs in natural soil microbiomes in pristine soil environments as well (Negreanu et al. 2012; Drewes et al. 2018; Kampouris et al. 2021). Aquatic environments, including recycled water, have been identified as a primary reservoir of ARB, and ARGs can survive even after disinfection (State Water Resources Control Board 2018). Evidence relating prevalence of ARB or ARGs in agricultural soils irrigated with TWW is conflicting (Bergeron et al. 2016; Gekenidis et al. 2018).

Some studies indicate a proliferation of ARGs and ARB (Dalkmann et al. 2012; Wang et al. 2014; Jechalke et al. 2013) while others indicate no significant increases in ARGs in TWW irrigated soils (Negreanu et al. 2012; Marano et al. 2019; Cerqueira et al. 2019a; Cerqueira et al. 2019b). A recent study by Kampouris (2021) found that any type of irrigation source (freshwater or TWW) could result in ARG disbursement in soils. Interestingly, the researchers found the abundance of specific genes was more prevalent in the higher intensity irrigation fields, supporting earlier findings by Negreanu (2012) where significantly higher levels of AR were found directly under irrigation drippers where the soil moisture content was higher (Negreanu et al. 2012; Kampouris et al. 2021). The potential for regrowth to occur in distribution systems from the WWTP to the point of use is also an area of research. In a study conducted by Fahrenfeld et al. (2013), a broader range of ARGs was found at the point of use after leaving the treatment facility.

One explanation to the inconsistencies observed across these studies, is the variability in research design, methods, and location. Factors including temporal and seasonal climates, soil types and soil microbiota, geographic location, water quality, target genes, and water intensity rates can result in different outcomes (Kampouris et al. 2021). Contrasting findings highlight the complex dynamic at play between the abiotic and biotic factors in agricultural soils and water sources.

More focused studies are warranted to unravel these intricate relationships and to better understand the AR and ARG proliferation in agricultural soils irrigated with recycled water. Information to date is incomplete, and the causes for antibiotic resistance are unknown (Drewes et al. 2018). A lack of standardized methods for assessing the occurrence, removal, and risks associated with ARB and ARGs further impeded understanding of this topic (Drewes et al. 2018).

Findings of the California SWRCB Science Advisory Panel on CECs in Recycled Water - Addressing Concerns Related to ARB and ARGs

Following an extensive literature review, the 2018 Science Advisory Panel concluded that ARB and ARGs do not significantly proliferate in recycled water and, due to a lack of conclusive evidence, they do not recommend monitoring for ARB and ARGs. However, the Panel does recognize the need for continued research in this area and did provide recommendations for further studies (Drewes et al. 2018). The State Water Board plans to continue following current and upcoming research and has funded collaborative research with WRF. They encourage utilities to collect ARB and ARG data to help develop science-based frameworks for future risk assessments.

4.5 Human Health Risks of Agricultural Water Reuse: Discussion and Research Needs

Gaps in knowledge, information, and data on the quality and quantity of recycled water and the relationship with agroecosystems can create obstacles to reuse projects. This section highlights areas where more research or additional data is needed to adequately address these barriers. Part 2 of this report discusses practical strategies for addressing some of these gaps in knowledge and data. Examples of some areas where there are still substantive research needs are highlighted below.

1) **Fate and transport of emerging contaminates in agricultural systems AND the significance of those findings for human health.**

In general, there is a lack of data and consistent research methods on plant uptake, groundwater contamination, CECs, ARBs, and ARGs in agricultural settings and recycled water. Occurrence, concentrations, treatment efficacy, and impacts to human health are not well understood. Illustrated here, in other literature reviews, research publications, and conclusions of the 2018 Science Advisory Panel, data on health effects related to agricultural reuse varies considerably. While some research findings indicate little to no human health risks from dietary exposure to some of these substances, others indicate that risk does exist. Holistic assessment of exposure to pathogens and CECs via recycled water relative to other sources of exposure can help contextualize conflicting findings on risk (Garner et al. 2016). This perspective was the basis behind the SWRCB CEC Science Advisory Panel's recommendation that additional monitoring and regulations on CECs and non-potable reuse were not warranted (Drewes et al. 2018) though this panel is periodically reconvened to assess current regulations relative to advances in science and knowledge.

2) **Improved research design, validation and standardization of methods, and collaboration between research teams to help reconcile inconsistent findings amongst ongoing fate and transport studies.**

Conflicting findings due to variations in experimental design, biases, assessment methods, and environmental conditions contribute to the inability to develop robust risk assessments. Teasing apart actual versus perceived risks is challenging when trying to assess actual risk from sparse, conflicting, and potentially biased data. Unknown health impacts can result in barriers to agricultural reuse, and recommendations on developing standardized methods have been voiced by stakeholders, researchers, and experts alike. Example research design inconsistencies contributing to variability in findings include differences in:

- Identification methods used
- Occurrence/Concentrations
- Monitoring methods
- Reporting
- Removal/Inactivation methods
- Associated Risks
- Non-standardized bioanalytical tools
- Target CECs or ARGs

3) **Systems-focused or meta-analysis type research synthesizing information on local context with findings on the fate and transport of water quality constituents of concern for public health.**

Likewise, local context and conditions all have significant impacts on microbial communities and the fate and transport of chemicals present in recycled water. This variability does not undermine the value of conducting research on these topics; rather, it underscores the importance of understanding context when interpreting or attempting to generalize these findings. Examples of some local contextual factors impacting findings:

- Soil types and characteristics: (e.g., organic matter, organic carbon)

- Climate and moisture
- Temperature
- Soil ecosystems: including biotic & abiotic factors
- Geographical locations
- Crop type
- Crop irrigation requirements and irrigation method
- Source water: variability in quality

4) Development of centralized repository for information, monitoring and research data on agricultural water reuse

A lack of centralized, compulsory, and accessible data and information can also be a roadblock for reuse. Currently, federal requirements for electronic reporting data on recycled water do not exist. While some publicly accessible information reported to the US EPA must be submitted electronically, such as those for the National Pollutant Discharge Elimination System (NPDES), these are not always readily nor electronically available for researchers, water planners, or others. Collecting state and national data on recycled water quality, quantity, and end-uses is time consuming and laborious, and may be outdated by the time the data are collated and analyzed.

It is understood that some of the information captured in these reports is sensitive and protecting end-users of recycled water is important. However, compulsory reporting and easily accessible information can drive progress, gain buy-in, and advance water reuse. For example, states with transparent and easily navigable water reuse programs, such as Florida, California, and Idaho are leaders in agricultural water reuse.

5) Foster the development of collaborative, knowledge sharing networks on water reuse that bridge the practitioner and research communities

While the current state of knowledge on human biological pathogens in municipal recycled water is fairly well understood, additional research into CECs, ARB, and ARGs relevant to agricultural settings are warranted. The National WRAP Collaborative is actively working to fill some of these gaps through collaborations and partnerships. Communication and partnerships between utilities, regulatory agencies, agricultural communities, and irrigation districts is needed to address some of these concerns and barriers to agricultural reuse. This includes continued convening of expert panels and multi and interdisciplinary collaborations across fields to ensure that all concerns and barriers are addressed appropriately and effectively. Inclusion of social, communication, and education experts can help co-develop communication tools and activities that can effectively and positively distill information on the perceived and actual health risks.

CHAPTER 5

Evaluate and Characterize Long-Term Impacts of Agricultural Water Reuse for Agricultural Producers

5.1 Introduction

5.1.1 Overview

Existing fit-for-purpose frameworks for water reuse tend to focus on the regulation of traditional constituents of concern for public health (e.g., pathogens and their related indicators). However, there is a growing need for an evidence-based framework applying these same principles to address agronomic concerns. The lack of water quality standards and limits for agricultural irrigation water is in part due to the complexities involved in agronomic systems, including soil-plant-water interactions, climate, crop type, and water quality (Ayers and Westcot 1985; Malakar et al. 2019).

Much of the water quality guidelines and recommendations for irrigation water of agronomic importance are focused on long-established concerns such as the effects of salinity, ion toxicity, and nutrients. While these are still of significant importance, contemporary water quality concerns have emerged to include long-term agronomic effects related to the accumulation of trace elements, heavy metals, and other chemicals.

5.1.2 Water Quantity and Quality Tradeoffs

Increased water scarcity in many regions has shifted traditional irrigation practices in efforts to protect food production impacted by limited water supplies. As freshwater sources become less available in quality and quantity, many water users are becoming more reliant on municipal recycled water to meet their needs. Producers and irrigators are also seeking out non-traditional irrigation sources (e.g., recycled water and degraded groundwater) and deficit irrigation strategies in the face of depleting resources (Swett 2020).

While municipal recycled water can provide stable and reliable irrigation supplies to alleviate water-stress induced impacts, distance between supply and demand, seasonal fluctuations, and competition for recycled water have been recognized as barriers to agricultural reuse. Strategies to overcome these obstacles can be achieved through stakeholder engagement to identify partnerships between municipal water providers, irrigation and water districts, and agricultural producers to identify needs, common goals, and opportunities that can deliver multiple benefits (See Part 2: Guidebook and Profiles). Irrigation districts and growers pursuing agricultural water reuse projects face a complex series of tradeoffs between the water supply benefits of recycled water and a range of potential, context specific water quality benefits and tradeoffs.

5.1.3 Chapter Overview

This chapter summarizes and contextualizes potential water quality issues surrounding the reuse of municipal recycled water for agricultural irrigation, with a focus on the potential long-term agronomic impacts from. Treatment can play an important role in mitigating both health and agronomic risks associated with recycled water use and is discussed in Chapter 2. This chapter focuses on on-farm agronomic impacts and the factors influencing whether these impacts are realized.

The main topics discussed in this chapter include:

- Pathways for Potential Agronomic Impacts
- Factors Impacting the Realization of Agronomic Impacts:
    - Irrigation Method, Rates, and Timing
    - Plant-Soil-Water Systems
- Water Quality Constituents of Agronomic Significance
- Emerging Agronomic Concerns and Research Needs

Additional information on specific, practical strategies for addressing agronomic impediments to agricultural water reuse is included in the companion guidebook (Part 2).

5.2 Pathways for Potential Agronomic Impact

5.2.1 Irrigation Water Quality

All irrigation water contains salts (e.g., sodium (Na+), chloride (CL-), and boron (B)), nutrients (e.g., nitrogen, phosphorous), and other constituents to some degree; however, recycled water may contain higher concentrations than what is present in freshwater supplies. And while all irrigation water sources pose some level of risk with the potential to impact crop and soil health, each source is generally associated with certain hazards. For example, contaminants typically associated with groundwater include trace elements, nanoparticles, pharmaceuticals, steroids, and agrochemicals, while contaminants in surface water and recycled water may include these in addition to human and plant pathogens, mycotoxins, and other chemicals of emerging concern (CECs) (Malakar et al. 2019).

5.2.2 Crop Health

Water Quality Parameters with the Potential for Long-term Agronomic Impacts:

- Salts – Salinity and sodicity
- Ion Toxicity – Boron, chloride, sodium
- Organics
- Metals and other inorganics
- Nutrients
- Chemicals of emerging concern
- Soil and plant health

Irrigating crops with water containing elevated concentrations of salts, minerals, and other compounds can lead to a number of direct and indirect agronomic consequences including saline or sodic soils, soil stress, mineral toxicity, alteration of plant-microbe interactions, plant diseases, damaged crops, and declines in yields (Swett 2020; Rosegrant et al. 2009; Santos Pereira et al. h2009; Hong and Moorman 2005; Raudales et al. 2014). The type and concentration of these constituents, namely salts, have the potential to damage plants, restrict crop yields, degrade soils, and may have long-lasting effects if not managed accordingly. Evaluating irrigation water quality is essential for selecting suitable crops with the greatest potential for optimal yields. Understanding water quality composition can help to anticipate problems and select management strategies to mitigate impacts.

5.2.3 Soil Health

Soils and soil environments must also be taken into consideration as soil ecosystems play a critical role in maintaining the physical and chemical quality of the soil, vital for crop health and production. Soils are complex systems responsible for a number of important processes including nutrient cycling and biogeochemical transformations, degradation and sequestration of contaminants, and disease prevention (Brussaard et al. 2007; Parikh and James 2012; Vadakattu et al. 1998).

Changes to the soil ecosystem can cause disruptions to these processes, which may lead to soil degradation, decreased yields, damaged crops, or even crop death (Brussaard et al. 2007). Research on the effects of salinity to soil health indicate that soil stress can lead to reduced diversity, abundance, and species richness of the soil biota (microorganisms and fauna) over time (Borneman et al. 1996; Nelson and Mele 2007; Ibekwe et al. 2010). Continued use of saline irrigation water may lead to the salinization of soils, an important consequence of using recycled water for agricultural irrigation if unmanaged. Understanding the potential long-term consequences to soil health can help guide management practices to overcome these challenges.

5.3 Factors Impacting Realization of Potential Agronomic Impacts

5.3.1 Irrigation Method, Rates, and Timing

Similar to managing irrigation method and timing to reduce risks posed to human health, irrigation management can also help to mitigate agronomic impacts. For example, overhead, drip, or flood irrigation can affect crops differently depending on the constituents in the reclaimed water, sensitivities of the crops, and timing of irrigation. Crop type, climate, water quality, and soil characteristics are all factors to consider when planning irrigation activities. When irrigation method cannot be modified, selecting crop type based on the other factors or irrigation timing and frequency may be more feasible.

Overhead irrigation allows water to come into direct contact with the crop which can have negative consequences to sensitive crops. For example, at concentrations exceeding plant tolerance thresholds, some constituents in reclaimed water, such as sodium and chloride, can cause crop damage to the leaves due to foliar uptake and/or surface burns (Rhoades et al. 1992). Frequent and light overhead irrigation can lead to leaf burn and saline stressed soils with non-uniform wetting (Wu et al. 2009). Thus, changing the frequency and duration of overhead watering events to heavier and less frequent event is one strategy to mitigate the effects of saline stressed damage. Less frequent and heavier watering allow the leaf surface and soils to dry out between events, which can reduce damage from salt stress (Wu et al. 2009). In addition, drip irrigation can reduce stress and minimize the negative effects of irrigating with saline water (Rhoades et al. 1992).

While leaching can be used to manage saline soils by using additional water to push the salts down from the root zone, this method may not be effective for sodic soils, which is closely associated with the irrigation water chemistry (Wu et al. 2009).

5.3.2 Plant-Soil-Water Systems

Plant-soil-water interactions are complex systems, influencing each other in continual feedback pathways. Plant health, growth, and physiology is influenced by soils, and in turn, plant roots modify the chemical, biological, and physical elements of the rhizosphere through the secretion of a suite of exudates. These ecosystems may become disrupted if the quality of irrigation water does not meet the needs of the intended end-use and may affect crop production.

While in general, the mechanisms for the fate and transport of salts, chemicals, and other compounds in soil and water environments are fairly well understood, information on plant uptake in agricultural environments is less understood, and crop-and-chemical-specific uptake is an area where research is needed.

Soil Ecosystems

Plant-root exudates - sugars, amino and organic acids, proteins, and other metabolites - create a competitive niche environment in the root zone that select for microorganisms with specific functions (Ehrenfeld et al. 2005). The biotic and abiotic interactions in soil ecosystems are responsible for a number of ecological functions such as nutrient cycling, biogeochemical transformations, degradation of pollutants, prevention of plant diseases, and overall soil health (Ehrenfeld et al. 2005; Vadakattu et al. 1998). Disruptions can result in degradation in soil and plant health as well other nutrient cycling processes (Brussaard et al. 2007; Zolti et al. 2019).

Recycled water, known to have elevated concentrations of salts, nutrients, trace elements, and chemicals, has the potential to affect the quality of soils and crops through deposition and accumulation of these substances over time. Undesirable effects on plant health and soils have been reported as a result of irrigating with recycled water (Assouline and Narkis 2013; Pedrero et al. 2014; Nicolás et al. 2016), with diversity and abundance of soil microorganisms decreasing in response to saline stress (Borneman et al. 1996; Ibekwe et al. 2010). Soil organisms play a critical role in maintaining soil health. Because soil health is vital for crop production, the potential effects of the long-term use of recycled water for agricultural irrigation should be considered.

Fate and Transport

Many complex factors influence the fate and transport of salts, chemicals, trace minerals, and heavy metals in soil and water environments. These include soil and crop characteristics, climate, and types and concentrations of constituents. Soil characteristics include biochemical oxygen demand (BOD), cation exchange capacity (CEC), redox potential (Eh), pH, and the clay and organic matter content (Wu et al. 2009; Antoniadis et al. 2017). Likewise, addition of biofertilizers, and humic substances, nano materials such as nano-iron can be useful additives to sequester uranium, selenium, and arsenic and reduce their uptake by plants.

Characteristics of the constituents, such as solubility, volatility, and degradation can be used to inform how they may potentially move and persist in the environment and become phytoavailable, although there are many complex factors at play. Light weight organics have a tendency to be more water soluble than heavier, lipid soluble organics, and may be difficult to remove during treatment processes. Many chemicals may volatilize or degrade during retention and storage or shortly after irrigation.

Irrigation water with high biochemical oxygen demand (BOD), the amount of dissolved oxygen required to break down organic materials, can increase soil stress and lower pH (more acidic). The ability for soil to buffer against acidification, retain valuable nutrients, and maintain structure is influenced by a soils ability to hold on to exchangeable cations, or positively charged ions (Culman et al. 2019). This cation exchange capacity (CEC) is characteristic of clayey soils with organic matter and retains nutrients, chemicals, and water better than course sandy soils. This is in part due to the smaller spaces between the small, fine particles.

One of the most influential factors affecting the solubility of metals, alkalinity of soils, and mobility and availability of inorganics is pH. pH is in turn influenced by BOD, CEC, and the redox potential (Nashikkar 1993; Wu et al. 2009; Antoniadis et al. 2017). Positively charged metal ions, such as sodium, calcium, magnesium, iron, and ammonium, are more mobile and bioavailable in acidic soils than their negatively charged non-metal counterparts. Metals can become mobilized and readily available for plant uptake when complexed with ligands, such as humic or fulvic acids. Non-metal anions, such as chloride, bromide, nitrates, phosphates, and sulfates become less mobilized and available to plants when in alkaline soils or complexed with organic material (Soares et al. 2015; Evangelou et al. 2004).

Plant Uptake

Plants take up nutrients and trace elements, heavy metals, organics, and other chemicals via roots or by absorption through leaves. In general, water-soluble organics are taken up through plant roots while lipid soluble organics are absorbed through the leaves (Fismes et al. 2002; Trapp and Legind 2011; Mahoney et al. 2021). Inorganics tend to concentrate in the non-edible portions, such as the roots, leaves, and stems even though uptake generally occurs at the roots. Some constituents may damage metabolic functions of plants when concentrations reach toxic levels leading to physiological and morphological changes including chlorosis, necrosis, or death.

Accumulation of toxic ions, trace elements, heavy metals, chemicals, and other contaminants of emerging concern may be inhibited by plant characteristics and defense systems. Plants are capable of handling excess amounts of contaminants using a range of systemic or acquired mechanisms activated by plant immune systems or plant-microbe interactions, including immobilization, sequestration, and elimination. Toxins can be sequestered to non-essential areas (outside of those required for metabolic functions, such as skins) or eliminated as complexes (Emamverdian et al. 2015). Microorganisms internal to a plant can also enhance plant health through endophytic relationships by initiating or inducing systemic resistance (ISR) mechanisms (Iniguez et al. 2004b; Otlewska et al. 2020).

5.4 Water Quality Constituents of Agronomic Significance

5.4.1 Overview

Water quality testing and monitoring tends to focus on parameters likely to impact human health, such as biological and viral pathogens. For reuse purposes, these requirements generally include biochemical oxygen demand (BOD), total suspended solids (TSS), turbidity (measured as NTU), and indicator organisms (e.g., total coliform bacteria, fecal coliform bacteria, or *E. coli*). However, growers are also concerned with other water quality parameters that can impact crops and soil health.

There are four main irrigation water quality related problems outlined by Ayers and Westcot (1985) that are important in agronomic settings: salinity, infiltration, ion toxicity, and other miscellaneous effects (pH, nitrogen, and bicarbonate). These issues can impact agricultural systems through both direct impacts on crops (e.g., ion toxicity) and declines in soil health over time (e.g., changes in infiltration capacity). Suitability of recycled water for agricultural irrigation can be assessed through monitoring these and other parameters including total dissolved solids (TDS), electrical conductivity (EC), and sodium adsorption ratio (SAR). Nitrates, bicarbonates, and pH may also be relevant for certain crops. Other emerging concerns include trace elements, heavy metals, and chemicals of emerging concern (CECs).

The following sections summarize information on the main constituents of agronomic concern related to the use of recycled water for irrigation, long-term effects, and agronomic thresholds for assessing soil-water-crop compatibility.

5.4.2 Agronomic Water Quality Concerns

Salts, Salinity, and Sodicity

Salts in irrigation water can contribute to saline or sodic soils, which limits a plants access to water and affects infiltration rates. Crop sensitivities to salts and other trace minerals vary widely across and within species and can cause injury to plants, decreased yields, or even death (Ayers and Westcot 1985). While some of these constituents are essential for plant growth (e.g., boron), they may cause damage when concentrations exceed maximum crop tolerance thresholds. Crop compatibility and strategic irrigation and nutrient management strategies can help to overcome some of these challenges.

In arid and semi-arid regions, the quality of irrigation water is especially important as evaporation can concentrate salts and other ions in soils resulting in build-up in the root zones, leading to crop damage and degraded soils (Ayers and Westcot 1985). Leaching can be used to remove salts but requires additional water to flush salts down from the root zone. However, in regions where water resources are significantly strained (often these same arid regions), water availability can restrict leaching as a feasible management practice.

Two main issues can result from elevated concentrations of salts in irrigation water and soils: salinity and sodium hazards. Both have the potential to have long-term consequences on crops and crop yields if not managed properly (Fipps 2021). While salinity affects the ability of a plant to access water, sodium affects the ability of water to infiltrate soils.

Ion Toxicity and Nutrient Deficiencies

The major ions essential for plant growth include calcium, magnesium, and potassium, with minor requirements from ions including boron, chloride, iron, manganese, zinc, and copper among others. At concentrations exceeding crop tolerance thresholds they can lead to toxicity. Additive consequences can further complicate salinity or sodicity problems and can affect a plants ability to access essential nutrients leading to nutrient deficiencies (Maas and Grattan 1999; Corwin and Yemoto 2020; Brdar-Jokanović 2020).

Ion toxicity can occur as a result of plant uptake through roots from the soils or from direct absorption through leaves from direct contact with water during overhead irrigation where ions accumulate in the tips and edges of leaves, which is where water loss is the greatest (Ayers and Westcot 1985). Leaf burn, deformation, chlorosis, necrosis, and defoliation are typical signs of ion toxicity. Recommendations on maximum concentrations of select ions and nutrients are summarized in Table 5-1 later in this chapter.

Nutrients

Reclaimed water can contain nutrients essential for plant growth, such as nitrogen and phosphorous. While discharge requirements to water ways require concentrations to be kept at a minimum to protect aquatic environments, removal of nitrogen and phosphorous for irrigation applications to agricultural fields may not be required (Wu et al. 2009).

Phosphorous levels in municipal reclaimed water generally do not meet crop requirements, but over time they may accumulate in soils thus reducing the need to supplement. In reclaimed water, nitrogen can range from 5 to 20 mg/L. However, excess concentrations of nitrogen, generally above 30 mg/L of total nitrogen, can cause overstimulation resulting in decreased quality and can amplify deficiencies of other nutrients (Lazarova and Bahri 2008; Wu et al. 2009). Efficient removal of these nutrients is minimal using secondary treatments and requires advanced or tertiary methods.

It is also important to note that consistent concentrations of nitrogen throughout the growing season may not be beneficial to all crops at all stages of growth and may actually cause negative consequences such as delayed maturity or decline in quality when concentrations are above what is needed (Ayers and Westcot 1985; Sheikh et al. 2019). For example, ranges of nitrogen common to reclaimed water (5 to 20 mg/L) may be too high for some crops in the later season, and blending with or switching to freshwater supplies may be needed to limit excessive growth (Wu et al. 2009).

Nutrient levels in reclaimed water used for agricultural irrigation have been identified as a perceived benefit, potentially reducing the need to apply additional fertilizers therefore reducing costs to growers; however, it is not recognized as a significant driver (Sheikh et al. 2019). As documented in the literature, practical applications may not be as incentivized since measuring nitrogen concentrations in reclaimed water before application is not a common practice.

Other Trace Elements and Heavy Metals

Inorganics, such as trace elements and heavy metals including barium, cadmium, chromium, copper, iron, manganese, magnesium, mercury, nickel, strontium, and zinc may be present in municipal recycled water. While some are not essential for plant growth (e.g., cadmium, mercury, and lead), all can be taken up by plants from the soil.

While concentrations for some of these may not be high enough to be of immediate agronomic concern, many of these there have small windows for which the concentrations can be in deficit or in excess, thus leading to nutrient deficiencies or toxicities (Tanji and Wallender, 2011; Wu et al. 2009). Table 5-1 summarizes the recommendations for maximum concentrations of trace elements. The severity of symptoms differs between crops and symptoms include leaf deformation, stunted growth and emergence, chlorosis, and tissue death (Brdar-Jokanović 2020). Because inorganics can persist in the environment with the potential to transform and become phytoavailable, accumulation may be hazardous to crops (Emamverdian et al. 2015).

5.4.3 Long-term Effects of Salts, Ions, Trace Elements, and Heavy Metals

Accumulation of salts, ions, trace elements, and heavy metals in soils can occur due to poor water quality and soil permeability, climate, or irrigation practices. Recycled water generally does not have high enough concentrations of trace elements to elicit toxicity, but the long-term use can lead to accumulations in soils. This can have negative effects on soils and crops especially under certain climates (mostly arid and semi-arid environments) and soil conditions (Rhoades et al. 1992; Wu et al. 2009; Brdar-Jokanović 2020).

Saline soils have been shown to disrupt soil biota that provide overall soil health, protection from plant pathogens, and provide key nutrient cycling processes. Studies show declines in microbial diversity and shifting of microbial community composition (Zolti et al. 2019), although some research indicates that these changes can be temporary and resolved through management practices to reduce salinity or alter other soil properties (Zolti et al. 2019).

Plant sensitivities to salts and other trace elements are a function of the tolerance to substances in the root zone or deposited on foliage and can range widely between and within crop species (Ayers and Westcot 1985; EPA 2012). Plants are typically more tolerant to saline soils than to saline irrigation water. Over time, however, salt deposition from irrigation waters can lead to accumulations in soils which can affect soil permeability, damage crops, decrease yields, and result in plant death (Ayers and Westcot 1985; Corwin and Yemoto 2020).

As salts and other ions increase in soils, so does osmotic pressure. In response, plants need additional energy to withdrawal water from the soil. This can inhibit access to water or nutrients resulting in similar physiological response as dehydration resulting in stunted growth, diminished crop yields, or darker, smaller, and thicker leaves can o (Ayers and Westcot 1985; Maas and Grattan 1999; Qian et al. 2001; Qian and Mecham 2005; Lazarova and Bahri 2008; Assouline and Narkis 2013; Fipps 2021)

Elevated concentrations of sodium, salinity (as TDS or EC), sodium adsorption ratios (SAR), pH, and dissolved organic carbon (DOC) in soils have been reported from the long-term irrigation (three to sixteen years) with treated recycled wastewater as compared to irrigation with freshwater sources (Qian and Mecham 2005; Lado et al. 2012; Zolti et al. 2019; Qian and Lin 2019) and can lead to yield reductions (Lado et al. 2012; Assouline and Narkis 2013; Zolti et al. 2019). For example, after five years of irrigation with recycled water, avocado and citrus orchids growing in clayey soils experienced a 20 to 40 percent reduction (Assouline and Narkis 2013). After three years, tomatoes and lettuce saw significant reductions in yield regardless of soil type (Zolti et al. 2019).

Iron, manganese, copper, boron, aluminum, and magnesium concentrations in soils have also been reported after long-term irrigation with recycled water (Qian and Mecham 2005; Lado et al. 2012). While some are essential for plant growth, concentrations exceeding plant tolerances can be toxic and lead to nutrient deficiencies (Maas and Grattan 1999; Corwin and Yemoto 2020; Brdar-Jokanović 2020). For example, phosphate requirements needed to achieve 50 percent yield can double in response to increased concentrations of sodium and chloride (Maas and Grattan 1999).

5.4.4 Agronomic Thresholds

The water quality classifications and general guidelines from the FAO can be useful a management tool to predict issues that may arise from the long-term use of recycled water. They can be helpful to identify and prioritize strategic management practices to mitigate impacts. Recommended values and degrees of restrictions are provided in Table 5-2 for salinity, infiltration and SAR, and ion toxicity as well as pH, nitrates, and bicarbonates. Note that these are general guidelines and are based on a number of conditional assumptions that may not apply to all situations. Table 5-1 summarizes the recommendations for maximum concentrations of trace elements.

Salinity

Water salinity can be estimated by measuring either total salinity as total dissolved salts (TDS; mg/L) or electrical conductivity (EC; µS/cm) (Wu et al. 2009; Fipps 2021). TDS is the measurement of all combined ion particles, including salt ions and dissolved organic, smaller than 2 microns (0.0002 cm), while EC is a measurement of the ability to pass electrical flows and is related to the ion concentrations.

While salinity thresholds vary by crop, TDS and EC values in irrigation water are recommended to be below 450 mg/L and 700 µS cm^{-1} with severe restrictions as values reach and exceed 2,000 mg/L and 3,000 µS cm^{-1}, respectively. When TDS and EC values are between these guidelines, moderate restrictions using appropriate management strategies (e.g., leaching) are recommended (Ayers and Westcot 1985; Fipps 2021).

Sodium and SAR

When sodium concentrations become greater than magnesium and calcium, the sodium adsorption ratio (SAR) increases resulting in decreased water movement or a decreased infiltration rate. This leads to sodic soils, characterized as having high pH values (alkaline) and a hard crusty surface. Due to humic acids and organic matter, sodic soils turn soft, slippery, and black when wet and develop a hard thick crust as they dry.

Generally, SAR values >18 contribute to the degradation of soil health, decreased nutrient phytoavailability, and an increased risk of soil erosion and plant diseases (Fipps 2021; Wu et al. 2009; Rhoades et al. 1992).

Unlike chloride and boron, sodium is not recognized as an essential element for plant growth. Effects of toxicity to sodium may take weeks to become visible with signs of leaf burn and necrosis on the outer edges of the leaves. Effects of poor infiltration as a result of high SAR can appear similar to sodium toxicity (Ayers and Westcot 1985).

Chloride Ions

Chloride ions are mobile, phytoavailable, and can be taken up and accumulate in leaves causing leaf drop, burn, and drying (Ayers and Westcot 1985). Recommended guidelines from the FAO indicate moderate restrictions when concentrations in water used for surface irrigation are between 4 and 10 mg/L and less than 3 when overhead irrigation is used (Ayers and Westcot 1985). Adverse effects to chloride toxicity can be seen in some crops when concentrations are as low as 100 mg/L for sensitive crops, or as high as 900 mg/L for tolerant crops (Lazarova and Bahri 2008).

Boron

In municipal reclaimed water, boron (another essential element for plant growth) can be present as a result of household detergents and other cleaning products (Goldberg and Suarez 2017), although this is becoming less of a concern as a result of eliminating borax from detergents (Sheikh et al. 2019).

Boron sensitivities vary between crops. When concentrations exceed 1 mg/L, toxicity can occur in sensitive plants (Ayers and Westcot 1985; Lazarova and Bahri 2008; Brdar-Jokanović 2020). Concentrations of boron in recycled water used for irrigation are recommended to be less than 2 mg/L for short term use and 0.75 mg/L for long-term use (Fipps 2021). Accumulations of boron in soils after long-term irrigation with recycled water have been reported in both golf courses (five years) and orchids (seven years) (Qian and Mecham 2005; Lado et al. 2012). Soil amendments, such as gypsum and sulfuric acid, can mitigate some of the effects (Rhoades et al. 1992).

Table 5-1. Recommended Water Quality Criteria for Agricultural Irrigation.

Source: EPA 2012 Water Reuse Guidelines adapted from Ayers and Westcot 1985.

Constituent	Maximum Concentrations for Irrigation (mg/L)	Remarks
Aluminum	5.0	Can cause non productiveness in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity
Arsenic	0.10	Toxicity to plants varies widely, ranging from 12 mg/L for Sudan grass to less than0.05 mg/L for rice
Beryllium	0.10	Toxicity to plants varies widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans
Boron	0.75	Essential to plant growth; sufficient quantities in reclaimed water to correct soil deficiencies. #1Optimum yields obtained at few-tenths mg/L; toxic to sensitive plants (e.g., citrus) at 1 mg/L. Most grasses are tolerant at 2.0 - 10 mg/L
Cadmium	0.01	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/L; conservative limits are recommended
Chromium	0.1	Not generally recognized as an essential element; due to lack of toxicity data, conservative limits are recommended
Cobalt	0.05	Toxic to tomatoes at 0.1 mg/L; tends to be inactivated by neutral and alkaline soils
Copper	0.2	Toxic to a number of plants at 0.1 to 1.0 mg/L
Fluoride	1.0	Inactivated by neutral and alkaline soils
Iron	5.0	Not toxic in aerated soils but can contribute to soil acidification and loss of phosphorus and molybdenum
Lead	5.0	Can inhibit plant cell growth at very high concentrations
Lithium	2.5	Tolerated by most crops up to 5 mg/L; mobile in soil. Toxic to citrus at low doses— recommended limit is 0.075 mg/L
Manganese	0.2	Toxic to a number of crops at few-tenths to few mg/L in acidic soils
Molybdenum	0.01	Nontoxic to plants; can be toxic to livestock if forage is grown in soils with high molybdenum
Nickel	0.2	Toxic to a number of plants at 0.5 to 1.0 mg/L; reduced toxicity at neutral or alkaline
Selenium	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of selenium
Tin, Tungsten, and Titanium	-	Excluded by plants; specific tolerance levels unknown
Vanadium	0.1	Toxic to many plants at relatively low concentrations
Zinc	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine textured or organic soils

Additional Water Quality Parameters

Other water quality considerations include pH, bicarbonate, and biodegradable organics (Ayers and Westcot 1985; Wu et al. 2009). The EPA recommends pH values for recycled water used for agricultural irrigation to stay between 6 and 8. This is mainly due to the influence of pH on metal solubility, phytoavailability, and resulting effects on plant growth, but other various abnormalities can also occur (Ayers and Westcot 1985; EPA 2012).

Bicarbonates in irrigation water can lead to an increase in soil pH which decreases bioavailability of many nutrients, such as calcium. Bicarbonates, elevated iron, and gypsum in irrigation water can leave unsightly deposits on crop leaves or fruit which can decrease market values (Ayers and Westcot 1985). Biodegradable organics deplete oxygen in soils, can reduce treatment efficacy, and are generally measured as biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC).

Table 5-2. Guidelines for Interpretation of Water Quality for Agricultural Irrigation[11].

Source: 2012 EPA Guidelines for Water Reuse, adapted from Ayers and Westcot 1985.

Potential Irrigation Problem		Units	Degree of Restriction on Irrigation		
			None	Slight to Moderate	Severe
Salinity *(affects crop water availability)* [A]					
	ECw	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 ECw and SAR together)* [B]					
	0 – 3	**and ECw =**	> 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) [C]				
	surface irrigation	SAR	< 3	3 – 9	> 9
	sprinkler irrigation	meq/l	< 3	> 3	
	Chloride (Cl) [C]				
	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			

[A] ECw 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.

[B] SAR is the sodium adsorption ratio; at a given SAR, infiltration rate increases as water salinity increases.

[C] 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 sensitive crops.

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[11] These guidelines are based on the following assumptions and are meant to be used as a tool; modifications to the guidelines can be made if actual conditions differ greatly from these assumptions: 1. The soil texture ranges from sandy-loam to clay-loam with good drainage and an arid to semi-arid climate with low rainfall, 2. That normal surface or sprinkler irrigation methods are used and applied infrequently as needed and the crop uses at least 50 percent of the stored water before the next irrigation event, and 15 percent or more of the water percolates below the root zone, and 3. A restriction on use does not indicate unsuitability but rather the crop may be limited or may require special management practices to achieve full yield potential (US EPA 2012).

5.5 Emerging Agronomic Concerns and Research Needs

Gaps in knowledge, information, and data on the quality (and quantity) of recycled water and its relationship with agricultural systems can create obstacles to reuse projects. This section highlights agriculture-specific areas where more research or additional data is needed to adequately address these barriers. The guidebook in Part 2 of this report discusses practical strategies for addressing some of these gaps in knowledge and data.

Agronomic impacts of the use of recycled water are an important topic with substantial opportunities for additional research. Many of the limitations of current research on the health risks of emerging contaminants in agricultural water reuse (Chapter 4) are equally relevant to agricultural systems. Fate and transport within agroecosystems and the role of local contextual factors (e.g., irrigation timing, soils, climate) are all equally important agronomic considerations. Given the similar basic research needs, aligned research needs are not discussed at length in this section. Agriculture-specific topics where additional research is needed are highlighted below.

5.5.1 Plant Pathogens

An overlooked yet potentially important area of agronomic concern is the transmission of viral plant pathogens from irrigating with recycled water (Bačnik et al. 2020; Rosario et al. 2009b). Studies show that municipal reclaimed water contains a diverse range of viruses found in greater numbers and with more frequency than in freshwater supplies, many of which are novel and relevant to plants, animals, and insects (Anderson-Coughlin et al. 2021; Rosario et al. 2009b). For example, the pepper mild mottled virus (PMMoV) is most notably known to be a potential water quality indicator and indicator of treatment efficacy. However, recent studies suggest that its presence in recycled water may have agronomic implications as well (Rosario et al. 2009a).

Other viruses of agronomic significance that have been detected in municipally treated recycled water include the tomato mosaic virus (ToMV) and cucumber green mild mottled virus (CGMMV) (Bačnik et al. 2020). Viruses belonging to the Tobamovirus genus are known to be highly stable and resistant to extremely high temperatures, passage through alimentary tracts, organic solvents, and detergents (Tomlinson et al. 1982; Fauquet et al. 2005), and their presence in municipal reclaimed water supplies throughout the United States is well documented (Bačnik et al. 2020; Rosario et al. 2009a).

The potential spread of viruses via reclaimed water is of concern due their highly stable nature and resistance to conventional wastewater treatment methods (Rosario et al. 2009a). While data on the presence of PMMoV and ToMV in irrigation systems in the US are not available, their presence has been identified in irrigation canals from other countries (Gosalvez et al. 2003; Boben et al. 2007). Irrigation water is a known route of infection for both humans and crops, and because municipal reclaimed water is likely the most commonly used source of recycled water for agricultural reuse (Sheikh et al. 2019), more research on recycled water mediated transmission of viral plant pathogens is warranted.

5.5.2 Salinity

Salinity issues are one of the main concerns surrounding agricultural reuse with municipal recycled water. There are emerging on-farm treatment methods that can help lower salinity. However, these methods are not generally cost effective and membrane-based methods create a concentrated waste stream that must be managed. Novel research seeks to find solutions for salinity issues utilizing bacteria and fungi that live within salt tolerant (halophilic) plants. These plant-growth promoting microorganisms (PGPM) help to regulate osmotic pressure, increase availability of water and other nutrients, and decrease salt stress by providing essential nutrients such as nitrogen, hormones, iron, and phosphates to crops so they can survive in these extreme environments (Otlewska et al. 2020). Research into PGPMs as biofertilizers to help alleviate salt induced stressed in sensitive plants is on-going and promising (Darwish et al. 2005; Otlewska et al. 2020)

Addressing Impediments and Incentives for Agricultural Reuse (WRF 4956)

Part 2: Strategies for Advancing Agricultural Water Reuse: Guidebook and Profiles

CHAPTER 6

Guidebook Introduction

6.1 Motivations for this Guidebook

Water systems across the United States are operating under unprecedented levels of stress. Climate change, changes in water use patterns, and other stressors are all driving the need for a paradigm shift in how we think about and manage water resources in all corners of the United States. Even in water abundant regions, the time has passed where we can think about sources of water supply in isolation. A One Water approach can help facilitate integrated planning of water resources (U.S. Water Alliance 2016). Water reuse, efficiency improvements, and stormwater capture and use are all foundational strategies in advancing the resilience of water systems to these stressors. As one of the largest water users, the agricultural sector sits at the frontline of growing water supply and quality challenges.

Climate change is dramatically changing the timing, quantity, and intensity of precipitation across the United States leading to droughts, floods, and changes in water supply reliability and quality. These changes directly impact the quantity, timing, and quality of water available for irrigation. Without irrigation, much of the agricultural production in the Western United States is not viable. Efficiency improvements can reduce the total amount of water used for irrigation while reuse can alter the quantity of supply available.

At present, more than 700 wastewater facilities in the United States are supplying recycled or treated wastewater for irrigation (234 MGD) or spray irrigation (587 MGD) (Thebo 2021). Agricultural water reuse is most common in California, Texas, and Florida, but occurs in 40 of 50 states. States not traditionally considered water scarce are increasingly investing in recycled water projects due to the water quality and resilience benefits alternative supplies can bring.

While agricultural water reuse is a geographically diverse and long-term practice, it is not yet common nor has its full potential been realized. Past analyses found that there is as much as 33,000 MGD of treated wastewater potentially available for reuse (Sheikh et al. 2019). Two past WRF projects, ‘Agricultural Use of Recycled Water: Impediments and Incentives’ (Sheikh et al. 2019) and ‘Economic and Environmental Benefits of Agricultural Water Reuse’ (Thebo 2021) highlight the opportunities, benefits, and tradeoffs of agricultural water reuse. This guidebook builds on past work to share resources and guidance on specific, real-world strategies for advancing agricultural water reuse.

6.2 Strategies for Advancing Agricultural Water Reuse

6.2.1 How Strategies and Classes of Strategies Were Identified

A standardized workflow was used to identify strategies highlighted in this guidebook (Figure 6-1).

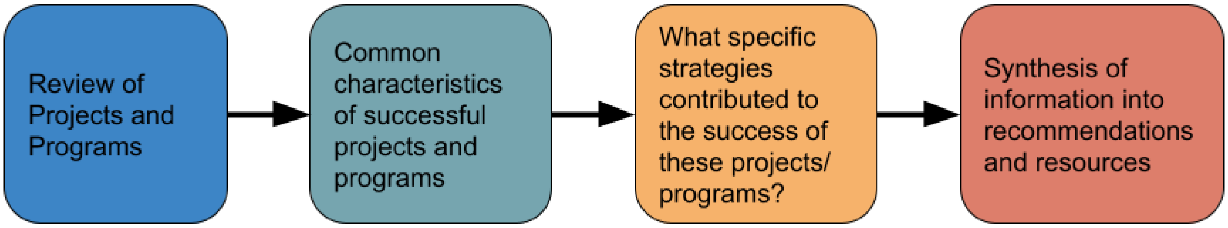

Figure 6-1. Workflow for Identifying Strategies to Highlight.

Project characteristics and strategies that have helped advance agricultural water reuse were identified through profiles, past WRF projects on agricultural water reuse (Sheikh et al. 2019 and Thebo 2021), and a review of WRAP Actions, literature, project, and program reports. Specific strategies were classified by theme and themes appearing consistently across projects, programs, and contexts are highlighted in the guidebook chapters. The strategies discussed in this guidebook are not intended as a comprehensive list of strategies, but instead highlight recurring strategies used by successful agricultural water reuse programs across the United States.

6.2.2 Overview of Classes of Strategies for Advancing Agricultural Water Reuse

Common Characteristics of Successful Agricultural Water Reuse Projects and Programs

There is no one-size-fits-all blueprint for successful agricultural water reuse projects or programs. Projects occur in both water scarce and water rich regions. Some projects are motivated by water quality improvements and regulatory compliance. Projects are initiated by diverse stakeholders and vary widely in size. Recycled water is used to irrigate everything from alfalfa to strawberries. Despite this breadth, our review of agricultural water reuse projects identified six foundational characteristics common across all the projects evaluated (Figure 6-2).

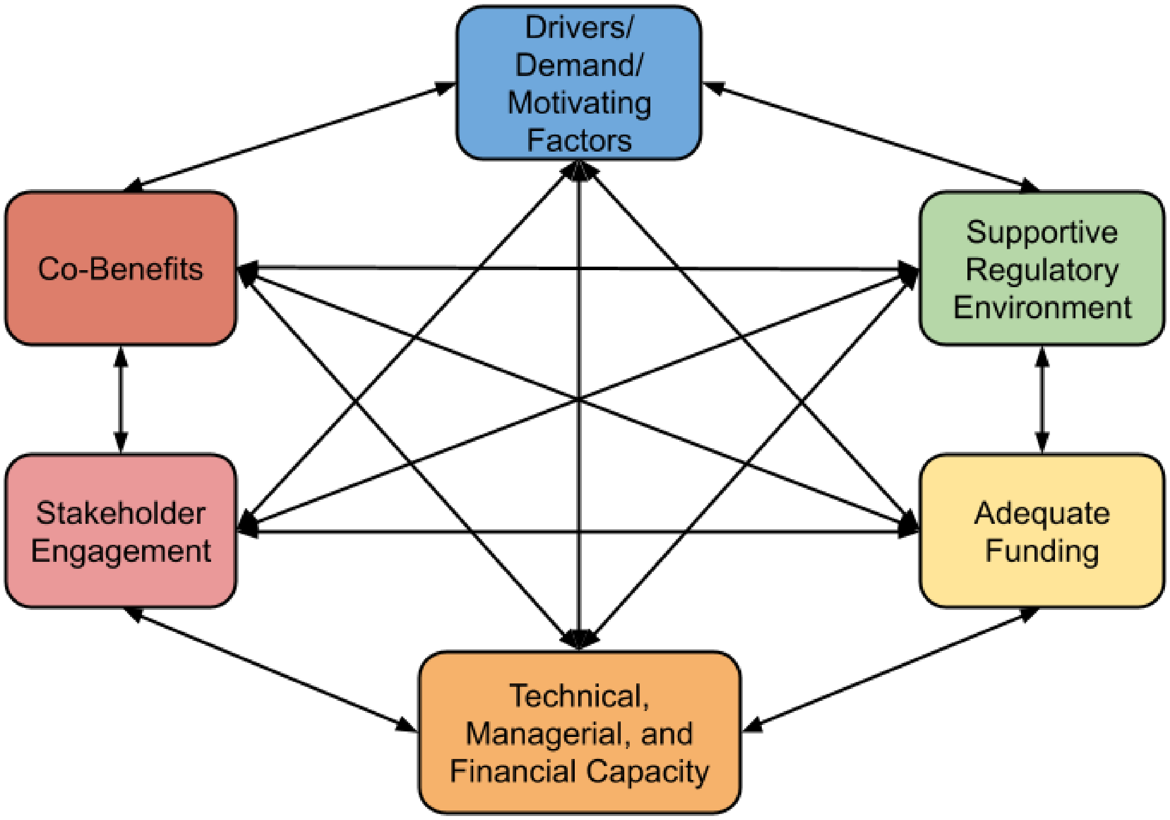

Figure 6-2. Common Characteristics of Successful Agricultural Water Reuse Programs.

Drivers/Demand/Motivating Factors: At a fundamental level, all projects had a reason for being that addressed some fundamental community need such as water supply or compliance with water quality permits.

Supportive Regulatory Environment: State regulatory programs provide clear guidance, permit types of reuse that address community needs, and align with local agricultural production.

Adequate Funding: Funding is secured across the entire project lifecycle from conceptualization through operation and maintenance. Funding secured from diverse sources. Innovations in cost-sharing.

Technical, Managerial, and Financial Capacity: Projects are aligned with the capacity of water agencies and growers to support the project and/or investments are made to build capacity.

Stakeholder Engagement: Meaningful engagement with a diverse range of stakeholders from the project outset. Adaptation of project plans to meet stakeholder needs.

Co-Benefits: Projects provide multiple benefits, often simultaneously addressing the needs or objectives of multiple stakeholders.

Innovation: Innovation was a cross-cutting theme across all six of the proceeding characteristics, manifesting through conjunctive management, cost-sharing approaches, design, and a host of other ways.

Classes of Strategies Highlighted in this Guidebook

Six classes of strategies that have supported stakeholders in building a strong foundation for agricultural water reuse projects and programs are discussed in the following chapters of this guidebook. These include:

- Fit-for-purpose regulatory approaches;
- Co-benefits in agricultural water reuse;
- Strategies for addressing human health and agronomic risks;
- Outreach and stakeholder engagement;
- Addressing technical, managerial, and financial barriers; and
- Role of research, data, and information in scaling.

These chapters are followed by a series of fifteen profiles discussing the real-world application of these strategies.

CHAPTER 7

Fit-for-Purpose Approach to Agricultural Water Reuse Regulations

7.1 What is a Fit-for-Purpose Approach?

The currently recognized best practice approach to recycled water planning and regulations is via a ‘fit-for-purpose’ approach. Regulations and projects developed using a fit-for-purpose approach to water reuse match the quality of recycled water supplied with the needs of different recycled water customers while remaining protective of public health and the environment. Agricultural water reuse projects are diverse with recycled water used to irrigate everything from forest products and fodder crops through strawberries consumed raw. The health risk profile of crops irrigated with recycled water varies widely with crops consumed raw posing the highest potential health risk. Regulations adopting a fit-for-purpose approach typically use risk-based approaches to develop multiple classes of recycled water suitable for different types of agricultural water reuse. Agricultural reuse projects employing this approach collaborate with local agricultural producers to understand the types of crops they produce, understand their water quality needs, and design treatment processes to meet these needs. Fit-for-purpose approaches can help create a win-win-win situation where public health and the environment are protected, treatment facilities are designed appropriately, and recycled water customers receive water that meets their water quality needs.

7.2 Characteristics of State Regulations on Agricultural Water Reuse

Recycled water use for agricultural irrigation is regulated at the state level with notable variation in approaches across states and between the eastern and western United States. State priorities around reuse, wastewater facility interest in reuse, agricultural interests and types of production, irrigation demand, volume wastewater available, and other factors all influence the scope and characteristics of how states approach the regulation of agricultural water reuse. Additional details on the characteristics and history of state reuse regulations and guidelines are included in Chapter 2 of the companion literature review to this guidebook. In their review, the project team identified seven components of state regulations common across states (Table 7-1).

Table 7-1. Common Components of Agricultural Water Reuse Regulations.

Regulatory Component	Description
Regulatory Approach	The formality of 'regulations' governing agricultural water reuse varies widely from formal regulations through guidelines and less formal incidental guidance and case-by-case review of projects.
Crop Classes	Division into food and non-food/processed food crops is common, though many states develop more granular classes separating our orchard or fodder type crops (for example).
Classes of Water	Classes of water are linked to the types of crops that can be irrigated with a given class of water. Each class has an associated level of treatment, water quality requirements, etc.
Level of Treatment	Level of treatment required for a given class of water/type of crop.
Public Access	Whether public access to the site is restricted or unrestricted.
Water Quality Parameters	Pathogen indicators, oxidizable material (BOD, COD), and water clarity (TSS, turbidity). Specific limits and parameters selected vary widely.
Monitoring Requirements	Varies widely in terms of monitoring frequency (daily, weekly), measures of norms (median, not to exceed in n samples), and maximum values.
Engineering Report and Operator Requirements	Permitting typically requires a detailed engineering report. Operator certification and/or availability requirements.

7.3 Key Benefits of a Fit-for-Purpose Approach

Fit-for-purpose approaches can help create a win-win-win situation where public health and the environment are protected, treatment facilities are designed appropriately, and recycled water customers receive water that meets their water quality needs. Overtreating water relative to current and future water quality needs is expensive both in terms of capital and O&M costs and the broader environmental impacts of additional energy use, GHG emissions, and resources used in treatment facilities. Conversely, only meeting minimum standards can leave facilities vulnerable to needing to upgrade to meet potential future standards for PFAS, PCPs, and other emerging contaminants. Fit-for-purpose approaches provide a useful framework, but facilities ultimately need to consider tradeoffs in their current and long-term water quality needs and level of risk-tolerance towards changing regulations. Nonetheless, fit-for-purpose approaches provide a flexible starting framework for risk-based approaches to water reuse planning that facilities can building on to address context specific needs and concerns.

CHAPTER 8

Co-Benefits of Agricultural Water Reuse

8.1 Role of Co-benefits In Successful Agricultural Water Reuse Projects

Agricultural water reuse projects occur within a complex system of diverse stakeholders, project objectives, and regulatory frameworks. Each of these entities operates within its own system of values, obligations, and needs. Agricultural water reuse projects often contribute to multiple objectives, most commonly water supply and water quality, but also a broader range of economic, social, and environmental goals and needs. The breadth of benefits and tradeoffs associated with a project are often referred to as the project's co-benefits or multiple benefits. One Water approaches to water management can help situate the benefits and tradeoffs of recycled water projects within the broader watershed context. In all successful agricultural water reuse projects and programs reviewed, co-benefits played an instrumental role in bringing stakeholders together and the success of long-term projects (see profiles, Thebo 2021; Sheikh et al. 2019, and others). Intentionally recognizing and realizing co-benefits can help build relationships with a broader range of stakeholders, optimize across multiple project objectives, and create win-win situations for all involved.

8.2 Benefits and Tradeoffs of Agricultural Water Reuse

WRF project 4829 'Evaluating Economic and Environmental Benefits of Water Reuse for Agriculture' identified over 100 distinct benefits and tradeoffs associated with agricultural water reuse (Thebo 2021). Seventeen classes of common project benefits and tradeoffs were grouped under six common themes of project objectives/drivers:

- Water quantity
- Water quality
- Economic
- Energy and GHG
- Risk and Resilience
- Social/Environmental

Each of the seventeen classes of common benefits and tradeoffs are described in Table 8-1.

Table 8-1. Classification of Common Project Drivers and Classes of Benefits and Tradeoffs.

Project Objectives/ Drivers	Classes of Benefits/Tradeoffs	Description of Benefit/Tradeoff Class
Water Quantity	Water Supply	Agricultural water reuse is commonly motivated by insufficient access to water supplies
Water Quantity	Sustained Access to Resources	When the use of alternative supplies offset withdrawals of surface or groundwater, these resources are available to other water users or at a future time. This is particularly valuable for those communities, growers, or irrigation districts with less senior water rights.

Project Objectives/ Drivers	Classes of Benefits/Tradeoffs	Description of Benefit/Tradeoff Class
Water Quality	Source Water Protection	Agricultural water reuse can reduce pollutant loads and/or provide in situ treatment, protecting surface and/or groundwater supplies used by water systems and communities and ecosystems.
Water Quality	Irrigation Water Quality	Agricultural water reuse can provide growers with a quality of water that is either better or worse than existing supplies, depending on context.
Water Quality	Enhanced Treatment Capacity	Agricultural water reuse can help enhance the treatment capacity of water systems at a lower cost via in situ treatment such as UV degradation. Agricultural water reuse projects also often entail upgrading existing treatment infrastructure to produce higher quality effluent.
Economic	Water Agency/Agricultural Producer Economics	Agricultural water reuse directly contributes to the economic bottom line of water agencies, agricultural producers, state and local governments. There are costs associated with infrastructure planning and development, but stakeholders can also benefit economically when reuse contributes to avoided costs and increased or sustained crop yields/production.
Economic	Regional Economic Development	Many communities' economies are increasingly reliant on access to water for outdoor recreation. Likewise, recycled water can help support local agriculture related businesses.
Economic	Household Economics	The household benefits/costs associated with agricultural water reuse are generally indirect, depending on water agencies overall water supply portfolio, approach to cost recovery for those investments, and water/wastewater rate structures.
Energy and GHG	Energy Use	Water systems consume large amounts of energy to convey and treat water. Particularly when water is imported across significant distances and/or elevations, local reuse can reduce the energy embedded in water. Likewise, the use of alternative supplies can reduce energy use for groundwater extraction.
Energy and GHG	Climate	The energy used for supplying and treating water produces significant quantities of greenhouse gas emissions. Reducing these emissions provides broader community and environmental benefits.
Risk and Resilience	Reducing Exposure to Risk	Water systems, agricultural producers, communities, and ecosystems are vulnerable to a broad range natural, physical, and financial risks. Climate change is increasing exposure to many water and climate related risks such as inadequate water supply, extreme temperatures, and flooding. In certain circumstances, water reuse can help communities lessen their vulnerability to these risks.
Risk and Resilience	Reputation	Water systems and agricultural producers interface directly and indirectly with the public, regulators, peer organizations, and other stakeholders and commonly viewed as stewards of community resources such as water. When water reuse is perceived as a prudent water management strategy, organizations can gain reputational benefits

Project Objectives/ Drivers	Classes of Benefits/Tradeoffs	Description of Benefit/Tradeoff Class
Risk and Resilience	Regulatory Compliance	Agricultural water reuse can help water systems comply with NPDES and other discharge permits through increased operational flexibility and avoided discharges. Using alternative supplies can also help agricultural systems comply with limits on water use and withdrawals.
Social/Environmental	Ecological Function	When water reuse displaces withdrawals for irrigation, this can leave more water in streams and the ground to support freshwater ecosystems.
Social/Environmental	Intrinsic/Aesthetic Value	As an essential component to life, water holds some level of intrinsic value for most humans. Many individuals also value the aesthetics of healthy surface waters. Likewise, healthy, productive agricultural lands hold intrinsic and/or aesthetic value for many humans.
Social/Environmental	Community Value	The community benefits and costs of agricultural water reuse are broad ranging, spanning access to water for recreation through the value of living in a community with a stable, resilient water or wastewater agency.
Social/Environmental	Crop and Soil Health	When the quality of alternative supplies available is sufficient for local agronomic conditions, it can improve soil health and support higher value crops and/or increase yields. When quality is poor and water is not available for leeching salts or other constituents, growers can experience declining soil health.

8.3 Benefit and Tradeoff Realization in Practice

Benefits and tradeoffs associated with agricultural water reuse projects are both direct and indirect and can take many forms including project inputs and outputs, ‘processes’ that occur as a result of the project, and longer-term outcomes and impacts associated with the project (Thebo 2021). Benefits and tradeoffs are inherently linked and co-dependent. For example, a reduction in nutrient discharges associated with agricultural water reuse is often directly linked with improved regulatory compliance and water agencies’ ability to meet permit requirements more cost effectively. These complexities all impact the degree to which potential benefits of agricultural water reuse projects are realized in practice.

Identification of the full range of potential benefits and tradeoffs is an important first step in ensuring that co-benefits are valued, but there is often a significant amount of additional work that must occur to ensure benefits are realized in practice. For example, reduced fertilizer use is a commonly cited benefit of agricultural water reuse, but this benefit can only be fully realized and estimated if agricultural producers can account for the nutrients present in recycled water. Likewise, many tradeoffs are condition and context dependent. For example, reuse may decrease flows in effluent dependent streams, but whether ecological impacts occur depends on local ecological vulnerabilities, the timing of flow reductions, and other factors. Robust stakeholder engagement can help project implementers understand and account for nuances surrounding the practical realization of benefits and tradeoffs of agricultural water reuse.

8.4 Additional Resources on Benefits and Tradeoffs of Agricultural Water Reuse

WRF 4956 Profiles (Chapter 13 in Guidebook)

Co-benefits and tradeoffs were a common theme across all profiles highlighted in this guidebook. Chapter 13 includes more details on the role of co-benefits and tradeoffs in each profile with several examples of the application of a One Water approach to water management.

Evaluating Economic and Environmental Benefits of Water Reuse for Agriculture (WRF 4829) (Thebo 2021)

The project report for WRF 4829 includes detailed information on benefits and costs associated with agricultural water reuse projects. Example benefit identification and assessment approaches are included. A list of benefits and costs identified in WRF 4829 is freely available through the companion online benefit library (https://bit.ly/37SR0VT). Benefits and costs in the online library are organized and sortable by project driver/objective (water supply, water quality, social and environmental); class of benefit/cost; and stakeholder group (water system, agricultural system, and people, community, and ecosystems).

Agricultural Use of Recycled Water: Impediments and Incentives (Reuse-15-08/4775) (Sheikh et al. 2019)

The project report from Sheikh et al. 2019 shares findings from a comprehensive global landscape assessment of the use of recycled water for agricultural irrigation. Multiple case studies and discussion of the benefits and challenges associated with recycled water project implementation are included. Results from a geospatial analysis assessing the potential for agricultural reuse of municipal recycled water in the United States are also included.

Drivers for and Against Municipal Water Recycling: A Review (Kunz et al. 2016)

Kunz et al. conducted a review of 25 studies evaluating drivers for and against reuse of municipal wastewater. Their review identified more than 150 unique drivers which were then categorized further based on the level of analysis and outcome investigated. These findings were then used to develop a framework to identify drivers of primary relevance. This framework was then applied at the city-level in four Australian cities.

Management Experiences and Trends for Water Reuse Implementation in Northern California (Bischel et al. 2012)

Bischel et al. conducted a survey of 71 wastewater program managers in Northern California asking about their program's drivers and barriers for recycled water project implementation. Findings from this study are included in this resource. Many of the identified drivers and barriers are closely related with the benefits and tradeoffs discussed earlier in this section.

A Multi-Benefit Approach to Water Management (Diringer et al. 2019)

A collection of several Pacific Institute projects builds the case for including multiple benefits in water management decision making and project planning. While not specifically focused on water reuse, much of the information is relevant to agricultural water reuse projects. Outputs include a framework highlighting themes of benefits, a resource library, and case studies of multi-benefit water projects.

CHAPTER 9

Human Health and Agronomic Risks of Agricultural Water Reuse: Strategies for Addressing

9.1 Overview

The companion literature review in WRF 4956 reviewed current scientific literature on human health and agronomic risks associated with the use of recycled water for agricultural irrigation. That literature review provides more detailed information on exposure and risks, identifies knowledge gaps, and discusses important contextual factors impacting the realization and magnitude of risks realized. This section synthesizes those findings in the context of existing agricultural water reuse programs to identify concrete strategies to help address concerns related to human health and agronomic risks associated with agricultural water reuse.

9.2 Addressing Human Health Risk Related Impediments

9.2.1 Strategies

While states manage recycled water and water reuse differently, municipal recycled water is generally consistent in quality and there have been no known instances food borne illnesses resulting from bacterial, viral, or parasitic infections in the US from irrigating food crops with recycled water. Treatment of municipal recycled water must meet specific water quality criteria before leaving a facility.

However, questions and concerns on how recycled water can impact human health, mainly surrounding CECs, ARBs, ARGs, and viruses, remain. As more information becomes available to bridge gaps in our understanding, technology, and management approaches, risks assessments for specific chemicals can be developed with greater confidence to facilitate trust and buy-in.

This section summarizes opportunities to overcome specific impediments to agricultural reuse from real or perceived human health risks and concerns; current ways these obstacles are being addressed; and areas where additional action, research, data, and information are needed. By addressing these impediments, risk assessments and best management practices can be developed to protect the public from any potential hazards.

Table 9-1 summarizes primary impediments to adoption of recycled water for agricultural irrigation, as they relate to human health, and provides opportunities for ways to overcome them.

Table 9-1. Summary of Health-Related Impediments to Agricultural Reuse and Opportunities to Overcome.

Impediment	Opportunities to Overcome
Perceptions or unknown water quality of recycled water	• Assess and compare quality of current water sources to potentially available recycled water • Site-specific assessments of water quality and compatibility with consideration to agronomic needs, environmental factors, and potential to impact human health • Understand buyer, programmatic, or regulatory requirements • Cost-benefit analysis as decision making tool
Unknown chemical makeup of recycled water	• Utilities can support by collecting data on water quality of influent and treated effluent • Compulsory, centralized, and electronic reporting • Increased access to data and information sharing
Current treatment technologies used may not remove or inactivate specific chemicals of concern	• Increased knowledge of chemical make-up of municipal recycled water that is site-specific • Pairing treatment technologies with target chemicals and intended end-uses • Guidance for best practices for on-farm treatments
Inconsistent research findings on the environmental fate of pathogens, CECs, ARBs, and ARGs in agricultural settings	• Standardized research, detections, and bio-analytical methods ○ Experimental design, methods, analyses ○ Agri-environmental factors ○ Water quality • Standardized, explicit, and transparent reporting and data analysis • Crop-specific research on plant uptake and accumulation
Inconsistent research findings on plant uptake, distribution, and persistence of biological pathogens, CECs, ARBs, and ARGs	
Unknown effects of the long-term exposure to consuming foods with low concentrations of CECs	• Increased research: ○ Dietary intake ○ Long-term effects at low concentrations ○ Impacts to vulnerable at-risk populations • Use of bio-analytical assays to identify potential physiological affects

9.2.2 List of Government Programs/Research

This section lists ways impediments to agricultural reuse due to human health-related concerns and risks are being addressed by government and regulatory programs.

- The National Water Reuse Action Plan (WRAP) Collaborative
  - Federal agencies are engaging with stakeholders to identify and address agricultural needs
  - Exploration and research of emerging concerns including microbiological
  - Chemical constituents of concern, and pharmaceuticals

    - Research on advanced water treatments
    - Fit-for-purpose specifications and guidelines for end-uses
- Evolving metrics – FSMA PSR Agricultural Water Rule still being developed, and specifically calls out recycled water
- Guidance on treatment options for EPA approved anti-microbials for pre-harvest agricultural water
- EPA and FDA co-development of protocol to develop and register EPA approved antimicrobial pre-harvest ag water
- The FDA is prescribing analytical methods and equivalent methods to test water quality for target organisms and have identified rapid tests and will consider providing guidance on testing methods specifically for on-farm, rapid, and low-cost test kits.
    - Indicator organisms for pathogenic enteric viruses
    - Methods to quantify and determine viral infectivity
- The California Science Advisory Panel (convened by the SWRCB) added two bioanalytical screening tools and identified ten additional in vitro bioassays that may be appropriate for screening recycled water to identify different types of CEC.

9.3 Addressing Agronomic Barriers to Agricultural Water Reuse

Table 9-2 provides a summary of impediments and strategies to overcome in-field operational impediments related to the long-term use of municipal recycled water for agricultural irrigation activities. Treatment and regulatory programs such as regional salt and nutrient management planning can also help manage water quality challenges upstream of farms.

The following agronomic management practices can be tailored to meet site-specific needs when irrigating with recycled water to decrease negative impacts and maximize crop yields:

- Select Tolerant Crops
- Crop Rotation
- Irrigation Supply and Management
- Appropriate soil amendments

Crop Selection Select compatible crops based on water quality, crop type, and soil characteristics, with consideration to the soil and water pH, BOD, TOC, salinity, EC, and trace elements including boron.

Crop Rotation Seasonally rotate crops based on water supplies and quality, to improve soil health, or to remediate soils from accumulations of chemicals, trace elements, or heavy metals.

Soil Amendments The addition of organic matter, humic substances, and biofertilizers can help alleviate impacts to salt sensitive crops (Darwish et al. 2005; Otlewska et al. 2020).

Irrigation Supply and Management Leaching and drainage are effective strategies to help avoid soil salinization and build-up around the root zone, to reduce negative water quality impacts, and prevent salinity build-up. However, the more saline the irrigation water, the more water will be required for leaching to flush away the salts from the root zone. This can create other problems such as groundwater and surface water contamination and may not be a viable option in already water stressed regions. Blending with other water sources can dilute salts, minerals, and other constituents of concern in recycled water to produce a quality sufficient for the end-use.

- Furrow methods are suitable when leaching demand is high
- Drip methods are ideal in water scarce regions due to the low irrigation rate required
- Modify Irrigation events including method, duration, and timing
- Less frequent and heavier irrigation events to replace more frequent and shorter events
- More frequent and short irrigation times can increase accumulation at the root zones leading to saline or sodic soils
- Surface deposition of chlorides, boron, or other toxins can cause leaf and crop damage in response to plant sensitivities
- Timing of fertilization, seeding, and chemical amendments
- Efficiency becomes more important in areas of water scarcity and high evaporation rates.
- Water should be applied as closely to the root zone using drip systems.

Table 9-2. Water Quality Issues of Agronomic Concern and Mitigation Strategies to Reduce Barriers to Adoption.

Data Source: Ayers and Westcot 1985.

Water Quality Issues	Constituents of Concern	Problem	Impacts	Mitigation Practices
Salinity	• Water soluble and readily mobile salts:	• Salt accumulation at root zone	• Saline water and soils reduce plant's ability to access water	• Leaching & Drainage[4] • Change more salt tolerant crop • More frequent irrigation/timing of leaching • Land grading • Timing of fertilization • Methods of irrigation and seeding • Blending water sources
Sodicity – Water infiltration rate – as SAR[1]	• Na+, Ca2+, Mg2+	• Salinity of water and Na+-Ca2+- Mg2+ ratio • Na+: Ca2+ (> 3:1)	• Soil crusting, dispersion, and structural breakdown • Reduction in ability of water to infiltrate soil[3] and plant does not receive water	• Change the soil or water chemistry, (e.g., adding gypsum, acid-forming amendment, organic residues) • Blending water sources • Change irrigation method
Specific ion toxicity	• Cl-, Na+, B	• Occurs within the plant itself • Plant uptake and accumulation of ions in sensitive crops[2] • Direct absorption through leaves from overhead irrigation	• Generally, occurs in the leaf tips where water loss is greatest, accumulation is more rapid in hotter climates • Often accompanies and complicates existing salinity or infiltration problems • Damage increases as concentrations in the applied water increase	• Change irrigation method from overhead to drip • Treatment prior to use
Miscellaneous	• N, P, Fe, bicarbonates, gypsum, pH	• Varies	• Excessive nutrients (e.g., N and P) cause excessive growth, lodging, or delayed maturity • Deposits on foliage from bicarbonates, gypsum, iron • Abnormalities due to unusual pH of water	• Varies • Treatment prior to use

[1] Sodium adsorption rate

[2] Perennial crops are more sensitive and damage can occur at low concentrations

[3] Infiltration rate can also be influenced by soil structure, compaction, organic matter, and chemical make-up

[4] Leaching frequency depends on water quality and crop salt tolerance

CHAPTER 10

Stakeholder Engagement

10.1 Motivation and Objectives

Extensive and early multi-level stakeholder engagement, including outreach and education, underpins most successful agricultural water reuse projects. This section outlines key considerations for successful engagement, highlights profiles of innovative or unique ways agricultural water reuse projects have engaged with stakeholders and the public, and shares resources to help entities develop a robust, actionable stakeholder engagement plan. This guide can be used alongside existing templates designed for general recycled water projects[12] to develop a plan specific for agricultural water reuse projects.

10.2 Importance of Diverse Stakeholder Engagement

Woven into the fabric of successful reuse programs from concept and design to implementation and beyond, robust stakeholder engagement plans are critical in designing a program that is both viable and relevant to meet the needs of specific agricultural water reuse programs. Because stakeholders, including the public, can influence the success or failure of a reuse project, it is critical to engage early and with diverse stakeholders across many sectors.

Understanding stakeholder needs, perceptions, motivations, and fears early on can help to address any challenges along the way. Current perceptions of agricultural water reuse are critical in developing effective programs need to gain acceptance and buy-in – an important component of any successful reuse project. Additional groups that otherwise might be overlooked may also be revealed. This not only ensures all voices are represented but avoids the bias and imbalanced priorities from the interests of a single group or groups.

While drivers, incentives, and approaches for agricultural water reuse can vary based on location, stakeholder and community needs, and local politics, successful projects will likely share recurring and action-oriented themes throughout the framework of their engagement plans, including:

- Early and diverse stakeholder engagement
- Identification of multiple benefits across sectors
- Facilitate two-way communication and engagement
- Transparent, accountable, and builds trust
- Understand and value stakeholder needs
- Continual and dynamic engagement

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[12] WateReuse Foundation developed a guidebook 'Marketing Nonpotable Recycled Water: A Guidebook for Successful Public Outreach & Customer Marketing' that includes templates, case studies, and findings from market research (Humphreys 2006).

A robust and effective plan takes a fit-for-purpose approach, pairing key stakeholders with appropriate engagement methods and approaches. A continuous, active, and dynamic engagement plan will evolve over the lifecycle of an agricultural water reuse program to address changing needs as new stakeholders, partnerships, markets, resources, and opinions are identified.

10.3 Key Stakeholders for Agricultural Water Reuse Projects

Stakeholders include all groups, communities, or individuals that are affected by or have a vested interest in a program or project. For many agricultural water reuse programs, especially those using municipal recycled water, stakeholders are well known and easily identified (e.g., water utilities, agricultural communities, and consumers). Increasingly, the many benefits associated with recycled water projects and integrated natural resources management are being realized to identify stakeholders outside of these traditionally recognized sectors. It is important to note that not all agricultural water reuse programs will have all the same stakeholders.

Here, we identify key stakeholders and interest groups relevant to agricultural water reuse projects using municipal recycled water. We then include example questions to help identify other potential stakeholder groups. This is by no means an exhaustive list, and some groups may serve in multiple capacities.

- Growers and Agricultural Producers
- Wastewater Treatment Facilities
- Irrigation Districts
- Consumers
- Local Communities
- Indigenous Peoples
- Nature/Ecosystems
- Regulators and Elected Officials
- Trusted Community Members or Representatives
- Academia
- Extension Agents

Example questions to identify less obvious stakeholders relevant for agricultural reuse

Who are the other water users in the area?
  - Power generation
  - Fertilizer manufacturers
  - Food and beverage industries (e.g., breweries)
  - Data centers
  - Down-gradient water users

Who has a vested interest in natural habitats and ecosystem functions?
  - Indigenous peoples
  - Non-governmental organizations
  - Local, State, and Federal agencies
  - Eco-tourism

Who can innovate and advance reuse in agriculture, especially in smaller communities?
  - Research and Development Companies
  - Small Tech Start-ups
  - Academia and Extension
  - Agricultural Programs and Groups

Who influences, supports, regulates, advocates for, or funds the agriculture community?
  - Buyers
  - Consumers
  - Agricultural Programs – LGMA, Western Growers

Are there sub-groups with unique perspectives, needs, or influence?
  - Young Farmers and Ranchers
  - National Women in Agriculture
  - Agribusiness Councils

When identifying trusted community members, it is important to note that not all stakeholder groups will have aligned trusts and pairing an identified trusted member or representative of one stakeholder group, may not have the same results when paired with another group. This is especially important when leveraging trusted reputations to champion for buy-in through outreach with other stakeholder groups. Knowing the audience is key!

10.4 Stakeholder Mapping

People and projects are fundamentally constrained by time and budget. Stakeholder mapping is a common tool for understanding how stakeholders might be approaching an issue and hone in on what types of stakeholder engagement may be most relevant and helpful for different groups. Influence vs. interest mapping is one strategy projects have employed in the development of stakeholder engagement plans and resources (Figure 10-1).

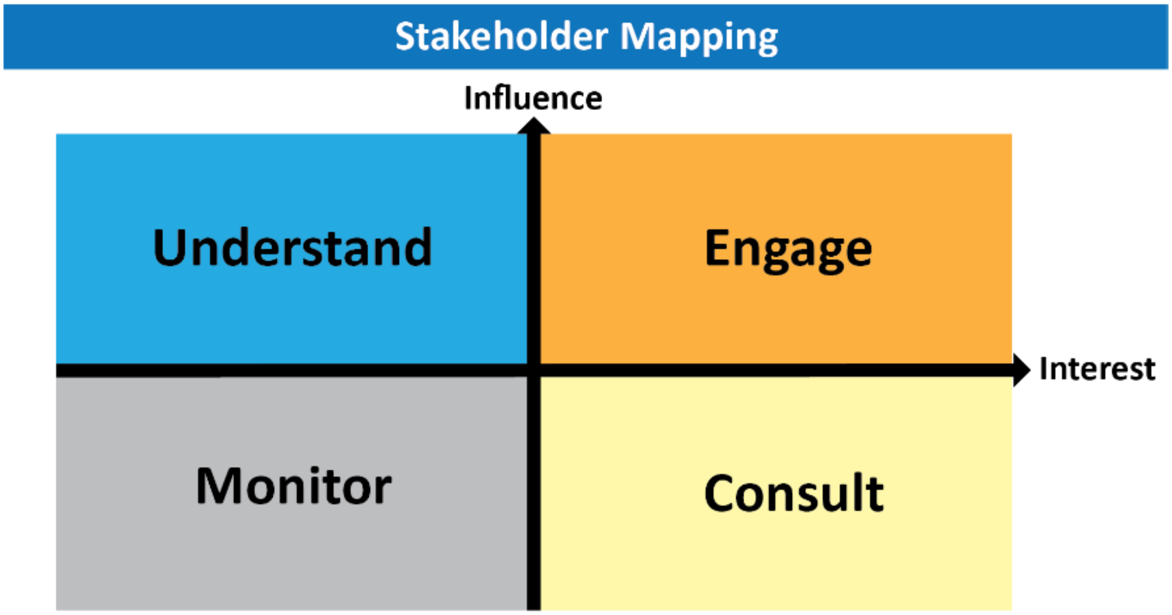

Figure 10-1. Framework for Stakeholder Mapping: Influence vs. Interest.
Source: US EPA 2022.

Brief descriptions of what engagement with stakeholders in each quadrant might look like are described below.

Engage (High Influence, High Interest): Deep engagement to understand and leverage resources/capacity.

Consult (Low Influence, High Interest): Deep engagement to understand. Important to support engagement of these stakeholders whenever possible.

Understand (High Influence, Low Interest): Aim to understand where these stakeholders are coming from.

Monitor (Low Influence, Low Interest): Conduct outreach and watch for shifts in stakeholder position to other quadrants.

10.5 Benefits of Stakeholder Engagement

The benefits of stakeholder engagement are extensive and will contribute to the overall success, benefits, and viability of an agricultural water reuse project. In general, the full range of benefits can be categorized into four key areas[13]: 1. Leveraging expert advice; 2. Identifying, building, and developing relationships; 3. Managing real or perceived risks; and 4. Receiving support for project implementation and information sharing. Each area provides many benefits, co-benefits, and opportunities.

The following section highlights the benefits within each of these themed areas. It is important to remember that some benefits may not be immediately, linearly, or directly gained – a commonality of all multiple or co-benefits[14].

10.5.1 Leveraging Expert Advice

All projects within an agricultural water reuse program are supported and enhanced by expert advice. They can help to identify how to improve, integrate, and implement a range of activities including operations, engagement, and products to establish best practices, management approaches, and policies. Experts help to identify, make connections, and develop relationships with other groups, including other experts.

Leveraging advice from experts helps to identify potential risks early on, both real and perceived, and can help to find solutions before they become a reality. This includes both risks to the project, stakeholder and underrepresented groups, and the environment. Respected experts, such as elected officials, those from regulatory agencies, agricultural communities, academia, and Extension can offer support to implement and advance a reuse program by advocating and championing. These stakeholders play a key role in information sharing, raising awareness, and reciprocal learning by disseminating relevant materials, such as guidance documents and outreach materials, to the right audiences.

10.5.2 Identifying, Building, and Developing Relationships

Sustained engagement with stakeholders can foster additional relationships within a community. Relationships, partnerships, and collaborations that are designed with built-in transparency and accountability foster confidence and trust to increase buy-in. This in turn can inspire or incentivize other partnerships, adjacent programs, or others to develop their own agricultural water reuse programs.

Strong relationships can continue to bring many benefits, including:

- Identify and bridge gaps in knowledge, research, and technology
- Maximize funding opportunities by aligning with local, state, and federal goals
- Find solutions through increased knowledge, awareness, and understanding of complex issues

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[13] The Healthy Business Stakeholder Engagement Guide outlines four main areas on the benefits to stakeholder engagement. (BSR 2017)

[14] For more information on multiple, or co-benefits, please refer to the section on multiple benefits in this guidebook.

- Drive innovation and technological advancements that are affordable, accessible, effective, and easy to implement
- Increase opportunities for eligible financing, cost-sharing, and seed-funding
- Develop, integrate, or modify systems, policies, and adjacent programs
- Reduce redundancies, streamline management, and encourage integrated and comprehensive solutions
- Identify opportunities to incorporate flexibility into programs to minimize obstacles

Table 10-1 provides examples of how engaging with expert groups can lead to and maximize benefits. Understanding the needs, challenges, fears, and motivations for using recycled water will be instrumental in ensuring that a reuse project is viable, accepted, and supports the anticipated goals.

Table 10-1. Realize a Full Range of Benefits and Opportunities by Engaging with Experts Across Sectors to Increase Knowledge, Awareness, and Collaborations.

Expert Stakeholder Group	Engage to Understand	Benefits and Opportunities
Growers and Producers	Current and future water quality and quantity needs, crop types and agronomic requirements, and irrigation system	Ensures water quality and quantity needs are met
Buyers	Buyer requirements may exceed programmatic or regulatory requirements for irrigation water (e.g., through involvement in LGMA)	Opportunity to engage and understand
Municipal Wastewater Treatment Managers	Knowledge on current treatment technologies, discharge volumes and locations, treatment system upgrade needs, current and projected allocations, motivation for reuse, permit requirements	Work with producers to design a fit-for purpose approach; Future planning and scenario analysis; Identify infrastructure funding opportunities
Irrigation Districts	Irrigation water demand and challenges in water availability, pricing, and distribution	Good resource to connect with local producers and growers; Identify existing resources to reduce infrastructure and construction costs; Supply diversification
Other water users (e.g., power generation, data centers)	Capture overall water demand, future water quality and quantity needs, understand potential for competition	Decrease competition by including all water users to identify ways to share and allocate recycled water using a fit-for-purpose approach
City and State Officials, Planners, Regulatory and Federal agencies	Understand local and state natural resources management needs, challenges, and goals; Discharge requirements (current and future directions); Recycled water regulations	Alignment of program goals with larger goals; Funding and financing; Regulatory assistance
Non-Profit and Industry Experts	Community and industry needs and concerns	Connect with a broader range of stakeholders; Understand practical/economic impacts of decisions

10.5.3 Managing Real and Perceived Risks

Engaging with stakeholders helps to identify real or perceived risks early on, provides space and time to preemptively assess solutions, change course, and mitigate effects before they occur.

Risks to the overall project, stakeholder groups, or the environment can obstruct agricultural water reuse programs. However, risks can be identified through increased awareness and knowledge gained by engaging with stakeholders. These include real or perceived risks associated with technical, human health, agronomic, environmental, and perceptions and can become an impediment if not addressed. Table 10-1 provides real-world examples of benefits gained by managing risks through engaging with stakeholders. The companion literature review developed with this project includes a synthesis of the current state of knowledge on health and agronomic risks potentially associated with agricultural water reuse and discussion on how regulatory frameworks have historically managed these risks.

10.5.4 Receiving Support for Project Implementation and Information Sharing

All stakeholders can support implementation of reuse programs and information sharing in some capacity. Respected community members, trusted officials from local and state agencies, and leaders or board members of utilities, for example, can provide support and share information to champion, advocate, and advance agricultural water reuse.

Benefits of leveraging stakeholder engagement to implement reuse programs and share information include:

- Adds additional layers of transparency and trust
- New connections and resources
- Identify opportunities for adjacent programs
- Expedite permits, streamline resources
- Disseminate information
- Champion and advocate to gain support and buy-in
- Inspires and incentivizes others for agricultural water reuse

10.6 Engagement Process

The engagement process can be broken down into five main steps (Box). While the method of engagement may differ in format, level of effort and time requirement, and at what stage engagement occurs in the program lifecycle, all approaches will involve some level of consulting, collaborating, or reporting. It is important to note that engagement can occur at all stages of an agricultural water reuse program from conception throughout the life of the program – past initial implementation. Creating flexibility in an engagement plan will allow it to evolve in response to the changing needs within the community.

Steps of the Engagement Process

1. Define purpose and outline benefits
2. Identify and prioritize stakeholder groups
3. Plan the engagement approach specific to the stakeholder group
4. Engage
5. Integrate learnings into program

10.7 Additional Resources on Stakeholder Engagement

1) Humphreys. 2006. “**Marketing Nonpotable Recycled Water: A Guidebook for Successful Public Outreach & Customer Marketing”** Alexandria, VA: WateReuse Foundation.

Notes: Includes templates, case studies, and findings from market research.

2) Brill, Carlin, and McNeeley. 2022. **“Stakeholder Engagement Guide for Nature-Based Solutions – Pacific Institute.”** Oakland, CA: Pacific Institute.

   Notes: While focused on nature-based solutions, includes resources and information relevant to stakeholder engagement in water management more broadly.

3) Chen. 2020. “**The Stakeholder-Communication Continuum: An Alternate Approach to Internal and External Communications**.” *Journal of Professional Communication* 6 (1): 7–33.

   Notes: Generic framework for working through range of stakeholder engagement activities.

4) County of San Diego. 2016. **Climate Action Plan Public Outreach and Engagement Plan**. County of San Diego.

   Notes: Well-regarded example of public outreach and engagement plan.

CHAPTER 11

Addressing Technical, Managerial, and Financial Barriers to Agricultural Water Reuse

11.1 Overview

This section discusses strategies for addressing technical, managerial, and financial barriers to agricultural water reuse projects. Resources and strategies for addressing three common areas of need are shared. These topics include:

- Capacity building
- Benefit identification and accounting
- Financial assistance and cost sharing

Robust stakeholder engagement and public outreach are foundational to successful project development and implementation and discussed in Chapter 10 of this guidebook.

11.2 Capacity Building

11.2.1 Overview

All water systems face technical, managerial, and financial challenges, but small and medium systems often have more limited capacity to tackle these challenges. Insufficient technical, managerial, and financial capacity are commonly cited organizational barriers to initiating and implementing agricultural water reuse projects even when there is a recognized need or desire for such projects.

11.2.2 What is Capacity Building?

The goal of building capacity is to strengthen an entity’s ability to perform and meet its objectives by increasing efficiencies in infrastructure, management, and operations (Brown et al. 2001). Capacity building is an integrated, intentional, multi-level practice (Figure 11-1). Within individuals and organizations, capacity building works to increase and enhance knowledge, skills, resources, communication, and collaborations. At the individual level this can occur through trainings, peer learning, real-world project and program profiles, and information sharing while investments in leadership training, infrastructure, information and technology, and other resources are necessary at the organizational level. At the programmatic level, partnerships and collaborations can build capacity through shared ideas, resources, and project costs.

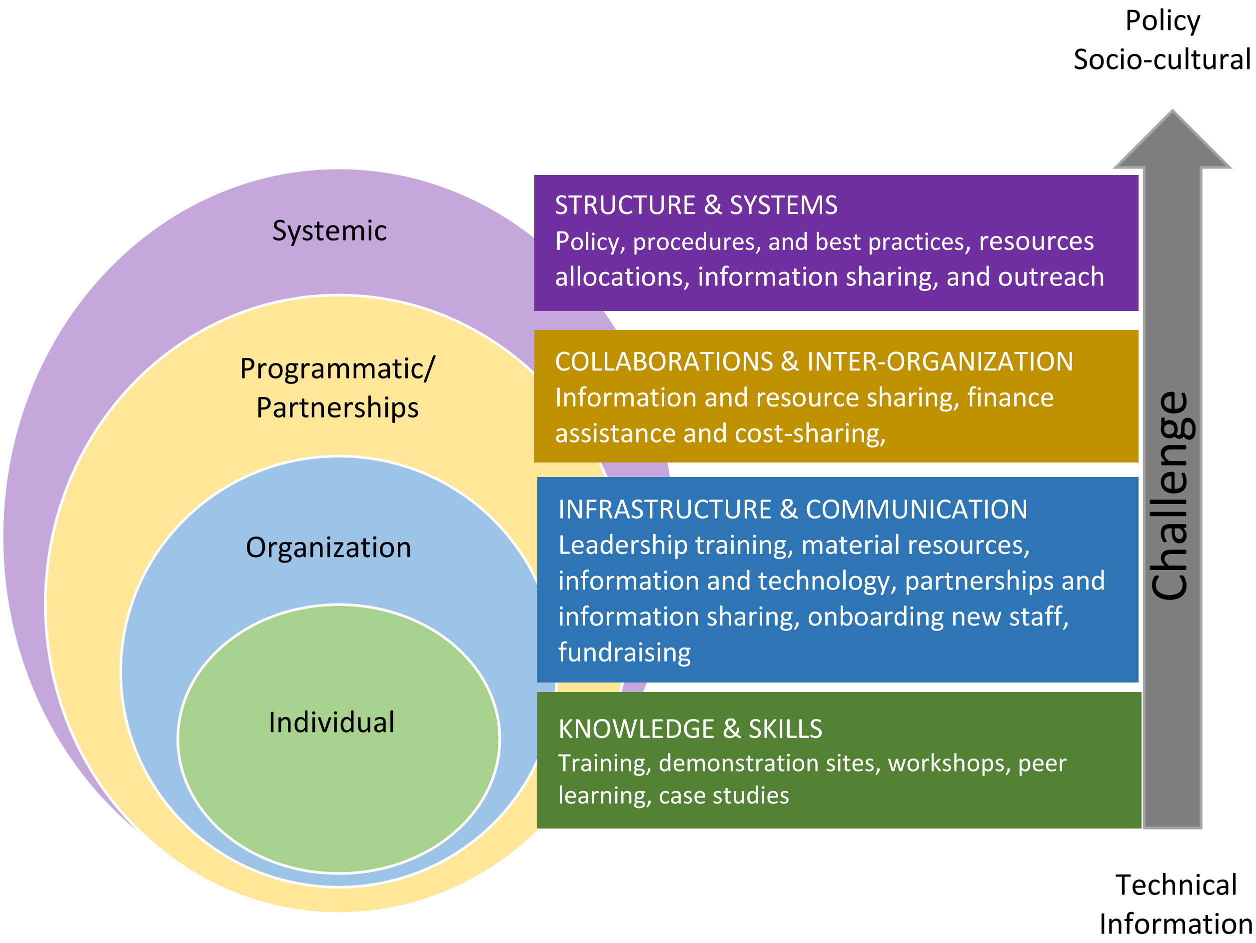

Figure 11-1. Examples of Capacity at Multiple Levels Within a System.
Data Sources: Synthesis of Clearwater Vic (2022), ASDWA (2015), USEPA (2022).

11.2.3 What Are the Benefits of Capacity Building in Water Systems?

Building capacity helps foster resilience to shocks and stressors (see Box) and puts water systems in a better position to take advantage of opportunities when they arise. USEPA outlines common characteristics of a 'high capacity' water system (Figure 11-2) (US EPA 2015). Investing in capacity building provides significant short- and long-term benefits for individuals, organizations, programs/projects, and systems. 'High capacity' water systems are typically more resilient, conduct long-term planning studies, and have a portfolio of 'shovel ready' projects that make them more competitive in funding programs. Many of these concepts are directly applicable to wastewater systems and agricultural water reuse projects as well.

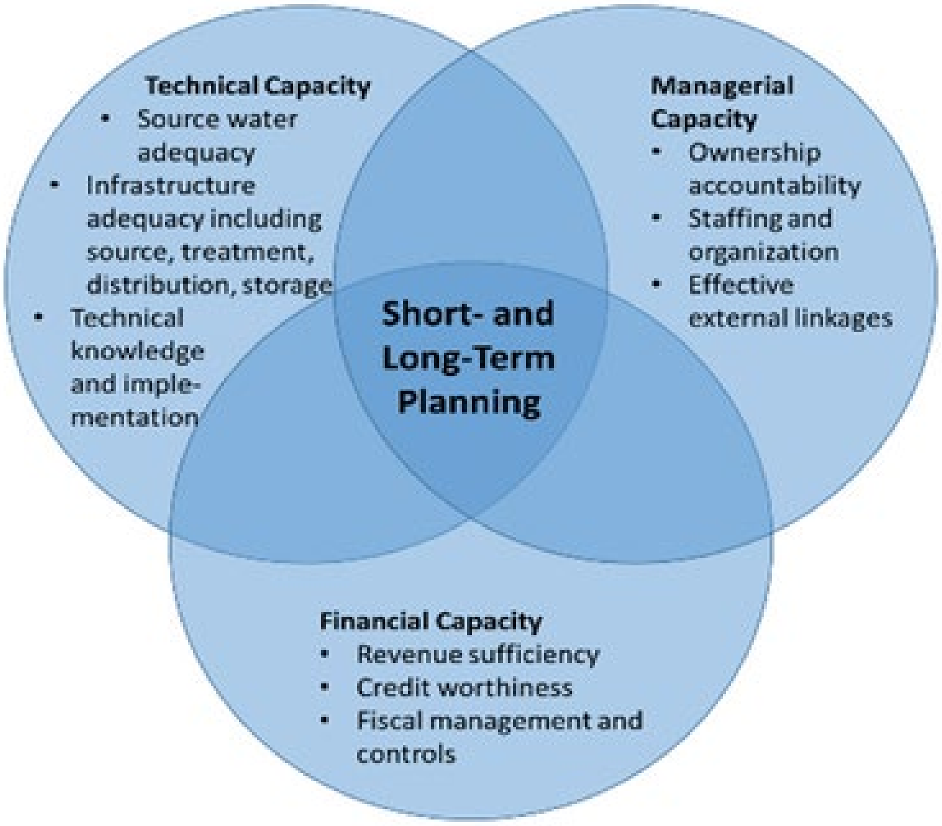

Figure 11-2. Common Components of Technical, Managerial, and Financial Capacity.
Source: US EPA 2015.

Capacity Building and Climate Change

The impacts of climate change are stressing water systems in unprecedented ways (Singh and Tiwari 2019; Kirchhoff and Watson 2019; Tram VO et al. 2014). Wastewater treatment and reuse systems in low-lying areas are more prone to flooding during extreme tidal and storm events which can cause service interruptions and uncontrolled discharges of wastewater. Drought and scarcity are reducing water supply availability and predictability at other times of year. Capacity building can help organizations build a solid TMF foundation while growing systems' innovation, adaptation, and climate-smart planning capabilities. All of these factors combine to build the resilience of water systems to the impacts of climate change.

11.3 Capacity Building in Agricultural Water Reuse Programs

There is no one size fits all approach to capacity building, but there are many good examples of capacity building strategies that have proven effective across diverse contexts in the United States. This section focuses on five capacity building approaches that have helped advance agricultural water reuse projects in the United States and includes references to relevant profiles conducted as part of WRF 4956. Capacity building strategies featured in this section include:

- Peer learning (including long-term examples)

- Permitting, technical, managerial, and financial support
- Information and resource sharing

Many of the profiles featured in Chapter 13 include examples of these strategies in practice. Relevant profiles are called out with each strategy's discussion.

11.3.1 Peer Learning and Longstanding Reuse Programs

Strategy: Learn from the experience of peer organizations and agencies to identify:

1) opportunities for innovation; and
2) strategies for identifying and tackling challenges.

Peer learning opportunities help organizations and individuals learn from real world examples of others successes and challenges. Profiles, site visits, industry associations, utility networks, and programs such as the WRF Research Priority Program[15] all create opportunities for peer learning. National and regional professional associations help facilitate many of these connections through conferences, continuing education, and other resources.

Long-term examples of water reuse programs are especially powerful and persuasive resources in advancing water reuse. These organizations have stood the test of time and navigated changes in policy, politics, customer demand, permit requirements and a host of other challenges. They provide reassurances surrounding potential public health, agronomic, and economic risks of agricultural water reuse. They are also more likely to experience securing government funding (e.g., grants or low-interest loans), have established partnerships where cost-sharing approaches provide additional financial support and can provide insight on how best to explore and identify financing opportunities. Israel, Jordan, and Australia are all international examples of long-term reuse programs. Sheikh et al. provides detailed profiles of these programs

The following profiles include information on long-term agricultural reuse projects:

- 13.7 - Regional Collaboration and Regulatory Programs Supporting Reuse in Small and Medium Communities in Idaho
- 13.8 - Land Application of Reclaimed Water Increases Crop Yields on a Rural Farm in Maryland
- 13.12 - Redefine and Expand Role of Wastewater Utilities to Provide Regional Environmental Co-benefits in Oregon
- 13.14 - Fit-for-Purpose Approach Facilitates Water Exchange and Maximizes Use Multiple Classes of Recycled Water in San Joaquin Valley
- 13.6 – Meeting Multiple Objectives via Active Management of De Facto Reuse in a Non-Arid Region

States adopting or expanding use of recycled water often use states, such as California and Florida, with long-standing programs as a model for guidelines and regulatory approaches. Some states have conducted in-depth analysis on multiple approaches employed by different

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[15] WRF 2023

states to guide and develop policy that can be modified to best meets their own state-wide needs and objectives. Profile 13.3 (Interagency Collaboration Within States to Advance Reuse) highlights the some of the ways Minnesota, Kansas, and Hawai'i have learned from other state regulatory programs to improve and tailor their programs to best address state needs.

States with recycled water programs take different approaches to managing and regulating requirements focused on the specific needs, drivers, or allowable end-uses. For example, recycled water programs in Idaho are centered around discharged requirements to receiving water bodies and are managed on a state-wide basis as land application. The state has extensive and comprehensive irrigation and nutrient management plans to prevent soil degradation, prevent groundwater contamination, and maximize crop yields. California on the other hand has extensive water quality criteria in place to protect public health as well as environmental protection. Approaches can be combined to develop policy that best meets specific needs.

11.3.2 Permitting, Technical, Managerial, and Financial Support

Strategies:

- *Develop and fund targeted assistance programs that provide direct permitting, technical, managerial, and financial support to communities with the greatest needs.*
- *Design assistance programs to address identified stakeholder needs and knowledge gaps.*

Permitting Support: Navigating the permitting process is a common barrier to agricultural water reuse projects. Requirements vary widely both across states and within states, depending on the type of reuse project. Permitting assistance programs can help organizations navigate the process and requirements from project conceptualization through permit issuance and beyond. Such programs can lessen the administrative burden on water agencies while also (potentially) reducing the amount of iteration state permit writers need to do on a given permit.

Technical, Managerial, and Financial (TMF) Support: Especially for small and medium water systems and producers, resources and staffing are often constrained. These limitations can hinder reuse projects at these organizations throughout project implementation, operation, and maintenance. Technical, managerial, and financial support provided through organizations such as the Rural Community Assistance Program (RCAP) regional programs, state technical assistance and extension programs can help organizations weigh their options and develop strategies for addressing technical, managerial, and financial challenges as they arise. Needs-based assessments can help TMF assistance programs target resources and information to communities struggling the most to implement water reuse projects.

Rural Community Assistance Partnership (RCAP)

RCAP is a national network of six regional organizations providing direct technical assistance, training, and capacity building on water, wastewater, solid waste management, and economic development in rural communities. Through the water and wastewater technical assistance programs RCAP manages through USDA, USEPA, and U.S. Department of Health and Human Services (HHS) they aim to build community resilience and sustainability while improving quality of life in rural communities. Cornerstone strategies in RCAP's approach include building long-term relationships with communities and working directly with communities with the greatest need. Through these efforts, RCAP served more than 3.4 million rural and tribal residents in over 2000 communities in 2020. Water reuse has helped rural communities across the United States manage water supply and water quality needs but is not a one size fits all solution and may or may not be locally appropriate. Water reuse is one strategy amongst a portfolio of options RCAP has worked on with partner communities.

Two profiles included in this guidebook highlight national, state, and regional programs building capacity through permitting and/or TMF support programs.

- 13.5 - Interagency Regulatory and Resource Management Partnerships to Support Agricultural Water Reuse in Florida
- 13.7 - Regional Collaboration and Regulatory Programs Supporting Reuse in Small and Medium Communities in Idaho

11.3.3 Information and Resource Sharing

Strategies:

- *Develop platforms for information and resource sharing at the national, state, and regional level informed by stakeholder needs and observed opportunities for enhanced information and resource sharing.*
- *Where understanding of the state of reuse is lacking, leverage state and national reporting requirements to capture basic information on current reuse programs and integrate this information into state and national funding priorities.*
- *Use information gathered through these processes to conduct needs-based assessments to target resources and set priorities for capacity building activities.*

Agricultural water reuse programs exist in over 40 states. Each project plus the immense amount of research and advocacy work conducted by universities and industry groups such as WateReuse hold a wealth of information. However, historically, the reach of this knowledge has been limited and/or existed in silos. The USEPA Water Reuse Action Plan (WRAP) is one example of a large-scale, open effort to share this information and foster collaboration and knowledge sharing amongst non-traditional stakeholders. This project (WRF 4956) is one such example of work contributing to the WRAP.

At a more fundamental level, basic information on reuse projects (e.g., capacity, level of treatment) is not collected in an integrated way. Several states, including Florida and California, have developed statewide mandatory reporting programs on wastewater treatment and reuse. These efforts facilitate a more holistic understanding of the state of reuse in a given state and help guide funding priorities.

Two profiles cover national and state information and resource sharing initiatives.

- 13.2 - Role of the National Water Reuse Action Plan (WRAP) in Advancing Agricultural Water Reuse
- 13.4 - Statewide Objectives and Streamlined Reporting Advance Adoption of Reuse in Agriculture in Florida

11.4 Benefit and Tradeoff Identification and Accounting

11.4.1 Overview

State and federal funding decisions on water reuse projects commonly use benefit cost analyses to compare across projects. Chapter 8 (Co-Benefits of Agricultural Water Reuse) in this guidebook highlighted the important role co-benefits play in motivating agricultural water reuse projects and engaging a diverse range of stakeholders. However, identifying and accounting for a broad range of benefits and tradeoffs is often challenging to implement in practice within traditional project development and funding cycles. Thankfully, incorporating co-benefits is not an all or nothing proposition. There are flexible strategies for incorporating co-benefits into project planning that align with data availability, project resources, and existing funder requirements. This section discusses approaches to benefit accounting approaches, highlights a framework for incorporating benefit identification and/or accounting throughout the project cycle, and shares resources with additional information on benefit identification and accounting approaches. Additional information on specific benefits and tradeoffs of agricultural water reuse can be found in Section 2 of this guidebook and the resources listed in that section.

11.4.2 Project Funding Requirements and Co-Benefits

Standard benefit-cost approaches often focus on monetizable benefits accruing to a limited number of stakeholders and omit non-monetizable and indirect benefits from consideration (Raucher 2006). Traditional approaches to benefit-cost analysis often overlook important risk management, resilience, and community benefits associated with agricultural water reuse projects. Triple-bottom-line approaches attempt to consider a wider range of economic, environmental, and social benefits (Thebo 2021). Aligned approaches such as integrated resource planning can help integrate co-benefits into funding decisions (Raucher 2011). While California’s Integrated Regional Water Management program has acknowledged limitations such as differences in the way benefits are accounted for across projects (California Department of Water Resources 2017), it is one of the more robust examples of integrated planning and funding approaches actually in practice (State of California n.d.).

11.4.3 Framework for Benefit Identification and Accounting

WRF 4829 (Thebo 2021) outlines a framework for systematically assessing the benefits and tradeoffs of agricultural water reuse projects (Figure 11-3). Robust stakeholder engagement is critical throughout to understand the project context, define project objectives, develop project baseline and alternative scenarios, identify and assess benefits and tradeoffs, and operationalize this information into projects and planning. Stakeholder engagement strategies are discussed in Chapter 10. Different projects and contexts require varying levels of detail and rigor in benefit identification and accounting. Limitations in data availability and resources also commonly limit the degree to which the value of specific benefits can be quantitatively assessed. Depending on project needs and capacity, activities can range from simple identification of potential benefits through detailed accounting and monetization of benefits for inclusion in formal benefit-cost analyses. The project report for WRF 4829 (Thebo 2021) includes several examples of the application of benefit identification and accounting approaches.

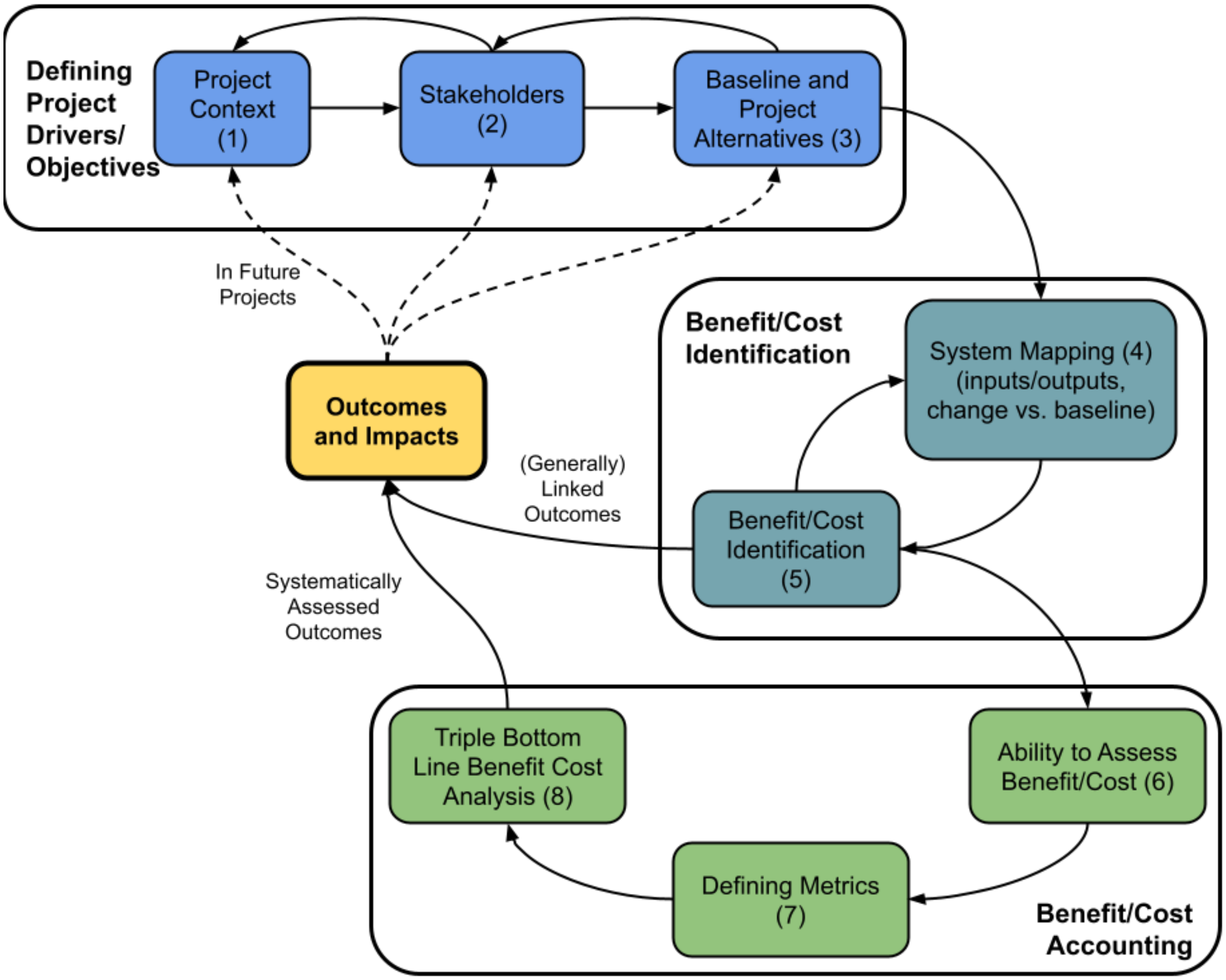

Figure 11-3. Framework for Benefit Identification and Accounting in Agricultural Water Reuse Projects.
Source: Thebo 2021.

11.4.4 Additional Resources on Benefit Identification and Accounting

Birol, Ekin, Katia Karousakis, and Phoebe Koundouri. 2006. “Using Economic Valuation Techniques to Inform Water Resources Management: A Survey and Critical Appraisal of Available Techniques and an Application.” *Science of The Total Environment* 365 (1–3): 105–22.

Bouzit, Madjid, Sukanya Das, and Lise Cary. 2018. “Valuing Treated Wastewater and Reuse: Preliminary Implications from a Meta-Analysis.” *Water Economics and Policy* 04 (02): 1650044.

DeSouza, Sachi, Josue Medellin-Azuara, Nathan Burley, Jay R. Lund, and Richard E. Howitt. 2011. “Guidelines for Preparing Economic Analysis for Water Recycling Projects.” UC Davis, Center for Watershed Sciences. Prepared for the State Water Resources Control Board by the Economic Analysis Task Force for Water Recycling in California.

Raucher, Robert S. 2006. “An Economic Framework for Evaluating the Benefits and Costs of Water Reuse.” Alexandria, VA: WaterReuse Foundation.

Raucher, Robert S. 2011. “Extending the Integrated Resource Planning Process to Include Water Reuse and Other Nontraditional Water Sources.” Alexandria, VA: WateReuse Foundation.

Thebo, Anne L. 2021. “Evaluating Economic and Environmental Benefits of Water Reuse for Agriculture (4829).” Denver, CO: The Water Research Foundation.

Structured Decision-Making Frameworks

- PrOACT (Project Management Skills. 2021)
- WRAP (ModelThinkers 2023)

11.5 Financial Assistance and Cost Sharing

11.5.1 Funding as a Barrier to Agricultural Water Reuse

Identifying and accessing eligible funding for agricultural water reuse programs is often cited as a primary barrier to adoption, especially in small and medium farms and in rural communities. In fact, 87% of wastewater program managers in Northern California cited economic/financial disincentives as the most important hindrance to their implementation of recycled water projects (Bischel et al. 2012). This section provides general and specific approaches that water utilities, agriculture, irrigation districts, and water resources managers have used to overcome financial barriers to recycled water projects for agriculture.

This section of the guidebook includes information and resources on financing agricultural water reuse programs, covering a range of topics including:

- Identifying and accessing funding opportunities eligible for agricultural water reuse programs
- Identifying and leveraging cost-sharing opportunities
- Financial, technical, and legal assistance for reuse programs
- Guidance documents, learning modules, webinars, and other non-governmental resources
- Unique and innovative ways to integrate and bundle funding opportunities

Funding Resources Table

Recycled water, water reuse, and agriculture are funded, managed, and supported by different agencies and organizations across the United States. Resources for financing agricultural water reuse programs are therefore often spread across many agencies and organizations, making it a challenge to locate, access, or even know where to start. This guide provides a list of resources as starting point in Table 11-1 (at the end of this section) for those interested in funding opportunities.

11.5.2 Funding Strategies

Agricultural water reuse programs are commonly financed through local, state, and federal funding programs in the form of grants and low-interest loans, cost-sharing, revenue streams, and seed-funding. Strategies presented here highlight real-world examples of unique and innovative ways to identify and access financial support, often bundling multiple funding opportunities to reduce upfront costs and pass savings along to agricultural producers and other water customers.

While challenges and approaches used to overcome them vary depending on the context, many strategies provide a useful model for others to follow and can be tailored to meet specific needs. Many successful projects have developed unique partnerships or leveraged multiple approaches to secure a range of funding opportunities.

Strategies for accessing funding for agricultural water reuse programs include:

- Infrastructure and distribution financing
- Cost-sharing
- Aligned objectives
- (Re)use existing resources
- Partnerships to reduce treatment upgrades
- Support to agricultural communities
- Seed funding
- Bundle funding

Infrastructure and Distribution Financing

Wastewater utilities often cite initial up-front costs and long-term maintenance and operational costs, treatment upgrades, and distribution as financial constraints to water reuse programs. Distance between supply and demand is cited as a significant impediment and, in these areas, financing for distribution is essential. Growers and irrigation districts can benefit when wastewater treatment facilities receive funding for constructing or upgrading existing infrastructure and treatment technologies, nutrient removal systems, and distribution pipelines.

Strategy: Partner with water utilities to leverage state and federal funding for infrastructure in the form of grant and low-interest loans for rural communities and large-scale projects, including centralized and decentralized reuse. Irrigation districts and growers benefit from low or fixed-rate costs of high-quality water and all customers benefit from the savings of low-interest rates.

Profile #13.13: Regional San's EchoWater and Harvest Water Projects received approximately $300 million in state and federal grants and low-interest loans based on the multiple public benefits it provides.

Funding: USBR WaterSMART Title XVI WIIN Act Water Reclamation and Reuse Programs and California's Water Storage and Investment Program (WSIP) of Proposition 1

Innovative Cost-Sharing

Local governments, agriculture, utilities, and other stakeholders can take advantage of cost-share funds to cover costs including infrastructure, water supply and water quality, and ecosystem restoration or enhancement among others. These agreements can be made between the funding organization or directly between partners involved in the reuse project (Figure 11-4).

Strategy: Work with stakeholders to identify multiple benefits to increase potential for innovative cost-sharing. This helps to cover and reduce upfront costs, lower interest rates, and can alleviate hardships to less financially secure partners by re-distributing the burden of cost. Loans can be taken out by eligible partners to be repaid later through cost-share agreements or revenues.

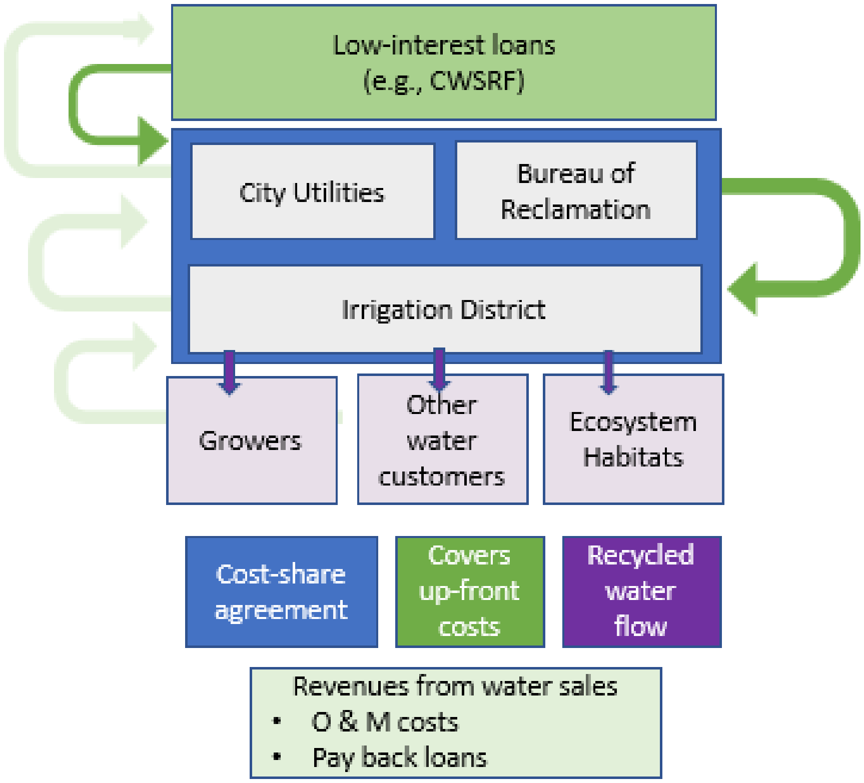

Figure 11-4. Funding Flows in Example Cost Share Model.

Profile #13.11: A multi-tiered cost-sharing approach between the City of Modesto, the US Bureau of Reclamation (USBR), and the partnering irrigation district secured water supplies at a fixed-base rate for agriculture. The city took loans out on behalf of the recycled water program to cover initial construction, to be repaid through revenues received by the irrigation district. The USBR pre-purchased recycled water from the irrigation district to be applied to future water purchases. This approach reduced up-front costs, kept water fees at a capped base rate, and saved customers money.

Aligned Objectives

Funding programs are often flexible and non-prescriptive in providing financial assistance to reduce impediments and often prioritize projects that achieve multiple benefits if they meet organizational, community, state, or regional objectives.

Strategy: Engage with state and federal funding entities to identify priority projects, communities, and objectives. Representation and support gained through these alliances can help to identify common goals, communities in need, and to facilitate approval during the application process.

Profile #13.9**:** The multiple benefits from the Pecan Reclamation project in San Tan Valley, Arizona aligned with local, state, and regional objectives to both support agriculture and reduce reliance on groundwater and Colorado River Water.

Funding: Arizona Department of Water Resources (ADWR) Groundwater Conservation Grant program.

Profile #13.8: Upgrading treatment systems at the Worton WWTP in a small town in Maryland protect the environment while improving rural communities.

Funding: Maryland’s SB 320 Bay Restoration Fund and USDA Rural Development Program, USDA Water and Waste Disposal Loan and Grant Program.

(Re)use Existing Resources to Reduce Costs

Offset high costs related to construction and upgrades that increase recycled water supplies, remove nutrients, or distribute recycled water by utilizing existing resources, such as distribution lines, irrigation systems, lagoons, and treatment ponds. Re-purposing or converting existing structures can minimize upfront costs, reduce fees incurred through interest, and keep projects within or under deadlines. This may be especially important for rural areas and smaller communities where budgets may be tight.

Strategy: Engage with stakeholders to identify where modifications or conversions can replace the need for new builds or equipment with consideration to storage needs and compatibilities between distribution systems, water quality, irrigation equipment, soil characteristics, and crop type.

Profile #13.9: The Pecan Reclamation project in Arizona constructed distribution lines adjacent to existing lines. The project team also realized that by tapping into the on-farm irrigation systems, additional costs could be avoided.

Profile #13.8: The Worton Wastewater Treatment Plant in Kent County, Maryland utilized existing infrastructure, retention ponds, and treatment lagoons and modified existing irrigation systems with wider tires and self-cleaning nozzles to reduce costs.

Profile #13.11: Modesto/Turlock - changed existing discharge location from San Joaquin River to Delta Mendota Canal. Recycled water blended with existing canal water and distributed to growers using existing infrastructure.

Partner to Avoid or Reduce Future Treatment Upgrades

Increasingly stringent discharge requirements are often a driver of water reuse in both non-water scarce and water scarce regions. While the existing quality of water may meet or exceed the needs for agricultural irrigation, treatment facilities may need to invest in costly upgrades to their systems in the future to remain in compliance.

Strategy: Partner with irrigation districts, growers, and wastewater treatment facilities to take a fit-for-purpose approach to reduce or eliminate expenditures for these upgrades and additional 'purple pipe' distribution systems.

Profile #13.11: The cities of Modesto and Turlock avoided future costs of upgrading the treatment facilities by providing recycled water for agricultural communities who had junior water rights and needed the additional supplies maintain crop production. By delivering recycled water to the irrigation district canals, rather than directly to growers through a costly purple pipe system, additional costs were avoided.

Unite Regulatory and Resources Management

Recycled water and water reuse are managed by different entities in the US. Resources and information are often scattered and difficult to find, access, or understand and eligibility for agricultural water reuse projects may not be clear.

Strategy: Unify the expertise of regulatory, resources management, and extension to provide financing support and assistance to growers and producers.

Profile #13.4: The unique partnership of experts leading the Agricultural Assistance Team in the Northwest Florida Water Management District work together to provide support and information to growers on how to find and access financial assistance and cost-share opportunities.

Seed Funding for Water Reuse Technology

One overlooked area of financing for water reuse projects that can directly benefit agriculture is financing for small research and development companies focused on water and water reuse technologies. To incentivize innovation and increase commercialization technology, programs provide seed money for small businesses to advance technologies that are economical, energy efficiency, and robust.

Strategy: Partner with small research and development companies to advance technologies that benefit agricultural through pilot studies or on-farm applications.

Funded Projects: Seed funds between $100,000 and $600,000 have been awarded to small businesses by both the USDA NIFA and the National Science Foundation (NSF) to improve treatment technologies for recycled water and increase water availability for agriculture that is affordable, energy efficient, and commercially available.

Funding Sources: There are eleven federal agencies that support the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, including USDA National Institute of Food and Agriculture (NIFA) and the National Science Foundation (NSF).

11.5.3 The Future of Financing Opportunities

Awareness of the benefits water reuse brings to many industries and communities continues to grow across the US. A national effort, supported by the Environmental Protection Agency (EPA), is underway to increase awareness, accessibility, understanding of eligibility, and integration of reuse programs into existing funding opportunities as part of the National Water Reuse Action Plan (WRAP) collaborative. As these efforts continue, more opportunities relevant to agricultural water reuse will become available. For more information on the EPA WRAP Actions in support of finance assistance, see the accompanying profile, 13.4.

11.5.4 Resources on Funding Programs

This section includes a compilation of resources and information on funding programs (Table 11-1).

Table 11-1. Compilation of Resources and Links for Financing Assistance and Support.

Agency and Resource	Financial Support - Resource Summary and Links
EPA Water Reuse Infrastructure Funding Programs *Online Compilation of Resources*	A streamlined and comprehensive resource of Water Reuse Infrastructure Funding Programs, organized by agency, that Ag Reuse projects may be eligible for: • Clean Water State Revolving Fund (CWSRF) • DOI Title XVI-Water Reclamation and Reuse • Rural Development Water and Environmental Programs • Drinking Water State Revolving Fund (DWSRF) • Water Infrastructure Finance and Innovation Act (WIFIA) (US EPA 2023b)
EPA Water Finance Clearinghouse *Web-based portal of comprehensive resources*	Web-based portal for infrastructure financing. Search for videos, webinars, articles, presentations, and other online tools for Ag Reuse opportunities: • Find Funded Programs, Sources, & Case Studies • Technical Assistance for Funding • Financing Approaches • Small Communities and Systems • Wastewater Treatment • Environmental Protection and Water Resiliency • Legal Issues/Barriers • Economically Distressed Communities • Learning Modules • Water Efficiency (US EPA 2017):::::
EPA Water Finance Clearinghouse *Web-based portal of Learning Modules*	Learning Modules covers a range of water infrastructure investments financing topics: • How to integrate federal funding sources to support activities • Financing municipal/agricultural partnerships • State Revolving Funds • Source water protection • Planning and Coordinating Information • Case Studies in Action • Water Infrastructure Finance and Innovation Act Finance (US EPA 2017):::::
EPA, WIFIA Program *Document of comprehensive list of WIFIA resources*	Compilation of information and resources on water reuse projects funded by the WIFIA in an easy-to-understand format. • Eligible projects • Credit Assistance • WIFIA Handbook • Webinars • Notice of Funding Availability • Funded Projects (WIFIA Program. n.d.)
EPA WIFIA Selected Projects *Online, searchable table and factsheets*	Searchable online table of WIFIA funded projects by state, project name, year, borrower, and loan amount; also provides a link to project specific factsheets.

Agency and Resource	Financial Support - Resource Summary and Links
EPA and CWSRF *Guidebook on water reuse and the CWSRF*	Concise and thorough guidebook on strategies for leveraging CWSRFs into Ag Reuse projects: **'Integrating Water Reuse into the Clean Water State Revolving Fund Eligibility'** • Matrix for source water and SRF eligibility • Cost Effective Analysis • State Priorities and Practices • Marketing and Outreach • Innovative Financing Strategies Beneficial to Ag Reuse Projects ○ Pass-Through Lending and Linked-Deposit Financing (US EPA 2021)
EPA *Fact Sheet on CWSRF Financing*	Summary of the CWSRF Program information including reporting, benefits, and financial assistance. **'Financial Support for Water Reuse from the Clean Water State Revolving Fund'** (US EPA, OW. 2020)
WateReuse *Guidebook on water reuse and the IIJA*	Clearly organized guidebook outlining eligibility, use of funds, cost-share, and priority projects (among others) for grant programs within the IIJA of 2021. **'A Water Recycling Practitioner's Guide to the Infrastructure Investment and Jobs Act of 2021'** • Large-Scale water recycling and reuse projects • Title XVI Water Reuse • State Revolving Funds • Small and disadvantaged communities (WateReuse Association 2021)
EPA WRAP *Matrix for SRF eligibility*	Matrix showing eligibility for assistance from the Clean Water and Drinking Water SRF based on source water and end-use for both (Matrix for source water and SRF eligibility n.d.)

Agency and Resource	Financial Support - Resource Summary and Links
USDA NRCS *Website and resources for Conservation Innovation Grants and resources*	The USDA Natural Resources Conservation Service (NRCS) Innovation Grants (CIG) is a competitive program that supports new approaches and technologies to conserve natural resources. • Interactive Maps Highlighting Previous CIG Projects • Search Tool CIG Projects • On-Farm Conservation Innovation Trials • Link to the State Revolving Fund Model Marketing Plan Eligibility • National and State Funding and Competition • Success Stories and Case Studies
USDA NRCS *Website and resources for Agricultural Management Assistance Program*	Provides assistance and financial funding to producers to construct or improve water management structures, among other activities. Website also provides program data beginning in 2009. (USDA 2023)
USDA Rural Development *Factsheet for water reuse in rural communities*	Provides guidance on the Rural Development Program for agricultural water reuse in small and rural communities on how to leverage funds from the USDAs Rural Utilities Service (RUS) Water and Environmental Programs (WEP). A compilation of awarded RUS WEP agriculture reuse projects is in development. (USDA 2020)

CHAPTER 12

Scaling Agricultural Water Reuse - Research, Data, and Information

12.1 Overview

Research, data, and information are essential to sustainably advancing and scaling water reuse projects and ensuring the potential benefits of projects are realized while minimizing unintended consequences. The companion literature review (Part 1) synthesizes current scientific information on potential health and agronomic risks of agricultural water reuse projects and how this relates to existing regulatory frameworks. This section focuses on highlighting research, data, and information strategies that have proven helpful in advancing and scaling agricultural water reuse programs. While this section focuses on agricultural water reuse of municipal recycled water, many of the strategies, tools, and resources are relevant to both different types of reuse and across a range of alternative supplies.

12.2 Developing and Scaling New Technologies

12.2.1 Pilots

In order for new technologies to be accepted by regulatory programs, they must demonstrate that they are adequately protective of public health and the environment. One such example of this is the development of the California SWRCB ‘Alternative Treatment Technology Report for Recycled Water’.[16] Technologies were required novel to demonstrate that they meet the filtration performance and disinfection requirements for compliance with Title 22, typically through pilots. Investment in basic research helps develop the initial proof of concept for new technologies, but additional investment or seed funding is needed to make these technologies commercially viable, effective, and affordable under real world operating conditions. This is commonly accomplished through pilot programs with utilities and farms. Pilot programs provide a unique opportunity for utility and grower innovation, capacity building, and testing performance under real-world conditions, often at a relatively low cost. Federal seed funding programs can provide funds for both initial applied research and commercialization of technologies (which commonly includes pilots).

Searchable Clearinghouse of Wastewater Technology (SCOWT)

SCOWT is an EPA managed, searchable resource library on the performance and cost-effectiveness of a wide range of wastewater treatment technologies. WRAP Action 4.9 (Incorporate Water Reuse Technology Resources into the SCOWT Platform) is working to increase information on centralized and decentralized reuse technologies within SCOWT.

SCOWT (US EPA 2023c)

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[16] (California State Water Resources Control Board 2014)

12.2.2 Seed Funding

Currently, eleven federal agencies, including the USDA National Institute of Food and Agriculture (NIFA), USEPA, and the National Science Foundation (NSF) participate in seed/pilot funding programs.[17] Pilot projects are typically funded through Small Business Innovation Research (SBIR) and Small Business Technology Transfer Programs (STTR). Recycled water projects have the potential to be incorporated into the following projects areas eligible for seed funding through these programs such as:

- Plant production and protection
- Conservation of natural resources
- Rural and community development
- Small and mid-sized farms
- Water reuse
- Wastewater technologies

Recycled water and wastewater treatment technologies are a consistent piece of SBIR/STTR funding programs. Funded treatment technologies fall under two broad classes – those adopted as part of centralized treatment systems and on-farm, decentralized treatment systems. In both cases, treatment technologies that are commercially viable need to be economically and technically feasible to operate, energy efficient, and produce high quality recycled water that meets regulatory requirements (e.g., FSMA PSR Agricultural Water Rules). Examples of some recent projects receiving seed funding are included in Table 12-1. Examples of common areas of funding include commercialization water reuse technologies and sensors to detect high priority contaminants of emerging concern (including PFAS) – an area of growing concern for irrigating crops with recycled water. Novel technologies developed may be integrated into small community wastewater systems to improve water quality and help WWTP to meet discharge requirements.

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[17] Additional information on SBIR/STTR funding is available through the SBIR website. This website includes a searchable database of funded projects, RFAs, and many additional resources.

Table 12-1. Examples* of the Types of Projects Awarded Seed Money Through SBIR and STTR Funding Programs to Increase Water Supplies for Agriculture.

Project Name	Awarded Entity	Seed Money
A chemically resistant membrane for water purification	ALA Systems Inc.	$225 000
Versatile biocatalytic processes for low-cost water reuse in agriculture	Microvi Biotech Inc.	$100 000
Energy positive wastewater treatment and reuse system for agriculture applications	Cambrian Innovation Inc.	$100 000
Novel adsorbent materials for wastewater treatment	Novoreach Technologies	$600 000

* The aim of this table is to provide illustrative examples of the types and scales of projects that have been funded through federal pilot funding programs. Details on additional funded projects available through (SBIR 2023).

12.3 Tools and Resources for Understanding and Managing Risks

Questions around data uncertainty and real or perceived risks of reuse are a common challenge faced by agricultural water reuse projects. Risk assessments are inevitably based on incomplete or imperfect information, but there are strategies, tools, and resources available to synthesize what we do know and ensure existing systems are minimizing risks in the face of imperfect information. Several of these strategies, tools, and resources are summarized below.

Risk-Based Regulatory Frameworks

Many state recycled water policies are developed using a risk-based approach (see Chapter 2). This approach sets water quality criteria based on acceptable health outcomes (e.g., increased probability of diarrheal disease not exceeding 1 in a million). Quantitative microbial risk assessment (QMRA) is a probabilistic, analytical approach for estimating risk of disease given a certain level of exposure (Alegbeleye and Sant'Ana 2021; Rock et al. 2019). Olivieri et al. used QMRA to assess the suitability of California's agricultural water reuse regulations and found them to be adequately protective of public health (Olivieri et al. 2014). The application of risk assessment methods to understand the impacts of CECs in recycled water used for irrigation is an active area of research (e.g., Weber et al. 2006; Garner et al. 2021; Lin et al. 2020). To date, agricultural water reuse regulations do not include standards for CECs.

Science Advisory Panels and State Sponsored Research

Science advisory panels have been widely used by the State of California to continually assess the current state of science on topics related to water reuse. Panels, such as the panel focused on CECs, has been convened multiple times over the past fifteen years in response to advances in science and/or changes to regulatory programs to allow new types of reuse (e.g., potable). State-sponsored research is also commonly used in California and elsewhere to develop the scientific basis of regulations. Reports from these panels and state-sponsored research are commonly publicly available and often relevant outside of California (Olivieri et al. 2016; Drewes et al. 2022; Sutton et al. 2022; Mahoney et al. 2021) .

Industry Standards

The California Leafy Greens Marketing Agreement (CALGMA) emerged out of a 2007 *E. coli* outbreak. The outbreak was not caused by the use of recycled water, but the food safety protocols and audit programs developed apply to croplands producing leafy greens (including those irrigating with recycled water). The voluntary standards, protocols, and audit program developed through the LGMA are driven by industry. Arizona has since developed a LGMA program that is nearly identical to the CALGMA. Until recently, these programs addressed on-farm food safety issues not addressed via state or federal regulations. Lessons learned through the LGMA programs have helped inform the development of FSMA.

Education and Outreach

Exposure pathways associated with agricultural water reuse are diverse (see Chapter 4). While this means there are many ways humans can be exposed to potential risks, there are also a broad range of risk mitigation strategies that can be employed in treatment facilities, on farms, and in households. At a basic level, signage and education programs on topics such as safe handling can help raise awareness of potential risks. The Produce Safety Alliance's grower training programs help prepare growers for compliance with FSMA.[18]

Improved Water Quality Monitoring

The field of water quality monitoring is rapidly evolving due to innovations in detection and measurement methods, technology, and other advances. What this means practically is that it is now possible to better understand what constituents are present in irrigation water with greater temporal frequency. However, additional work is needed to make these technologies usable and cost effective in the field. Better measurement of water quality constituents is one important step towards improving current risk assessment approaches.

12.4 Continued Innovation Within Government Programs and Reuse Projects

As the science on water reuse continues to evolve, regulations change – new types of reuse such as potable reuse are allowed, water quality criteria are refined, and programs are streamlined. Likewise, the needs of communities and agricultural systems are changing. Climate change is shifting historical patterns of water availability, population and water use patterns are changing, much of our nation's water infrastructure is nearing the end of its useful life. All of these factors necessitate continual innovation within government programs, new and existing water reuse projects. Multiple profiles in Chapter 13 highlights innovative examples of programs and projects tackling these challenges with a few recurring examples of innovative strategies highlighted below.

Expanding the Number of Water Sources Recycled

Monterey One Water (Profile 13.12) is pioneer in agricultural water reuse with a long history of piloting innovative treatment technologies, conducting public outreach, and managing an extensive water reuse program. However, the water quality and supply challenges that motivated the initial reuse projects have not gone away. To further tackle these challenges,

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[18] (Cornell College of Agriculture and Life Sciences 2023)

they began to look more holistically at all the supplies of water available within their service area. This has led to the integration of cannery water, stormwater, and other underutilized local supplies into the existing recycled water program. Integrating multiple sources of water into their recycled water supply has both expanded the supply of recycled water available and facilitated the expansion of other applications such as groundwater recharge.

Conjunctive Management

A common theme across multiple profiles (e.g., Harvest Water (#13.15), Clean Water Services (#13.14), Oxnard (#13.11)) was the importance of conjunctive management of recycled water in securing funding and support from diverse stakeholders. With conjunctive management, a given supply of recycled water can be used to address multiple objectives (and provide multiple benefits) over the course of the year. This approach addresses one substantial challenge of agricultural water reuse – demand for recycled water typically only exists during the growing season. Examples of this in practice include using the recycled water to recharge groundwater during non-growing seasons and supplying recycled water to wetland and riverine ecosystems during critical ecological periods.

Capacity Building Through Interagency Collaboration

Two common agricultural barriers to water reuse are navigating multi-agency regulatory programs and understanding potential agronomic impacts of reuse. These barriers (and others) led to the creation of the Agricultural Assistance Team and Mobile Irrigation Lab in northwest Florida (Profile 13.5). These support programs arose from the collective recognition that barriers to agricultural reuse and irrigation efficiency span multiple agencies and regulatory programs. The Northwest Florida Water Management District (NFWMD), City of Tallahassee, NRCS, and Florida Department of Agriculture and Consumer Services all support these programs. The Agricultural Assistance Team and Mobile Irrigation Lab provide a one-stop shop for accessing support programs including permitting support, technical assistance, and funding resources. Reuse in Florida is somewhat unique in the direct links the state recycled water program creates with efficiency programs and irrigation water quality. These differences are reflected in the breadth of support provided by the Agricultural Assistance Team and Mobile Irrigation Lab.

12.5 Data and Information to Support Scaling

12.5.1 Overview

Any discussion on scaling water reuse should include the basic question ‘What type of reuse makes the most sense, where?’ Agricultural water reuse provides many benefits and can be a great option in areas where supplies of wastewater are connected with irrigated agricultural lands, either by proximity or conveyance infrastructure. This section highlights key findings from a GIS analysis taking a high-level look at basic questions surrounding the supply of and demand for recycled water and agricultural water reuse.

Chapter 2 in this report provides a detailed update on the current state of agricultural water reuse regulations in the United States. This assessment found that agricultural reuse of treated municipal wastewater occurs in 43[19] states with 23 states allowing irrigation of all agricultural products (Figure 2-2). See Chapter 2 for additional details on state regulations and guidelines. Our assessment in WRF 4775 conducted a detailed assessment of supplies of recycled water potentially available for reuse and the proximity of these supplies to irrigated croplands (Sheikh et al. 2019). Up to 33,000 MGD of treated effluent is potentially available for reuse (Figure 12-1). Among WWTP with un-reused effluent, 44 percent are within five miles of irrigated croplands (Figure 12-2). This chapter takes a deeper look at a range of factors impacting demand for recycled water – water use for irrigation, irrigation in water stressed catchments, and locations with degraded groundwater quality.

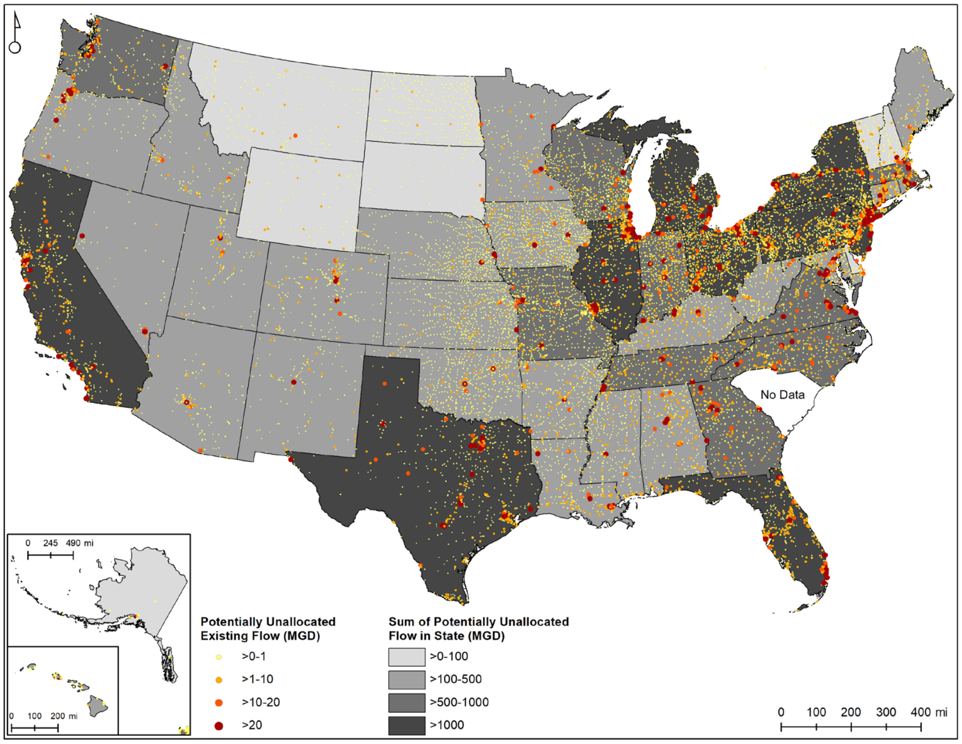

Figure 12-1. Quantity of Treated Municipal Wastewater Effluent Potentially Available for Reuse by Facility and Sum of Potentially Reusable Effluent by State.

Source: Sheikh et al. 2019.

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[19] 27 states have formal regulations or guidelines while the remaining states provide incidental oversight (n=9) or allow agricultural reuse on a case-by-case basis (n=6).

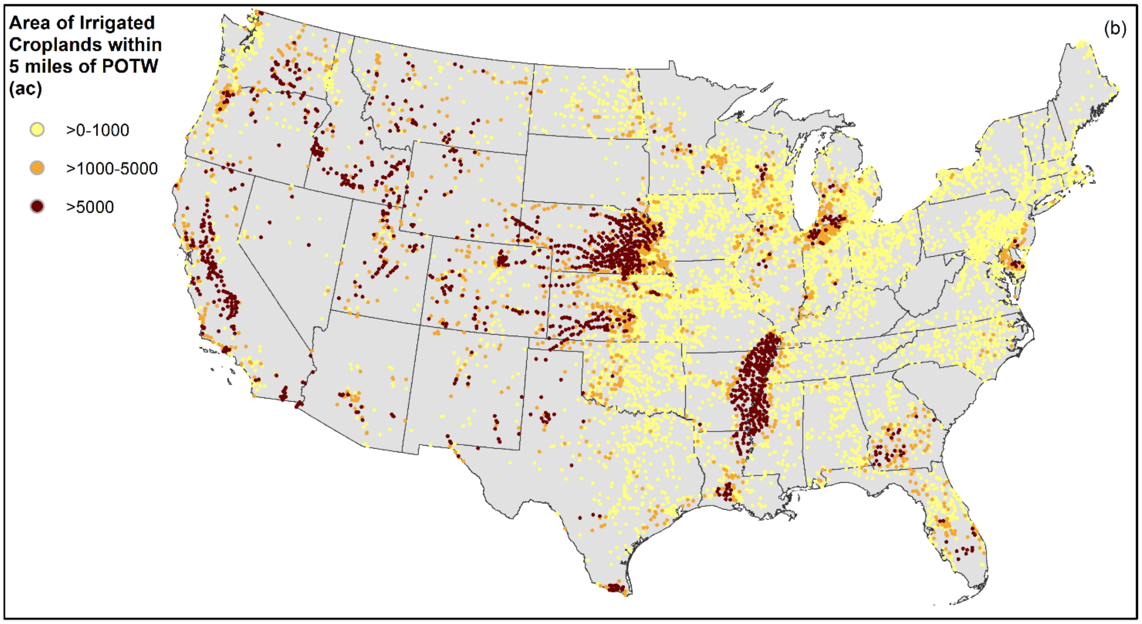

Figure 12-2. Area of Irrigated Croplands Within Five Miles of WWTP with Effluent Potentially Available for Reuse.

Source: Sheikh et al. 2019.

12.5.2 Factors Impacting Demand for Agricultural Water Reuse Projects

Agricultural water reuse projects are motivated by a broad range of drivers including water supply, water quality, and regulatory requirements. This section examines how these drivers and other fundamental constraints vary spatially across the United States. Water use for irrigation is a function of local weather conditions, type of crop grown, irrigation method, soils, and other factors. Additional details on methods and results will be included in a companion journal article.

How much water is used locally for irrigation?

Eighty-eight percent of U.S. counties, including many counties in non-water scarce regions, use some amount of water for irrigation[20] (Figure 12-3). Figure 12-3 shows the total amount of water used for irrigation by county. Potential demand for recycled water may exist when irrigated croplands are located close to WWTP with effluent available for reuse.

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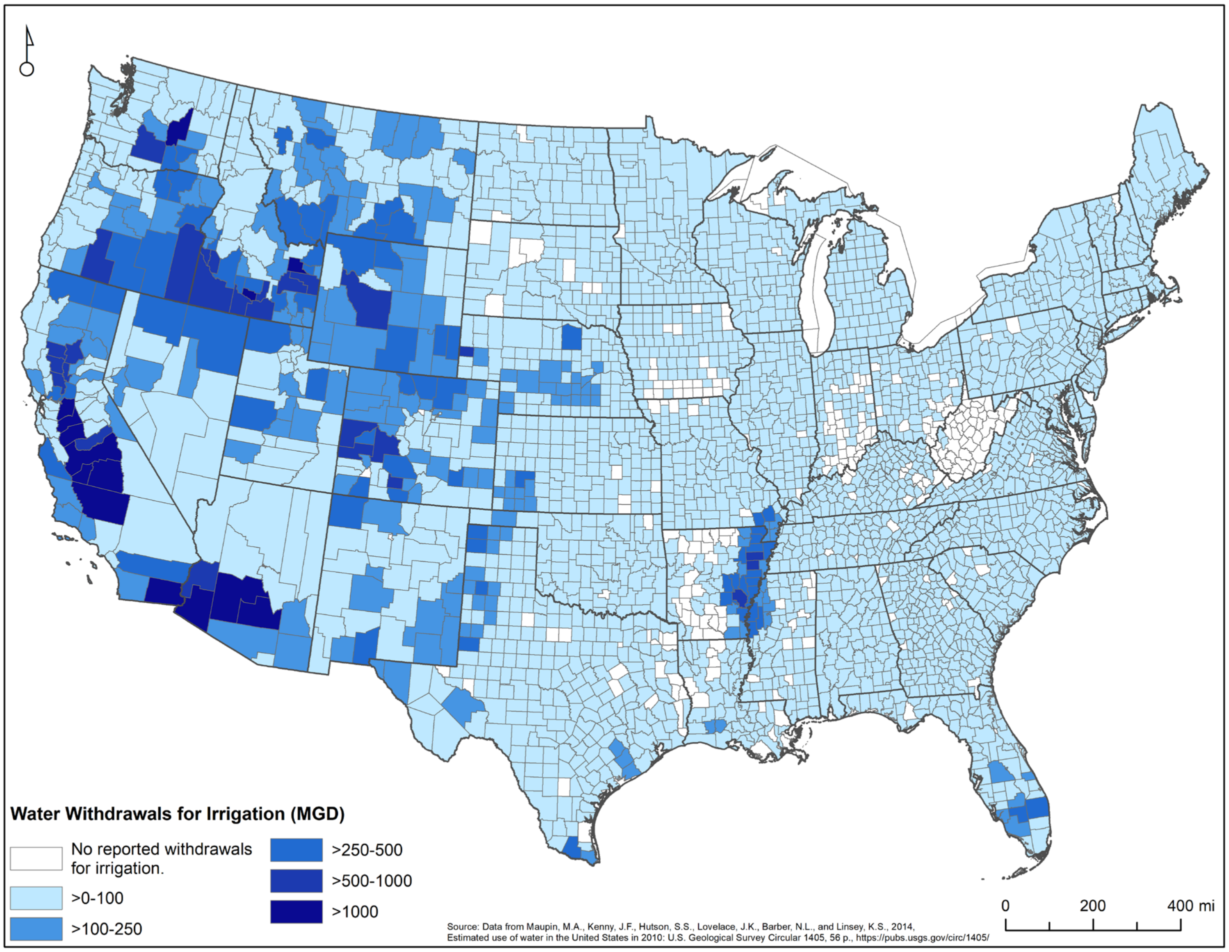
[20] The USGS National Water Use data do not currently differentiate irrigation for agriculture and other purposes in all states. Where these uses are separated, agricultural irrigation accounts for the majority of irrigation outside of urban areas.

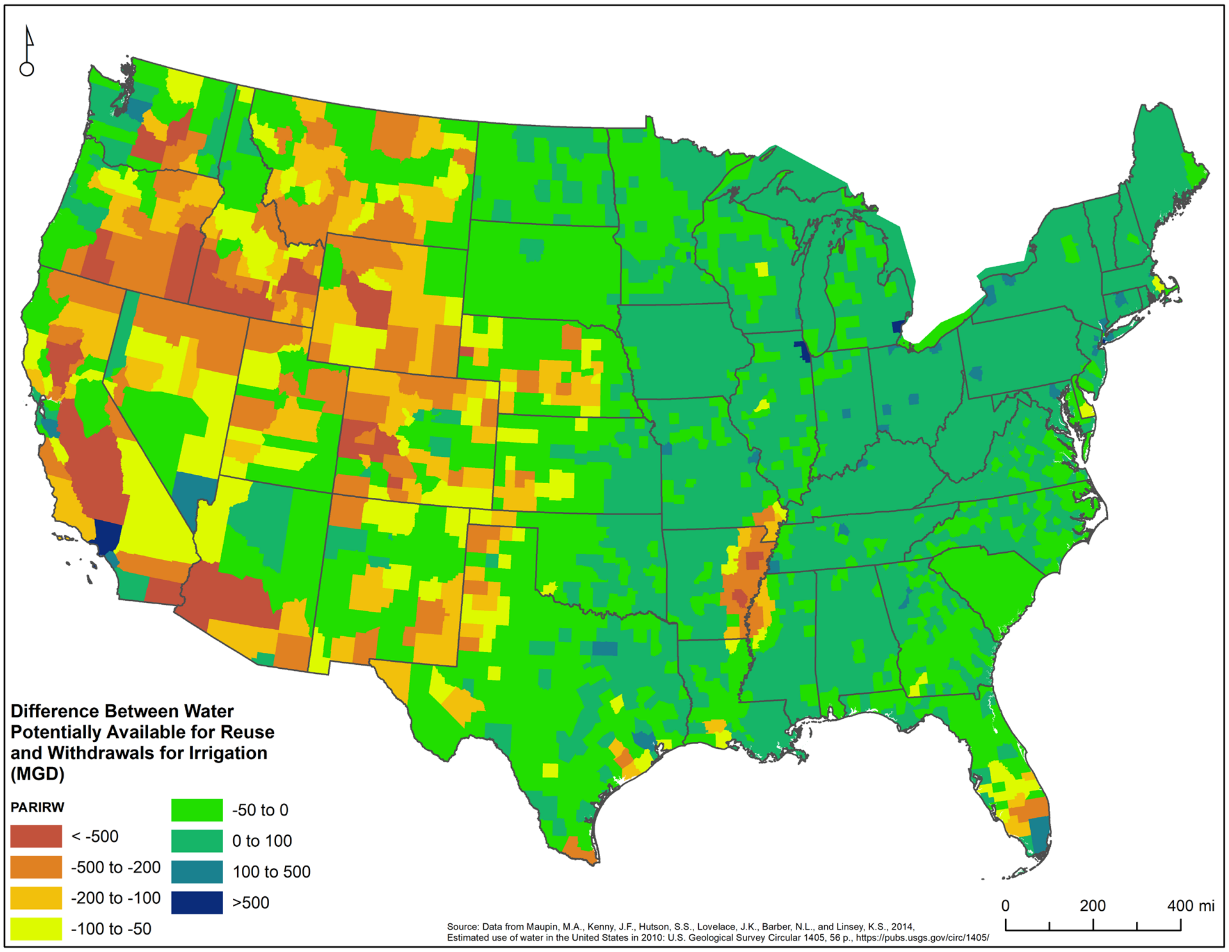


Source: Data from Maupin, M.A., Kenny, J.F., Hutson, S.S., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2014, Estimated use of water in the United States in 2010: U.S. Geological Survey Circular 1405, 56 p., https://pubs.usgs.gov/circ/1405/

Figure 12-3. Total Water Withdrawals for Irrigation by County.
Data Source: Maupin et al. 2014.

How does water use for irrigation compare to the quantity of effluent potentially available for reuse?

Municipal wastewater production exceeds or is within 50 MGD of water use for irrigation in 88 percent of U.S. of counties (Figure 12-4). Whether these supplies can be used by agricultural producers hinges on a broad range of practical, context specific factors (discussed elsewhere in this report). Nonetheless, these findings indicate that recycled water could make locally significant contributions to water supply portfolios in many areas of the country.



Source: Data from Maupin, M.A., Kenny, J.F., Hutson, S.S., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2014, Estimated use of water in the United States in 2010: U.S. Geological Survey Circular 1405, 56 p., https://pubs.usgs.gov/circ/1405/

Figure 12-4. Comparison of Effluent Potentially Available for Reuse and Withdrawals for Irrigation by County. *Data Source*: Maupin et al. 2014; Sheikh et al. 2019.

What watersheds are facing water quantity and quality stressors known to motivate agricultural water reuse projects?

Water supply and quality challenges are widespread across the United States and do not always match traditional conceptualizations of 'water scarce' or 'water rich' regions (Figure 12-5). Agricultural water reuse can help augment supplies in water scarce regions. Reuse is also becoming increasingly common in regions of the country that are not water scarce per se, but experience supply shortages during critical periods of crop production. In areas facing water quality challenges, agricultural reuse can help reduce discharges from WWTP and reduce agricultural fertilizer use (when nutrient concentrations in recycled water are known by growers).

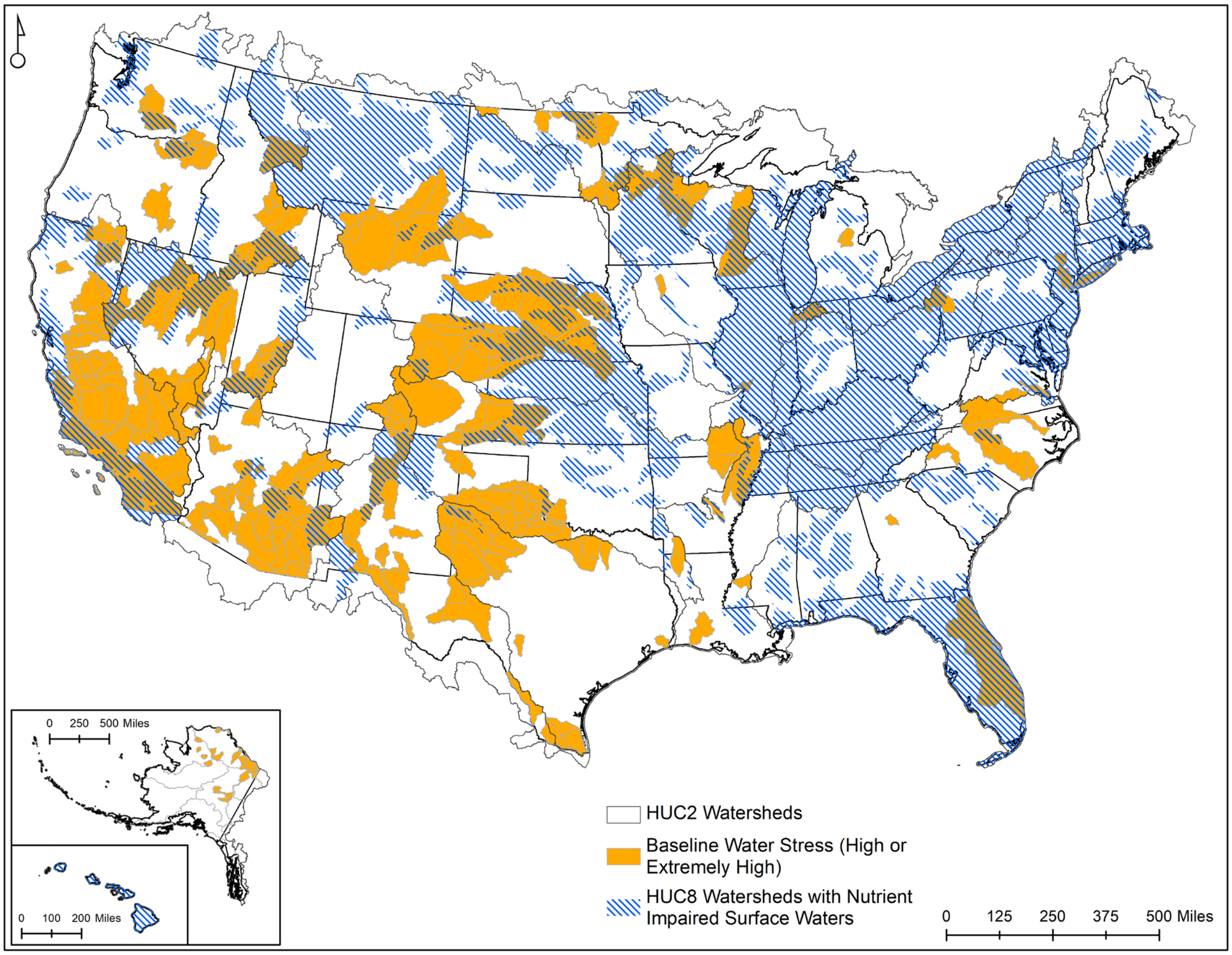


Figure 12-5. Watersheds with Nutrient Impaired Surface Waters and/or Facing Water Stress.
Data Source: Water Stress Indicator (WRI AQUEDUCT v3.0); 303(d) Listed Waters (USEPA).

Where is the quality of groundwater used for irrigation degraded?

Concerns about salinity are a primary agronomic concern associated with the use of recycled water for irrigation (see Chapter 5). However, where the quality of local irrigation water supplies are degraded, recycled water may be preferable to existing supplies. Due to hydrogeologic conditions and/or pollution, the quality groundwater supplies exceed recommended agronomic thresholds in many areas of the U.S. (Figure 12-6). Data from the 2018 USDA Irrigation and Water Management Survey show a substantial number of growers reporting diminished yields due to the salinity of irrigation source waters (US Department of Agriculture (USDA) 2018; Sheikh et al. 2019).

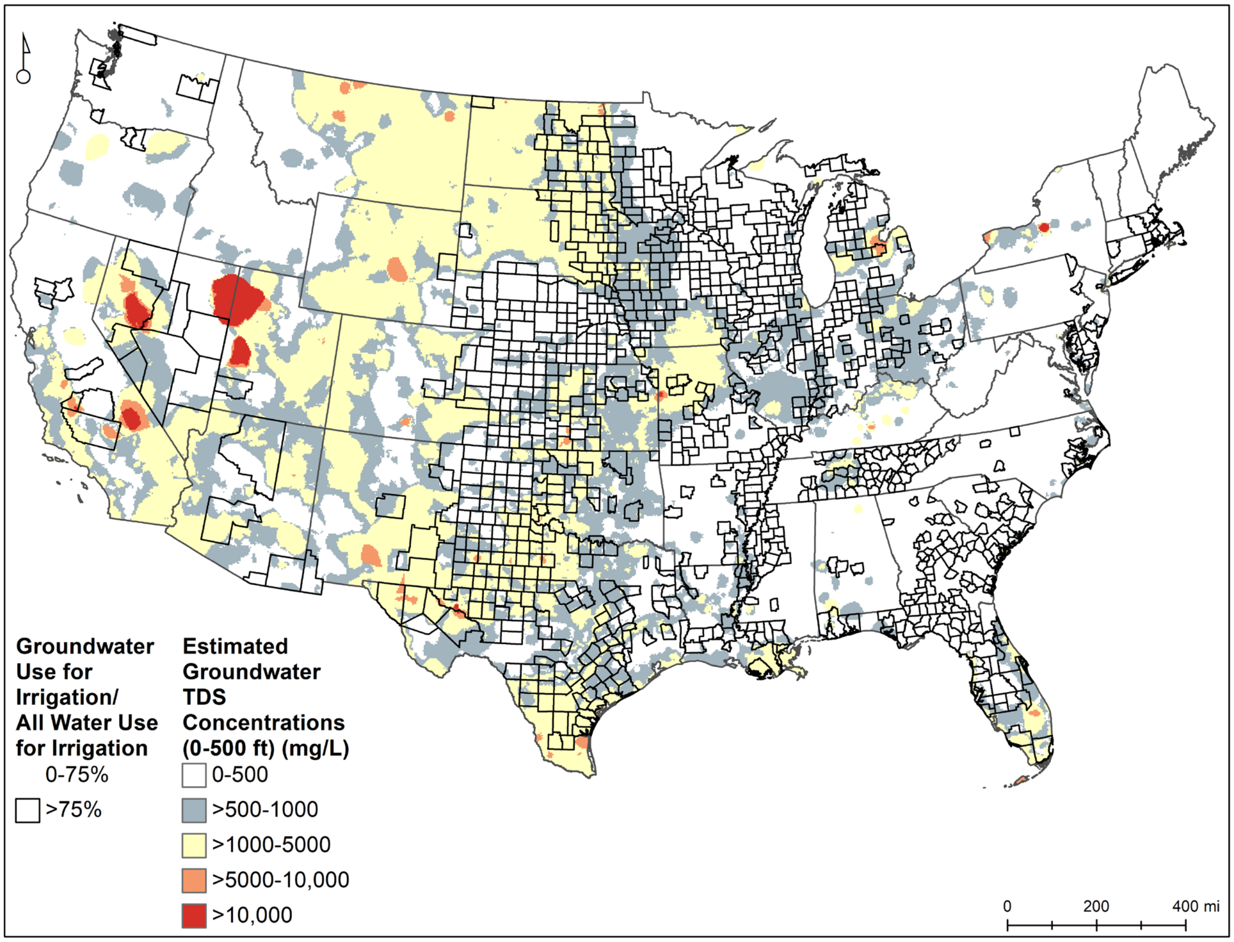


Figure 12-6. Counties Dependent on Groundwater for Irrigation and Areas Where Groundwater Quality Exceeds Agronomic Thresholds.

Data Source: Stanton 2017.

12.5.3 Findings and Recommendations from Geospatial Analysis Findings

This section focuses on findings and recommendations arising from the geospatial analysis while Chapter 14 makes more general recommendations.

State Recycled Water Policies: While there are opportunities for unifying state regulations on agricultural water reuse (Figure 2-2), regulations in most states appear to roughly match the types of agricultural production most common in that state (Figure 2-3). For example, recycled water policies in states that produce few crops consumed raw often do not include this class of reuse in their regulations. Unifying state regulations could help reduce confusion on agricultural water reuse policies, but, where regulations exist, limitations on permitted uses may not be a substantive barrier at the present time. However, with climate change, patterns of agricultural production are shifted and this limitation may be a greater barrier in the future. States currently lacking regulations or guidelines may benefit from evaluating the regulations of neighboring states and using those regulations as a model.

Potential for Agricultural Water Reuse: There is significant unrealized potential for increasing agricultural water reuse across the United States (Figure 12-1). Data indicate that treated effluent could meet a substantial portion of agricultural irrigation demand in most U.S. counties (Figure 12-4). However, realization of this potential depends on a wide range of context specific factors including:

- Distance between WWTP and irrigated croplands (Figure 12-2);
- Quality, accessibility, and reliability of existing irrigation water supplies (Figure 12-5); and
- Local drivers of water reuse projects such as water quality impairments and scarcity (Figure 12-6).

The findings from this analysis provide basic insights into areas where exploring greater investments in agricultural water reuse many prove beneficial. They also highlight regions where other types of reuse may better match local needs. Additional research is needed to explore these nuances of potential.

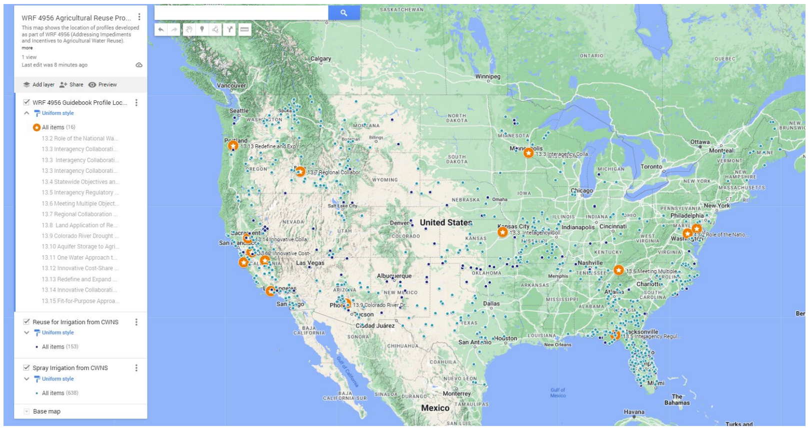
CHAPTER 13

Profiles of Projects and Programs Addressing Barriers to Agricultural Water Reuse

13.1 Introduction

13.1.1 Background

Agricultural water reuse occurs across the United States with projects motivated by water supply, water quality, and a host of locally significant drivers. These projects are supported and advanced through a broad range of government and technical assistance programs. The thirteen profiles[21] featured in this section highlight successful, long-term projects, innovations in project delivery, and/or government programs advancing agricultural water reuse. Profiles in this report were selected to highlight the use of different qualities of water, scales of projects, and the range of crops irrigated. These profiles are not meant to be exhaustive case studies, but instead brief profiles highlighting specific strategies, barriers, and programs advancing agricultural water reuse across the country. Profile write-ups were developed through document review, interviews, and other publicly available resources. The project team sought direct feedback on write-ups from relevant stakeholders and incorporated this feedback into the profiles included here. However, after multiple attempts, we were unable to get direct feedback on a handful of the profiles. As such, profile contents should be considered the views and synthesis of the report authors. The location of WRF 4956 profiles are included in the project webmap[22] (Figure 13-1) (https://bit.ly/AgReuseProfiles) with additional details in Table 13-1. Strategies discussed earlier in this guidebook were identified, in part, through these and other profiles.



WRF 4956 Agricultural Reuse Pro...
This map shows the location of profiles developed as part of WRF 4956 (Addressing Impediments and Incentives to Agricultural Water Reuse).
more
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☑ WRF 4956 Guidebook Profile Loc...
Uniform style
All items (16)
13.2 Role of the National Wa...
13.3 Interagency Collaborati...
13.3 Interagency Collaborati...
13.3 Interagency Collaborati...
13.4 Statewide Objectives an...
13.5 Interagency Regulatory ...
13.6 Meeting Multiple Object...
13.7 Regional Collaboration ...
13.8 Land Application of Re...
13.9 Colorado River Drought ...
13.10 Aquifer Storage to Agri...
13.11 One Water Approach t...
13.12 Innovative Cost-Share ...
13.13 Redefine and Expand ...
13.14 Innovative Collaborati...
13.15 Fit-for-Purpose Approa...

☑ Reuse for Irrigation from CWNS
Uniform style
All items (153)

☑ Spray Irrigation from CWNS
Uniform style
All items (638)

Figure 13-1. WRF 4956 Agricultural Reuse Profile Locations and Other Irrigation-Related Reuse Projects Identified in the 2012 USEPA CWNS Data.

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[21] The terminology used in Chapter 14 purposely mirrors the language used by case example subjects. For example, in some regions the term ‘reclaimed water’ is preferred over ‘recycled water’.

[22] The map also includes data on facilities reporting reuse for irrigation or spray irrigation in the 2012 USEPA Clean Watersheds Needs Survey data. Data from the CWNS are included as-is and contain known limitations (US EPA 2023d).

Table 13-1. Description of WRF 4956 Profiles.

Section	Profile	Geographic Region	Key Characteristics
State and Federal Programs			
13.2	Role of the National Water Reuse Action Plan (WRAP) in Advancing Agricultural Water Reuse	National	Collaborative effort focused on development and dissemination of information to advance water reuse
13.3	Interagency Collaboration Within States to Advance Reuse	Minnesota, Kansas, Hawai'i	Overview of state programs fostering interagency collaboration and communication to advance reuse
13.4	Statewide Objectives and Streamlined Reporting Advance Adoption of Reuse in Florida	Florida	Nation's most comprehensive state inventory of water reuse.
13.5	Interagency Regulatory and Resources Management Partnerships to Support Agricultural Water Reuse in Florida	Florida	Longstanding, state agency managed technical, managerial, and financial support program.
13.6	Meeting Multiple Objectives via Active Management of De Facto Reuse in a Non-Arid Region	Multiple Southeastern States	Indirect reuse in a non-arid region; Water-energy-reuse nexus; Unique water management approach.
13.7	Regional Collaboration and Regulatory Programs Supporting Reuse in Small and Medium Communities in Idaho	Idaho	Supporting water reuse in small/medium communities; Water quality drivers
Local and Regional Projects			
13.8	Land Application of Reclaimed Water Increases Crop Yields on a Rural Farm in Maryland	Maryland	Multi-benefit project between ag and utility, environmental benefits, partnerships (ag, county, utility)
13.9	Colorado River Drought Contingency Planning and Agricultural Reuse in the Rural Southwest	Arizona	Agricultural water reuse and drought in the arid west
13.10	Aquifer Storage to Agriculture: Advanced Treatment System Creates Flexible, Local Supply in California	California	High quality reuse for food crops; Overcoming grower impediments to reuse; Advanced treatment
13.11	Innovative Cost-Share Agreement Secures Reliable Water Supply at Affordable Cost in San Joaquin Valley	California	Blending tertiary recycled water with existing canal supplies.
13.12	Redefine and Expand Role of Wastewater Utilities to Provide Regional Environmental Co-benefits in Oregon	Oregon	Holistic resource management and reuse to advance regional environmental goals and priorities
13.13	Innovative Collaborations Increase Water and Ecological Resilience in the Sacramento-San Joaquin Delta	California	Conjunctive management of water for enhanced agriculture, ecosystem, and groundwater management benefits
13.14	Fit-for-Purpose Approach Facilitates Water Exchange and Maximizes Use Multiple Classes of Recycled Water in San Joaquin Valley	California	Water exchanges with local irrigation district; Supplying multiple qualities of recycled water for different purposes

International Perspectives on Agricultural Water Reuse

Countries such as Israel, Australia, Jordan are pioneers in agricultural water reuse. These countries have long standing reuse programs. Israel and Jordan use all or nearly all available effluent. WRF 4775 (Sheikh et al. 2019) includes detailed profiles of agricultural water reuse programs in these countries. Reznik et al. provides detailed discussion of the economic implications of long-term reuse in Israel (Reznik et al. 2017). Additional international case studies are included in the 2012 EPA Guidelines for Water Reuse (US EPA 2012).

13.1.2 Additional Resources

Profiles help raise awareness of existing water reuse success stories and provide a venue for sharing practical, context specific experience. Other excellent sources of case studies on agricultural water reuse include:

Water Reuse Action Plan (WRAP): Several WRAP actions develop case studies on water reuse projects across the globe which include some agriculture-focused case studies.[23] Examples include:

- WRAP Action 11.3 (Develop and Highlight Case Studies Relevant to International Contexts)
- WRAP Action 1.2 (Prepare Case Studies of Successful Water Reuse Applications)
- WRAP Action 1.3 (Develop Case Studies of Low-Input Solutions)
- WRAP Action 1.6 (Addressing Barriers to Agricultural Water Reuse)

CONSERVE: The CONSERVE Project focuses on agricultural use of a variety of sources of water. Multiple case studies and other outreach products were developed. These are available through the project website (CONSERVE 2021)

WRF 4775 (Agricultural Reuse – Impediments and Incentives (Sheikh et al. 2019)): Project report contains >10 case studies on agricultural water reuse, including profiles of international agricultural water reuse programs in Israel, Australia, and other regions.

2012 EPA Guidelines for Water Reuse (US EPA 2012): Appendices D and E in the guidelines contain nearly 100 U.S. and international case studies on projects and programs within the U.S. and abroad.

13.2 Role of the National Water Reuse Action Plan (WRAP) in Advancing Agricultural Water Reuse

Program: WRAP – The National Water Reuse Action Plan

Organization: United States Environmental Protection Agency and Collective of 30+ Partner Organizations

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[23] Additional details on all WRAP actions can be found via the online platform.
https://www.epa.gov/waterreuse/national-water-reuse-action-plan-online-platform

Location: National Initiative (entire United States)

Drivers:

- Water security, sustainability, and resiliency;
- Equitable and just access to water reuse;
- Reuse that is straightforward and easy to implement; and
- Meet long-term water needs within communities on a national scale

Program Highlights:
Advances water reuse across the United States by:

- Fostering collaborative and interagency efforts;
- Increasing transparency and accountability;
- Streamlining access to information and resources on water reuse; and
- Sharing resources and knowledge

Purpose and Need
Communities depend on safe and resilient water supplies to support human, habitat, and economic health and wellbeing. While recycled water can be a cost-effective way to diversify water portfolios, resources needed to develop robust and successful reuse programs can be disparate, difficult to find or understand, and eligibility for funding opportunities are often not well communicated. For states and communities unfamiliar with water reuse, it is especially important to provide information that can inspire, motivate, and reassure the safe use of recycled water. To advance water reuse in communities across the United States, research, technology, and policy can be unified to overcome obstacles, avoid redundancies, and drive advancements. To promote collaborations and expand water reuse projects, including agricultural reuse, the National Water Reuse Action Plan (WRAP) Collaborative was developed to facilitate discussions across sectors to form new partnerships.

Figure 13-2. Action Leaders Are Key Experts From Public and Private Entities.
Source: US EPA 2019.

Collaborative Partnerships as a Strategy to Advance Water Reuse

An important element of any successful water reuse project is collaboration between a wide range of entities. Since 2020, the National WRAP team has been facilitating these partnerships to improve the security, sustainability, and resiliency of the nation's water resources. To address a range of impediments to the adoption of recycled water, WRAP Actions are led by experts from nearly thirty public and private organizations. Over 100 action leaders and partners from federal, state, tribal, local, and private sectors (Figure 13-2), are working together to find solutions to meet the nation's current and future water needs. These collaborative partnerships, work to identify barriers, research needs, and real-world strategies across a range of topics to develop reuse programs across the nation. Increasing data and information, integrating management practices, and enhancing the availability, accessibility, and sharing of information are a consistent theme throughout all WRAP Actions.

WRAP Action Strategic Theme Areas

To address technology, policy, and programmatic challenges the WRAP has identified eleven key strategic theme areas. Each themed area is comprised of distinct actions (WRAP Actions) headed by leading experts and collaborating partners with support from EPA. A key goal of each WRAP action is to unify and coordinate policy, research, and technology within and across sectors to avoid redundancies, meet multiple needs, and to catalyze action surrounding water reuse. WRAP Actions work to recognize and find strategies best fitted for the unique needs and characteristics of communities with consideration to geography, community needs and size, and capabilities. Actions within each themed area are continually updated and additional actions are added as new information and research becomes available. Transparency and accountability are key to any reuse project, therefore themed areas are designed with concrete actions using implementation milestones, routine progress reports, and are easily accessible to the public. Table 13-2 provides a brief description of each strategic themed area.

Table 13-2. Strategic Theme Areas of the National WRAP Collaborative.

Data Source: US EPA 2020.

Theme Area	Description
Integrated Watershed Action	Enable consideration of water reuse with integrated and collaborative action at the watershed scale.
Policy Coordination	Coordinate and integrate federal, state, tribal, and local water reuse programs and policies.
Science and Specifications	Compile and refine fit-for purpose specifications.
Technology Development and Validation	Promote technology development, deployment, and validation.
Water Information Availability	Improve availability of water (quality and quantity) information.
Finance Support	Facilitate financial support for water reuse.
Integrated Research	Integrate and coordinate research on water reuse.

Outreach and Communications	Improve outreach and communication on water reuse.
Workforce Development	Support a talented and dynamic workforce.
Metrics for Success	Consider water reuse metrics that support goals and measure progress.
International Collaboration	Build on the experiences of international partners.

WRAP Actions Supporting Agricultural Water Reuse

While WRAP actions aim to advance water reuse in general, several actions directly highlight and advance policy, technology, and research on agricultural reuse. Benefits to agriculture may occur directly or indirectly through partnerships and integrated approaches. As more stakeholders, sectors, and industries are engaged in the beginning stages of reuse project development, additional and potentially overlooked benefits and partnerships may be realized. It is important to note that barriers to agricultural reuse are location and site specific, and an impediment in one location may act as a driver in another. This section highlights three strategic themed areas, each highlighting a WRAP Action that directly benefits agriculture. For a more comprehensive list of WRAP Actions in direct or indirect support of agricultural reuse, please see Appendix B.

Integrated Watershed Action

Action 1.6 – Address Barriers to Water Reuse in Agriculture Through Improved Communication and Partnerships

WRAP Action 1.6 and Water Reuse Foundation’s (WRF) Project 4956

Addressing Impediments and Incentives for Agricultural Reuse

This profile is part of a larger collection of decision support materials developed as part of a WRF project 4956 ‘Addressing Impediments and Incentives for Agricultural Reuse’. Several outputs from WRF 4956 directly contribute to WRAP Action 1.6 ‘Address Barriers to Water Reuse in Agriculture Through Improved Communication and Partnerships’. Outputs include a technical and evidence-based guidance document, additional profiles, and outreach and communications materials. These guidance documents will serve as a resource and communications toolkit for those interested in expanding or developing agricultural reuse programs. Innovative, unique, and real-world approaches to overcome impediments and advance agricultural reuse are provided as actionable strategies that can be tailored to meet specific and local needs. The focus of WRF 4956 is reuse of municipal recycled water while WRAP Action 1.6 considers a broader range of water sources for reuse.

Agricultural water reuse faces multiple societal, institutional, and regulatory barriers. Action 1.6 develops resources to support diverse stakeholders in overcoming these barriers. Outputs include guidance on strategies used by successful projects to overcome barriers, synthesis of current scientific knowledge on the relative risks of agricultural water reuse, guidance on regulatory programs impacting agricultural water reuse, and an international convening of agricultural water reuse experts. Partners collaborating on this action include non-governmental agencies, domestic and international university partners, and federal agencies. At the international level, research to identify and bridge gaps in policy, research, and technology is driven by diverse stakeholder collaborations and will provide valuable lessons applicable to the US. Leveraging multiple efforts, guidance and communication materials are being developed to highlight effective strategies to overcome obstacles, increase coordination and knowledge, and improve clarity of regulations and policy.

WRAP Action 1.6 directly benefits agriculture by:

- Providing stakeholders with actionable strategies to overcome a range of obstacles
- Identifying opportunities to advance centralized and decentralized agricultural reuse
- Identifying and navigating relevant regulations and policies
- Increasing opportunities for cross pollination of ideas across a range of sectors

Water Information Availability

Action 5.1 - Foster U.S. Department of Agriculture Watershed-Scale Pilot Projects to Share Water Information to Support Water Reuse Actions

While funding programs for water quality and quantity are a national priority, the USDA recently expanded these opportunities to include water reuse projects. The decision reflects the important role recycled water plays in both maintaining and enhancing water resources, agricultural productivity, and habitats. Action 5.1 seeks to support water reuse programs in agriculture at the watershed-scale through increased funding and information sharing.

The USDA’s Natural Resources Conservation Service’s (NRCS) Conservation Innovation Grants (CIG) program promotes new approaches to practices and technologies that conserve natural resources on private lands.

WRAP Action 5.1 directly benefits agriculture by:

- Driving collaborative innovation in resource conservation
- Prioritizing funding for water reuse, water quality, air quality, energy, and wildlife habitat
- Information sharing on the agricultural benefits of water reuse
- Improving nutrient management and increasing irrigation efficiency
- Reducing on-farm energy usage and increasing innovation and technology

Finance Support

Action 6.4 Compile and Promote Existing U.S. Department of Agriculture Funding and Resources for Rural Communities

Finding or accessing eligible funding for recycled water projects can be challenging or confusing. The costs associated with infrastructure and distribution to bring recycled water from the supply location to where it is needed on-farm, is often cited as a major impediment to agricultural reuse, especially in small to medium farms, in rural communities, and when distances between the two are great. Action 6.4, led by the USDA's Rural Utilities Services (RUS) works to identify, compile, and promote infrastructure funding opportunities available to rural communities. Technical assistance is available to assess and improve current wastewater operations, navigate reuse opportunities, and to support loan and grant applicants through the process.

WRAP Action 6.4 directly benefits agriculture through:

- Water and wastewater infrastructure funded projects
- Rural Development's Water and Waste Disposal Loan and Grant Programs
- Trainings programs that promote water reuse
- Technical assistance and support during the funding process

Information on additional WRAP Actions with relevance to agricultural water reuse are included in Appendix B. For detailed information on the National WRAP strategic themed areas and associated WRAP Actions, please visit US EPA 2023a.

13.3 Interagency Collaboration Within States to Advance Reuse

Program Names:

- Minnesota Interagency Workgroup on Water Reuse
- Kansas Water Vision and (Health Impact Assessment)
- Hawai'i Water Reuse Task Force

Organizations*:

Minnesota: Department of Health (DOH); Board of Water and Soil Resources (BWSR); Department of Labor and Industry (DLI); Department of Natural Resources (DNR); Metropolitan Council; Department of Agriculture (MDA); Pollution Control Agency (MPCA); University of Minnesota Water Resources Center

Kansas: Kansas Water Office, Department of Agriculture, Water Authority, Health Institute, Department of Health and Environment

Hawai'i: State of Hawai'i Department of Health, Board of Land and Natural Resources, Fresh Water Council of Wai Maoli: Hawaiʻi Fresh Water Initiative, Board of Agriculture, Honolulu Board of Water Supply, Hawai'i Community Foundation, Hawai'i County Department of Environmental Management, Honolulu County Department of Environmental Services, Maui County Department of Environmental Management, Kauai County Department of Public Works, Senate and House Committees on Water and Land, Legislative Reference Bureau

*Organizations are state agencies except when noted otherwise

Drivers:

- **Minnesota:** Need for statewide guidance or policy on reuse
- **Kansas:** Development of 50-year state water vision
- **Hawai'i:** 2030 target to increase use of recycled water by 30 MGD

Program Highlights:

Minnesota:

- Recommendations attuned with the water reuse needs and priorities of Minnesota
- One Water perspective on water reuse in Minnesota:
    - Incorporates multiple sources of water – wastewater, stormwater, rainwater, etc.;
    - Multiple scales of reuse – centralized and decentralized; and
    - Considers wide range of types of reuse – agricultural, groundwater recharge, non-potable within buildings.
- Clean Water, Land and Legacy Amendment provides non-traditional, long-term funding supporting the work of the Interagency Workgroup on Water Reuse, agricultural water quality management, and other resources

Kansas:

- Collaborative development of vision for state's water future; and
- Use of Health Impact Assessment to distill complicated findings on reuse and incorporate community perceptions and preferences in weighing options.

Hawai'i:

- Ambitious plan for expanding water reuse;
- Focus on specific strategies and policy changes needed to overcome barriers to reuse;
- Recommends mandatory reuse zones; and
- Integrated recommendations covering a broad range of types of reuse.

13.3.1 Overview

This profile features three unique examples of state-level collaborations advancing water reuse. In all three cases, the governor or legislative branch recognized a need for additional collaboration and state-specific resources on water reuse and mandated the formation of a state-level entity to address these challenges.

13.3.2 Minnesota: Interagency Work Group on Water Reuse

In 2015, the Minnesota Department of Health was directed by the state legislature to form an Interagency Workgroup on Water Reuse. The Workgroup was tasked with conducting a comprehensive study on current water reuse in the state including identification of challenges and opportunities and examining the various approaches used to develop water reuse policies in other states and nations (Water Reuse Interagency Workgroup 2018). Regulatory and non-regulatory approaches were examined to develop a set of recommendations to inform Minnesota-specific approaches (Water Reuse Interagency Workgroup 2018).

Several characteristics make the outputs of the Minnesota Interagency Working Group especially unique. The Workgroup considered reuse from a true One Water perspective. Recommendations from the working group incorporate multiple sources of water (wastewater, rainwater, stormwater, graywater, industrial process water, and subsurface water); consider multiple scales of reuse including both centralized and decentralized systems; and assess a wide range of types of reuse (e.g., agriculture, onsite water systems, groundwater recharge). This approach allowed for more holistic consideration of the benefits and tradeoffs of reuse. It also highlighted the extremely complex regulatory system a holistic water reuse program operates within. Table 13-3 crosswalks different sources of water for reuse against the regulatory agencies with jurisdiction at different points in the reuse cycle. The second unique characteristic is Minnesota's 'Clean Water, Land and Legacy Amendment' to the state constitution. This voter approved amendment provides a dedicated source of funding for clean water programs through 2034. These funds supported the work of the Workgroup and support a broad range of initiatives including technical assistance and various agricultural water quality management programs that are otherwise challenging to fund through traditional sources.

Table 13-3. Minnesota Reuse Regulation or Guidance by Water Source.

Source: Water Reuse Interagency Workgroup 2018.

Source	Capture/Storage	Treatment	Distribution	End Use
Rainwater	**DLI:** regulates collection from roofs and catchment systems **MPCA:** guidance through Stormwater Manual	**DLI:** regulates water quality treatment requirements	**DLI:** regulates use within buildings and drainage systems to discharge point **DNR:** regulates if volumes used more than 10,000 gallons per day or one million gallons per year, with some exceptions	*Irrigation: not specifically regulated* **DLI:** regulates use for toilet flushing **MDH:** guidance on infiltration in vulnerable groundwater areas **USEPA:** regulates injection **MDA:** regulates food processing, food crop irrigation, etc.
Stormwater	**MPCA:** guidance through Stormwater Manual **DLI:** regulates conveyance within piping	**MPCA:** guidance through Stormwater Manual	**DLI:** regulates use within buildings by variance **DNR:** regulates use except for water withdrawn from "constructed management facilities for storm water"	**MPCA**: guidance on irrigation through Stormwater Manual **DLI:** regulates toilet flushing by variance **MDH:** guidance on infiltration in vulnerable groundwater areas **USEPA:** regulates injection **MDA:** regulates food processing, food crop irrigation, etc.
Graywater	**DLI:** regulates diversion within buildings by variance **MPCA:** regulates, requirements similar to septic tank and disposal systems, with lower design flows and smaller tanks	**MPCA:** regulates through wastewater standards, no requirements specific to graywater **DLI:** regulates use within buildings by variance	**DLI:** regulates use within buildings by variance **MCPA:** regulates through wastewater standards **MDH:** regulates separation distances from wells	**MPCA:** irrigation – wastewater standards apply **DLI:** use in buildings – regulates by variance **MDA:** regulates food processing, food crop irrigation, etc.
Wastewater	**MPCA:** regulates disposal of wastewater, requirements for septic tanks, pumps, and dispersal in trenches, seepage beds, mounds or at-grade systems **DLI:** regulates use of public sewer/water	**MPCA:** regulates through NPDES and SDS permits, referencing California Titles 17 and 22 requirements; offers guidance on reuse; and regulates treatment and disposal of waste residuals	**MDH:** regulates separation distances from wells	**MPCA:** regulates irrigation as a discharge to land, guidance on reuse for nonpotable use **DLI**: regulates use in buildings by variance **MDA:** regulates food processing, food crop irrigation, etc.
Industrial Process Water	*Depends on process*	*Determined by end use or discharge permit* **MPCA:** regulates treatment and disposal of waste residuals	**DLI:** regulates up to water supply backflow preventer (prior to industrial use) or if industrial reuse is supplying plumbing fixture or plumbing system	**MPCA:** regulates discharges **MDA and MDH:** regulate food processing
Subsurface Water	**DLI:** regulates capture/storage by variance	**MDH:** regulates if treated for drinking water	**DLI:** regulates use within buildings by variance	**MPCA:** regulates pollution containment **MDH:** regulates supplementation of potable water supplies

Minnesota Resources:

Advancing Safe and Sustainable Water Reuse in Minnesota (Water Reuse Interagency Workgroup 2018)

Clean Water Fund of the Clean Water, Land and Legacy Amendment (Minnesota Department of Health 2023)

13.3.3 Kansas: 2050 Water Vision and Health Impact Assessment

In 2013, Kansas's Governor Brownback issued a call for multi-agency and stakeholder collaboration on the development of a 50-year water vision. A 'Vision Team' including representatives from the Kansas Water Office and Department of Agriculture was established and led engagement efforts with a diverse range of stakeholders across the state. The team produced a comprehensive report that summarized the state of water resources management in Kansas and identified future management priorities (Kansas Water Office 2015). Much of Kansas relies on the highly stressed High Plains Aquifer. Reuse plays a prominent role in the recommendations in the state's Water Vision. Kansas also considers reuse holistically. Motivated by the state's large agricultural industry, discussion of reuse includes stormwater capture, water from livestock and other agricultural operations, and other sources (in addition to reuse of municipal wastewater).

Following the prioritization of reuse in the Kansas Water Vision, the state contracted the Kansas Health Institute to conduct a health impact assessment (HIA) to understand potential health effects of municipal water reuse in Kansas (Hartsig et al. 2017). Health impact assessment is decision support approach used to assess potential health effects of a policy or program on people and communities. HIA uses a synthesis approach to combine qualitative and quantitative metrics on level of evidence with findings from interviews and surveys with local communities and subject experts (National Research Council 2011). In the Kansas example, HIA was used to look holistically at the water supply benefits and economic costs of reuse in conjunction with potential health risks.

One recommendation that came out of the HIA was that Kansas develop a more formal water reuse program and/or policy (see also Chapter 2). Agricultural reuse of treated wastewater is relatively common in Kansas with >130 projects permitted through existing land application programs (Kansas Water Office 2022). This approach can streamline regulatory approvals, but may have public health objectives that can differ from those is a formal reuse policy. HIA is a useful planning tool that can help weigh tradeoffs and support decision making in complex environments.

Kansas Resources:

A Long-Term Vision for the Future of Water Supply in Kansas (Kansas Water Office 2015)

Potential Health Effects of Municipal Water Reuse in Kansas: Kansas Health Impact Assessment Project (Hartsig et al. 2017)

13.3.4 Hawai'i: Water Reuse Task Force

In 2018, Hawai'i's state legislature issued a resolution (No. 86 S.D. 1) requesting that the Department of Health convene a task force to identify barriers and solutions to expanding water reuse in Hawai'i. Hawai'i is experiencing increasing levels of water stress due to decreased precipitation and increased evaporation. These hydrologic changes led to the development of Wai Maoli, the Hawai'i Freshwater Initiative (Stanbro 2022). The Initiative aims to conserve 40 MGD, recharge 30 MGD, and reuse 30 MGD by 2030. This would roughly double current levels of reuse. The task force was convened to help Hawai'i develop regulatory and non-regulatory strategies to meet the Initiative's reuse goals. At present, Hawai'i's recycled water standards include three classes of recycled water that are roughly analogous to California's Title 22 classes.

The Water Reuse Task Force had four broader legislative recommendations and numerous specific recommendations addressing more specific topics (State of Hawai'i Department of Health 2018).

1) Establishment of water reuse zones and mandate to use recycled water;
2) Groundwater recharge with recycled water;
3) Adoption of regulations for onsite non-potable water reuse systems; and
4) Request for funding for demonstration projects.

These recommendations are reflective of the diverse nature of reuse in Hawai'i and recognition of limitations in the state recycled water guidelines that are barriers to realizing the full potential for reuse in Hawai'i. Recommendation #1 is relatively uncommon (most reuse programs are voluntary), but includes grace periods and provisions on cost and supply availability to limit adverse hardships associated with compliance. Agricultural water reuse was noted as important for food security and multiple secondary recommendations to incentivize agricultural reuse, demonstrate successes, and streamline current policies were included.

Hawai'i Resources:

Water Reuse Task Force Report (State of Hawai'i Department of Health 2018)

13.4 Statewide Objectives and Streamlined Reporting Advance Adoption of Reuse in Florida

Program Name: Florida Water Reuse Inventory

Organizations: Florida Department of Environmental Protection; State legislature

Drivers: Water scarcity and degraded water quality

Program Highlights:

- Nation's most comprehensive state inventory of water reuse;
- Formalized statewide objectives for water reuse and conservation to better manage water resources;

- Consumptive water users are required to use reclaimed water wherever feasible;
- Comprehensive, consistent, and statewide data collection on permitted reuse systems;
- Annual water reuse data is streamlined, user friendly, and electronically submitted; and
- Publicly accessible data and transparency of reclaimed water projects helps to promote and expand water reuse.

Program Description

To ensure water supply resiliency well into the future, Florida has taken a unique, integrated approach to managing the state's water resources. Reclaimed water plays a key role in the management of wastewater, water resources, and ecosystems alike. Initially, reuse was largely motivated by managing wastewater, but the state soon realized reclaimed water could play a larger role in managing many valuable resources. In the interest of the public, reuse of reclaimed water and water conservation are formal state objectives established to ensure future water demands are met while protecting natural ecosystems (§ 403.064 FS).

At the state level, water reuse and water conservation have become formal objectives[24], and local governments are encouraged to adopt and incentivize water reuse. Under Chapter 62-40 F.A.C., consumptive water users are required to reuse or recycle water as long as it is 'economically, environmentally, and technically feasible' (F.A.C. 2013). To facilitate water reuse, the Department of Environmental Protection (FDEP) developed a comprehensive water reuse program. As part of the program, domestic wastewater facilities with permitted capacities of 0.1 MGD or greater[25] are required to submit annual reuse reports[26] (Form 62-610.300(4)(a)2) for each reuse system to the FDEP (FDEP 2017). This information is the basis for the Florida Water Reuse Inventory, the most comprehensive database on permitted reuse systems in the world (FDEP 2022a). The map in Figure 13-3 is from the 2021 Reuse Inventory Report and shows reuse flows per capita for each county and an average for each person – nearly 39 gallons per day, per person. Examples of the information captured by the Florida Water Reuse Inventory, including changes over the past five years, are included in Table 13-4.

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[24] Conserving water and using reclaimed water are formal 'state-wide objectives and are considered to be in the public interest'. § 403.064 and § 373.250 Florida Statutes (FS) (Florida Legislature (FL) 2017b; 2017a)

[25] Facilities under the 0.1 MGD may voluntarily submit the annual reuse form and are included in annual reports.

[26] Annual reuse reports are reported on the Florida Department of Environmental Protection Form 62-610.300(4)(a)2., F.A.C. (FDEP 2022a).

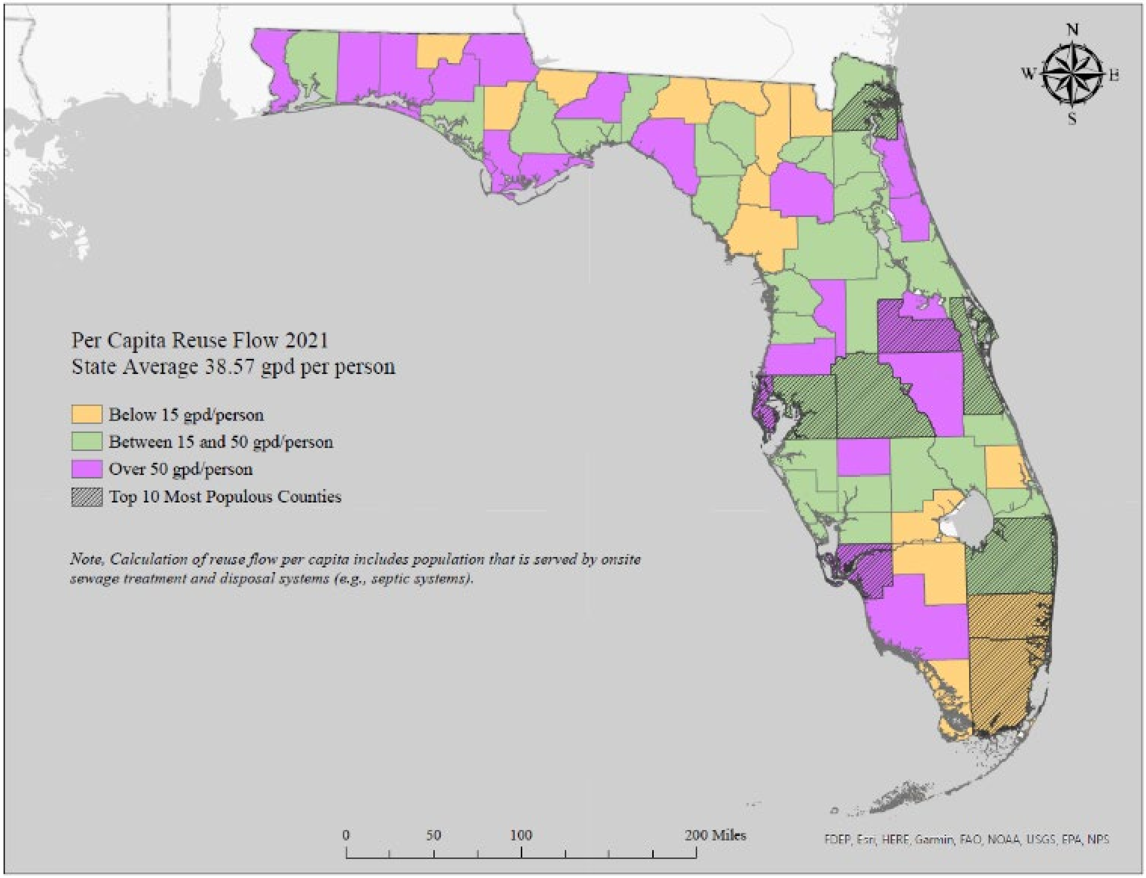

Figure 13-3. Map of Per Capita Reuse Flows by County.
Source: FDEP 2022b.

The reuse reports capture valuable data on volumes of reclaimed water produced; average flow available for reuse; end-uses, including capacity, flow, and area; and outfall/disposal locations. If reclaimed water is used to irrigate edible crops, an inventory including location and contact information of the farm, crop type, application method, and approximate area must also be included in the report. In addition to volumetric and end-use information, facilities also provide rates and rate structures for reclaimed water. These, and other facility data, including disinfection level, source water, and permitted capacity (among others), are submitted electronically by each facility where they are used to generate an annual reuse inventory report. The compulsory forms are relatively short and straightforward, making the process user-friendly and may lead to wider participation with fewer reporting errors.

Table 13-4. Summary of Information Included in Florida's Water Reuse Inventory.

	2016	2021
Domestic Facilities not Providing Reclaimed Water for Reuse		
Total # of reported facilities	43	54
Total capacity (MGD)	195	1,052
Total flow (MGD)	130	527
Domestic Facilities Providing Reclaimed Water for Reuse		
# of reported facilities	478	455
Total capacity (MGD)	2,376	2,779
Volume of reclaimed water produced (MGD)	1,592	1,701
Volume of reclaimed water beneficially reused (MGD)	760	908
Percent of total domestic wastewater that is reused	44%	53%
Total # of reuse systems	431	383
Reclaimed Water Use in Agriculture		
Total acres of crops irrigated with reclaimed water	36,237 *	30,000
Edible crops	12,739 (65 farms)	6,738 (10 farms)
Other crops	23,498 (100 farms)	23,329 (82 farms)
Percent of reclaimed water used for agricultural irrigation	8%	7%
Volume of reclaimed water to irrigate all crops (MGD)	64.7	63
# of reuse systems for irrigating edible crops	17	-
Total Water Usage in Agriculture		
Estimated Irrigation demands for all crops, state-wide 2020 (MGD)	1,946	
Estimated Irrigation demands for all crops, state-wide by 2030 (MGD)	1,946	

* Approximately 79% of all farmlands produced citrus.
Data Sources: (FDEP 2017; 2022b; FDAC 2021)

The database supports the state's management of its valuable water resources now and into the future. Entities interested in participating in reuse projects can easily access information on existing and successful reuse programs, including all end-uses of reclaimed water. This level of transparency may help to remove social stigmas and increase positive perceptions associated with reuse projects, especially where reclaimed water is used to irrigate crops. Collecting detailed volumetric data and end uses of reclaimed water enables the state to manage and plan for future water demands across many sectors and with greater accuracy (FDEP 2017).

Lessons Learned/Approaches to Overcome Impediments/Strategies Employed

A lack of consistent data infrastructure across the US has long been cited as a significant impediment to managing water supplies and promoting water reuse ("The Internet of Water Coalition" 2022). State-wide compulsory reporting and comprehensive data collection and management can be a useful model to overcome this impediment. While most states do require some level of water withdrawals and usage data to be reported, inconsistency in data reporting between water users, producers, and providers creates challenges in managing water resources. These differences can be seen even within the same sector (e.g., domestic wastewater facilities) and between cities or counties within the same state. States seeking to streamline the reporting process to better manage their water resources and expand the use of reclaimed water can develop a similar cohesive state-wide database.

13.5 Florida Agricultural Programs with Unified Objective Build Capacity, Deepen Relationships, and Conserve Water

Program Name: Agricultural Assistance Team; Mobile Irrigation Lab, Statewide Best Management Practices, and Agricultural Ground and Surface Water Management (AGSWM)

Organizations: USDA Natural Resources Conservation Service (NRCS), Florida Department of Agriculture and Consumer Services (FDACS), Florida Department of Environmental Protection (FDEP), State Water Management Districts (WMD)

Location: Florida

Drivers: Protect and conserve water and natural resources; Manage water supplies

Program Highlights:

- Extensive, long-term, and agency led collaborative assistance programs to support agricultural communities;
- Integrating irrigation and nutrient management to establish state-wide BMPs for a range of agricultural commodities; and
- A dedicated and pro-active staff of experts that work directly with growers.

Funding Highlights:

- State and District run programs are provided at no cost to growers
- State supported cost-shares and reimbursement opportunities to growers
- 40 M in Alternative Water Supply Funding from the state for water resource and water supply development

Background

Florida is surrounded by, and often inundated, with water. The State's water supply is supported by diverse sources including rivers, lakes, streams, springs, wetlands, and aquifers. It is home to the Okeechobee Lake, the largest freshwater lake in the southern US and ranks within the top five states as having the highest average annual precipitation. While not generally thought of as a water scarce state, approximately 70% of the state is water restricted or is within a water resource caution area (Kates 2023). Florida's freshwater demands are expected to increase by 13% between 2020 and 2040 to meet the needs of a growing population (Florida DEP 2023a). As traditional groundwater supplies are not expected to fully support future demands, a multifaceted approach with clear, aligned objectives and goals are needed to create resilient supplies. Beginning in the 1980's, the State developed unique approaches to managing and protecting water and natural resources. To ease tensions between regulatory agencies and the agricultural industries, the two groups came together to find strategies that worked for everyone (Whealton 2023). With key stakeholder input, state agencies actively engaged with growers to outline the issues at hand and to understand grower needs and feasibilities. The State also understood that water and natural resources needed to be managed across the state with a unified objective – to conserve water and promote alternative water supplies. To reach these goals, the state would first need to gain buy-in from the agricultural communities. Programs were therefore designed to promote voluntary participation rather than mandatory involvement – providing benefits to the grower, the state, and the environment (Whealton 2023).

Within the State, the Florida Department of Environmental Protection (DEP) oversees the state's five water management districts[27] (WMD) to meet existing and future needs while supporting agriculture and protecting the state's natural resources. The WMDs (a subset of the Florida DEP) have developed four key mission areas: water supply, water quality, flood protection, and natural systems. At the regional level, districts (which section Florida up by unique geographic areas along drainage basin divides) are responsible for implementing programs that support these areas by developing regional water supply plans, monitoring water quality, implementing programs and projects to protect and conserve resources, and managing water flows within natural systems.

Regional water supply plans are developed every five years and include water supply and water resource development. Water supply development occurs when new supplies are added to existing ones. Where traditional water supplies are insufficient, alternative water supply sources[28] are identified for further development (Thorpe 2023). Water supplies are developed when new sources are added to existing ones. Alternative supplies include municipally reclaimed, or recycled, water, desalination, and seawater or brackish ground water.

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[27] Florida's five Water Management Districts are the Northwest Florida, St. Johns River, South Florida, Southwest Florida, and the Suwannee River districts.

[28] Alternative water supplies include municipal recycled water, process water or 'wash water' (e.g., vegetable wash water), tailwater recovery ponds, and desalination from seawater or brackish groundwater.

Alternative Water Supplies for Agricultural Irrigation in Florida: Municipally Reclaimed Water, Tailwater Recovery Ponds, and Surface Waters

Municipal Reclaimed Water

In Florida, municipal reclaimed water is the most common source for new public water supplies, while water from tailwater recovery ponds and other non-traditional surface water (e.g., ponds and lakes) are often used to create new supplies for agriculture. As a national leader in water reuse, the State beneficially reused approximately 908 million gallons per day (MGD) of municipally reclaimed water in 2021. Of this, approximately 63 MGD (an increase of 18.4% from 2020) was used to irrigate 30,000 acres of agriculture (6,738 acres of edible crops (on 10 farms) and approximately 23,400 acres of other crops (on 82 farms) (Florida DEP 2022b). The CONSERV II project in the City of Orlando and Orange County is the largest of its kind in the world. Developed out of a need to expand wastewater treatment and discharge requirements, it was the first project in Florida permitted by the FDEP to irrigate crops intended for human consumption with reclaimed water. Today, an average of up to 2,737 acres of citrus is irrigated with reclaimed water each year as part of the project (Water Conserv II 2020).

One challenge Florida agriculture faces when considering using municipally reclaimed water is a commonly cited one. Often, the distance between supply and demand is too great; fields are often too far from water lines (Estes 2023). Another issue is the treatment levels from smaller municipalities may not be permitted for public access distribution, thus making it off limits to most commodities in the state (Estes 2023).

Other Alternative Water Supplies

However, other alternative water supplies, including tailwater, ponds, and lakes, are currently being used to reduce groundwater withdrawals. The FARMS (Facilitating Agricultural Resource Management Systems) cost-share reimbursement program has been funding alternative water projects for over 20 years. This program is a public/private partnership developed by the Southwest Florida WMD and the Florida Department of Agriculture and Consumer Services. Through the program, approximately 242 alternative water and water conservation projects have been funded, saving an average of 31.5 MGD (11.5 BGY) of groundwater in the Upper Floridan aquifer and other priority areas (SWFWMD 2018; Estes 2023). Of these, 175 projects were funded specifically for alternative water supplies and saved on average 21 MGD, or about 10.3 BGY of groundwater in the Upper Floridan aquifer and other priority areas (Estes 2023). Like most Florida programs, FARMS takes a multifaceted and incentivized approach incorporating techniques from both alternative water supply BMPs and water conservation BMPs (i.e., irrigation efficiencies, soil moisture and climate telemetry, and others) to support growers, promote sustainability, and conserve groundwater (SWFWMD 2018).

Water resource development can be thought of as the ‘formulation and implementation of regional water resource management strategies’, as defined by the FDEP (Florida DEP 2023b). This is accomplished developing and implementing programs that protect, conserve, and manage natural resources; by collecting data on water supplies and quality; and by providing technical assistance to growers. Examples of such programs include the Agricultural Assistance Team, The Mobile Irrigation Lab (MIL), and nutrient and irrigation BMPs, discussed below.

The success of Florida's programs hinges on several factors. First, the state actively involved growers in program development early on; and continues to listen to their needs to find strategies that work for everyone. As a result, programs are district specific and have evolved over the years. The State and Districts incentivize no-cost programs by providing beneficial tools to growers that support their needs, reduce water use (which provides a cost savings to the farmer and a resource benefit to the environment), and improve water quality, all while increasing crop yields - a 'win-win' for all stakeholders. It is important to note that in Florida, conserving water and developing new water supplies are occurring simultaneously – they are complementary approaches critical to securing a water resilient future.

Programs in Support of Agriculture and State-wide Objectives

While the programs in this profile may not be directly linked to overcoming barriers to agricultural reuse specifically, the technical, financial, and other forms of support these programs offer are important for creating trust, transferring knowledge, sharing information, and for the adoption of complementary conservation and management approaches. Other states and entities can use these approaches as a resources management model.

Each WMDs has a unique landscape and needs. Programs may therefore have a different framework and approach based on the needs of the district and the growers within. Some programs may not be available in all districts or may provide different services across districts. These programs are site and location specific using complementary techniques and management approaches that are tailored for each situation. This flexibility allows programs to evolve with the needs of the communities both within and across districts.

Multi-agency programs in Florida supporting agricultural communities, natural environments, and future water needs.

Agricultural Assistance Team	• Help to implement BMPs to increase efficiencies and reduce water use • Information on funding & cost-shares • Help farmers navigate the regulatory landscape, e.g.,. permitting or exemptions
Mobile Irrigation Lab	• Technical support for irrigation systems including troubleshooting • Training for irrigation systems • Promote partnerships between funding agencies
Nutrient and Irrigation BMPs	• State-wide BMPs which reduce water use and help improve water quality • Site-and-situation specific plans developed by the USDA NRCS

Figure 13-4. Summary of Programs Supporting Agricultural Producers, Water Resources, and Natural Environments in Florida.

While differences in the details of the programmatic structure vary between the districts, there is a common thread - a shared vision of increasing water conservation and efficiencies through active engagement with, and support for, agricultural communities. In some cases, regulatory and resource management agencies work together to find solutions, develop and implement site specific BMPs using complementary approaches, and foster inclusion and trust with water users. Districts (and other state and federal agencies) work directly with growers to provide assistance on a number of areas, summarized in Figure 13-4.

Programs provide a range of services, including technical, regulatory, and funding (including cost-share opportunities) support; training on best management practices (BMPs) and ways to improve irrigation efficiencies specific to their needs; and provide assistance on navigating permitting and regulatory compliance. This highlights how state-wide objectives and programs can increase communication between different agencies, facilitate concerted efforts that increase education and knowledge sharing, and more effectively manage resources to achieve water management goals. The sections below provide a general overview of some of these programs. While it is beyond the scope of this profile to include all state-wide programs, all districts have robust and effective programs with highly competent staff and each district may vary in services offered [29].

The Agricultural Assistance Team

In some districts, the Agricultural Assistance Team is made up of experts from Regulatory Services, Resources Management, and other District staff to assist agriculturalists directly. Beginning in the early 1990's, this program continues to actively engage with growers by provide support and information on best management practices, cost-share and funding opportunities, and issues related to permitting and regulatory compliance (NWFWMD 2017a). Resource management systems (RMS) are encouraged by the USDA NRCS in farm planning and management. The program benefits the water management districts within the state by protecting water and natural resources, and the agricultural industry by providing essential services that affect day-to-day operations.

The Ag Team meets farmers in the field and pulls "tools" out of the toolbox to meet their needs. This may be an MIL visit, an AGSWM farm plan layout (in the Southwest Florida WMD), or exemption consultations to help farmers meet state-wide objectives of protecting natural resources while supporting crop production all within the bounds of existing regulatory framework (Whealton 2023). The Ag Team can also help growers identify ways to increase efficiencies and reduce water use, improve water quality through nutrient and irrigation best management practices, and provides regulatory and compliance support. They help to simplify and streamline the regulatory process by helping growers navigate each stage of the permitting and exemption process.

Mobile Irrigation Lab

Mobile Irrigation Labs (MILs) have been serving agricultural communities, cost-free, in Florida since the 1980s through partnerships between the USDA NRCS, the FDACS, and the WMDs. Like other programs, MILs provide different services across the state. In general, a MIL Team actively engages with the farmers to promote water conservation, improve knowledge, increase information transfer, and to help growers meet water use permit conditions (FDACS 2015; SWFWMD n.d.).

Site specific evaluations of irrigation systems are conducted to provide recommendations on improving irrigation efficiencies and identify opportunities for growers to improve water conservation which leads to cost savings and improvements to downstream water quality (FDACS n.d.). Assistance, technical support, and training is also available to irrigation decision makers to develop irrigation water management plans (IWMPs) that increase efficiencies and reduce operating costs (USDA et al. 2017). MIL Teams also functions as a liaison between State and Federal funding agencies in support of water conservation efforts and to enhance partnerships between organizations (FDACS 2015).

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[29] For additional information on each of these programs, the FDEP website provides links to each of the WMDs

MILs have the ability to help growers increase irrigation efficiency by up to 17% (SWFWMD n.d.). In the Northwest Florida WMD, MILs have helped growers conserve more than 9.25 BG of water across 57,000 acres of irrigated land (NWFWMD 2017b).

Nutrient and Irrigation BMPs

The Florida Department of Agriculture and Consumer Services develops and adopts state-wide BMPs based on the different types of agricultural commodities. Together, the Florida Department of Agriculture and Consumer Services (FDACS), Department of Environmental Protection (DEP), the Water Management Districts, and USDA NRCS work together to provide practical and cost-effective ways to help growers reduce the amount of fertilizers, animal waste, and other pollutants entering water resources.

Agricultural BMPs are designed to manage three important agronomic aspects to reduce environmental impacts while maintaining crop production. They are site, location, and situationally tailored. BMPs focus on:

- Nutrients, based on crop needs, soil conditions, and nutrient sources
- Irrigation methods and scheduling to reduce nutrient losses
- Protection of water resources

Flexibility and State Agency Engagement Allows Ag Programs to Evolve

Unique to the Southwest Florida WMD, the Agricultural Ground and Surface Water Management (AGSWM) program was developed in response to permitting challenges faced by growers. Because surface water permit design for urban settings are often an ill-fitting solution in agricultural settings, the District found an innovative solution as an alternative to permitting requirements (SWFWMD 2018). They developed a process that would provide exemptions from surface water permits for certain agricultural activities by using customized BMPs on their farms. A rating system classifies these as either ‘ordinary’, ‘temporary’, or ‘permanent’ depending upon the crop.

An AGSWM exemption, typically implements resource management system plans using BMPs that comply with technical standards for the category they are applying for. The Ag Team also works with water use permitting reviewers to provide a ‘holistic agricultural regulatory review process (SWFWMD 2018).

Growers participating in this voluntary program can receive detailed plans with BMP implementation based on their specific need. While the Southwest Florida WMD manages this program, they provide funding to the USDA NRCS to develop comprehensive, site-and-situation specific farm plans for growers utilizing Conservation Practices (BMPs). Together, the NRCS and the Ag Team provide complementary approaches and techniques to reduce construction and permitting costs; avoid permitting issues and enforcement actions, delays, and fees; and provide BMPs to meet grower specific needs while helping to encourage sustainable agriculture.

13.6 Meeting Multiple Objectives via Active Management of De Facto Reuse in a Non-Arid Region

Program Name/Organization: Tennessee Valley Authority

Location: Tennessee River Basin (Portions of Alabama, Georgia, Kentucky, Mississippi, North Carolina, Tennessee, and Virginia)

Drivers: Changing water supply needs; Shifts in agricultural production; Active management to support power generation

Program Highlights:

- Active management of de facto water reuse in a non-arid region
- Public power company managing water resources
- Adapting to changing agricultural conditions in non-arid region
- Agricultural water reuse as a watershed protection strategy

Program Description:

While water in the Tennessee River Basin has historically been withdrawn more intensely (gallons per day per square mile) than any other river in the contiguous river in the US, the majority (95 percent) is returned to be beneficially used again (Sharkey and Springston 2022). This practice, called de facto, or incidental, reuse supports many activities within the basin providing water used for drinking, power generation, recreation, and for irrigated agriculture. In 2020, total withdrawals were approximately 8,370 MGD. Of this, 6,530 MGD was used for generating thermoelectric power, 94 MGD was used for irrigation purposes, and 7,965 MGD (95.2%) was returned to be reused (Sharkey and Springston 2022).

Because the river supports a range of water intensive activities, withdrawals must be carefully managed to ensure levels are maintained to support the region into the future. The Tennessee Valley Authority (TVA), a public power company generating electricity for over 10 million people each year, and the largest user of water on the river, is tasked with this responsibility [30]. TVA's jurisdiction is limited to the waters and lands within the drainage basin of the Tennessee River and includes parts of seven states – Alabama, Georgia, Kentucky, Mississippi, North Carolina, Tennessee, and Virginia (Figure 13-5). Permits are issued by the TVA for withdrawals, construction of all water intake structures, and temporary withdrawals for irrigation, including agriculture. TVA regulates withdrawal rates, timeframes, and allowable uses (TVA n.d.). States also manage their own water resources and issue withdrawal and discharge permits based on different needs and priorities.

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[30] In 1933, Congress assigned this task to the Tennessee Valley Authority (TVA), a public power company, giving them authority to protect the waters and lands of the Tennessee River, control floods, and support agriculture ("Tennessee Valley Authority Act (1933)" 2021).

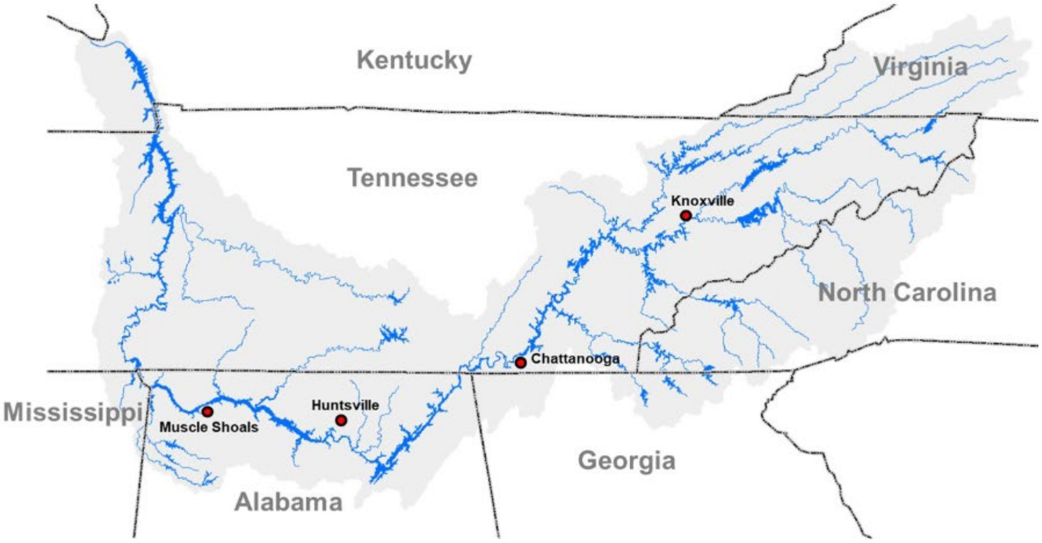

Figure 13-5. Tennessee River Watershed.
Source: Sharkey et al. 2022.

Permits are issued by the TVA for withdrawals, construction of all water intake structures, and temporary withdrawals for irrigation, including agriculture. TVA regulates withdrawal rates, timeframes, and allowable uses (TVA n.d.). States also manage their own water resources and issue withdrawal and discharge permits based on different needs and priorities.

Changes in Agricultural Production in the Tennessee River Valley

In 2000, Alabama withdrew approximately 47 MGD of water for irrigation, including agricultural crops. In the Middle Tennessee River Valley Watershed, one of the largest agricultural producing regions in Alabama, soybeans, cotton, corn, and other specialty crops are important commodities to the local economy (Brantley et al. 2021).

In recent years, the USDA Natural Resources Conservation Service (NRCS) has been working with farmers to convert rain fed agriculture to irrigated agriculture in some Alabama watersheds. This shift to irrigating crop lands provides multiple benefits and is funded by the Watershed Protection and Flood Prevention Program (Public Law 83-566). First, it supports agriculture in the region by maintaining crops in periods of drought and improving the quality of the soil. More broadly, the watershed will see decreased erosion and sediment pollution, and reduced nutrient runoff into groundwater and surface waters. Because much of the water withdrawn from the river is returned, incidental reuse already occurs on agricultural lands irrigated with Tennessee River water. As irrigated agriculture continues to rise in the region, incidental reuse is also likely to grow.

Between 2015 and 2020, withdrawals for irrigation increased by 49 percent (from 63 MGD to 94 MGD) despite a 16.5 percent decrease in the total volume withdrawn. (Sharkey and Springston 2022). This happens because water used for irrigation is lost to the environment through evapotranspiration or to groundwater. This loss is called consumptive loss, and the water cannot be returned to the river to be used again. Estimates indicate that by 2045 irrigation withdrawals will reach 149 MGD, an increase of 58 percent from 2020 volumes (Sharkey and Springston 2022). Due to the consumptive loss inherent in irrigation, the effect will be an increase the total net water demand by 18 percent as seen in Figure 13-6.

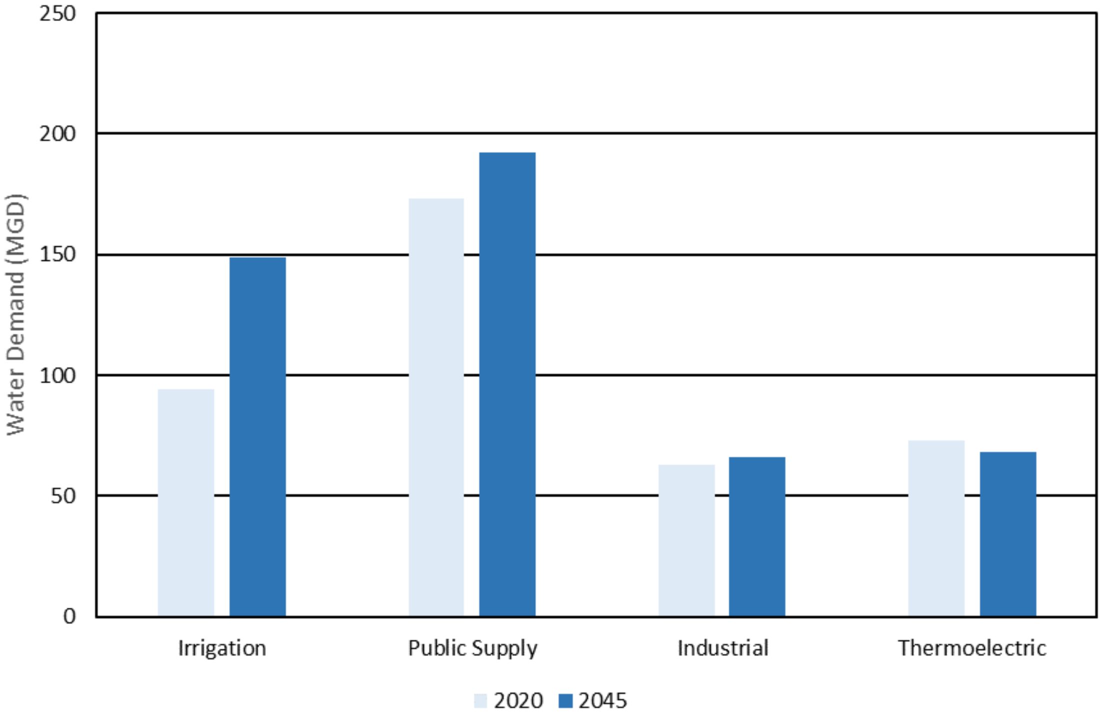

Figure 13-6. Projected Changes in Net Water Demand in the Tennessee River Basin between 2020 and 2045.
Source: Sharkey and Springston 2022.

In general, agriculture in the Tennessee River Valley (TRV) is rainfed, however, during dry seasons and droughts irrigation is often used to reduce crop losses and increase crop yields (Hutson et al. 2003). As drought conditions worsen across the US, predictions suggest that climate and precipitation in the TRV may be more stable than other agricultural producing regions of the US. This could lead to an increase in agriculture in the region (Hutson et al. 2003; Bowen and Springston 2018). Irrigated agriculture is already expanding as producers in the region convert rainfed farmland to irrigated farmland to reduce crop damage, improve soil health, and protect watersheds and basins (Sharkey and Springston 2022; Newby and Curl 2022).

13.7 Regional Collaboration and Regulatory Programs Supporting Reuse in Small and Medium Communities in Idaho

Program Name/Organizations: Idaho Department of Environmental Quality (IDEQ)

Location: Idaho

Drivers: State water supply and quality objectives; Supporting reuse in small and medium communities

Project Highlights:

- Extensive, long-standing reuse program primarily serving small and medium communities;
- Mature fit-for-purpose regulations; and
- TMF assistance provided through state and active network of professional organizations.

Program Description

Idaho has a long history of irrigating crops with recycled water that is supported by a robust state water reuse regulatory program and technical assistance supports. While the treatment of wastewater using land application was initially the main driver of reuse in Idaho beginning in 1977, managing land application of recycled water to prevent contamination of surface and groundwater supplies was quickly recognized as a growing need (Sheikh et al. 2019; IDEQ 2007). In response, the Wastewater Land Application Permit (WLAP) Program was developed as a state-wide regulatory program to meet both needs and the state issued its first reuse permit in 1989. To date, there are over 148 Reuse permits issued by the Idaho Department of Environmental Quality [31] (IDEQ) that allow recycled water (Classes A-E) to be used for a number of beneficial uses, including irrigation of agricultural crops (IDEQ 2022) (Figure 13-7).

Initiation of water reuse projects typically occurs at the community level and is often closely integrated with planning activities and/or needs identified through those processes. Idaho cities are often involved with the Association of Idaho Cities (AIC) whose mission is to develop and advocate for policies that strengthen and support cities. Water reuse is a topic of discussion at AIC meetings and amongst member cities. Drivers and barriers to agricultural reuse projects are often site and region specific and include issues such as drought/seasonal limits on water availability, water quality, and capital costs for infrastructure and land to support reuse. As discharge requirements become increasingly stringent, especially for nitrogen and phosphorus, WWTPs may be incentivized to shift to reuse permits rather than discharging to surface waters due to the high cost of system upgrades. Cities and towns considering a water reuse project should reach out to IDEQ early-on to schedule Pre-Application Conferences to discuss their plans and the required contents of their reuse permit application. Overall, engaging all the stakeholders early on in planning, having a facility plan, having funds or receiving project funding for infrastructure/capital improvements that may be needed to treat and distribute recycled water, and the technical assistance needed to address the project’s needs have helped Idaho communities ensure reuse projects address their specific needs and help overcome barriers.

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[31] All issued permits and water quality certifications can be accessed on the IDEQ permits website at (IDEQ 2022).

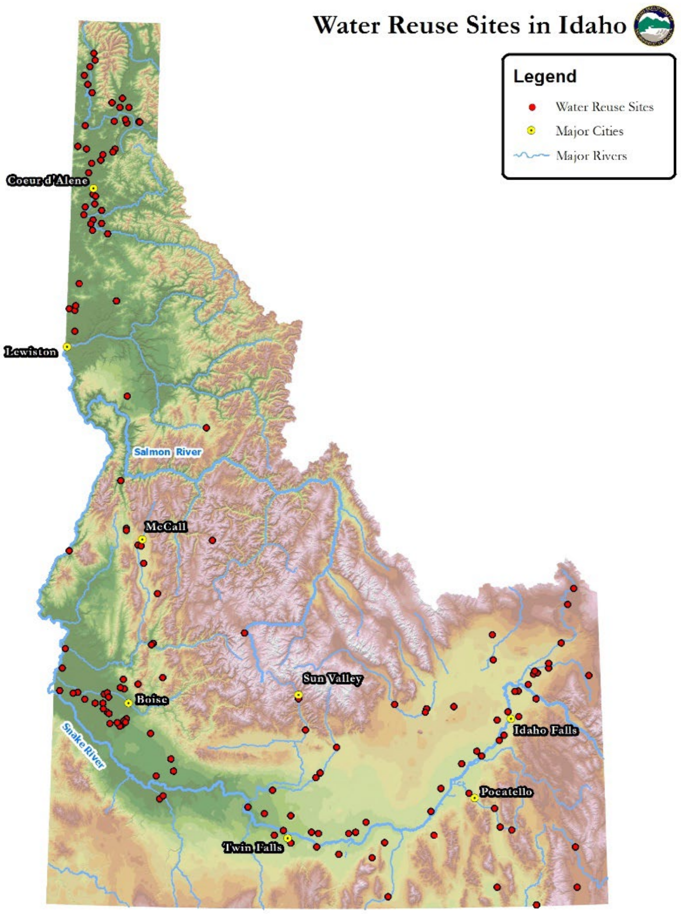

Figure 13-7. Location of Water Reuse sites in Idaho, Based on Permits issued as of 2022.
Source: IDEQ 2022.

Industrial and municipal reuse permits are issued by IDEQ for five to ten years. Reuse permits consider the use and class of the recycled water and site-specific details such as operating seasons, disinfection limits, crop or vegetation allowed, grazing practices, and often include hydraulic and nutrient loading limits, monitoring requirements, buffer zones, and annual reporting requirements. The annual report submitted to DEQ is a narrative summary that discusses data collected during the year and documents the permittee's compliance with the reuse permit. Annual reports may include the site-specific information on the: irrigation water requirements (IWR) for each crop, hydraulic loading rates, irrigation type and efficiency, and soil data. When a reuse permit is issued reuse permit handoff meetings are designed to assist permittees in understanding the requirements and reporting in their permit. To help permittees meet these requirements, the program provides guidance and training (IDEQ 2007).

The use of the recycled water will be defined in the reuse permit. If land application is one of the uses, then the sites that the recycled water may be applied to will be in the permit. Reuse permittees have compliance activities such as site-specific 'Plans of Operations' and 'Quality Assurance Project Plans' for buffer zones, agricultural management, runoff management, nuisance and odor control, waste solids, and monitoring and reporting. Site specific plans help avoid impacts to agricultural soils, crop yields, and water systems and allow sustained use of recycled water on the same fields over the long term (IDEQ 2007).

To assist reuse sites with developing permit required plans[32], IDEQ provides extensive information on reuse of municipal and industrial recycled water. Guidance and technical information are designed to have a high level of technical specificity while allowing permittees and their responsible parties to adapt practices to meet their specific needs. Among the numerous documents, '*Guidance for Reclamation and Reuse of Municipal and Industrial Wastewater*' serves as a starting point for reuse of recycled water for land application. This web-based guidance will evolve with technological advancements and research findings, allowing for flexibility and expansion of water reuse applications well into the future (IDEQ 2007). All documents, training manuals, standard operating procedures, and memorandums are easily and publicly accessible on the IDEQ website.

Operators of reuse sites that use Class B through E recycled water must hold both their wastewater treatment operator's license and a land application operators certificate.[33] Training, continuing education, and technical seminars for wastewater treatment operators, land application operators, and other water professionals interested in reuse applications are provided by IDEQ, NGOs, and professional associations including the Idaho Rural Water Association (IRWA), Pacific Northwest WateReuse Section, and Pacific Northwest Clean Water Association (PNCWA), and Rural Community Assistance Corporation (RCAC). Most training in Idaho offers operator continuing education units (CEUs) (IWRA 2021). Conferences provide project updates and highlight regional innovation in reuse. Trainings are tailored to the needs of specific groups (e.g., operators). Topics covered include technical and regulatory requirements, crop and nutrient management, and advice on how best to approach and develop relationships with interested growers.

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[32] A complete list of guidance documents related to recycled water can be accessed on the IDEQ website at (IDEQ 2021).

[33] DOPL 2023

Longstanding Agricultural Reuse Program in Hayden, Idaho

Recycled water produced by the Hayden Area Regional Sewer Board (HARSB) has been used to irrigate crops since 1992. The reuse program in Hayden was motivated by a need to limit discharges to the Spokane River during low-flow periods. This need led to the somewhat unusual situation where HARSB holds both a reuse permit[1] and a standard IPDES[1] permit to discharge to the Spokane River when discharge restrictions are not in place and recycled water is not needed for irrigation.

Seasonal restrictions on discharges to the Spokane River are in effect when flows fall below 2,000 cubic foot per second (cfs), typically between 01 April and 31 October (IDEQ 2017b). This generally coincides with the growing season, and 100 percent of the Class C recycled water produced at the HARSB is used to irrigate crops. Approximately 421 acres of poplar and birch trees, alfalfa hay, teff grass, and oats are irrigated at the city owned Reuse Farm (IDEQ 2017b; HRSB n.d.).

Recycled water containing ammonia, nitrogen (N), and phosphorus (P) discharged to the Spokane River has the potential to degrade the quality of the groundwater, the area's main water supply (Sheikh et al. 2019). While new IPDES requirements may permit discharges to the Spokane River year round, the HARSB will likely continue applying recycled water via land application because of the flexibility and financial benefits it offers (Sheikh et al. 2019). Because permits are based on annual loadings and not daily maximums, concentrations of P and N are easier to keep within limits if discharging occurs during only part of the year. This also reduces costs incurred by growers for fertilizer and water systems to remove nutrients. As of 2010, approximately 12,000 lbs of nitrogen and 4,300 lbs of phosphorus were recycled at the Hayden Area Regional Wastewater Facility each year (Bracken 2012) .

13.8 Land Application of Reclaimed Water Increases Crop Yields on a Rural Farm in Maryland

Project Name/Organizations: Worton Wastewater Treatment Plant; Dill Family Farm

Location: Delmarva Peninsula, Kent County Maryland

Drivers: Water quality compliance for utility; Water supply for grower

Project Highlights:

- Long-standing, planned reuse and land application program in non-arid rural community;
- Increased treatment capacity while keeping nutrient loads at or below existing levels to protect and enhance Chesapeake Bay and its tributaries;
- Leveraged diverse federal and state funding for small to medium sized rural communities and farms;
- Coordinated permitting efforts between three distinct permitting entities;
- Additional water supplies during dry seasons have improved crop yields;
- Collaboration with grower in a region where recycled water use is uncommon;

- Supports growth and development while preserving community values and character; and
- Innovative approaches using existing resources, peer learning, and coordination between public-private sectors.

Project Description

The natural environment and agriculture are fundamental to the character and identity of the small rural community of Kent County, Maryland for decades. While the Worton Planning Commission encourages community and economic growth, planning efforts ensure these vital local resources are preserved and integrated into future developments. Within the Delmarva Peninsula, the water systems of the Chesapeake Bay are sensitive or impaired, and discharge requirements have become more stringent over the years (Kent County Planning Commission 2007; 2018). When the Worton-Butlertown Wastewater Treatment Plant (WWTP) needed to increase capacity to keep up with the growing population while reducing nutrient loads discharged to the impaired waters of the Chesapeake Bay, water managers and decision makers devised an innovative approach to overcome several impediments while providing multiple benefits.

To achieve these goals and end the moratorium on new sewer line connections, the WWTP upgraded the treatment systems and the Effluent Land Application System (ELAS). A state-of-the-art system using a GE Zenon membrane bioreactor system first reduces phosphorous and nitrogen concentrations to at, or below, 4.8 mg/L and 0.3 mg/L, respectively (CEAM 2011; Kent County Government 2021). Following nutrient removal, ultra-filtration membrane and ultraviolet light disinfection purify it even further (Kent County Government 2021). Currently, the facility treats approximately 75,000 gallons per day but was constructed with a design capacity of 250,000 gallons per day to accommodate the growing population (Kent County Government 2021). The land application system currently irrigates 68 acres of agricultural lands and is maintained by the Kent County Department of Water and Wastewater Services (Kent County Government 2021).

For over twelve years, the Dill family has irrigated upwards of 75 acres of corn, wheat, and soybeans used as animal feed with between 15 and 18 MGY (16, 813 to 20,175 AFY) of high quality, tertiary treated reclaimed water (Cribbs 2020; Kent County Government 2021) delivered via a two-mile distribution system from the Worton WWTP (Figure 13-8). Much of the agriculture in the region relies on rain as the main source of water for irrigation and yields during dry seasons can be substantially reduced. The additional supplies of reclaimed water have increased annual crop yields on the family farm by up to 100 bushels per acre, depending on the crop. During seasons with average precipitation, access to supplemental water supplies has helped increase yields by 30 bushels an acre and can nearly double yields during especially dry seasons (MDE n.d.; Cribbs 2020; Suri and Goldstein n.d.).

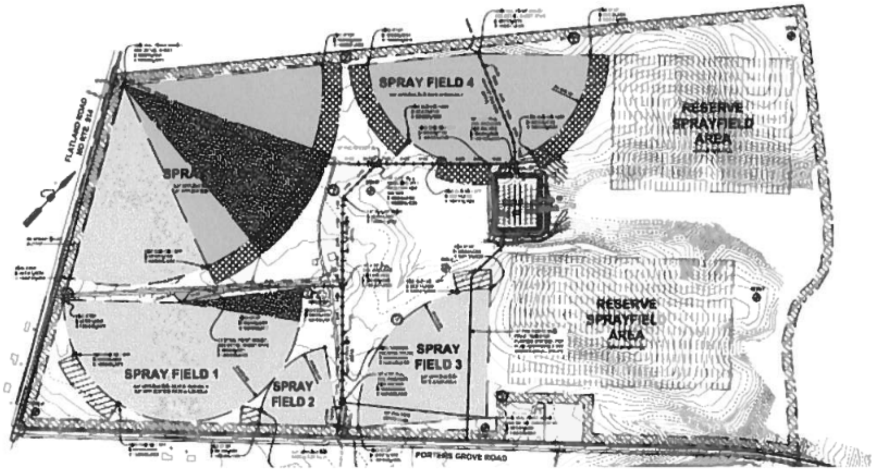

Figure 13-8. Map showing the location of Worton – Butlertown Spray Fields and Ground Water Monitoring Wells.
Source: MDE 2018a.

Irrigation Timing is as Important as Quantity!

Crops need to be irrigated at critical moments during the growing cycle, otherwise crop yields and quality suffer. Locally dependent recycled water can be used to supplement rain-fed agriculture during times when rain events do not meet timing or volumes required to support crop health.

To learn more about how the Worton-Butlertown WWTP supports local agriculture and increases crop yields by delivering high-quality recycled water to the nearby Dill Family Farm, a video from the **CONSERVE** team is available on YouTube (CONSERVE Water for Food 2019).

The project also utilized existing resources to stay within budget and improve system operations. Using existing lagoons and ponds in lieu of new builds cut construction costs and kept the project within the target deadline. Treatment lagoons at the WWTP were converted to storage lagoons where water could be held when discharges to surface waters (between 01 May and 01 November) or farmland (discharges to groundwater) were not allowed. While spray irrigation is permitted between 01 November and 30 April, restrictions are enforced under certain circumstances (e.g., precipitation, high winds, freezing, or saturated soils) to prevent degradation of groundwater supplies (MDE 2018b).

Peer learning played another key role in the success of the project. Researching existing land application systems and interviewing operators provided insight on current best practices as well as areas for improvement. For example, best practices that might otherwise be missed in desktop research were learned during on-site visits. For example, rutting in fields and clogging of spray nozzles were reduced by installing wider tires and self-cleaning strainers on the irrigation units (CEAM 2011).

Location, filtering capacity of the soil, crop type, and willingness to use reclaimed water made the Dill family farm an ideal candidate for the project. Extensive research and peer learning coupled with stakeholder and public engagement were instrumental for the County to establish trust and public buy-in. In addition, the extensive coordination required for permitting and design between Kent County, MDE, MALPF, USDA Rural Development, NRCS, and the privately owned Dill family farm, were also key to the success of this reuse project.

Overcoming Regulatory Impediments

Collaboration was critical to overcoming impediments to this reuse project. Upgrades to the WWTP were necessary to remain in compliance with not only discharge requirements to impaired surface waters on the 303(d) List[34], but also allowed the reclaimed water to be used to irrigate crops via land application and permitted as discharge to groundwater (CEAM 2011). Discharges to surface waters and discharges to groundwater are managed by two different entities within the Maryland Department of the Environment (MDE). Thus, coordination between the two departments was required for approval of a dual discharge permit (CEAM 2011; MDE 2018b). In addition, the selected farmland, owned by the Dill family, was also part of the Maryland Agricultural Land Preservation Fund (MALPF)[35], and therefore further coordination between the land owner, the WWTP, and the MALPF was required to ensure no violations would result from the application of reclaimed water (CEAM 2011).

Financial Assistance and Programs

The facility upgrades and construction of the distribution, retention, and on-farm irrigation systems at the WWTP and Dill family farm cost approximately $11.5 million and was supported by grants and loans through federal and state programs (Cribbs 2020). The U.S. Department of Agriculture has provided financial assistance to the facility over the years through grants and low interest loans under the Rural Development Program and the Water and Waste Disposal Loan and Grant Program. Between 2008 and 2017, approximately $900K of grant money has been awarded to the treatment facility under the Rural Development program and $130K of low interest loans (Office of Ben Cardin 2009; 2017).

Funding Programs Used:

- **USDA Rural Development Program –** Funding to protect the environment and improve rural communities and economies by supporting essential services, infrastructure improvements, and financial support to local businesses.
- **USDA Water and Waste Disposal Loan and Grant Program –** Funding for sanitary sewage and solid waste disposal in eligible rural areas
- **Maryland's SB 320 Bay Restoration Fund** – Financed by WWTP users to upgrade WWTPs with enhanced nutrient removal technology
    - Similar funds from septic system owners used to upgrade on-site systems and use of cover crops to reduce nitrogen loading

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[34] The waters in the 303(d) List are impaired due to total phosphorus, total nitrogen, total suspended solids, fecal coliform, and impairments to the biological community.

[35] The farm is enrolled in the USDA's Conservation Reserve Enhancement Program (CREP) which is supported by the USDA's Farm Service Agency and the Natural Resources Conservation Service, the Maryland Department of Agriculture, and the Kent Soil and Water Conservation District. The farm is situated on 19 acres of CREP buffers, waterways, ponds, and grade stabilization which protect water quality and decrease erosion and runoff.

13.9 Colorado River Drought Contingency Planning and Agricultural Reuse in Arizona

Project Name/Organization: New Magma Irrigation and Drainage District; Pecan Water Reclamation Facility (PWRF); EPCOR

Location: San Tan Valley, Arizona

Drivers: Off-set reductions to agriculture in support of the Drought Contingency Plan (DCP) agreement; Protects groundwater in support of the Arizona Department of Water Resources management plan; Supports the agricultural economy

Project Highlights:

- Support broader state wide and regional goals to reduce Central Arizona Project (CAP) water usage in Arizona;
- A long-term solution supportive of local agriculture that offsets DCP reductions of Colorado River Water distributed by the Central Arizona Project;
- Facilitates the DCP agreement and therefore provides indirect benefits to all CAP and Colorado River water users in Arizona;
- Provides an additional 2,200 AFY of recycled water for agricultural irrigation in the receiving area;
- Partnerships and cost-sharing between irrigation districts, agriculture, and wastewater treatment facilities; and
- Multiple benefits across sectors that extend beyond service area helped to leverage State funding under the Groundwater Conservation Grant Program.

Project Description

In Arizona, approximately 36 percent (2.8 AFY) of the State's water supply is sourced from the Colorado River and delivered to water users via the Central Arizona Project (CAP). Severe shortages in the Colorado River system, most especially in Lake Mead, have initiated reductions of Colorado River water as part of the Drought Contingency Plan [36] (DCP). Further, states in the Lower Basin are aiming to conserve and create additional supplies, including recycled water, for Lake Mead storage [37] (ADWR 2022).

For Arizona, who holds lower priority status to Colorado River water, these reductions account for approximately 30 percent of the total CAP supply and 18 percent of the Colorado River supply (CAP 2022). As the State's largest water user, accounting for over 70 percent of total supplies, agriculture will experience a 65 percent reduction of water from the Colorado River as

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[36] The Drought Contingency Plan (DCP) is an agreement between the seven states in the Colorado River Basin (Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming) and Mexico outlining voluntary reductions and increased conservation to prevent water supplies in the Basin from reaching critically low levels.

[37] Contributions from the lower basin states, Arizona, California, and Nevada, vary by state and are based on projected elevations of Lake Mead. Annual contributions of 192,000 AF are required from Arizona when elevations in Lake Mead are between 1,045 and 1,090 feet, and increase to 240,000 AF when elevations fall below 1,045 feet (Bureau of Reclamation 2018; ADWR 2022; US Bureau of Reclamation 2019).

a result (ADWR 2020; CAP 2022). At the same time, the Arizona Department of Water Resources (ADWR) is tasked with protecting depleting groundwater supplies and managing water users in areas heavily reliant on groundwater, called active management areas (AMAs). Without alternative water supplies, such as recycled water, agriculture and irrigation districts are likely to offset these DCP reductions by pumping groundwater in these AMAs to meet irrigation demands, which is in direct opposition of the management goals of the ADWR.

In the greater Phoenix area, agriculture sales (as of 2017) have a market value of around $1.2 billion (EPCOR 2020). This vital part of the State's economy is threatened as a result of these DCP reductions. In the San Tan Valley area of the southern Phoenix AMA, the New Magma Irrigation and Drainage District (NMIDD)[38] delivers CAP water to 27,410 acres of farmland (George Cairo Engineering n.d.; USBR 2019a) (Figure 13-9). While all groundwater for agricultural irrigation in the NMIDD is privately pumped and not supplied by the NMIDD, reductions of CAP water will likely drive growers to return to pumping groundwater if other supplies cannot be provided.

To provide a long-term solution in support of both the DCP and ADWR efforts of creating alternative water supplies, conserving both Colorado River water and groundwater, the managing corporation for the Pecan Water Reclamation Facility (PWRF), Edmonton Power Corporation (EPCOR), has committed to provide renewable water supplies that will offset DCP reductions to agriculture in Arizona. As the only private water company in support of the DCPs, EPCOR has constructed a new pipeline that delivers 2,200 AFY of high-quality recycled water from the newly upgraded PWRF to the NMIDD. New pipelines within the four-mile project area were constructed adjacent to existing NMIDD lines. Using existing irrigation systems, recycled water is further distributed by NMIDD directly to growers in the San Tan Valley to irrigate crops and other agricultural activities.

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[38] The NMIDD has been receiving industrial recycled water from the Resolution Copper Co. mine since 2009. It is conveyed via a 27-mile-long pipeline where it is first blended with CAP water before delivering to farmers in the San Tan area to irrigate crops (USDA 2021)

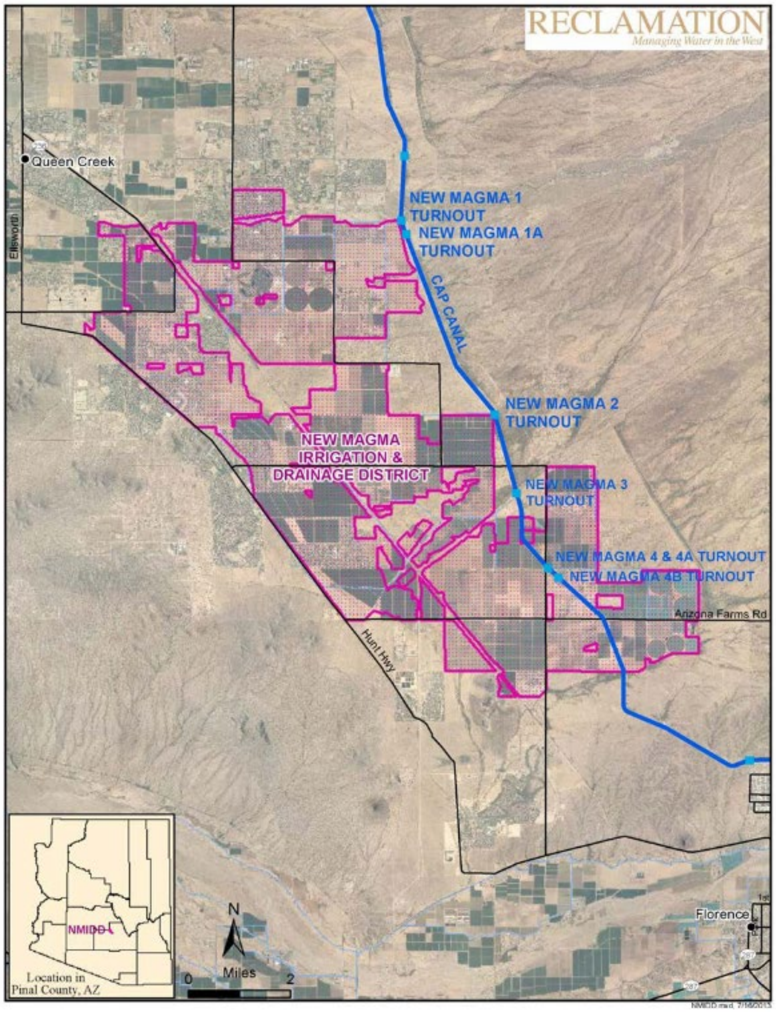

Figure 13-9. New Magma Irrigation & Drainage Service Area.
Source: USBR 2019b.

Recycled water conveyed from the PWRF to the NMIDD Groundwater Savings Facility (GSF)[39] is used to offset pumped groundwater gallon-for-gallon (EPCOR 2020). This will directly replace groundwater that would otherwise need to be pumped in order to offset the DCP reductions. This additional supply has the potential to reduce groundwater withdrawals by up to 35 percent and provides approximately 15 percent of the total annual irrigation demands within the receiving area of the NMIDD (EPCOR 2020).

This project provides multiple benefits across sectors that extend beyond the immediate project area and past the timeframe of the 2026 DCP reductions. The occurrence of overflows at the PWRF that has been a challenge in the past, is mitigated by providing the NMIDD with regular supplies of recycled water that would otherwise be wasted (EPCOR 2020). This additional resource allows EPCOR and the irrigation district to provide efficient and reliable

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[39] The NMIDD is one of eight groundwater savings facilities (GSF) in the Phoenix AMA that participates in indirect recharge by providing surface water, such as CAP or recycled water, in lieu of pumped groundwater in return for long-term storage credit.

service to all customers, including growers, and supports local economies. The State's management goals set by the ADWR are also met by reducing the need to pump already deficient groundwater supplies. These benefits are realized by all Colorado River users and CAP customers as the demand on the river are reduced.

Financial Assistance and Funding Programs: The project was awarded $250,000 from the State's Groundwater Conservation Grant monies under the State's General Fund, covering nearly 10 percent of the $2,610,960 total cost of the New Magma Irrigation Lines. The remaining funds were provided by EPCOR, the private managing entity of the PWRF. The Arizona Department of Water Resources (ADWR) provides funding for such projects that conserve groundwater in Active Management Areas (AMAs) (ADWR 2021).

This project was awarded based on meeting the four priority criteria for funding from the ADWR:

1. Additional contributions;
2. Innovative qualities;
3. Demonstrates high impact; and
4. Demonstrates multiple benefits.

13.10 Aquifer Storage to Agriculture: Advanced Treatment System Creates Flexible, Local Supply in California

Project Name/Organizations: City of Oxnard; Pleasant Valley County Water District
Location: Oxnard, CA

Drivers: Water scarcity; Cost of imported water; Limits on groundwater withdrawals

Project Highlights:

- Advanced treatment technology to produce high quality recycled water able to be used for multiple purposes and diverse customers
- Engagement with growers - water quality education, economic analysis highlighting potential profits, and priority agreements to growers who signed on first
- Comprehensive outreach campaigns to transform water resources management and perceptions of recycled water
- Overcoming barriers including:
    - Competition between ag and non-ag users
    - Perceptions of water quality
    - Challenges of exchanging access to groundwater

Project Description:

The City of Oxnard, CA sits at the center of a thriving agricultural industry in Ventura County. In the late 1990s the GREAT Program[40] was developed to create supply resiliency for projected population and economic growth. Agriculture in the region relied heavily on groundwater and recharge and costly imported water were determined to be insufficient to replace withdrawals. Replacing groundwater with recycled water would stabilize the imbalance between supply and demand and create a barrier to prevent seawater intrusion (City of Oxnard 2018).

Early on, the city understood the importance outreach and education would have on the success of the project and in gaining buy-in from growers. Using a comprehensive outreach and communication campaign to educate via media, videos, presentations, and factsheets as well as in-person demonstrations and tours, Oxnard's grower and public awareness efforts gained regional and industry attention. These efforts were a key factor in gaining grower and public buy-in. The Oxnard Advanced Water Purification Facility also serves as an interactive learning center to educate, promote, and transform water resources management.

While recycled water in Oxnard has been used for agricultural irrigation since 2016, reuse was initially met with resistance. Growers were reluctant to give up groundwater rights despite the quality and quantity of their current sources being threatened (Sheikh et al. 2019). Agronomic impacts to salt sensitive crops, such as berries, using a water source of unknown quality were also a concern. To overcome grower impediments, the City presented information and educational material on water quality, financial gains, and other advantages to using recycled water to irrigate their crops (Lozier and Ortega 2010; Sheikh et al. 2019). Hands on demonstrations were used to show how the quality of recycled water was better fitted for their high-value, salt sensitive crops. They were also presented with a detailed economic analysis revealing greater profits and other significant advantages to irrigating with recycled water over groundwater (Sheikh et al. 2019).

Realizing these multiple benefits, grower concerns were assuaged, and they exchanged their long-held groundwater access for high-quality recycled water to irrigate their crops (Lozier and Ortega 2010). The system sends high-quality recycled water to growers for unrestricted reuse through irrigation systems in the Pleasant Valley County Water District and Oxnard Recycled Water Pipeline (City of Oxnard 2017) (Figure 13-10). The value of the recycled water has been fully realized by growers in the Oxnard Plain, and in some cases, growers have adopted new farming practices including hydroponic farming (City of Oxnard 2018).

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[40] The Groundwater Recovery Enhancement and Treatment (GREAT) Program was initiated in 1999 in response to a need for potable supplies due to increasing population and decreasing and degrading water supplies (City of Oxnard 2018).

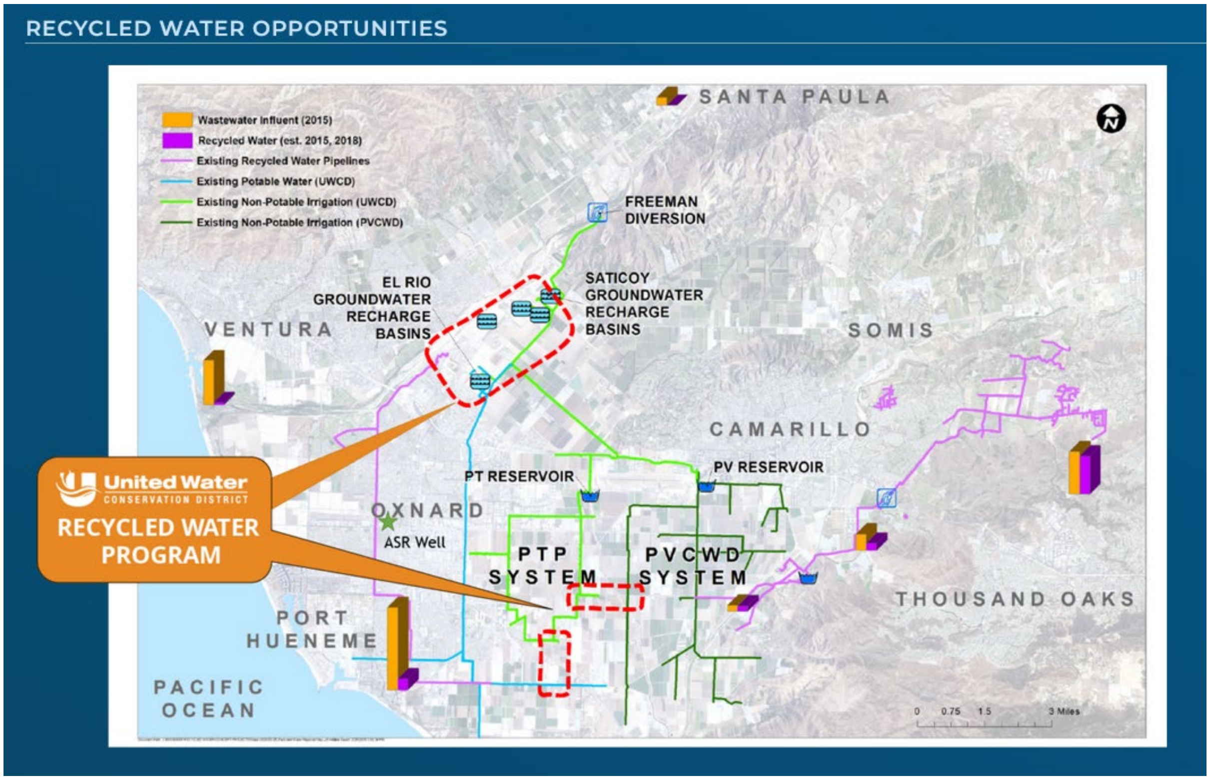

Figure 13-10. Oxnard Recycled Water Opportunities.
Source: United Water Conservation District 2019.

More recently, the city has taken steps towards indirect potable reuse (IPR) using recycled water, motivated by further cutbacks of groundwater supplies and the increasingly high cost and energy requirements to import water (City of Oxnard 2018). Forward thinking using an integrated One Water approach[41] combining water reuse, groundwater management, and desalination is used to create a resilient, high-quality, and locally controlled resource. To provide flexibility in allowable uses, including IPR, the water is treated to an extremely high quality (Figure 13-11). Treated wastewater from the Oxnard Wastewater Treatment Facility is delivered to the Oxnard Advanced Water Purification Facility (AWPF) where it undergoes further treatment including microfiltration (MF), reverse osmosis (RO), and advanced oxidation with ultraviolet light and hydrogen peroxide (AOP).

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[41] The One Water concept views all water sources as valuable finite resources that should be managed using an integrated management approach to meet the needs of the ecosystem and communities.

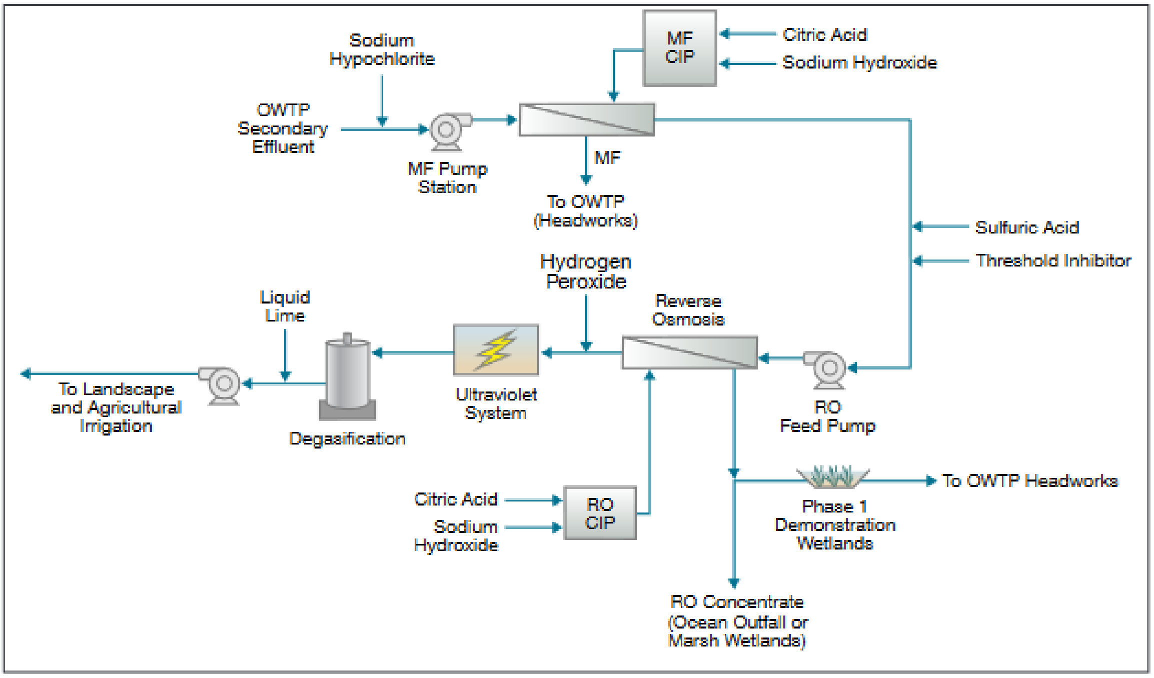

Figure 13-11. Oxnard Advanced Water Purification Facility Treatment Processes.
Source: City of Oxnard 2017.

As part of a long-term plan, the City will be able to use this ultra-pure recycled water to serve diverse customers for many purposes such as groundwater recharge, as part of an aquifer storage and recovery (ASR) scheme for indirect potable reuse (IPR), to irrigate schools, golf courses, and agricultural fields, and to potentially restore diminished coastal salt marshes (Lozier and Ortega 2010). Currently, additional pipelines are being constructed that will deliver up to 5,200 AFY of recycled water to agricultural customers (City of Oxnard 2017).

13.11 Innovative Cost-Share Agreement Secures Reliable Water Supply at Affordable Cost in San Joaquin Valley

Project: North Valley Regional Recycled Water Program (NVRRWP)

Organizations: Cities of Modesto and Turlock; Del Puerto Water District

Location: Modesto and Turlock, California (San Joaquin Valley)

Drivers: Water Supply; Wastewater Discharge Requirements (Water Quality)

Project Highlights:

- Innovative cost share agreement;
- Securing reliable water supply at affordable cost for junior water rights holders;
- Use of existing irrigation infrastructure for conveyance (via changes to NPDES permit);
- Blending tertiary recycled water with existing canal supplies;
- Reduced groundwater withdrawals in the San Joaquin Valley;
- Increased water quantity at a fixed rate for agriculture;

- Restoration of 10,000 acres of previously fallowed fields;
- Preservation of wildlife refuge in the Central Valley Project Improvement Act (CVPIA); and
- Reduced financial burden for many stakeholders.

Funding and Cost Share
Project cost - $90M
Cost Share - $25 M from USBR RWSP
Federal **Funding** - $ 8.5 M in grants
State Funding - $20 M in grants and loan principal forgiveness; balance borrowed using low-interest State Revolving Fund loans.

Project Description
The North Valley Regional Recycled Water Program (NVRRWP) highlights how the role of water rights, partnerships, innovative cost-sharing agreement, and multiple benefits led to the success of this recycled water project. Water scarcity and meeting increasingly stringent discharge requirements motivating the project. During a previous drought in California, Del Puerto Water District (DPWD), an irrigation focused water district and a junior water rights holder in the west side of Central Valley, was receiving less than five percent (zero percent between 2014 and 2015) of their Central Valley Project water allocation (Sheikh et al. 2019). As a result, water in the DPWD was being purchased at a high cost.

At the same time, Turlock Regional Water Quality Control Facility (TRWQCF) and the Modesto Jennings Wastewater Treatment Plant (MWTP) were looking for alternate options for their treated wastewater. Prior to the NVRRWP, treated effluent was either discharged to the San Joaquin River or applied to fodder crops for disposal. While the MWTP had recently updated the treatment system, partnering with the DPWD helped to avoid future costs of upgrades to the WWTP. By directly connecting the recycled water from the two cities to the Delta Mendota Canal, the NVRRWP also avoided the cost of ‘purple pipe’ distribution required if delivering directly to growers (Sheikh et al. 2019). However, a transfer of water rights was needed because the recycled water would be discharged to the canal instead of to the San Joaquin River, which reduces flows to downstream users.

A unique cost-share approach was used to finance the project which reduced construction costs, decreased the borrowed amount, lowered interest, and secured water supplies at a fixed base-rate (not to exceed $225 per acre feet). Clean Water State Revolving Fund (CWSRF) loans were taken out by the City of Modesto and the City of Turlock for the NVRRWP, which will be paid back by the DPWD through water sales. The US Bureau of Reclamation (USBR) Refuge Water Supply Program (RWSP) also pre-purchased 20% of the cost of recycled water, providing $25M to be applied to all future purchases (SLDMWA 2018). When the funds are depleted, the RWSP will then pay the DPWD monthly for the base cost. Grants were also awarded by the USBR WIIN Program and the State of California, in the amount of $8.5 million from Federal funds, and $20 million from California’s Proposition 1 Water Recycling and other State funds.

Officially online at the end of 2018, the NVRRWP project provides high quality tertiary treated recycled water blended with existing canal water supplies (Figure 13-12). Recycled water from the TRWQCF and the MWTP to the Delta-Mendota Canal (DMC); combined pipeline lengths total 13 miles. Currently, Modesto supplies approximately 20,000 AFY of recycled water while Turlock supplies around 7,500 AFY.

Figure 13-12. Recycled Water as Conveyed to Del Puerto Water District.
Source: North Valley Regional Recycled Water Program 2022.

The recycled water also provides additional water supplies to designated wildlife refuges (USBR 2015). Under a purchasing exchange contract with the USBR, the DPWD is obligated to deliver up to 20% of the available supply (7,500 AFY) to CVPIA-designated wildlife refuges. The remaining 20,000 AFY of recycled water is used to irrigate nearly 34,000 acres of farmland in the District, nearly 70% of which is permanent crops including nuts, citrus, and stone fruits[42], which cannot be fallowed (DPWD 2020).

By 2065, recycled water volume is expected to reach approximately 59,000 AFY providing 43,000 AF for agricultural irrigation and 16,000 AF for wildlife refuges (SLDMWA 2018). The increase in volume of recycled water could potentially irrigate nearly double the acreage currently being irrigated and restore over 10,000 acres of unproductive and fallowed fields[43]. As of 2020, the Program provides local growers with high quality water to irrigate crops on 137 farms covering approximately 34,000 acres (DPWD 2020). The unique approach provides a long-term solution to secure affordable water resources, protect the environment, and maintain agricultural viability in the San Joaquin Valley for years to come.

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[42] There is a total of 43,815 irrigable acres in the district, however nearly 10,000 acres are fallowed for economic or water supply reasons.

[43] Over the last several decades regulatory restrictions, contractual limitations, and restricted pumping resulted in an increase of fallowed fields in the region; approximately 10,000 acres in 2020 (DPWD 2020).

Table 13-5. Current Allocations and Future Projections of Recycled Water Available for Agricultural Irrigation.
Data Source: Del Puerto Water District 2020.

NVRRWP Recycled Water and Allocations	Volume (AFY)
2020 Total Recycled Water Produced	**27,000**
Agricultural irrigation,	20,000
IL4 Water for wildlife refuge	7,000
2065 Recycled Water Projections	**59,000**
Agricultural irrigation	43,000
IL4 Water for wildlife refuge es	16,000

13.12 Redefine and Expand Role of Wastewater Utilities to Provide Regional Environmental Co-Benefits in Oregon

Organization: Clean Water Services

Location: Washington County, Oregon

Drivers: Improve water quality; NPDES permit compliance, Watershed co-benefits

Project Highlights:

- Holistic resource management and reuse to advance regional environmental goals and priorities within Tualatin River Watershed;
- Consolidation of 26 local WWTP into four regional facilities operated under a single, combined NPDES permit;
- Redefine and expand the role of a ‘water utility’ into a more holistic, One-Water approach including management of surface waters, wastewater, stormwater, watershed management, and resource recovery;
- Enhance and leverage natural ecosystems to support diverse habitats while improving water quality;
- Use shared goals to foster partnerships between public and private entities and develop strategies and programs to achieve them; and
- De facto reuse in downstream communities.

Project Description

Clean Water Services (CWS) has expanded and redefined the role of a water utility provider to develop the largest water reuse program in Oregon. Unique partnerships between cities, utilities, non-profits, and others – united through a shared goal of protecting natural resources – were instrumental in the success of CWS. To improve the quality of water being discharged to the 712 square mile Tualatin River Watershed, CWS consolidated the operations of 26 wastewater facilities in Washington County[44], Oregon under the CWS umbrella. Currently, CWS provides surface water management and sewer services to over 600,000 residents across twelve urban cities in the county (CWS 2022). By integrating traditional wastewater and sewer

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[44] In 1970, in response to declining water quality of the Tualatin River Watershed as a result of poorly treated wastewater being discharged to the watershed, 26 wastewater treatment facilities formed the United Sewerage Agency (USA). To reflect the additional involvement of water resources management and recovery, in 2004 USA rebranded to Clean Water Services (CWS 2022).

services with surface water management, including management of stormwater, watershed, and resource recovery they have taken on a broader role using a One Water approach to protect the Tualatin River and watershed.

To ensure these efforts are large-scale and long-lasting, CWS extends their involvement in watershed stewardship by inspiring community engagement, facilitating partnerships, and advising on conservation and management plans, such as the Oregon Department of Agriculture's Tualatin River Watershed Agricultural Water Quality Management Area Plan (ODA 2018). The Summary Box highlights two landscape conservation projects managed by the community-based partnership, Tree for All, where agriculture and natural habitats not only co-exist, but thrive to support ecosystems and local economies.

A Common Vision Supports Healthy Habitats and Productive Agriculture

Tree for All, a community coordinated public-private partnership serves as an extension of Clean Water Services to further protect the State's watershed. Over 40 partners work together using an ecosystem-based approach that supports the health of the watershed and local economies. The Tualatin River Farm and the Carpenter Creek North Natural Area highlight how communities can work within natural systems to support agriculture, riparian forests, and wetlands.

The Tualatin River Farm showcases the many nature-based approaches Tree for All uses across projects - all within 62-acres. To restore the landscape and encourage the reintroduction of native species, the community decommissioned tile drains and installed filter strips next to agricultural fields, converted monocultures to diverse forests, and planted native vegetation. As a result, the working farm, research facility, and demonstration site co-exist to support thriving populations of native wildlife and local businesses and economies - a valuable asset to the community (Tree for All 2019).

Farming in the Carpenter Creek North Natural Area was once threatened as invasive plants dominated the landscape and degraded the soil and water quality. Local partnerships and interagency cooperation between the Soil and Water Conservation District and Farm Services Agency are key to the restoration efforts in the area. Communities continue to work together to improve water and soil health by removing non-native species and installing natural habitats - creating space for native plants, wildlife, and pollinators to thrive once again. Now, the 115 acres consists of productive agricultural oat-fields, enhanced wetlands, and healthy riparian forests (Tree for All 2018).

In addition to these unique partnerships and mergers, the four wastewater treatment facilities (WWTFs) operating under CWS, have one combined watershed-based National Pollutant Discharge Elimination System (NPDES) permit – the first of its kind. Each year, these facilities, which also function as resource recovery facilities, produce approximately 24 BG of high-quality recycled water to near drinking water quality standards by that can be reused or safely discharged to the river. During the treatment process, 32 dry tons of organic material is recovered from the four facilities, producing nutrient rich biosolids that can be used as soil amendments.

Two of the facilities, Rock Creek and Durham, are equipped with advanced technology to remove excess nutrients in addition to treating wastewater. To stay in compliance with phosphorous discharge limits for the Tualatin River (≤0.1 mg/L), phosphorous and ammonia are further recovered from the wastewater using advanced treatment technologies through another unique partnership. A resource recovery company[45] recovers these resources and then converts them to an eco-friendly fertilizer, producing approximately 780 tons each year. The recovered resources are then beneficially reused in the agriculture and nursery industry. A third facility, Forest Grove, sends treated wastewater to Fernhill for further treatment using 700 acres of wetlands to further improve the water quality before flowing to the Tualatin River. Fernhill supports a number of diverse flora and fauna while acting as an educational space to learn about water and water reuse.

Of the nearly, 24 BG of recycled water produced at the four facilities each year (66 MGD), approximately 64 MGY is directly used for irrigation while the rest is discharged to the 80-mile-long Tualatin River[46]. Other major wastewater facilities also discharge treated effluent to the river providing a significant percentage of downstream summer flows to the Tualatin River, and the receiving Willamette River (ODA 2018). Because the treated wastewater is discharged to the river to be reused again for beneficial uses downstream, including irrigation and drinking water, communities using the water are participating in incidental, or de facto reuse.

13.13 Innovative Collaborations Increase Water and Ecological Resilience in the Sacramento-San Joaquin Delta

Project: Harvest Water
Organizations: Sacramento County Regional Sanitation District (Regional San)
Location: Southern Sacramento County, California (Sacramento-San Joaquin Delta)

Drivers: Water scarcity; Effluent discharge diversification; Protect ecosystem functions within the Cosumnes River Basin; Protect agricultural and open space

Project Highlights:

- Conjunctive management of water for enhanced agriculture, ecosystem, and groundwater management benefits;
- Resources recovery
- Active engagement with agriculture communities;
- Extensive public outreach and education programs for all ages;
- Partnerships with diverse stakeholders; and
- Multiple benefits align with state objectives

Total Cost: Estimated $597 million

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[45] Ostara Nutrient Recovery Technologies.

Funding:

- $291.8 million of California State grant conditionally awarded through the Water Storage Investment Program (WSIP) of Proposition 1[47], based on multiple public benefits – ecosystem and water quality benefits.
- $30 million of federal funding from the U.S. Bureau of Reclamation's (USBR) WaterSMART Title XVI WIIN Act Water Reclamation and Reuse program[48].
- $1.6 billion of low-interest financing from the California's Clean Water State Revolving Funds was used for a separate treatment upgrade and nutrient removal project (known as EchoWater), which allows Regional San to produce high quality recycled water. The low-interest loans help to pass savings on to ratepayers and minimize future rate increases.
- The remaining balance of capital costs and costs ineligible for grant funding will be financed by Regional San through cash reserves, as well as recycled water and wastewater treatment rate revenues. Regional San will continue to seek additional grant and loan funding for Harvest Water.

Project Description

Harvest Water is a planned conjunctive reuse program in the Sacramento-San Joaquin Delta of California, driven by water scarcity and protection of valuable ecosystem functions[49] (see Figure 13-13). As one of the largest water recycling programs in California, the project has the potential to deliver up to 50,000-acre feet per year (AFY) of disinfected tertiary treated recycled water for beneficial reuse in southern Sacramento County. Prior to Harvest Water, upgrades to the existing treatment systems at the Sacramento Regional Wastewater Treatment Plant (SRWTP) to facilitate water recycling included advanced treatment processes for nitrogen and ammonia removal, filtration, and disinfection as part of the EchoWater Project. EchoWater is one of the largest public works projects in the Sacramento region and a vital first step for advancing recycled water use in the region (Regional San 2015). EchoWater will be complete in mid-2023. Harvest Water expects to break ground in 2023.

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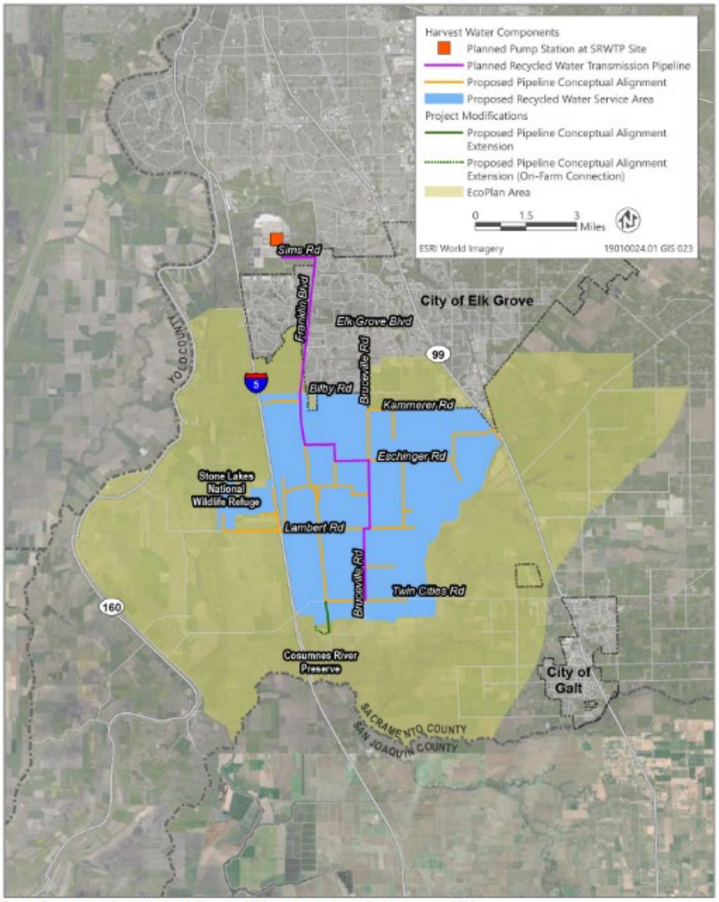
[47] Information on California's Proposition 1 Water Storage Investment Program can be found at CWC 2023

[48] Information on the USBR WaterSMART Title XVI Water Reclamation and Reuse Program can be found at (USBR 2023)

[49] Additional information on the Harvest Water Program can be found on the California Water Commission website (CWC 2023)



Source: Data received from Woodard & Curran in 2020; adapted by Ascent Environmental in 2020

Figure 2-2 Project Area

Figure 13-13. Project and EcoPlan Area.
Source: Ascent Environmental 2020.

The innovative, forward thinking, and unique approach of the Harvest Water Project has earned Regional San, the owner and operator of the regional wastewater conveyance system, a place in the spotlight. For the third time, they have been recognized as a ‘Utility of the Future Today’. The success of the project highlights the importance of joint planning and collaboration with diverse stakeholders, including environmental groups, agricultural, water suppliers, and non-governmental organizations. Engaging with stakeholders was critical in every phase of project development to ensure that multiple interests were supported.

Innovative ways the Harvest Water Project promotes recycled water use for agriculture and the environment are provided in Table 13-6. As a result of these combined approaches, water supplies are managed as an integrated system creating a reliable and locally controlled water supply, strengthening the region’s economic health, and providing multiple benefits for all stakeholders.

Currently, recycled water is discharged from the SRWTP into the Sacramento River while agricultural and municipal activities rely heavily on diminishing groundwater supplies. Long-term regional water scarcity could potentially lead to the conversion of working agricultural fields to non-agricultural uses. In addition, groundwater overdraft has been cited as a contributor of declining flows in the Cosumnes River and the riparian corridor within the Delta (Regional San 2016). The Cosumnes River and its watershed are of global importance, supporting an abundance of wildlife, including threatened and protected species. As the last unregulated and undammed river west of the Sierra Nevada, over $100 million has been publicly invested to restore and protect the area since the 1980s.

Under the new program, Regional San will instead divert the high quality recycled water to irrigate approximately 16,000 acres of agricultural fields and habitat lands. (Regional San 2019). During the growing season, an estimated average of 32,500 AFY of recycled water will irrigate crops with volumes increasing up to 49,500 AFY in the winter. Providing recycled water for irrigation will allow for significant reduction in local groundwater pumping, known as in-lieu recharge. That reduced pumping will allow the groundwater basin to recover, with groundwater elevations expected to increase up to 35 feet in the center of the Harvest Water Program area.

An integral part of the success of Harvest Water are the transmission and distribution systems delivering recycled water to grower’s irrigation systems or on-farm water storage systems. Extensive outreach, planning, and coordination with local growers ensures that each part of the system will be designed, constructed, and located to most efficiently meet agricultural needs. Distribution mains spanning approximately 25 miles will connect the customer’s service connection laterals to the transmission pipeline (Ascent Environmental 2020). Construction is scheduled to begin in 2023 with delivery to agriculture customers expected as early as 2025 (Ascent Environmental 2021; Regional San 2023; CWC 2021). Benefits to agricultural communities and local economies can be realized while simultaneously enhancing essential ecosystem functions. A summary of the multiple benefits resulting from the Harvest Water Project are summarized in Table 13-6.

Table 13-6. Multiple Benefits from the Harvest Water Project.
Data Source: Regional San 2016.

Increases regional water resiliency and self-reliance by providing a reliable and drought resistant water supply	Protects many ecosystems and ecosystem functions
Provides up to 50,000 AFY to irrigate up to 16,000 acres of agriculture	Restores groundwater levels which increases instream flows in the Cosumnes River
Reliable and safe agriculture water supplies used to preserve working farmlands	Supports threatened species - Swainson's Hawk, Sandhill Cranes, Chinook salmon, and Giant Garter Snake
Restores up to 35 feet of depleted groundwater in 15 years	Protects 5,000 acres of riparian and wetland habitat
Reduces discharge of salts to the Sacramento River and Delta. The western Delta is listed as impaired by salinity.	Protects 353 acres of vernal pool complex habitat
Groundwater storage of 225,000 AF in 10 years	Groundwater storage of 370,000 over course of project

13.14 Fit-for-Purpose Approach Facilitates Water Exchange and Maximizes Use Multiple Classes of Recycled Water in San Joaquin Valley

Organizations: City of Fresno; Fresno Irrigation District (FID)
Location: Fresno, CA (San Joaquin Valley)

Drivers: Water Supply; Water Quality Improvements; Regulatory Compliance

Project Highlights:

- Partnership between City of Fresno and Fresno Irrigation District;
- Exchanging access to recycled water for surface water from Kings River (for municipal use); and
- Supplying multiple qualities of recycled water for different agricultural uses

Project Description

The City of Fresno, California is home to more than 500,000 people and located within the productive agricultural environment of the San Joaquin Valley. The combination of these two factors has led to innovative water management partnerships between the City of Fresno and Fresno Irrigation District.

Figure 13-14. Supplying Recycled Water in Fresno, CA.

Source: City of Fresno 2023.

Historically, groundwater was Fresno's primary water supply, but as those resources have diminished, the city has made substantial investments to diversify their water supply portfolio via water exchanges, recycled water, and urban stormwater capture and recharge. Fresno's current municipal water supply portfolio is comprised of groundwater (55,000 AFY in 2020) from the Kings Basin, surface water via the Central Valley Project (CVP) (average 53,680 AFY) and exchanges with Fresno Irrigation District (average 131,600 AFY), recycled water[50] (4757 AFY in 2020) (City of Fresno Department of Public Utilities 2021). The city is a junior water rights holder and received minimal allocations from the CVP and Kings River during the 2012-17 drought. FID is a senior rights holder on the Kings River, but even so, their allocations are typically exhausted by late summer, at which point growers switch to groundwater. Likewise, Kings (groundwater) Basin is considered critically over drafted and subject to curtailments in groundwater withdrawals in coming years. Both the city and FID face substantive water supply challenges. In response to these needs, the City of Fresno and FID have developed a unique, long-term partnership to more fully utilize the city's treated wastewater (Figure 13-14).

Fresno has an overall permitted capacity of 91.5 MGD (102 TAFY) and typically produces approximately 5 MGD (5.6 TAFY) of disinfected tertiary recycled water that is used to supply the City of Fresno Recycled Water System. The remaining effluent is undisinfected secondary effluent. The city has a longstanding direct reuse program with growers adjacent to wastewater treatment facilities, supplying approximately 10 TAFY for irrigation of non-food crops. The remaining effluent is discharged to percolation basins. The SWRCB considers the water infiltrating through the percolation basins to be equivalent to Title 22 tertiary treated recycled

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[50] Recycled water use is expected to increase to 14,220 AFY by 2025 as additional agricultural and landscape irrigation projects come online. Agricultural irrigation is expected to increase from 3845 to approximately 7900 AFY. Exact amounts depend on demand from additional recycled water users and treatment capacity.

water by the time it reaches groundwater aquifers. FID has extraction wells near the percolation basins to withdraw the infiltrated effluent from beneath the percolation basins. The City of Fresno and FID have had an ongoing exchange agreement since 1974. Per the current agreement, FID supplies 0.46 AF of surface water to the City of Fresno for every one acre-foot of recycled water supplied to FID (subject to max/min limits) (City of Fresno Department of Public Utilities 2021).

This unique arrangement provides a range of benefits the City of Fresno, FID, and local growers. All are able to diversify their supply portfolios. FID is able to extend their irrigation season while Fresno gains access to high-quality surface water from the Kings River. Direct and indirect use of undisinfected secondary effluent for agricultural water irrigation helps the city avoid wastewater discharges while, historically, reducing or avoiding costly treatment upgrades. However, groundwater quality is a growing concern and the city is facing limits in their percolation basins (since salts are not removed through current treatment processes) (Carollo Engineers 2010). The city is currently updating its Recycled Water Master Plan (City of Fresno Department of Public Utilities 2021). These updates will provide guidance on the future of recycled water in Fresno. The long-term, fit-for-purpose approach adopted in Fresno has facilitated a win-win situation for the City of Fresno, FID, and local growers while building regional water resilience.

CHAPTER 14

Conclusions and Recommendations

Agricultural water reuse is an intrinsically heterogeneous practice – motivated by a diverse range of drivers including water quantity, water quality, and other priorities and occurring across all regions of the United States. These factors have important implications for how incentives and impediments influence different projects and how projects are conceived of, implemented, and operated. Despite this heterogeneity, several common characteristics were observed across successful projects and programs reviewed in WRF 4956. Successful projects:

- Address multiple objectives and deliver co-benefits to diverse stakeholders;
- Engage with stakeholders early and meaningfully;
- Invest in innovation, capacity building, and partnerships; and
- Are supported by regulatory programs that support reuse while remaining protective of public health and the environment.

Advancing agricultural water reuse requires supporting and empowering stakeholders in their work through the common barriers of securing needed permits and funding and navigating engagement and outreach.

The preceding guidebook, profiles, and literature review dig deeper into each of these topics while also pointing to recommendations and research needs, both fundamental and applied. A subset of these recommendations and research needs are discussed below.

Multiple Objectives and Co-Benefits

Agricultural water reuse projects can provide a multitude of benefits, but not all do. Applied research is needed to better characterize the value of and conditions needed for realization of key benefits such that these benefits can be better incorporated into funding and policy decisions.

Stakeholder Engagement

Stakeholder engagement and outreach are consistently recognized as critically important, but often remain more of an art than a science. Updated, applied research is needed to understand what is working and not working in modern stakeholder outreach and engagement, given increasing demand for agricultural water reuse and shifts in public perception around reuse.

Innovation

Agricultural water reuse projects are innovating in exciting ways – conjunctive management, system-level planning to incorporate diverse sources of water, and advances in treatment, for example. Designing funding programs to foster innovation, support pilots and provide seed funding can help develop transferrable, scalable knowledge. One Water approaches can provide a framework for integrated management of water reuse within the broader watershed context.

Capacity Building

While we are seeing substantive innovations in agricultural water reuse, many small or low-resource agencies and growers are struggling to maintain basic operations. Greater investments in TMF capacity building programs are needed to support small and low-resource stakeholders through agricultural water reuse projects. Likewise, there is a need for applied research to develop evidence-based guidance on successful capacity building programs supporting reuse.

Partnerships and Collaboration

Partnerships open doors for leveraging innovative funding models and peer learning which can help facilitate greater realization of co-benefits. Agricultural water reuse is full of partnerships, many unexpected. The profiles in this project highlight some of these, but a more in depth look at what makes for successful partnerships in reuse may prove fruitful.

Regulatory Programs and Water Quality

Robust regulatory programs are one cornerstone in building and maintaining agricultural producer's and consumer's confidence in recycled water. Investments in science advisory panels and basic research can help align regulations with the current best available knowledge and technologies. Additional work is needed to translate findings on CECs, including PFAS, into measures of risk to human health and agronomic systems. There is comparatively less research on the long-term agronomic risks of agricultural water reuse. There are strategies that can help manage some traditional agricultural water quality concerns such as salinity, but more research is needed to make existing technologies cost-effective and avoid unintended consequences.

Robust Decision Making on Agricultural Water Reuse

Underpinning each one of these recommendations and research opportunities is a fundamental need to better support decision making in the face of both great uncertainty and access to more information than we ever imagined. These challenges necessitate more robust, user friendly decision support approaches coupled with adoption of best practices in stakeholder engagement and partnerships. Tools such as scenario planning, HIA, and related approaches can provide frameworks for envisioning a region's water future. Realistic, context specific assessments of the benefits and tradeoffs of agricultural water reuse can help communities adapt to and build resilience to stressors such as climate change, changing population, and aging infrastructure.

APPENDIX A

Fit-for-Purpose Classes of Water for Agricultural Water Reuse: Examples from Four States

A.1 California

Agricultural irrigation remains one of the most common beneficial use of recycled water in California (~190,000 of 728,000 AF in 2020) (California State Water Resources Control Board 2021). California is the nation's top producer of a diverse range of commodities including numerous fruit and nut crops while also producing large quantities of fodder crops such as alfalfa to support the state's dairy and cattle industries. The diversity of agricultural production in California is reflected in the state's tailored approach to regulating recycled water use in agriculture (Table A-1).

Table A-1. Classes of Recycled Water Used for Agricultural Irrigation in California.

Recycled Water Class		**Undisinfected Secondary**	**Disinfected Secondary-23**	**Disinfected Secondary-2.2**	**Disinfected Tertiary**
Crops that Can be Irrigated		Food crops that must undergo commercial pathogen-destroying processing before being consumed by humans; Orchards and vineyards where recycled water does not come in contact with edible portion; Fodder and fiber crops and pasture for animals not producing milk for human consumption; Seed crops not eaten by humans; Non-food-bearing trees, nursery stock, and sod if there is no irrigation for 14-days before harvest/sale/public access.	Ornamental nursery stock/sod; Pasture for animals producing milk for human consumption	Food crops where the edible portion is produced above ground and not contacted by the recycled water	Food crops, including all edible root crops, where the recycled water comes into contact with the edible portion of the crop
Treatment Description		Oxidized wastewater	Oxidized and disinfected	Oxidized and disinfected	Oxidized, filtered, and disinfected
BOD		NS*	NS	NS	NS
TSS		NS	NS	NS	NS
Turbidity		NS	NS	NS	2 NTU**
Pathogen Indicators	Indicator Organism	N/A	Total Coliform	Total Coliform	Total Coliform
	7-day Median (MPN/100 ml)	NS	23	2.2	2.2

Recycled Water Class		Undisinfected Secondary	Disinfected Secondary-23	Disinfected Secondary-2.2	Disinfected Tertiary
	Max in any one sample within a 30-day period (MPN/100 ml)	NS	240	23	23
	No sample to exceed (MPN/100 ml)	NS	NS	NS	240

* Not specified in state regulations.
** Regulations require coagulation and/or continuous monitoring of filter influent with additional treatment if various turbidity thresholds are exceeded (see CA regulations for details).

A.2 Florida

Florida is the nation’s largest user of reclaimed (recycled)[51] water, reusing approximately 2 MAFY. However, most reclaimed water use in Florida supports urban irrigation with only about 60,000 AFY used for agricultural crops (Florida Department of Environmental Protection 2021). Citrus is the most common edible crop irrigated with reclaimed water in Florida though the majority of agricultural irrigation (86%, 51,000 AFY) in Florida is for irrigation of non-food crops. Regional differences in the use of reclaimed water in Florida are reflected in Florida’s regulatory approach (e.g., regulations oriented around public access vs, specific beneficial use classes).

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[51] Florida uses the term reclaimed vs. recycled water in their state regulation. The two terms are synonymous in this context.

Table A-2. Classes of Reclaimed Water Used for Agricultural Irrigation in Florida.

Reclaimed Water Class		**Slow-rate land application systems; Restricted public access**	**Slow-rate land application systems; Public access areas, residential irrigation, and edible crops**
Crops that Can be Irrigated		Pastures and areas used to grow feed, fodder, fiber, or seed crops; Trees, including managed hardwood or softwood plantations	(1) Irrigation of edible crops that will be peeled, skinned cooked or thermally processed before consumption is allowed. Direct contact of the reclaimed water with such edible crops is allowed. (2) Irrigation of tobacco or citrus is allowed. Direct contact of the reclaimed water with tobacco or citrus is allowed, including citrus used for fresh table fruit, processing into concentrate, or other purposes. (3) Irrigation of edible crops that will not be peeled, skinned, cooked, or thermally processed before consumption is allowed if an indirect application method that will preclude direct contact with the reclaimed water (such as ridge and furrow irrigation, drip irrigation, or a subsurface distribution system) is used. (4) Irrigation of edible crops that will not be peeled, skinned, cooked or thermally processed before consumption using an application method that allows for direct contact of the reclaimed water on the crop is prohibited.
Treatment Description		Secondary + Basic Dinfection*	Secondary + Filtration (as needed for TSS control) + High-level disinfection
BOD		NS	NS
TSS		<10 mg/L (for subsurface application)	≤5 mg/L prior to disinfection
Turbidity		NS	NS
Residual Chlorine		≥0.5 mg/L after 15-min contact time	≥1.0 mg/L after 15-min contact time
Pathogens/ Indicators	Indicator Organism	Fecal Coliform	Fecal Coliform
	Arithmetic Mean of the monthly geometric means (CFU or MPN/100 ml)	<200	NS
	Geometric mean of daily samples during a period of 30 consecutive days (monthly) (minimum of 10 samples) (CFU or MPN/100 ml)	<200	NS
	% Not to Exceed	No more than 10% of the samples collected during a period of 30 consecutive days should exceed 400 CFU or MPN/100 ml	Over a 30 day period (monthly), 75% of the fecal coliform values shall be below the detection limits
	Maximum any one sample (CFU or MPN/100 ml)	800	25
	Giardia and Cryptosporidium	NS	Once every 2-5 years; Resample if Giardia >5 viable cysts/100 L or >22 Cryptosporidium oocysts/100 L

A.3 Idaho

Idaho is unique among states with robust reuse programs in that it has many long-standing examples of municipal reuse in smaller communities. Agricultural irrigation is the primary beneficial use of recycled water in Idaho. Many of these projects were motivated by a need to better manage nutrient discharges to surface or groundwater. What has evolved is a relatively unique set of regulations that are tailored to the state's unique reuse needs while adopting best practices from other western states (e.g., California's approved technologies list, log reduction approach) (IDEQ 2017a) . Additional details are included in the Idaho Administrative Rules: https://adminrules.idaho.gov/rules/current/58/580117.pdf

Table A-3. Classes of Recycled Water Used for Agricultural Irrigation in Idaho.

Recycled Water Class	**E**	**D**	**C**	**B**	**A**
Crops that Can be Irrigated	Fodder, Fiber, Commercial Timber	Processed Food Crops; Ornamental nursery crops; Seed crops; Pasture for non-milk producing animals	Orchards and Vineyards (no contact); Pasture for milk producing animals	Food Crops (not processed)	Food Crops (not processed)
Treatment Description	NS	Oxidized + Disinfected	Oxidized + Disinfected	Oxidized + Clarified+ Filtered+ Disinfected	Oxidized + Clarified+ Filtered+ Disinfected
BOD$_5$	NS	NS	NS	NS	Monthly mean not to exceed 10 mg/L
TSS	NS	NS	NS	NS	NS
Turbidity	NS	NS	NS	Daily mean not to exceed 5 NTU or exceed 10 NTU at any time	Limits vary with type of filtration (0.2 avg, 0.5 max NTU w/membrane filtration; 2 avg, 5 max NTU for sand/media)
Chlorine Residual	NS	NS	NS	1 mg/L after 30-min	450 mg-min/L or Treatment train capable of 5-log reduction in viruses.
Total Nitrogen	NS	NS	NS	Case-by-Case	Max monthly arithmetic mean: 30 mg/L
pH	NS	NS	NS	NS	6.0-9.0
Pathogens/ Indicators Organism	NS	Total Coliforms	Total Coliforms	Total Coliforms	Total Coliforms

Recycled Water Class		E	D	C	B	A
	Median results for last n-days for which analyses have been completed (MPN/100 ml)	NS	230 (3-day)	23 (5-day)	2.2 (7-day)	2.2 (7-day)
	Maximum in any sample (MPN/100 ml)	NS	2300	230	23	23
	Monitoring Frequency	NS	Monthly	Weekly	Daily	Daily
Certified Operator Responsible for Distribution and Use		Y	Y	Y	Y	N

A.4 Minnesota

Minnesota has a long-standing spray irrigation program using recycled water for irrigation of non-food crops. The primary driver for these programs is nutrient management. In recent years, the state has expanded their efforts around reuse to develop more formal regulations modeled on those developed in California. Minnesota’s reuse policies were developed by an inter-agency workgroup and also include guidance on the reuse of stormwater (Interagency Workgroup on Water Reuse 2018).

Table A-4. Classes of Recycled Water Used for Agricultural Irrigation in Minnesota

Recycled Water Class	Disinfected Secondary-200*	Disinfected Secondary-23	Disinfected Tertiary
Crops that Can be Irrigated	Fodder, fiber, and seed crops; Food crops not for direct human consumption; Orchards and vineyards with no contact between edible portion; Non food bearing trees, such as Christmas trees, nursery stock and sod farms not irrigated less than 14 days before harvest	Ornamental nursery stock and sod farms with restricted access; Pasture for animals producing milk for human consumption	Food crops where the recycled water contacts the edible portion of the crop, including root crops

Recycled Water Class		Disinfected Secondary-200*	Disinfected Secondary-23	Disinfected Tertiary
Treatment Description		Secondary + Disinfection (or stabilization pond with >210 days storage)	Secondary + Disinfection	Secondary + Filtration + Disinfection
BOD5		NS	NS	NS
TSS		NS	NS	NS
Turbidity		NS	NS	2 NTU daily average; 10 NTU daily maximum turbidity
Chlorine Residual		NS	NS	NS
Total Nitrogen		NS	NS	NS
pH		NS	NS	NS
Pathogens/ Indicators	Indicator	Fecal Coliform	Total Coliform	Total Coliform
	7-day Median (MPN/100 ml)	200 MPN/100 ml	23 MPN/100 ml	2.2 MPN/100 ml
* In Minnesota, this class is commonly called spray irrigation.				
** Minnesota regulations modeled on CA regulations.				

APPENDIX B

Water Reuse Action Plan Actions Relevant to Agricultural Reuse

Table B-1. WRAP Actions Relevant to Agricultural Water Reuse by Theme.

Policy Coordination		
WRAP Action Leader	**WRAP Actions**	**Description**
U.S. Department of Agriculture (USDA)	2.12 Leverage Existing USDA Programs for Consideration of Agricultural Water Reuse	The U.S. Department of Agriculture (USDA) is committed to leveraging programs to encourage reuse through integrating water reuse into agricultural programs by providing financing, grants, technical assistance, and conservation initiatives. The Natural Resources Conservation Service (NRCS) gives priority to projects that integrate multiple approaches to conservation in innovative ways and develop new partnerships. Flexible programs allow for innovation and are likely to enhance agricultural reuse: - The Watershed and Flood Prevention Operations Program - Watershed Rehabilitation Program - Environmental Quality Incentives Program - Regional Conservation Partnership Program - Environmental Quality Incentives Program – Conservation Innovation Grants Program - Agricultural Conservation Easement Program
WaterSMART Priority Areas: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/newsroom/releases/?cid=NRCSEPRD1688015 **Conservation Innovation Grants:** https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/newsroom/releases/?cid=NRCSEPRD1579239		
Envirospectives; WateReuse; EPA;	2.16 Support Local and Regional Reuse Projects	**Identify Challenges, Opportunities, and Models for Interagency Collaboration**
Multi-Agency Water Reuse Programs – Lessons for Successful Collaboration: https://www.epa.gov/system/files/documents/2022-03/multi-agency_water_reuse_programs-lessons_for_successful_collaboration_march_2022.pdf		
	2.6 Strategies to Enable Recycled Water Projects Under the NPDES Permitting Program	**Develop Materials on how NPDES Permits Can Facilitate Water Reuse**
Navigating the NPDES permitting process for water reuse projects strategies to enable recycling and protect water quality: https://www.epa.gov/system/files/documents/2022-03/navigating_the_npdes_permitting_process_for_water_reuse_projects_march_2022.pdf		

Information Availability		
WRAP Action Leader	**WRAP Actions**	**Description**
U.S. Department of Agriculture (USDA)	5.1 Foster USDA Watershed-Scale Pilot Projects to Share Water Information	**Foster U.S. Department of Agriculture Watershed-Scale Pilot Projects to Share Water Information to Support Water Reuse Actions** The U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service's (NRCS) Conservation Innovation Grants (CIG) • Foster watershed-scale projects to share water information to support water reuse actions • A competitive grants program driving collaborative innovation in resource conservation • Priorities in water reuse, water quality, air quality, energy, and wildlife habitat
USDA NRCS CIG: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/financial/cig/?cid=nrcs143_008205		
The Water Research Foundation (WRF)	5.2 Identify Water Quality Monitoring Practices for Reuse Applications	**Identify Water Quality Monitoring Practices for Reuse Applications** To coordinate, leverage, and share information on current and emerging monitoring practices and treatment performance to reduce redundancies and maximize impacts. This • Develop options for evaluating and monitoring quality of recycled water, including novel methods, for a range of end-uses • Refine existing bioassays to assess biological activity, including endocrine activity, and develop a Bioanalytical Toolkit • Engage with the water sector to educate and disseminate research results to advance water monitoring
U.S. Geological Survey (USGS)	5.4 Develop National Integrated Water Availability Assessments	**Develop National Integrated Water Availability Assessments** Integrated Water Availability Assessments (IWAAs) • Provides data on current and future water availability based on quantity, quality, and water use • National Water Census of supply and demand incorporating factors such as climate, land use, population, or other changes • Assesses water availability as a useful tool for water managers
USGS IWAAs: https://www.usgs.gov/mission-areas/water-resources/science/integrated-water-availability-assessments-iwaas		

Finance Support		
WRAP Action Leader	**WRAP Actions**	**Description**
U.S. Environmental Protection Agency (EPA)	6.1 Compile Federal Funding Sources and Develop Interagency Decision Tool	**Compile Existing Federal Funding Sources for Water Reuse and Develop an Interagency Decision Support Tool** A streamlined resource of federal funding opportunities in support of water resiliency and water reuse projects • Funding sources by agency – USEPA, USDA, USDOI • State Revolving Funds, WIFIA Program, Water & Waste Disposal Loan & Grant Program, Title XVI – Water Reclamation and Reuse
Water Reuse Infrastructure Funding Programs - https://www.epa.gov/waterreuse/water-reuse-infrastructure-funding-programs		

U.S. Environmental Protection Agency (EPA)	6.2A Communicate Eligibility of Water Reuse in SRF Programs	**Clarify and Communicate the Eligibility of Water Reuse Under the Clean Water and Drinking Water State Revolving Fund Programs** • Clarify eligibility of water reuse projects • Clarify eligibility for the full range of potential source waters for reuse and different end use applications
Matrix of sources of water and end uses: https://www.epa.gov/sites/default/files/2020-02/action_2.6.2a_matrix_0.png Integrating water reuse into the SRFs - https://www.epa.gov/sites/default/files/2021-04/documents/cwsrf_water_reuse_best_practices.pdf Financial Support for Water Reuse: https://www.epa.gov/sites/default/files/2020-07/documents/action_2.6.2a_milestones_4_and_5_cwsrf_reuse_assistance_final_061220_508_0.pdf		
U.S. Environmental Protection Agency (EPA)	6.2B Support and Communicate WIFIA Funding	**Continue to Actively Support and Communicate the Eligibility of Water Infrastructure Finance and Innovation Act Funding for Water Reuse** • Promote the eligibility of Water Infrastructure Finance and Innovation Act (WIFIA) financing for water reuse projects • Assess the extent water reuse is mentioned in the materials • Work to clarify and communicate the eligibility of WIFIA funding for water reuse projects
Water Reuse Project funded by WIFIA - https://www.epa.gov/sites/default/files/2020-07/documents/action_2.6.2b_milestone_1_wifia_-_reuse_projects_list_508.pdf Action Complete Fact Sheet- https://www.epa.gov/sites/default/files/2021-04/documents/wrap_action_6.2b_summary.pdf		
U.S. Department of Agriculture (USDA) Rural Utilities Service (RUS)	6.4 Compile and Promote Existing USDA Resources for Rural Communities	**Compile and Promote Existing U.S. Department of Agriculture Funding and Resources for Rural Communities** • Identify, compile, and promote U.S. Department of Agriculture (USDA) funding opportunities for water and wastewater infrastructure projects • Rural Development's Water and Waste Disposal Loan and Grant Program • NRCS Conservation Innovation Grant • Provide information and technical assistance to rural communities and farmers on assessing opportunities for water reuse
Water reuse for small and rural communities - https://www.epa.gov/sites/default/files/2020-10/documents/action_2.6.4_milestone_1_and_2_rus_reuse_projects_october_2020_508.pdf		
U.S. Bureau of Reclamation (BOR)	6.5 Develop Reclamation's Large-Scale Water Reuse Funding Opportunity	**Develop the Bureau of Reclamation's Large-Scale Water Recycling and Reuse Funding Opportunity** Bipartisan Infrastructure Law (BIL) gives authority and funding for new large-scale water recycling and reuse grants • Invest opportunities in our infrastructure • Increase Reclamation's efforts to support partners, stakeholders, Tribal nations, and communities in the 17 western states covered by Reclamation • Provides a federal cost share of up to 25 percent for water reuse projects • Priority is to be given to projects that serve multiple purposes, address environmental impacts from Reclamation projects, or are multi-state or regional in nature
Infrastructure Investment and Jobs Act - https://www.congress.gov/bill/117th-congress/house-bill/3684/text		

Integrated Research

WRAP Action Leader	WRAP Actions	Description
The Water Research Foundation (WRF)	7.2 Develop a Coordinated National Research Strategy of Water Reuse	**Develop a Coordinated National Research Strategy on Water Reuse** To best leverage water reuse research efforts, a coordinated national water reuse research strategy to develop a nationwide water reuse research roadmap. It will include a prioritized list of research needs across various water reuse applications and sources of water for potential reuse, including those specific through public input. The Scope of Work for WRAP Action 7.2 can be access at: https://www.epa.gov/system/files/documents/2022-07/Attachment%20C_WRAP%207.2%20Scope%20of%20Work%20June%202022_508.pdf
U.S. Environmental Protection Agency (EPA)	7.5 Coordinate and Promote Water Reuse Technology in Federal Small Business Innovation Research (SBIR) Programs	**Coordinate and Promote Water Reuse Technology in Federal Small Business Innovation Research (SBIR) Programs** This action seeks opportunities to optimize water reuse technology development and commercialization through Federal Small Business Innovation Research (SBIR) solicitations. Past and current water reuse projects funded through SBIR are evaluated technology gaps and help inform development of common language for reuse technology priority areas for SBIR solicitations. Information on SBIR projects, including those benefiting agriculture directly, can be accessed at: https://www.epa.gov/system/files/documents/2022-07/Action%207.5%20Coordinate%20and%20Promote%20Water%20Reuse%20Technology%20in%20Federal%20SBIR%20Programs.pdf.

Integrated Watershed

WRAP Action Leader	WRAP Actions	Description
US EPA	1.1 and 1.4 Federal Policy and Programs in Support of Water Reuse at the Watershed Scale	**Develop and leverage Federal Policy and Water Partnership Programs to Support Water Reuse and Integrated Water Resources Management (IWRM) at the Watershed Scale** A federal policy for integrating water reuse into water management at watershed scales is being developed and will unify the disparate federal programs and clarify policy to encourage water reuse practices across a range of industries, including agriculture. To maximize economic, social, and environmental benefits in an equitable and just way, the EPA is leveraging strong partnerships and integrated management approaches between multiple stakeholders to support local needs. Promoting Water Reuse through Partnership Programs: https://www.epa.gov/sites/default/files/2021-04/documents/wrap-partnerships-action-uw-and-nep-inventory-report.pdf
WateReuse; Environment Council of the States (ECOS); Pacific Institute; EPA; FDA; University of Arizona; USDA	1.2, 1.5, 1.6 Real-world strategies to support and address barriers to water reuse	**Prepare and Disseminate Case Studies to Promote, Support, and Provide Solutions to Overcoming Barriers to Water Reuse** Examples of successful projects can facilitate and advance adoption of water reuse by sharing lessons learned, innovative strategies, unique partnerships, and highlight multiple benefits that extend past water quality and quantity. Compilations of successful examples will include: • Projects using an Integrated Water Resources Management (IWRM) Framework • Solutions through low-input, low-cost, and simple technologies to meet local water needs – especially relevant to small and rural communities ○ Small irrigation systems using municipal recycled water; On-farm treatment technologies

		• Innovative and unique approaches to overcoming a range of impediments to agricultural reuse including regulatory, societal, and institutional barriers
Pacific Institute; EPA; FDA; University of Arizona; USDA	1.6 Address Barriers to Water Reuse in Agriculture	**Address Barriers to Water Reuse in Agriculture Through Improved Communication and Partnerships** Guided by stakeholder engagement and previous research, technical guidance, communication, and outreach materials will directly contribute to advancing agricultural reuse. The tailored guidebook and accompanying profiles provide growers, water utilities, irrigation districts, and regulatory agencies with real-word approaches to develop or expand robust water reuse programs. Guidance includes how to: • Leverage innovative, unique, and actionable strategies to overcome a range of impediments • Identify and engage with a range of stakeholders, including those not traditionally recognized • Discover multiple benefits that can reveal additional partners and financing opportunities • Find, access, and stack funding opportunities - including state and federal funding, cost-shares, and seed funding

Additional Strategic Themed Areas

Agency	Action Number & Title	Description
U.S. Environmental Protection Agency (EPA)	International Collaboration 11.3 Develop and Highlight Case Studies Relevant to the Water in Circular Economy and Resilience (WICER) Framework	Underserved communities in the United States and middle-income countries can benefit from exchanging examples of innovative water reuse solutions that reflect their shared experiences. The World Bank developed a streamlined approach for preparing water reuse case studies from around the world as part of a new Water in Circular Economy and Resilience (WICER) framework. This action leverages the resources of the World Bank and EPA to develop case studies tailored to the needs of underserved Americans and similar international communities, focusing on financial, institutional, and policy aspects for centralized and decentralized water reuse systems. **List of water reuse projects (2021)** - https://www.epa.gov/system/files/documents/2022-02/action-11.3-milestone-1_water-reuse-projects.pdf Agricultural water reuse case studies
Compile Existing Fit-for-Purpose Specifications	Science and Specifications 3.1	The REUSExplorer tool compiles existing fit-for-purpose specifications (e.g., chemical and microbial) for different sources of water for potential reuse and end-use applications. This compilation relies on federal, state, and international sources to inform water reuse best practices and facilitate broader implementation of reuse projects. The tool was launched in January 2022, and the first set of end-use content is accessible online here. https://www.epa.gov/waterreuse/national-water-reuse-action-plan-online-platform?action=3.1

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