OVERCOMING WATER SCARCITY FOR A MORE SUSTAINABLE FUTURE: NAVIGATING BARRIERS AND CREATING SOLUTIONS TO IMPLEMENT WATER RECYCLING

by

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(Under the Direction of Laurie Fowler)

ABSTRACT

As water scarcity is increasing worldwide, the recycling of wastewater is essential to maintain water resources for human use and ecosystem health. Despite the success of specific water recycling projects across the globe, the practice is still not widespread and in only a few cases, is water recycled for drinking, or potable use. When decision makers are considering whether to adopt water recycling practices, they must consider many interconnected factors including public support, state and local policies, costs, infrastructure and technology requirements, and environmental impacts. In this dissertation, I focus on expanding knowledge regarding barriers to water recycling and methods to overcome them. An analysis of state water recycling policies resulted in recommendations to decrease consumer perception of risk and mistrust in utilities through the adoption of particular legislative provisions. A consumer choice survey investigated the willingness to pay of consumers for recycled water based on terminology. 'Purified water' was found to be the most preferred term, generating the highest willingness to pay scores, and should be used in policy documents as well as outreach programs to cultivate public acceptance. Finally, an assessment of environmental impacts of the forms of recycling (nonpotable, indirect potable, and direct potable) utilizing case studies found that all resulted in decreased nutrient discharges into the environment, nonpotable recycling showed no significant increase in water depletion, and there were mixed results for energy consumption. These results, which address previously untested hypotheses, increase the knowledge available to decision makers in overcoming barriers to water recycling.

INDEX WORDS: Water Sustainability, Water Recycling, Environmental Policy, Public Perception, Environmental Economics

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Water is the most important resource for life on this planet. Access to water, however, is variable. While water is a renewable resource, it is not evenly distributed through space and time. We are currently experiencing unprecedented droughts in the western United States at the same time that Southern India is faced with devastating monsoons [1]. This variability, coupled with increasing scarcity due to climate change and population growth, leads to 3.6 billion people worldwide living in areas that are water-scarce at least one month per year. This number is projected to increase to approximately 4.8–5.7 billion in 2050 [2–4]. Additionally, developing nations are often overlooked in assessments of water scarcity and plans to increase water resource access and sustainability [5]. Human water scarcity and threats to biodiversity are linked, but in many cases, mitigation is focused on increasing water supplies for human uses and ignoring the impact on ecosystems [6].

Water withdrawals for consumptive use are shown to decrease in-stream flows which can lead to decreased species richness and increased pollution [7–9]. Dramatic changes in flow rate are additionally impacted by wastewater effluent, especially in intermittent streams and drought-prone areas where flows are sometimes comprised of up to 100% discharged effluent [10,11]. Increasing water pollution not only negatively impacts ecosystem health, but also decreases the availability of water resources for human consumption [12]. Globally, over 80% of wastewater is released into the environment without undergoing any treatment, causing widespread pollution [13]. While in developed countries, most water discharged into the environment is regulated to some extent, permits are often set at levels which do not successfully protect the environment [14]. Even when regulations have sufficient protections for the environment from a single discharge, releases of low levels of contaminants into the environment over time and from multiple polluters can cumulatively have large negative impacts on ecosystem health [15–18]. Effluent treated to below dangerous limits of contaminants still differs drastically from the pre-use environmental conditions and can have severe impacts on the ecology of the system [10].

With increasing demand and decreasing supply of water for consumers coupled with negative environmental impacts that often result in stricter regulations of water withdrawals, communities are widely implementing conservation strategies. However, in many cases increases in demand outpace the potential water savings of conservation [19]. Additionally, the extent to which water conservation strategies expand resource supply is varied, and many result in no change or even in increased water consumption [20–23]. For example, a study investigating the impacts of subsidies to incentivize use of more sustainable drip irrigation as a replacement to flood irrigation showed no decreases in water depletions [20]. Increasing supply by building a storage reservoir or importing water can be successful in some areas but is costly and rarely an option for utilities, especially in developing nations and rural communities. Water recycling, however, has the potential to both increase water resources for human use and decrease contaminant release into water bodies, thereby decreasing negative environmental impacts. Water recycling is defined as the intentional capturing of wastewater or greywater for beneficial use as a freshwater source for industry, agriculture, or residential uses [24]. Despite the human and environmental benefits, water recycling is minimally implemented worldwide.

Significant research has been done investigating the potential barriers to water recycling that limit its implementation which include the ‘yuck factor,’ perception of risk, cost increases, and mistrust in utilities [25–29]. These barriers are impacted by many factors including socio-economic variables such as gender, income, and education, and the level of contact consumers have with the initial use of the recycled water, before it was reclaimed, both real and perceived [26,30–32]. There are three main categories of recycled water, nonpotable, indirect potable, and direct potable, each of which have different barriers to implementation. Nonpotable water is not suitable for drinking but is used in irrigation and industry. Indirect potable and direct potable recycled water are both of drinking water quality, the difference is in the treatment process. Indirect potable recycling utilizes an environmental buffer in the treatment train, such as a reservoir or groundwater aquifer, before it is reused while direct potable recycling does not.

Much of the research focuses on the physical implementation of water recycling and overcoming issues of contamination and safety [33–37]. Emerging contaminants have additionally become the focus of significant research due to the potential concentration of these contaminants in recycled water coupled with insufficient monitoring requirements [37–45]. Some studies identify how targeted public outreach campaigns can contribute to the successful adoption of a water recycling project [35,46–51]. This dissertation aims to investigate overcoming public perception barriers to water recycling through policy and economic analysis. It also evaluates the ecological benefits of different forms of water recycling.

My dissertation combines a policy review and analysis, consumer surveys and case studies to investigate how municipalities can overcome barriers to water recycling. I begin in Chapter 2 which focuses on implementing state water policies to overcome perceived risk with the consumption of recycled water. This study summarized the water recycling policies in the 15 states in the United States that have addressed this issue with a goal of determining those strategies commonly used in successfully implemented policies. Recommendations for the state of Georgia are designed to assist Georgia and other states in their development of state policies. Chapter 3 investigates the impact of recycled water terminology, cost, and water restrictions on the acceptance of recycled water. A survey was completed in four communities in the United States to understand consumer willingness to pay based on these factors. Finally, Chapter 4 compares the environmental impacts of different forms of water recycling to assist decision makers in determining which best fits their goals. Using case studies from municipalities that have implemented nonpotable, indirect potable, and direct potable recycling I determine the impacts on the environment of water withdrawals, contaminant release, and energy usage.

CHAPTER 2

AN ANALYSIS OF AND RECOMMENDATIONS FOR COMPREHENSIVE STATE WATER RECYCLING POLICY STRATEGIES IN THE U.S.[1]

[1] Hopson, M. and L. Fowler. Accepted by *Resources, Conservation and Recycling.* Reprinted here with permission of the publisher.

ABSTRACT

To combat increasing water scarcity, many U.S. communities are considering potable water reuse to expand water supplies. Negative public perceptions, however, have been shown to inhibit the implementation of recycling projects. Our analysis was initiated in response to a request by the water reuse committee of a water utility organization in the U.S. state of Georgia who believe that comprehensive state water recycling legislation will contribute to public support for potable reuse. Because no guidance otherwise exists, the managers asked us to review the legislation enacted by other U.S. states to recommend elements appropriate for adoption in Georgia. We analyzed the laws of the fifteen states which have enacted comprehensive water recycling legislation to determine how they addressed these elements and to recommend those policies we found most likely to assuage public concerns. These include involving both the state health and environmental agencies in developing and implementing recycling regulations, streamlining and simplifying the permitting process to combine wastewater treatment and reuse permits, and requiring utilities to develop outreach programs for consumers of recycled water. Strategies we did not anticipate but found noteworthy and included in our recommendations were appointment of a diverse group of stakeholders to contribute to legislative and regulatory drafting, holding public listening sessions during the drafting process, and requiring utilities to consider reuse as a supply option in their ongoing planning. As Georgia and other states consider the adoption of water recycling legislation, they should consider these recommendations to assure the public that the practice is safe and may play a critical role in providing for resilient water supply and environmental protection.

INTRODUCTION

Water is necessary for all living beings to survive, yet it is a finite resource. The amount of water on earth and in its atmosphere is constant and cycles through environmental and human systems. The amount of freshwater, which is most often used to meet human demands, is miniscule, 22,300 cubic miles of water which is only 2.5% of the total global water [52]. As the human population continues to grow, so does the strain on water resources. Consequently, communities across the globe are turning to water recycling, or the treatment of previously-used water for subsequent use in the same geographic area. Water recycling can substantially reduce the amount of water a community withdraws from rivers, lakes, and groundwater aquifers, thus protecting environmental health and instream uses such as ecological habitat and human recreation [53–55].

Despite the numerous benefits to humans and the environment from water recycling, there are still relatively few water recycling projects underway, with only five direct potable reuse projects in place globally [56]. Current barriers include cost, technology requirements and negative public perceptions of the practice [55,57]. Many dislike the thought of drinking and bathing in water that was previously used; this is called the "yuck" factor and is closely related to the public's concerns about the risk of consuming recycled water and their mistrust of water utilities [27,58–63]. Negative public perceptions have stopped water recycling projects from being implemented in communities around the world [64].

A potential method to address and eliminate the barrier of negative perception is adoption of state recycling legislation that promote potable reuse and assure its safety, and public knowledge of these policies has been shown to have a large impact on support for recycling [65]. A study investigating perceptions in Perth, Australia found that the source of concerns for a significant number of individuals who were unsure of or did not support water recycling was their uncertainty about treatment standards [66]. In Arizona, research showed that individuals who did not think regulations assured the safety of reclaimed water were the least likely to approve of potable water uses such as cooking or drinking [67]. Additionally, a recent unpublished survey in the United States showed that over 57% of respondents indicated that they would be more comfortable drinking recycled water if governmental policies provided oversight of water quality and use [68].

In the United States, the Safe Drinking Water Act and the Clean Water Act are the federal laws that mandate water quality standards for the protection of public health and the environment, yet they do not specifically address the issue of water recycling. The Safe Drinking Water Act requires that all potable water meet drinking water standards, but it does not address the unique characteristics of recycled water. Recycled water oversight through traditional drinking water standards is often not adequate to assure the public of recycled water safety [35]. There does not appear to be any attempt by Congress to address these issues at the federal level any time soon. Therefore, it is up to the individual state governments to develop water recycling policies to promote the practice, ensure that reclaimed water is treated appropriately for specific uses, and thus assure the public that water recycling is no threat to human health or the environment.

One of the first questions a state considering drafting water recycling legislation will ask is how other states approach the issue. Recognizing this, the U.S. Environmental Protection Agency's (EPA) *National Reuse Plan Draft* released in 2019, specifically lists among its highest priority actions to support the consideration of water reuse, the compilation of state policies and approaches to implement water reuse programs (Action 2.2.1) [69]. The January 26, 2022 update on the progress of the plan's recommended actions states that "work has begun to compile and organize state policy and regulatory documents" [70]. Neither the EPA nor any other entity has subsequently published this compilation or analysis, however, prompting this study as a first step.

This analysis was initiated in response to a request by the water reuse committee of a water utility organization in the state of Georgia who believe that comprehensive state water recycling legislation will contribute to public support for potable reuse. To date only fifteen states have enacted laws comprehensively addressing water recycling [71]. We analyzed this legislation as described in the methods section below, then specifically discussed our findings element by element. We identified specific approaches that are likely to allay public concerns about reuse and incorporated these in our recommendations for states who are considering drafting legislation. To address the initial request from the Georgia water reuse committee, we note specific recommendations for the Georgia legislature where warranted.

METHODS

For purposes of this report, we use "recycled" and "reused" water interchangeably to refer to treated domestic wastewater that is used, treated, and then used again, potentially more than once, before it passes back into the water cycle. Reclaimed water is previously used water that has been treated to recycled water quality but has not yet been reused [72]. Direct potable reuse is the introduction of reclaimed water directly into a drinking water plant. Indirect potable reuse is deliberate augmentation of a drinking water source such as a river or lake or an aquifer, which provides an environmental buffer prior to subsequent treatment and use as drinking water. Nonpotable use is recycled water that is not of drinking water quality but is suitable for other uses such as irrigation and industrial uses.

To determine which states have enacted comprehensive water reuse legislation, we first researched the publicly-available policies of all of the states listed in the *EPA 2017 Potable Water Compendium* as having addressed potable reuse: Arizona, California, Florida, Hawaii, Idaho, Massachusetts, Nevada, North Carolina, Oklahoma, Oregon, Pennsylvania, Texas, Virginia, and Washington [71]. To ensure that no policies had been overlooked, we used the Westlaw search engine to identify all state legislation that referenced "water recycling" or "water reuse"; the results disclosed Colorado as an additional state which we incorporated in our review. EPA's 2021 update of the Potable Water Compendium added Montana and New Mexico as having adopted recycling legislation. From this combined list of 17 states, we removed Pennsylvania and Montana because they have not actually adopted recycling legislation, only regulatory water recycling criteria documents [73,74]. While these documents facilitate water recycling, they were beyond the scope of this study which focuses on legislation.

All water recycling legislation, regulations, and guidance documents were investigated and summarized; see the supplementary material. To determine trends and commonalities between the state laws we started with a list of elements that we determined were critical to the public perception issue and were likely to be addressed in each state's legislation: legislative goals, agencies responsible for oversight, types of recycling allowed and associated water treatment criteria and permits required. At the suggestion of the Georgia water reuse committee, we added to this list the states' treatment of liability and references to funding. We identified all elements of each state's legislation, isolated those elements that were common to more than one state, including those on our list, analyzed the individual approaches taken and noted other significant attributes of the legislation. Based on this analysis, we made recommendations for states contemplating the drafting of comprehensive water recycling legislation and noted any advice specific to Georgia.

RESULTS AND DISCUSSION

Even in the absence of express state recycling legislation, current drinking and wastewater regulations may allow for some recycling. For example, in Georgia gray water recycling is allowed in the state health code. “Guidelines for Water Reclamation and Urban Water Reuse,” a guidance document issued by the state environmental agency, allows for nonpotable reuse for irrigation and industrial processes [75]. Gwinnett County has implemented both an indirect potable recycling system and a direct potable recycling pilot project. However, water managers in the state are interested in expanding recycling, and potable reuse specifically, and are calling for the adoption of comprehensive state legislation to legitimize, facilitate and promote the practice. As a first step, they are looking at other states for legislative models. We present and discuss our findings thematically below.

Legislative Goals and References to Potable Reuse

The first step for most states is outlining their intentions regarding water recycling. An explicit description of the purpose of the legislation explains to the general public why increasing water reuse is important to the state. Four of the states we analyzed (California, Colorado, Florida, and Washington) expressly described their commitment to water recycling which sends a strong signal for support. These states specified compelling goals including decreasing pressures on potable water supplies, protecting ecosystem health, conserving water resources, and meeting future water needs. For example, the California legislature states “It is hereby declared that the primary interest of the people of the state in the conservation of all available water resources requires the maximum reuse of reclaimed water in the satisfaction of requirements for beneficial uses of water" [76]. The use of the term 'beneficial' reuse indicates that recycling will be approved only to support specific goals such as water source sustainability and conservation. For example, the WateReuse organization, a national group comprised of water utilities, businesses, government agencies and nonprofit organizations that is focused on increasing usage, policies, and acceptance of water recycling, defines beneficial reuse as "the use of reclaimed water for purposes that contribute to the water needs of the economy and/or environment of a community" [72].

Recommendation Be clear in communicating that recycling is in the public interest of the state and specify the anticipated impact of recycling; providing adequate clean water for beneficial uses, protecting instream uses for aquatic health and recreation, and promoting resilience are goals that should resonate among all states. The Georgia legislature might specifically mention the contribution of recycling in providing for reliable water supply in a time of increasing droughts as this has been an ongoing concern and subject of substantial litigation in recent years [77].

Stakeholder/Public Involvement in the Development of Regulations and Permit Issuance

Common sense suggests that the best way to allay public concerns is to give the public an opportunity to express these concerns and to involve them, and representatives they trust, in developing policies to address them. Providing for this input imparts important information to the state, while increasing public trust in the legislative and regulatory process. It also promotes public participation and awareness of water resources, determined to be key factors in the success of water recycling projects [27,28,78]. To this end, and to encourage buy-in of all affected participants in the recycling chain, two states (Washington and Arizona) established advisory committees. Arizona's Blue Ribbon Panel on Water Sustainability was convened in

2009 by the Governor and included a broad range of members including industry, agriculture, community leaders, scientists, and agency members. This stakeholder group recommended changes in policy and practices to optimize water recycling. Specific recommendations included decreasing permitting redundancy, creating a state training and certification program for the operation of reuse systems, increasing incentives for recycling through tax exemptions and credits and increasing education and outreach [79]. Public listening sessions for these recommendations were held in 2015 and 2016 which led to rulemaking in 2018 that included the removal of the state's prohibition on direct potable reuse [80]. Washington's advisory board included a broad range of stakeholders that utilize or might be impacted by the use of reclaimed water along with individuals with technical expertise and knowledge of new advancements in technology [81]. This combination of individuals helped ensure protection for the environment and human health in addition to increasing public support through their involvement. Additionally, Oklahoma's "Water for 2060 Advisory Council" was created in 2012 to recommend incentives to increase water conservation, including the use of water recycling and reuse systems, to meet the ambitious end goal of consuming no more freshwater in 2060 than they did in 2010 [82]. Soliciting input from an advisory committee that includes leaders of diverse interests to assist with the development of reuse policy increases both the likelihood of a more well-informed policy due to more experience at the table and also its successful passage through the legislature [78]. States promote public engagement in recycling projects through other routes as well. For example, Massachusetts requires utilities to provide an education program to inform residents, users, and contractors that may encounter recycled water about the use of the water and any relevant safety concerns [83].

The federal Clean Water Act provides for opportunities for public involvement in the issuance of all NPDES wastewater discharge permits by the states and EPA. To further include the public in decision-making, three states (California, Massachusetts, and Washington) have enacted policies requiring public notification, hearings, and the opportunity to comment on applications for specific recycling projects. Evidence supports the fact that diverse stakeholder participation can increase the quality of environmental decision making [78].

Recommendation: Establish an advisory board representing diverse interest groups to identify barriers to reuse and strategies for overcoming them through policy initiatives. The state should directly provide for meetings around the state, as well as the opportunity for written comment, so the public may share their concerns with the advisory committee before it finalizes its recommendations.

In the case of Georgia, where recycling legislation has been introduced in past years but not passed, or in other states where the route to passage is not clear, the appointment of an advisory board in the form of a legislative study committee to provide guidance in initial legislative drafting, is particularly relevant. The legislature may elect to create the legislative study committee one year and wait until the next year to draft comprehensive water recycling, after it hears from the advisory committee as well as the public. This would alleviate unforeseen political roadblocks that might derail passage of initial legislation and allow for a more informed exploration and discussion of each potential legislative element before a more comprehensive bill is introduced the following year.

Responsible Agencies

Among the many reasons state agencies are charged with oversight of recycling projects is to assuage any mistrust the public might have of their local utilities and ensure public and environmental health and safety. It should be noted that citizens may not trust their local governments or utilities for a variety of reasons totally unrelated to reuse practices, yet this distrust is a large impact on consumer support for recycling. There are two state agencies that are assigned responsibility for oversight and enforcement of water recycling policies in the states we analyzed: either the environmental protection agency, the public health agency, or both. For ten of the fifteen states, the environmental protection agency or its water management division is responsible (Figure 2.1). Two states assigned responsibility to the health department, two states assigned it to both the environmental protection and health departments and one state assigned it to the environmental protection agency with input from the health department. Allowing for shared, but clearly defined, roles facilitate the protection of public health as well as the health of the environment by requiring communication and collaboration between the two agencies. This should reduce the public's perception of risk.

Providing primary recycling oversight to the same agency which issues permits for wastewater discharge, drinking water, and water withdrawal takes advantage of the agency's institutional expertise and existing relationship with the major players. It simplifies the process, particularly where multiple permits are required, and allows for easy communication. Most states assign authority for issuing permits to the same agency which establishes regulations on allowed uses, water treatment criteria and treatment requirements. The exception is California where the environmental protection agency issues permits, and the health department develops regulations. It is notable that in Washington, the Department of Agriculture was explicitly charged with providing technical assistance in developing regulations and guidelines [84]. This agency's inclusion is particularly useful to promote and safeguard nonpotable reuse for irrigation purposes. In California, a Memorandum of Agreement was developed between the Department of Health Services, the State Water Resources Control Board and the Regional Water Quality Control Boards to define their responsibilities and to promote future collaboration and coordination [85].

The state oversight agency has the authority to impose management, monitoring and reporting requirements on the recycling entity. Arizona, for example, requires the Department of Environmental Quality to design and conduct specific training and certification programs for recycling operators [86].

Recommendation: Assign primary responsibility to the agency that regulates wastewater treatment with input from the public health agency. Recruit technical assistance from the state agriculture department in developing nonpotable irrigation reuse guidelines. Where multiple state and regional agencies play critical roles, consider using a Memorandum of Agreement to facilitate coordination.

Permit System

The number and types of permits required for water recycling vary among states. Most require multiple permits if the entity treating the reclaimed water is also a wastewater treatment facility that discharges effluent: one permit for the quality of the discharge water and one for the quality and usage of the recycled water. Additional permits are sometimes required such as in Colorado which requires the users, in addition to the recycled water providers, to apply for permits to utilize recycled water, or Idaho, which requires an additional permit from the agency responsible for groundwater regulation. Redundancies in permitting can be a barrier to the implementation of holistic management of water systems, of which recycling is an integral component in many locations. States such as Florida and Washington streamline and simplify the permitting process by limiting the number of permits required. Florida specifically combines wastewater and recycled water permits if they occur at the same facility. These combined and streamlined permit systems can decrease confusion of both recycled water providers and consumers. It should be noted that to this end, EPA is in the process of developing guidance to inform state wastewater permitting agencies about water reuse and allow them to consider and implement reuse practices within their existing NPDES authority [69].

Two states do not have specific permit application forms for water recycling and instead require a letter to be submitted to the overseeing agency which is responsible for issuing written approval for the project.

Recommendation: Combine reuse permits with drinking water and/or wastewater treatment discharge permits (whichever is appropriate) to eliminate redundancies, confusion, and unnecessary costs.

Categories of Recycled Water and Water Treatment Criteria

Eleven states use a system in which they designate categories that include several allowed uses for recycled water and develop water treatment criteria and requirements for each category. Arizona, for example, has five categories of water quality assigned alphabetical letters with “A+” being the highest quality and “C” being the lowest quality and each includes corresponding allowed uses, water quality criteria, and treatment requirements [87]. Many states, including Arizona, specify that uses not specifically listed under a category may be considered on a case-by-case basis by the agency overseeing the recycling permits.

The number of categories is assigned by the states, from two to five categories. The fewer categories used, the greater the likelihood that reclaimed water may be treated to a higher level than is necessary for a given use, decreasing efficiency and cost-effectiveness [88].

Water treatment criteria established by most states include monitoring and treatment standards for some or all of these elements: turbidity, total suspended solids, biological oxygen demand, fecal indicator bacteria, or total coliforms (Figure 2). The Environmental Protection Agency (EPA) recommends testing for disinfection efficiency, suspended and particulate matter, and organic matter, which most states require [89]. Measuring disinfection efficiency includes monitoring viruses or bacteria, measuring suspended and particulate matter includes monitoring total suspended solids or turbidity, and measuring organic matter includes monitoring carbonaceous biological oxygen demand, biological oxygen demand, or total organic carbon. Multiple states including North Carolina require monitoring of an indicator virus due to their higher resistance to treatment which can indicate contamination that is not shown with bacterial monitoring alone [90]. Utilizing criteria already measured for drinking water and wastewater treatment will decrease the cost of implementing new treatment practices, and when possible, these should be utilized, and the required levels adjusted for different recycled water uses. Evidence has shown that increased monitoring of contaminants decreases the perception of risk by consumers, can increase their willingness to use recycled water, and can support municipal project implementation [33,91].

Recommendation: Develop criteria for constituents specifically recommended by EPA in the forms currently required of wastewater and drinking water monitoring: fecal coliforms, turbidity, total organic carbon, residual chloride, biological oxygen demand, and pH with the addition of indicator virus and nutrient monitoring. Solicit input from the state advisory committee or the heads of the state’s water, environmental protection and public health departments to determine the appropriate number of water use categories to adopt, balancing efficiency and flexibility concerns with the protection of human and ecosystem health.

Mandates to Evaluate the Potential for Recycling

Legislation in four states requires the consideration of reuse in planning efforts. California, Hawaii, Florida, and Oregon require entities to conduct feasibility studies on reuse as a part of mandatory water management plans; these entities include urban water suppliers, counties, district governing boards, water suppliers of a certain size, or wastewater users in water stressed areas. In Oregon, if the feasibility study shows that reuse is economically, ecologically, and technologically possible, the decision not to implement reuse requires an explanation to the governing agency. In addition to requiring a consideration of water recycling feasibility in required regional planning, Florida mandates a reuse feasibility study to accompany any wastewater permit application in those parts of the state which are designated Water Resource Caution Areas where existing water sources are not sufficient to meet projected demand in twenty years; most of the state falls within these areas. The feasibility study must evaluate the financial costs and benefits of recycling, potential water savings, environmental and water resource benefits, constraints and an implementation schedule. If the study determines that recycling is feasible, wastewater treatment plant management must give “significant consideration to its implementation” [92]. Additionally, water management districts may require water users to utilize reclaimed water instead of surface water or groundwater when it is available, feasible and is of sufficient quality and quantity for the user’s needs [93].

A mandatory reuse feasibility study will increase the utilities’ and state’s understanding of barriers to recycling. This may lead to concerted efforts to overcome these barriers; it might also demonstrate that barriers are not as prolific as expected for some communities. In the case of potable reuse and the creation of a closed water system, the target users are drinking water facilities. Water recycling and drinking water treatment facilities are not always owned or operated by the same groups. To address this fact, California requires water suppliers to investigate the technical and economic feasibility of potential reclaimed water usage by consumers, including for potable water uses in their water supply plans[94].

The cost and effort required to conduct the feasibility analyses has the potential to be extensive, so funding and technical resources should be allocated by the state when possible. The legislature might task a state agency such as the environmental protection agency or the environmental financing authority to develop a template, including a list of resources that might be used to help the applicant undertake the analysis and to provide technical assistance to that end.

Recommendation: Require evaluation of the potential for reuse in permit applications for wastewater discharge and water withdrawals to include an economic and technological feasibility analysis and assessment of public support. Provide state financial and technical resources to assist.

Liability

Liability for the use of reclaimed water is a concern for recycled water users and treatment facilities due to perceived risk. If a treatment facility is to be held liable for damages that occur from the use of their water by individuals over which the facility has no control, it may be less likely to consider implementing water reuse. Only three of the 14 states specifically address liability in their regulations (Florida, Oklahoma, and Texas). One (Texas) assigns liability to the water treatment facility only if the water is not of the quality they reported it to be while liability for any damages that occur through the misuse of the water is assigned to the user. Similarly, Florida assigns all liability for water usage to the treatment facility unless the user is found to be negligent.

Recommendation: Legislators and other key stakeholders should assess different scenarios and be prepared to explain how current law and proposed legislation address liability; the Attorney General may help determine whether an express legislative statement regarding liability is needed.

Funding

Initial infrastructure and construction costs for reuse facilities can be a barrier to project implementation. As a result, many states provide funding to assist in financing water reuse projects. Funding includes specific programs created specifically for reuse projects (California and Hawaii) and more general programs to increase water conservation which include reuse projects (Florida, Oklahoma, and Oregon). The Florida Water Management District Governing Board created a Water Protection and Sustainability Program Trust Fund, using funds from state property tax collection, to provide financial assistance for recycling initiatives and other alternative water sources [95]. Sixty-five percent of the $100 million allocated funded the implementation of alternative water supply, including recycling, which generated 842 million gallons of "new" water per day. While the program was terminated via a standard sunset provision in 2009, the increase in water resources indicates the success of the program's goal. Oregon allocated $2 million in lottery funds to establish the Water Conservation, Reuse and Storage Investment Fund which can be used to pay up to $500,000 for feasibility studies for water reuse, conservation, or storage projects [96,97]. Additionally, federal cost-share, loan and grant programs including the Clean Water Act State Revolving Funds and the Water Infrastructure Finance and Innovation Act can be used to supplement state and local funding [98,99]. The EPA is working with states to clarify the extent of reuse projects' eligibility under these programs [69].

Recommendation: Provide access to appropriate state funds to pay for recycling projects and studies. The Georgia legislation might specifically clarify that communities may use the Special Purpose Local Option Sales Tax (SPLOST) program for this purpose; SPLOST is frequently used to fund local capital improvement projects [100].

Potable Recycling

We found that there were 15 states that required permits for nonpotable recycling and 12 that required permits for indirect potable recycling. There were three states that approved indirect recycling on a case-by-case basis compared to five for direct potable recycling. Out of the states studied, only Virginia specifically prohibits direct reuse while multiple others do not include specific direct potable reuse policies and instead require written authorization from the overseeing agency [101].

Water Rights Issues

Due to increasing water and scarcity concerns and the subsequent difficulty in procuring new withdrawal permits, particularly in the states operating a prior appropriation water rights regime, there are benefits to retaining wastewater specifically for future reuse rather than discharging it to the environment. The Arizona legislature allows such storage in groundwater aquifers. Reclaimed water dischargers are given credits which they can use to access water at a later date [102]. This allows for aquifer recharge which benefits the environment while also protecting the discharger's right to withdraw in the future. In addition, Arizona allows trading of the reserved groundwater withdrawal credits between users.

Using a river, lake, or aquifer as an environmental buffer, as in the case of indirect potable recycling, may be more acceptable to consumers than direct potable reuse which is still in early stages of adoption. If legislators, state agencies and utilities believe their citizens are not ready to embrace potable reuse, they should consider adopting water reuse legislation allowing for indirect and nonpotable reuse and calling for investigation of the potential for direct potable reuse. The legislation can be amended over time to allow for direct potable reuse. Arizona is an example of a state that used a phased approach; it enacted reuse legislation in 1985 which it updated twice, in 2001 and 2018, as a result of availability of new technology, improved understanding, and increasing water scarcity.

CONCLUSION

Water recycling, including potable reuse, is part of the solution to growing water scarcity around the globe, yet projects are difficult to implement due to negative public perceptions and financial constraints. State policies have the potential to address these concerns through the regulation of quality and use of recycled water and allocation of financial resources. Our work provides a framework for future potable water recycling legislation by highlighting common strategies of leading states and recommending specific provisions.

Our findings indicate substantial consistency in the components of state recycling legislation: the clear expression of compelling recycling goals, the designation of trusted state agencies to provide oversight on both the environmental and health aspects of recycling, the establishment of allowable uses, water quality criteria and permit requirements for recycling, and provisions for funding, though their treatment of these vary. Streamlining the regulatory process by giving the state environmental protection agency which already oversees wastewater permits and most other water management decisions oversight for reuse projects is important, but including the health department in specific areas, including the development of regulations implementing the legislation, is important to protect human health and satisfy public concerns. Several states address the issue of liability for damages incurred as a result of recycling.

Provisions for broad stakeholder and public participation in the development of policy and programs were included in some states' legislation; the literature shows this to be imperative to the implementation of water recycling. Many factors in both the legislative process and the elements of recycling legislation are dependent on state issues, so it is essential to understand and take these into account. For example, in Georgia, where recycling legislation has been introduced but not passed, the creation of a legislative study committee with diverse representation and provisions for hosting public listening sessions around the state, are particularly appropriate.

Future research should be conducted to investigate other aspects of the success of common policy strategies, including whether they result in an increase in the number of recycling facilities and projects in a state. Our prediction is that the adoption and implementation of comprehensive state water recycling policies as recommended above will provide the support communities need to implement water recycling to increase water supplies while protecting the environment.

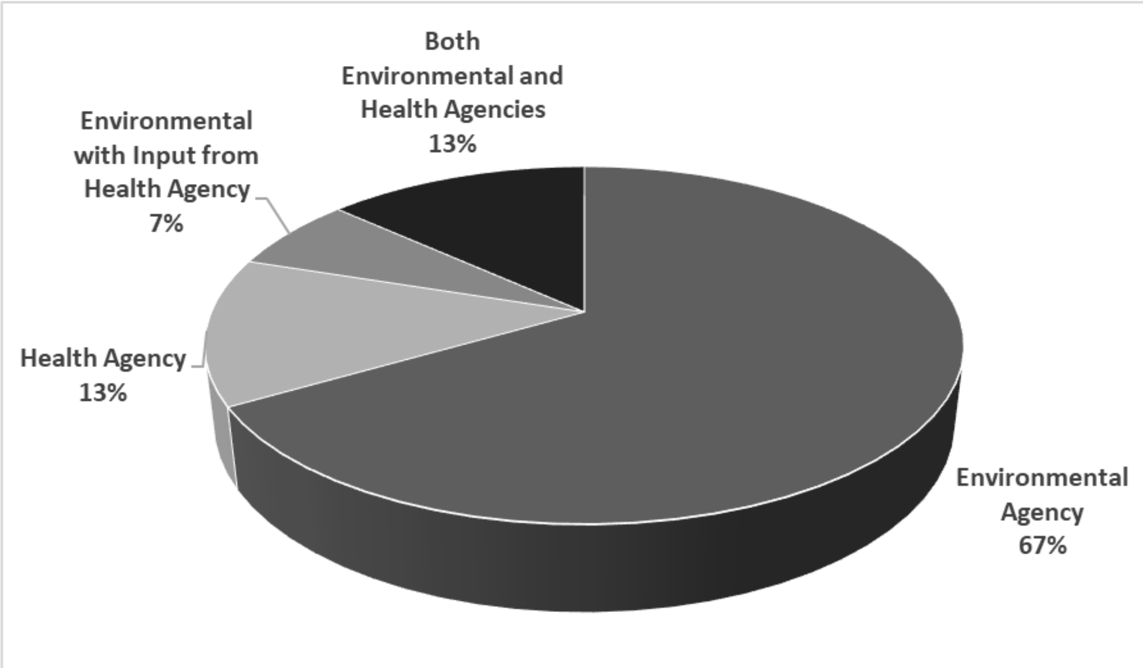

Figure 2.1: The state agencies responsible for regulating/permitting water reuse in the 15 states studied.

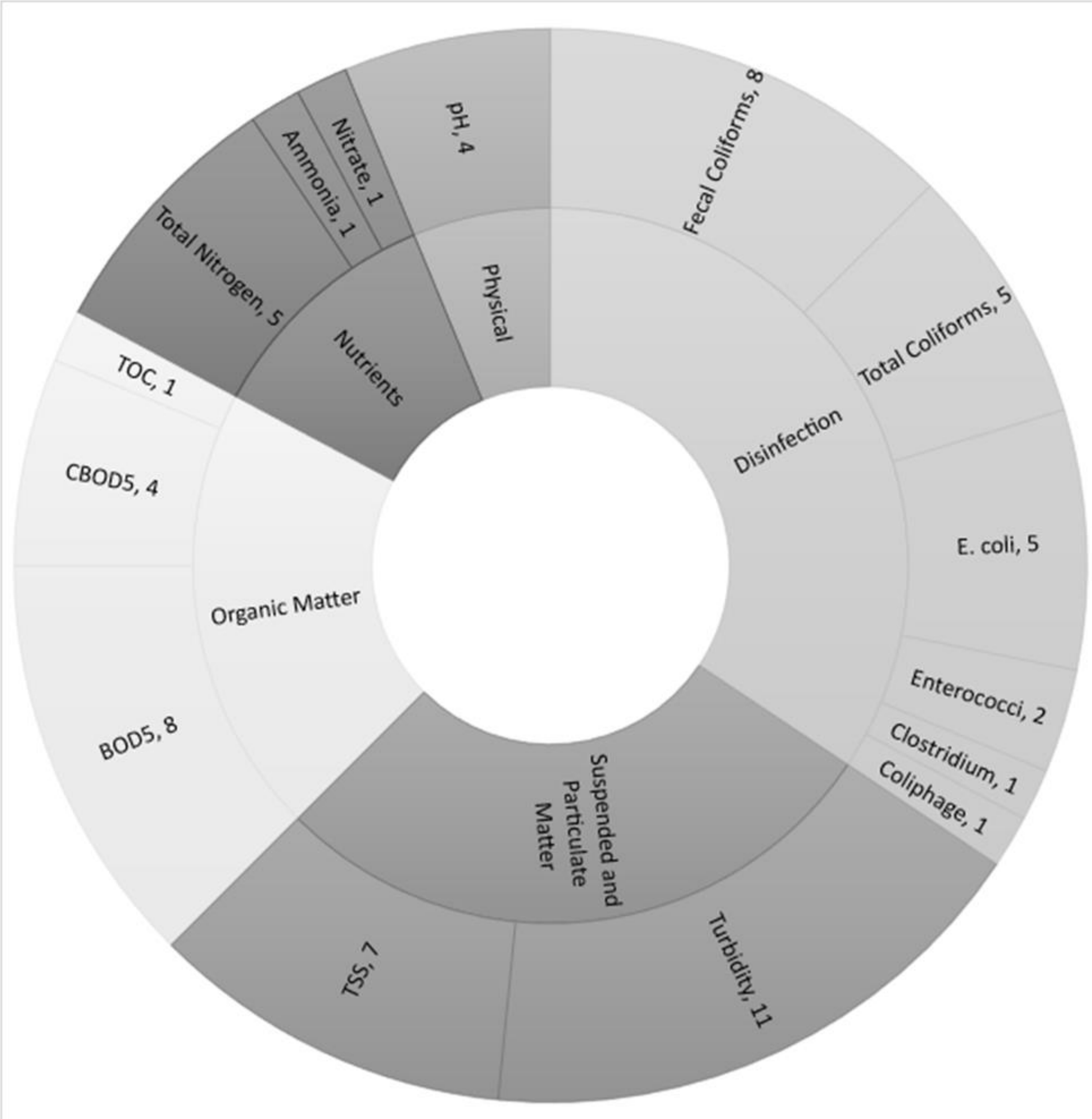

Figure 2: The constituents addressed by recycled water regulations in the states studied. The inner ring shows general categories of constituents, and the outer ring shows the specific constituents regulated and the number of states regulating each.

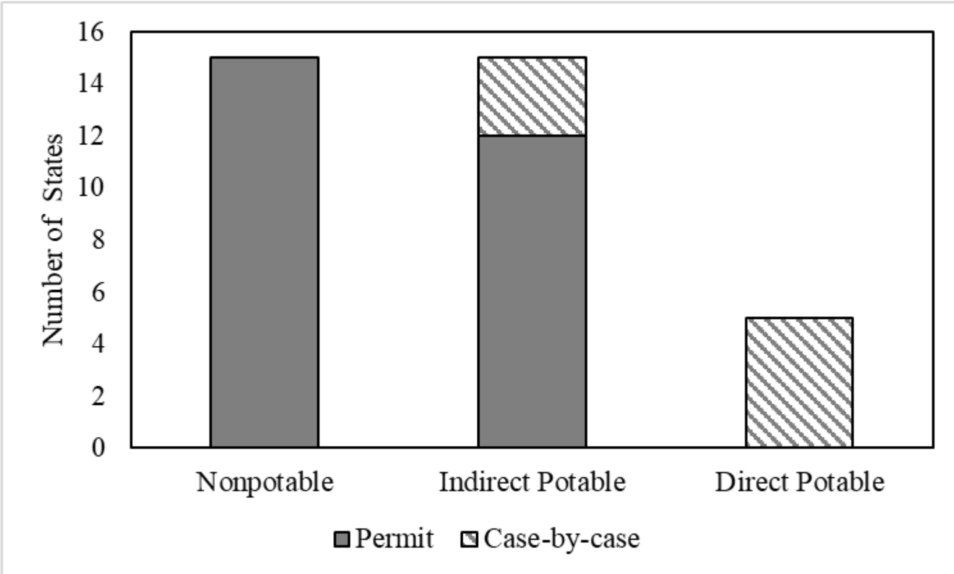

Figure 3: The number of states that require permit applications to approve water recycling (grey) and the number that allow recycling to occur on a case-by-case basis despite not having standard permits (striped) for each type of water recycling (nonpotable, indirect potable, and direct potable).

CHAPTER 3

IMPACT OF TERMINOLOGY AND WATER RESTRICTIONS ON CONSUMER WILLINGNESS TO PAY FOR POTABLE RECYCLED WATER IN THE U.S. [2]

[2] Hopson, M., G. Colson, J. Mullen, and L. Fowler. To be submitted to *Water Resources and Economics.*

ABSTRACT

Rapidly growing human populations are increasing the strain on water resources through increased demand and decreased supply, prompting many municipalities to consider water recycling. One barrier to the implementation of water recycling projects is the cost of water recycling, both for the municipality and the consumers. This research uses a consumer choice survey of 1000 individuals in the United States to evaluate consumer willingness to pay for potable recycled water, considering the impact of terminology ('purified water,' 'recycled water,' 'reused water,' 'reclaimed water' and 'treated wastewater') and future water restrictions. Analysis of survey responses calculated willingness to pay using mixed logit models. While the results show that restrictions do not have a substantial impact on willingness to pay, the impact of terminology is significant because individuals were not willing to pay as much for water with most of the alternative terms than for the status quo option. 'Purified water' was the only term that did not result in a significant decrease of consumer willingness to pay, indicating the potential for municipalities to avoid decreasing recycled water cost to offset negative perceptions and incentivize use. Shifting from the commonly used 'recycled water', a less preferred term, and towards 'purified water' should extend to common vernacular as a way to increase both consumer acceptance and willingness to pay. Terminology is an important factor to utilize in public communication and policymaking to increase willingness to pay for potable water recycling and therefore the potential for successful project implementation and the future protection of water resources.

INTRODUCTION

Water scarcity threatens the security of communities worldwide and is increasing at an alarming rate. Two-thirds of the world's population live in areas with severe water scarcity at least one month of the year [4]. Rapidly growing human populations increase the strain on these stressed resources through increased demand and decreased supply caused by deteriorating water quality [103–105]. Droughts and other climate change impacts exacerbate the issue [106–108]. Additionally, economic water scarcity, where water resources are available but human populations lack the financial ability to develop infrastructure for water distribution, is a wide-spread problem [104,109]. Organizations around the globe are investing in water recycling, the act of treating water that has been used previously to be used again in the same geographical area, to increase water availability and stability.

Increasing the number of successful water recycling projects is imperative to assure adequate supply for humans and ecosystems, yet many barriers exist that limit the practice. One of these barriers is the cost of water recycling, both for the municipality and the consumers. The cost that consumers will be required to pay can impact their level of support for a project, regardless of whether the potential cost increase is real or perceived [110]. Treating wastewater for reuse often requires expensive infrastructure, for which consumers expect to pay [111,112]. Many utilities consider decreasing the cost of reclaimed water to incentivize use, especially to offset the negative perceptions that often accompany recycled water, and it has been shown that financial incentives and decreasing monthly bills can increase acceptance of the practice [110,113–115]. However, a price set too low can incentivize overuse by consumers, contrary to the goal of water recycling, which is to increase water supply without depleting resources [112]. Additionally, utilities must ensure that they cover costs.

Significant research has been conducted investigating consumer support and willingness to pay for nonpotable water, or water that is not of drinking water quality and instead is used for irrigation and industrial uses [116–119]. Factors that impact willingness to pay for recycled water are numerous and often interrelated, including socio-economic factors, knowledge, and perceptions [117,120]. The distance between the initial use and the use by consumers impacts the willingness of consumers to use recycled water [121,122]. It is well known that acceptance of recycled water decreases with increased human contact to the recycled water due to the perception of potential health risk and the 'yuck factor.' For example, nonpotable water for irrigation of golf courses and toilet flushing has been shown to have high acceptance by consumers, with a positive willingness to pay, although often lower than that of potable water [30,117,123–125]. Irrigation of produce for consumption, however, has been shown to have less acceptance and a lower willingness to pay [116,126]. Additionally, adding distance between the initial use and final use through treatment systems such as adding an environmental buffer where recycled water is released into the environment for 'natural treatment' can greatly decrease negative perceptions [62]. The impact of distance between initial use and final use of recycled water can extend beyond the physical distance and instead be based on the perception of that distance. In the water industry "reused water" and "tertiary treated wastewater" can be used interchangeably for the same quality of water, yet can result in significant differences in consumer acceptance. Words that are associated with the initial use, such as "treated wastewater," have been shown to create less public acceptance than words such as "purified water" that do remind the public of the previous use [30,118]. Changing the terminology is not changing the recycled water, only the consumer's perception of its quality and safety, and therefore their willingness to pay for it [118].

Perceptions of water scarcity have also been shown to impact consumer acceptance and willingness to pay for recycled water [110,127]. There are varied perceptions of water scarcity around the globe, which often do not match the actual scarcity of the area. For example, in the western United States, a highly drought-prone region, there is a common belief that water is not scarce [123]. In Canada, however, there is a common belief that water scarcity is increasing and therefore water restrictions will increase in the future, even with their abundant water resources [125]. Research is varied on whether consumers are willing to pay to avoid water restrictions [128,129]. However, awareness of water scarcity has been shown to increase the acceptance of water recycling and the public's willingness to pay for recycled water [25,125].

Significant research has been done to evaluate the impact of water scarcity and terminology on consumer willingness to pay for nonpotable recycled water. A study in Canada showed that individuals are willing to pay to use nonpotable recycled water to avoid water restrictions [125]. Another study in Crete, Greece, showed that farmers are more willing to utilize recycled water for irrigation if it is labeled 'recycled water' instead of 'treated wastewater' [118]. Utilities are often faced with decisions on whether to implement potable or nonpotable recycling, and the consumers' willingness to pay is an important factor in their decision-making. There has been no research, however, on the impact on potable water, or water of drinking water quality. Unlike many nonpotable recycling systems, potable systems often require extensive and costly infrastructure. While studies of consumer willingness to pay have compared some terms together, there have been no studies that investigate consumer perception and consumer willingness to pay for the range of terminologies studied here.

This research uses a consumer choice survey to evaluate consumer willingness to pay in the southern United States for potable recycled water, considering the impact of terminology, future water restrictions, and demographic factors. Based on the choices made by respondents, the willingness to pay for each attribute can be evaluated. We expect consumers of recycled water will to be willing to pay less for recycled water when it is labeled with terms that connect the water to its previous use and as we expect them to be willing to pay to avoid increased water restrictions increase.

METHODOLOGY

Data collection

A discrete choice experiment was used to measure consumers' willingness to pay for recycled water. Surveys were distributed in four cities in the United States in February 2022: Atlanta, Georgia; Denver, Colorado; San Antonio, Texas; and San Diego, California (Figure 3.1). These cities were chosen due to their geographic variability and presence of water scarcity and restrictions (Table 3.1). Online surveys were distributed through a platform service with compensation for responses and anonymous data results. Surveys were collected until the desired 1000 complete responses were compiled, with at least 250 responses per city. All respondents were required to be at least 21 years of age and live in one of the four selected cities.

Given the number of attributes (cost, terminology, and future restrictions) and levels in each attribute, which ranged from seven to nine, a fractional factorial design was used to minimize necessary responses (Table 3.2). Thirty-six choice scenarios (four blocks of nine scenarios) were generated using Ngene software (D-error of 0.0007). Each choice scenario consisted of three alternatives: a status-quo option and two alternatives consisting of combinations of water attributes. Additionally, the attributes of cost and restrictions were based on city-specific information, resulting in different choice sets based on the city of residence identified by the respondent [130]. While the displayed costs and restrictions were different between cities, the relationship to the status quo was consistent (Table 3.3).

To household preferences for alternative terminologies and types of water, the respondents were given three options of "Water delivered to your home would be." The first option (Option 1) was always the status quo, "The same water you receive now." The remaining terms were either "purified water," "recycled water," "reused water," "reclaimed water" or "treated wastewater". The second attribute, cost, was based on per person/per month values. This was determined using the average per gallon price for municipalities in the area, multiplied by the average usage per person based on 2010 USGS data[130]. That value was given for the status quo option for each city, with the remaining two options' costs as 60% more, 40% more, 20% more, the same, 20% less, 40% less, and 60% less than the average city water cost (Table 3.2).

The third attribute, restrictions, was provided to respondents using a graph with one bar displaying the current restrictions and the other bar showing future water restrictions. The number of 'day' and 'time' restrictions for each city was averaged for the previous five years and given in the 'current restrictions' bar. For the survey, day restrictions were defined as "Outdoor landscape watering with sprinklers or irrigation systems is only permitted before 10:00 am and after 6:00 pm two days a week, designated by your mailbox number" and time restrictions were defined as "Outdoor landscape watering with sprinklers or irrigation systems is only permitted before 10:00 am and after 6:00 pm." To assess how much consumers are willing to pay to avoid additional water restrictions, we varied the number of restrictions into 7 levels. The levels were the same as the status quo, reduce day restrictions by 50%, reduce day restrictions by 25%, increase day restrictions by 25%, increase day restrictions by 50%, all day restrictions to time restrictions (all time), all time restrictions to day restrictions (all day). Finally, demographic information was collected to compare the collected sample to the population of the United States.

Model

Random utility theory states that when making a choice from a set of alternatives, individuals will choose the option that optimizes utility *U*. Utility is composed of *V* and *ε* which are observed and unobserved utility from attributes respectively. Without being able to measure the unobserved utility, the probability *P* of an individual respondent *n* choosing an alternative *i* depends on the representative utility of the chosen option V_{ni} and all alternatives V_{nj} shown in equation 1.

$$[1] \qquad P_{ni} = \frac{e^{V_{ni}}}{\sum_j e^{V_{nj}}}$$

This model, however, assumes that all individuals in the population have the same preferences. The mixed logit model overcomes this constraint and allows for preference heterogeneity, or variation in preferences among the population. In this model, the coefficients vary over a distribution $f(\beta|\theta)$ where coefficients β depend on θ which represents a vector of parameters [131]. Based on the variation of coefficients, the mixed logit choice probability is integrated to create a function in which the logit choice probability is weighted by the density of $f(\beta|\theta)$ as shown in equation 2.

$$[2] \qquad P_{ni} = \int \frac{e^{V_{ni}(\beta)}}{\sum_j e^{V_{nj}(\beta)}} f(\beta|\theta) d\beta$$

Data Analysis

Five mixed logit models were estimated. Models 1, 2, 3, and 4 included only the respondents from a single city; Atlanta, Denver, San Antonio, and San Diego respectively. Model 5 included all survey respondents. The mixed logit models were run with random and correlated coefficients and 1000 Halton draws. Willingness to pay for each model was determined using the bootstrap method with 1000 iterations. All analyses were completed in STATA 17.

RESULTS

A total of 1050 complete responses were received. Results from the comparison between the demographics of the survey and the U.S. did not demonstrate substantial differences (Table 3.4).

When asked what factors impact the respondent's decision to use recycled water, the most popular response indicated health (42%), approximately one-quarter indicated cost (23%) or the environment (22%), and 13% indicated restrictions (Figure 3.3). Less than 1% stated none of the factors impacted their use (10 out of 1050 respondents). The distribution of responses for each city were similar, with health remaining the most popular response, and restrictions as the least popular response (Table 3.5)

The coefficients of alternative terms from all models are negative, indicating that individuals have a lower probability of choosing options that were not the status quo term "the same water you receive now" (Table 3.6). This result is consistent across all models and significant for all coefficients with the exception of 'purified water.' This indicates that the probabilities of choosing the status quo and 'purified water' are not always significantly different.

Willingness to pay based on terminology is generally consistent between models (Table 3.6). All values for willingness to pay were negative, indicating that respondents prefer the status quo to any alternative term. Respondents on average preferred the terms 'purified' and 'reclaimed' over 'reused,' 'recycled,' and 'treated wastewater' (Figure 3.4). While still less than the status quo, all cities indicated that they would be willing to pay the most for purified water.

Only for households in Denver (model 2) was there a significant difference in willingness to pay between 'purified water' and their current water (model 2, Table 3.7). This shows that for Atlanta, San Antonio, and San Diego (models 1, 3, and 4), households on average valued 'the same water you receive now' and 'purified water' relatively equal.

Households in Atlanta (model 1) significantly discounted the alternative terminologies (-$8.06 ('reclaimed water'), -$13.48 ('reused water'), -$14.4 ('recycled water') and -$16.53 ('treated wastewater'), Table 3.6). 'Purified water' resulted in a nonsignificant decrease of -$1.60. When combined with the status quo cost of $20.82, the willingness to pay ranges from $19.22 for 'purified water' and $4.29 for 'treated wastewater.'

Individuals were willing to pay -$0.024 to avoid one additional 'day' restriction.

All households in Denver (model 2) significantly discounted the alternative water terminologies (-$4.07 ('purified water'), -$6.93 ('reclaimed water'), -$11.99 ('reused water'), -$16.16 ('recycled water'), and -$18.28 ('treated wastewater') Table 3.6). When combined with the status quo cost of $24.25, the willingness to pay ranges from $20.18 for 'purified water' and $5.97 for 'treated wastewater.' Individuals were willing to pay $0.019 to avoid one additional 'day' restriction.

Households in San Antonio (model 3) significantly discounted the alternative terminologies (-$8.68 ('reclaimed water'), -$10.25 ('reused water'), -$12.67 ('recycled water'), and -$16.18 ('treated wastewater') Table 3.6). 'Purified water' resulted in a nonsignificant decrease of -$1.18. When combined with the status quo cost of $15.11, the willingness to pay for 'purified water' was $13.93. This was the only model which resulted in a situation where individuals would need to be paid $1.07 to consume 'treated wastewater.' Individuals were willing to pay $0.012 to avoid one additional 'day' restriction.

San Diego households (model 4) significantly discounted the alternative water terminologies (-$12.22 (‘reclaimed water’), -$15.79 (‘reused water’), -$19.53 (‘recycled water’) and -$27.93 (‘treated wastewater’), Table 3.6). ‘Purified water’ resulted in a nonsignificant decrease of -$3.25. When combined with the status quo cost of $43.17, the willingness to pay ranges from $39.92 for ‘purified water’ and $15.24 for ‘treated wastewater.’ Individuals were willing to pay $0.021 to avoid one additional ‘day’ restriction.

On average, all households (model 5) resulted in a statistically significant difference in willingness to pay between the alternative terminologies and their current water (-$9.99 (‘reclaimed water’), -$15.0 (‘reused water’), -$17.31 (‘recycled water’) and -$22.3 (‘treated wastewater’), Table 3.6). There was not a significant change in willingness to pay for ‘purified water’ (-$2.25). Consumers were willing to pay $0.020 to avoid additional water restrictions.

Despite variations between surveyed cities (models 1-4), all show that ‘purified water’ has the highest willingness to pay ($13.93- $39.92), and ‘treated wastewater’ has the lowest (-$1.07 - $15.24). These results indicate a lack of qualitative differences based on city-specific geographical variation. When standardized as percent change to disregard differences in status-quo cost, the general trends of survey-wide preferences do not change, despite some change within city preferences (Figure 3.5).

The coefficients of restrictions for all models are negative, indicating that individuals have a lower probability of choosing options with increased ‘day restrictions’ (Table 3.6). Based on the significant negative values of the willingness to pay, on average respondents are willing to pay less for water with increased future ‘day’ restrictions. To avoid 30-days of ‘day’ restrictions, individuals are willing to pay between $0.37 and $0.71. This decrease results in a minor impact on willingness to pay, ranging from only 1.4-3.4% of the status quo water cost. Despite the significance of willingness to pay to avoid water restrictions, given the small change in value, especially compared to the significant changes based on terminology, restrictions do not have a major influence on willingness to pay.

DISCUSSION

These results support the hypothesis that consumer willingness to pay for potable recycled water is impacted by terminology. ‘Reclaimed water’ generated the second highest willingness to pay response which contradicts previous research that showed significantly more public support for the term ‘recycled water’ than ‘reclaimed water’ [132]. ‘Purified water’ is the term that generated the highest willingness to pay response out of all the terms tested in this study. These results were uniform across all four study sites and support previous studies which indicate that the public prefers terminology that does not remind them that wastewater is being reused, and they are less likely to feel disgust when terms such as ‘recycled water’ and ‘reused water’ are used as opposed to terms such as ‘treated wastewater’ [133,134]. As consumer willingness to pay for ‘purified water’ was not significantly different from the status quo in four of the models, there is the possibility that municipalities will not need to decrease the water price to offset negative perceptions and incentivize use. This is especially important in potable water recycling, where significant increased infrastructure costs can be a major barrier.

Currently, some projects utilize terminology other than the alternative terms we tested (‘recycled water,’ ‘reused water,’ ‘treated wastewater,’ and ‘reclaimed water’). These include NEWater in Singapore and PureWater in Colorado Springs, Colorado. However, many policies and public outreach efforts around the U.S. continue to utilize the term ‘recycled water.’ Shifting the standard terminology away from ‘recycled water’ and towards ‘purified water’ needs to extend beyond project titles and into common vernacular to increase both consumer acceptance and willingness to pay. Additionally, more research should be completed to compare the unique terms for recycled projects that municipalities employ and a broader term such as ‘purified water’ that was measured in this study.

The potential to avoid increases in the number and severity of restrictions was not found to have a major influence on willingness to pay, which could be caused by two factors. First, the change from past to potential future restrictions was based on moving from ‘time restrictions’ to ‘day restrictions’ which may not be a substantial enough shift to result in a large change. Previous research has shown that individuals are not willing to pay to avoid water restrictions which are not sufficiently severe, such as a ban on outdoor watering [128]. Secondly, based on the survey design all the cities chosen for this study had restrictions in place for at least the last five years to allow for assessment of impacts of future increases and decreases in the number of restrictions. However, this could decrease respondents’ sensitivity to changes in restrictions because they have all been subject to restrictions in the past. Model 1 for Atlanta, GA showed the highest impact of restrictions on willingness to pay (3.4% change from status quo); Atlanta has the least number of total days with restrictions and the lowest number of ‘day restrictions’ of the cities studied. Therefore, it is possible that locations with few or no water use restrictions might be more willing to pay to avoid restrictions, which should be investigated. However, given both the negligible impact on willingness to pay subject to changes in restrictions, and the limited number of individuals who state that restrictions impact their decision to drink recycled water, focusing on other factors consumers specified as more important such as health, environment, and cost could have a greater impact on consumer support and willingness to pay.

CONCLUSION

This paper represents the first known attempt to study consumer willingness to pay for potable recycled water in the United States. Results demonstrate the importance of terminology on consumer willingness to pay and the consistency of preference for the term ‘purified water’ across cities in the United States. The potential for using potable recycled water to avoid or reduce water restrictions was shown to not have a significant impact on willingness to pay nor was this a priority for respondents considering potable recycled water. Shifting the standard terminology away from ‘recycled water’ and towards ‘purified water’ needs to extend beyond project titles and into common vernacular to increase both consumer acceptance and willingness to pay. Terminology is an important factor for municipalities and policy makers to incorporate in public communication, policy making, and project implementation to ensure consumer support for potable water recycling and therefore the future protection of water resources.

Figure 3.1: Sample site locations for survey collection. Site 1 is Atlanta, Georgia, Site 2 Denver, Colorado, Site 3 is San Antonio, Texas, and Site 4 is San Diego, California.

Figure 3.2: Example choice scenario question format. Option 1 is the status quo option, with options 2 and 3 a combination of alternatives.

Select the option where the water delivered to your home would be the same water you receive now.

<table>
<tr><th></th><th>Option 1</th><th>Option 2</th><th>Option 3</th></tr>
<tr><td>Water delivered to your home would be:</td><td>The same water you receive now</td><td>Reclaimed Water</td><td>Reused Water</td></tr>
<tr><td>Price (per person per month)</td><td>$28.91</td><td>$26.18</td><td>$19.81</td></tr>
<tr><td>Water Restrictions</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td></td><td>○</td><td>○</td><td>○</td></tr>
</table>

Time restrictions: Outdoor landscape watering with sprinklers or irrigation systems is only permitted before 10:00 am and after 6:00 pm.
Day restrictions: Outdoor landscape watering with sprinklers or irrigation systems is only permitted before 10:00 am and after 6:00 pm two days a week, designated by your mailbox number.

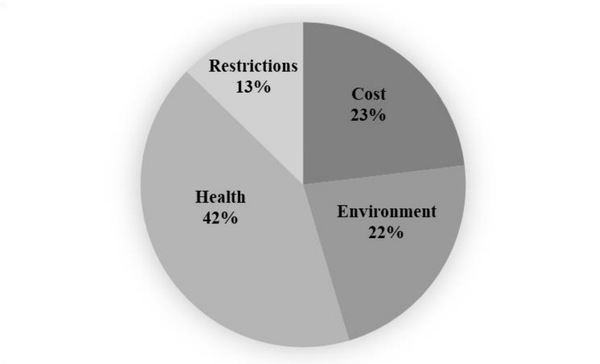

Figure 3.3: Percent of respondents that indicated restrictions, cost, health, or the environment were factors they considered when deciding to drink recycled water (n=1050).

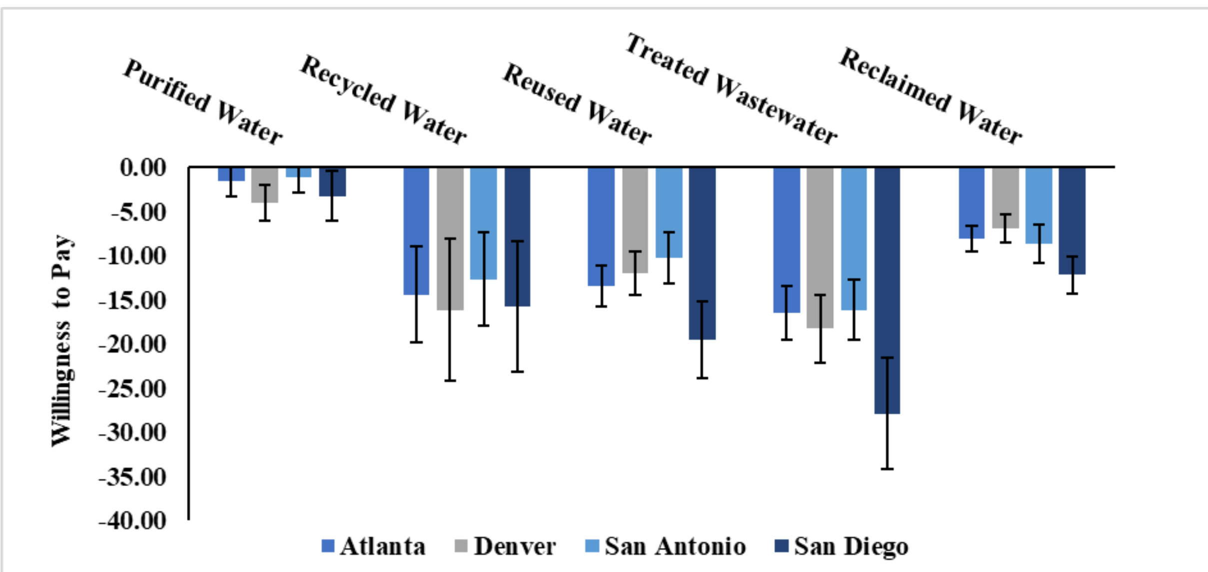

Figure 3.4: The consumer willingness to pay for alternative terminology in the four sampled cities. Error bars show standard error.

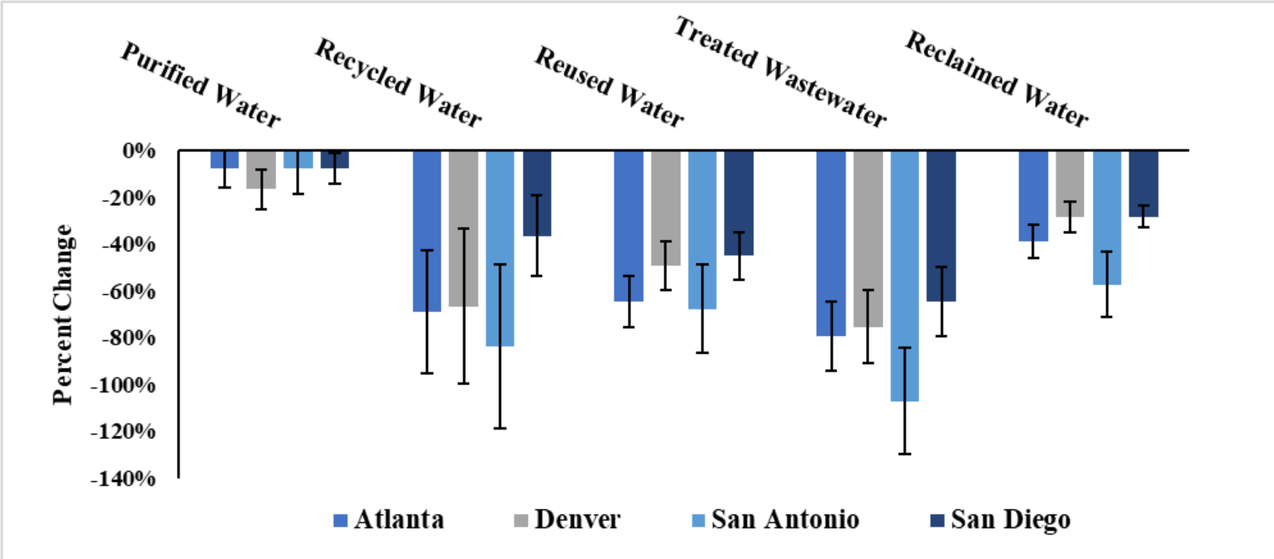

Figure 3.5: The percent change of willingness to pay for alternative terminology in the four sampled cities with standard error bars.

Table 3.1: City specific information on population, climate, average annual temperature and precipitation, scarcity, restrictions, and presence of water recycling for surveyed locations [77,135–141].

	Atlanta, Georgia	Denver, Colorado	San Antonio, Texas	San Diego, California
Population	420,003	600,158	1,327,407	1,307,402
Climate	Humid subtropical climate	Transition between Cold semi-arid and humid subtropical climates	Humid subtropical climate	Cold semi-arid and Warm-summer Mediterranean climate
Temperature (°F)	63.6	51.2	68.4	64.7
Precipitation (in.)	50.43	14.48	35.57	9.79
Scarcity	-Litigation between Georgia and nearby states over water resources	-Almost all water used in Denver comes from snow melt	-Approximately 73% of the potable water comes from groundwater aquifers	-Around half of the water resources come from the diminishing Colorado River
Restrictions	313 days	365 days	365 days	365 days
Water Recycling	-Indirect potable recycling in Lake Lanier -Nonpotable recycling system	-Nonpotable recycling system	-Nonpotable recycling system	-Pure Water program -Nonpotable recycling system

Table 3.2: Attributes and levels for willingness to pay survey design.

Attribute	Levels
Terminology	The same water you receive now, treated wastewater, reused water, reclaimed water, recycled water, purified water
Cost	60% less, 40% less, 20% less, current, 20% more, 40% more, 60% more
Restrictions	Current, reduce day restrictions by 50%, reduce day restrictions by 25%, increase day restrictions by 25%, increase day restrictions by 50%, all day restrictions to time restrictions (all time), all time restrictions to day restrictions (all day)

Table 3.3: Cost attributes for each site location. Costs are dollars per person per month. Current values were used in the status quo choice option.

	60% less	40% less	20% less	Current	20% more	40% more	60% more
Atlanta	8.33	12.49	16.66	20.82	24.98	29.15	33.31
Denver	9.70	14.55	19.40	24.25	29.10	33.95	38.80
San Antonio	6.04	9.07	12.09	15.11	18.13	21.15	24.18
San Diego	17.27	25.90	34.54	43.17	51.80	60.44	69.07

Table 3.4: Demographic comparison between survey sample and the U.S.

Demographic comparison	Survey	U.S.
Number of Individuals	1,057	308,745,538
Gender		
Female	59.7%	50.8%
Male	39.5%	49.2%
Education		
Did not finish high school	2.6%	11.4%
High School diploma or GED	30.8%	46.9%
2-year college (associate's degree)	23.0%	8.6%
4-year college (bachelor's degree)	26.5%	20.3%
Graduate or professional degree	17.1%	12.8%
Income		
Under $34,999	29.4%	26.5%
$35,000 to $49,999	16.8%	11.9%
$50,000 to $74,999	20.9%	17.4%
$75,000 to $99,999	13.4%	12.8%
$100,000 to $149,999	12.1%	15.7%
$150,000 to $199,999	3.9%	7.2%
$200,000 or more	3.4%	8.5%
Average Individuals in Household	2.74	2.61
Households with Children	32%	30%
Race		
Native American or Alaska Native	2.6%	1.7%
Native Hawaiian or Pacific Islander	0.4%	0.4%
African American or Black	10.8%	13.6%
White	71.7%	74.8%
Asian	4.4%	5.6%
Other race	1.2%	7.0%

Table 3.5: Percentage of survey respondents from each city that indicated a factor impacted their choice to drink recycled water.

Factor	Atlanta	Denver	San Antonio	San Diego
Cost	37%	38%	35%	45%
Environment	34%	43%	33%	38%
Health	71%	65%	71%	73%
Restrictions	15%	25%	22%	24%

Table 3.6: Coefficients of mixed logit models for each surveyed city. Values in parenthesis are standard error.

	Model 1: Atlanta, GA Log likelihood -1720.65	Model 2: Denver, CO Log likelihood -1879.18	Model 3: San Antonio, TX Log likelihood -1951.00	Model 4: San Diego, CA Log likelihood -1681.72	Model 5: All respondents Log likelihood -7286.22
Cost	-0.174 (0.117)**	-0.147 (0.010)**	-0.146 (0.139)**	-0.103 (0.007)**	-0.125 (0.005)**
Purified Water	-0.313 (0.183)	-0.618 (0.177)**	-0.186 (0.155)	-0.256 (0.182)	-0.285 (0.086)**
Recycled Water	-2.59 (0.669)**	-3.02 (0.849)**	-2.11 (0.431)**	-1.42 (0.460)**	-2.38 (0.262)**
Reused Water	-2.44 (0.264)**	-1.78 (0.214)**	-1.55 (0.205)**	-2.09 (0.261)**	-1.90 (0.115)**
Treated Wastewater	-3.00 (0.322)**	-2.69 (0.306)**	-2.51 (0.283)**	-3.07 (0.367)**	-2.82 (0.163)**
Reclaimed Water	-1.40 (0.159)**	-1.00 (0.148)**	-1.37 (0.160)**	-1.24 (0.155)**	-1.28 (0.078)**
Restriction	0.004 (0.001)**	0.003 (0.0006)**	0.002 (0.0006)*	0.002 (0.0006)**	0.003 (0.0003)**

* $p<0.05$ ** $p<0.01$

Table 3.7: Willingness to pay for each city. Values in parenthesis are standard error.

	Atlanta	Denver	San Antonio	San Diego	All Respondents
Purified Water	-$1.60 (1.67)	-$4.07 (2.02)*	-$1.18 (1.65)	-$3.25 (2.84)	-$2.25 (1.16)
Recycled Water	-$14.4 (5.48)**	-$16.16 (8.04)*	-$12.67 (5.32)*	-$15.79 (7.42)*	-$17.31 (3.25)**
Reused Water	-$13.48 (2.31)**	-$11.99 (2.51)**	-$10.25 (2.86)**	-$19.53 (4.35)**	-$15.0 (1.62)**
Treated Wastewater	-$16.53 (3.09)**	-$18.28 (3.84)**	-$16.18 (3.39)**	-$27.93 (6.31)**	-$22.3 (2.19)**
Reclaimed Water	-$8.06 (1.48)**	-$6.93 (1.60)**	-$8.68 (2.11)**	-$12.22 (2.12)**	-$9.99 (0.938)**
Restrictions	$0.024 (0.001)**	$0.019 (0.0076)**	$0.012 (0.0084)**	$0.021 (0.011)**	$0.020 (0.0046)**

* $p<0.05$ ** $p<0.01$

CHAPTER 4

EVALUATING ENVIRONMENTAL IMPACTS FROM NONPOTABLE, INDIRECT POTABLE, AND DIRECT POTABLE WATER RECYCLING USING U.S. CASE STUDIES [3]

[3] Hopson, M., L. Fowler, and A. Rosemond. To be submitted to *Water Resources.*

ABSTRACT

Due to increasing water scarcity, many municipalities are considering the adoption of water recycling practices. Among the impacts and tradeoffs that decision makers must assess are the potential environmental ramifications of these practices; these will vary depending on the particular form of recycling being considered– nonpotable, indirect potable, or direct potable. Knowledge regarding the extent to which each of these practices impact three critical environmental considerations– availability of source water for instream uses, nutrient discharges, and energy consumption– is limited, thus the need for this study. To assess the array and interplay of potential impacts, three facilities, each of which practices a different form of recycling, were selected. Pre-recycling and post-recycling data were compared for water depletion, total phosphorus and nitrogen discharges, and total energy consumption, to determine the environmental impact of each practice. Water depletion, or the difference between withdrawals and discharges, did not change for nonpotable recycling but increased for indirect potable, likely due to additional losses during treatment and transportation. The release of nutrients into the environment decreased as a result of each recycling practice. There was no significant change in total energy after adoption of the nonpotable recycling system, but comprehensive data was not available for indirect or direct potable recycling. Despite study limitations, this research indicates substantial variation in environmental impacts requiring evaluation of tradeoffs by stakeholders during recycling project consideration. Further research is needed to assess the environmental impacts of recycling infrastructure development, which was not addressed here, and the significance of site-specific variations.

INTRODUCTION

In many areas in the United States, rapidly growing human populations coupled with precipitation and temperature impacts of climate change are threatening the sustainability of water resources beyond what conservation practices alone can mitigate [4,19,142,143]. To protect water resources for current and future generations, many utilities are considering water recycling, or the act of treating water that has been used previously to be used again in the same geographical area [144]. Instead of discharging wastewater downstream where it leaves the local water system, water recycling keeps the water in the same community to be used again, therefore increasing the available water for human use. Despite this increase in human water availability, there is the possibility that the process of recycling may decrease the water available for instream uses due to losses during transportation and treatment.

Water recycling can be grouped into three broad categories based on the recycled water use, quality, and treatment process (Figure 4.1). All three forms of recycling– nonpotable, indirect potable, and direct potable recycling– utilize treated wastewater to expand potable water supplies, but their techniques, and therefore impacts, differ (Table 4.1). The decision-making process for water recycling implementation is complex and impacted by many factors including public support, regulations, technology, cost, and environmental concerns and tradeoffs [64]. While many managers and consumers share a desire for environmental protection and conservation, the significance of environmental impacts will vary based on utility-specific goals.

Three of the major environmental impacts of water use and wastewater treatment practices are the availability of source water for the protection of aquatic health and biodiversity, the quantity of contaminants released into the environment, and the energy used in the recycling and transmission process [53,145,146]. Knowledge regarding the extent to which nonpotable, indirect potable, and direct potable recycling impact each environmental factor is limited, thus the need for this study.

Throughout the human water use system, negative impacts occur which have the potential to be mitigated through recycling. Withdrawing water from water bodies causes negative impacts in surface and groundwater systems [147]. Decreasing surface water availability for instream uses by organisms has severe negative ecological impacts such as decreased species abundance and richness [148]. Additionally, increasing trends of diminishing groundwater levels, especially in confined aquifers surrounded by impermeable material, can cause negative impacts including decreased surface water flows, land subsidence, and saltwater intrusion [54,149]. After human use and wastewater treatment, release into rivers and aquifers can have significant negative impacts on the environment even when treated to discharge permit requirements [150]. Release of even low concentrations of contaminants by a multitude of wastewater dischargers can cumulatively cause environmental degradation [151]. In the U.S. eutrophication caused by excess nutrients is a widespread problem in which increased algal growth is stimulated, algae die because of excess production relative to consumption, and create biomass for breakdown by bacteria which consume oxygen, resulting in numerous negative impacts [152–155]. Throughout the human water treatment system, a significant amount of energy consumption occurs, resulting in an estimated 4%-12% of total U.S. energy use and 30% of utility operating costs [156–158]. Decreasing energy use in the water treatment sector is gaining more interest as concerns for greenhouse gas emissions through energy generation increase [159].

The potential for implementation of each form of water recycling to alter the environmental impacts of water treatment varies. Understanding these variations and tradeoffs is critical to inform decision making by utility managers. To our knowledge, an evaluation and comparison of the environmental impacts of these water recycling strategies has never been completed. Data were collected from three utilities in the U.S. that have each implemented one of the three water recycling systems: nonpotable, indirect potable, and direct potable systems. Pre- and post-recycling comparisons for water depletion, nutrient discharge, and energy consumption allow us to compare the potential impacts of each recycling system. Our predictions are that (1) despite the fact that wastewater is being reused, the water depletion, or the difference between withdrawals and discharges, will increase with all three recycling practices due to water losses as a result of additional treatment required and distribution of reclaimed water to users; (2) the discharge of nutrients into the environment will decrease across all three water recycling practices as a result of increased treatment; and (3) energy use will either increase with additional reclaimed water treatment or remain static if offset by decreases in water withdrawals and drinking water treatment.

METHODS

Site Descriptions

NC-Nonpotable Recycling

In Chapel Hill, North Carolina, the Orange Water and Sewer Authority (OWASA) manages the city's drinking, wastewater, and nonpotable water recycling system (Table 4.2). Drinking water comes from three surface water reservoirs, the Cane Creek Reservoir, University Lake, and Quarry Reservoir. Combined, these sources can provide 10.5 million gallons per day (MGD) [160]. The current drinking water demand of approximately 7 MGD is satisfied by the Jones Ferry Rd Drinking Water Treatment Plant which has a capacity of 20 MGD. Tertiary treatment here includes filtration and disinfection utilizing chlorine and chloramines. Drinking water flows through 390 miles of distribution pipes to consumers. Wastewater travels through 350 miles of pipes to the Mason Farm Wastewater Treatment Plant (WWTP). This facility has the capacity to treat up to 14.5 MGD, but currently treats approximately 8 MGD before it is discharged into Morgan Creek. The tertiary wastewater treatment technology includes filtration, disinfection utilizing ultraviolet light, and oxygenation. Beginning in April 2009, a portion of the reclaimed water from the wastewater treatment plant is recycled for nonpotable use. The nonpotable recycling system can meet a peak demand of 3 MGD, but current demand averages 0.66 MGD. This system sends nonpotable water through approximately five miles of pipes directly to users including the University of North Carolina at Chapel Hill and UNC Hospitals; these consumers pay for the construction and maintenance of the distribution lines.

VA-Indirect Potable Recycling

The Hampton Roads Sanitation District (HRSD) serves 1.7 million people with 17 separate treatment plants across southeast Virginia with a combined capacity of 249 MG (Table 4.2) [161]. As the largest aquifer in Virginia, the Potomac Aquifer provides approximately 155 MGD for use in the eastern region of the state. Due to overuse, environmental degradation including saltwater intrusion and land subsidence are increasing, prompting HRSD to implement the Sustainable Water Initiative for Tomorrow (SWIFT) program in 2018 to return reclaimed water to the aquifer after use. The SWIFT Research Center is the second stage of a three-stage plan to replenish the aquifer. It takes treated wastewater (prior to disinfection) from the Nansemond Wastewater Treatment Plant and provides advanced treatment including ozone-biologically active filtration and ultraviolet disinfection before injecting the water into the aquifer. The Center can produce and recharge up to one million gallons of reclaimed water per day.

The Potomac Aquifer is part of the Northern Atlantic Coastal Plain aquifer system that stretches from New York to North Carolina and provides drinking water for millions of people. It is a confined aquifer, meaning it is surrounded by clay and bedrock. Despite substantial precipitation in the area, there is limited natural aquifer recharge due to the small recharge area located in the fall zone, the transition zone between the coastal plain and piedmont regions [162]. The aquifer is stratified into three regions (upper, middle and lower) separated by confining units with limited movement vertically through the confining units. The recharge well at the SWIFT Research Center discharges reclaimed water into each of the three regions. The third stage of the SWIFT plan will result in additional facilities which will treat and discharge a cumulative 100 MGD into the Potomac Aquifer throughout the district.

TX-Direct Potable Recycling

The Colorado River Municipal Water District (CRMWD) serves the Texas cities of Odessa, Big Spring, and Snyder and it provides water to approximately 135,000 people. The CRMWD includes a network of pipelines that connect Lake J.B. Thomas, E.V. Spence Reservoir, O.H. Ivie Reservoir, and two groundwater well fields, together forming a comprehensive water supply system for the region (Table 4.2). Despite the numerous water sources, severe droughts have put the supply at risk, resulting in the construction in 2013 of the Raw Water Production Facility which treats approximately 1.5 MGD from the Big Spring Wastewater Treatment Plant. Using microfiltration, reverse osmosis, and ultraviolet disinfection, the facility treats reclaimed water to drinking water quality standards. This water is then blended in the pipeline with water from the E.V. Spence Reservoir, at a maximum ratio of 50 percent reclaimed water, before it flows to the drinking water treatment plants in the area for additional treatment [163]. Brine from the reverse osmosis treatment at the Raw Water Production Facility is discharged into the brackish water in Beals Creek and any wastewater that is produced, such as from flushing the treatment system, is sent back to the wastewater treatment plant.

Data Collection

In general, our analysis consisted of comparing *before recycling data* with *after recycling data* to assess the environmental impacts of the three methods of recycling (Table 4.3). In some cases, the necessary information was not monitored or reported directly by the utility, so assumptions were made as detailed below. Comprehensive water demand data was not available for any site, however, average population change for each of the locations ranged from -0.3-1.7%, and therefore any change in water demand was not considered essential to include in the analysis [164].

NC-Nonpotable Water Recycling

Data were collected from OWASA for the months of January 2008-January 2011. As the nonpotable-NC system was implemented in April 2009, data from January 2008- March 2009 were classified as *before water recycling* and May 2009-December 2011 data were classified as *after water recycling*. To determine the change in environmental water availability, the amount of water withdrawals, discharges, and reclaimed water use were collected in units of total million gallons per month (MGM) and compared before and after recycling. Data regarding total nitrogen and total phosphorus were collected in concentrations of mg/L in the discharge from the wastewater treatment facility to assess the change in nutrient discharges pursuant to recycling. To determine the change in energy use, data were collected in monthly total kWh for each step of the treatment process including the two withdrawal pumps located at University Lake and Cane Creek Reservoir, the Jones Ferry Road Drinking Water Plant, and the Mason Farm Wastewater Treatment Plant.

VA-Indirect potable recycling

The design of the indirect potable-VA recycling system redirects a portion of the reclaimed water discharge from the Nanesmond Wastewater Treatment Facility to the SWIFT Research Center for further treatment and aquifer injection. After injection, the water is retained by the environment and is subsequently available for reuptake by drinking water systems. However, the recycling itself has no impact on the quantity of drinking water withdrawn or used, only on the output of wastewater from the system. Based on this knowledge, we assumed that there was no change in withdrawals due to the implementation of water recycling, and therefore we did not collect withdrawal data.

The SWIFT Research Center began operating in May 2018; the HRSD provided data from May 2018 - August 2021 and the Nansemond WWTP provided data for May 2016 to March 2020. Data from the WWTP from May 2016-May 2018 were classified as *before water recycling* and June 2018-March 2020 data were classified as *after water recycling*. Months with no flow at the SWIFT Research Center, when the plant was not recycling water, were removed from the analysis. To determine the change in water depletion due to recycling, the total discharge from the Nansemond WWTP from May 2016-2018 was compared to the combined discharge from the Nansemond plant and the SWIFT Research Center from June 2018-March 2021. The impact on the Potomac Aquifer was determined using aquifer discharge data from the Center and aquifer levels at six well sites which were measured every 12 hours and averaged per day. The monitoring sites varied in depth and distance from the injection point in the aquifer with ‘SAT’ sites located 50 feet from the discharge point, with three depths of upper, middle, and lower Potomac Aquifer measurements. ‘MW’ sites were located 340, 390, and 440 feet from the discharge point in the upper, middle, and lower regions respectively.

To determine the impact of recycling on nutrient discharge we compared the concentration of total phosphorus and nitrogen discharged from the inflow and outflow of the SWIFT Research Center. Data from the Nansemond WWTP did not include nutrient discharge concentrations. We assumed the inflow nutrient concentrations from the SWIFT Research Center (available data) to be the amount of discharge from the Nansemond WWTP as there was likely no significant change in nutrient concentrations in the transportation of water between the two facilities.

Energy use at the Center was collected in units of monthly total kWh, however, no data were available for the Nansemond WWTP which precluded an analysis of the change in total energy use for the entire treatment and recycling system.

TX-Direct potable recycling

To determine the impact on water withdrawals and discharges, data were collected from the Big Spring drinking and wastewater treatment plants for 2012 and 2014. The Raw Water Production Facility began operation in 2013, therefore data from 2012 were classified as *before water recycling* and 2014 data were classified as *after water recycling*. Inflow into the drinking water facility is the combined flow of water pumped from reservoirs and recycled water from the Raw Water Production Facility which are blended in the pipeline. The proportion of the drinking water plant inflow that is composed of recycled water is unknown for 2014 but this data is from CRMWD for the Raw Water Production Facility in 2020. The average 26% percent of inflow composed of recycled water in 2020 was therefore used as a proxy for 2014. To determine the impact of recycling on withdrawals the drinking water inflow data from 2012 were compared to the inflow from 2014 reduced by 26%. The loss in water from recycling treatment for direct potable-TX recycling was determined to be the difference between the total monthly inflow and outflow of the recycling facility in 2020.

Data for the total phosphorus inflow were collected quarterly and averaged to estimate influent total phosphorus concentrations; we characterized this as the amount of phosphorus that was no longer being released into the environment as a result of recycling. After treatment at the wastewater treatment plant, the water is pumped into the Raw Water Production Facility where the amount of phosphorus is measured, followed by treatment with microfiltration and reverse osmosis. Microfiltration is known to be successful at removing total phosphorus from wastewater, especially if treated initially with coagulation [34,165]. The water is then treated with reverse osmosis which traditionally has an output of highly concentrated brine. However, given the initial use of microfiltration, it is likely that the concentration of phosphorus influent into the reverse osmosis system is very low [166,167]. The brine phosphorus concentration is not monitored but for the reasons stated above, we assume that it is low. Furthermore, because no water is released into the environment from the Raw Water Production Facility, we characterize the avoided phosphorus discharge as the inflow into the Raw Water Production Facility.

No energy data were available; however, energy consumption is assumed to be higher with the implementation of recycling due to the addition of the Raw Water Production Facility which was not utilized in the traditional water treatment system.

Data analysis

All statistics were completed in STATA 16.1.

Water withdrawals, discharges, and water depletion

The impact on environmental water availability was defined as water depletion, or how much water was withdrawn from the initial source and not discharged back into the environment.

An increase in water depletion would indicate a decrease in water available in the environment for other uses. Water depletion was determined for nonpotable-NC recycling by comparing the change in monthly withdrawals and discharges before and after recycling. For indirect potable-VA recycling water depletion was determined by the change in total water discharges into the environment before and after recycling. Significance for both were determined using 95% confidence intervals [168].

Statistical analyses for nonpotable-NC recycling were conducted using a generalized linear model with gaussian family and identity link function, chosen based on AIC values, to compare water withdrawals and discharges before and after implementation. Due to the impact of time on changes in the variables, the error terms are not independent, a requirement for ordinary least squares regressions. To compensate, heteroskedastic and autocorrelation consistent Newey-West standard errors were utilized [169]. To test the impact of recycling on water withdrawals and water discharges, the monthly averages of water flow were tested with covariates of recycling (categorical), average monthly temperature, and total monthly precipitation.

Data analysis for indirect potable-VA recycling utilized ordinary least-squares linear regressions to evaluate the impact of flow rate on aquifer depth at six different sites for indirect potable-VA recycling utilizing SWIFT outflow as the independent and aquifer depth as the dependent variable, averaged per day.

Nutrient concentration and discharges

Total monthly discharge or total nitrogen and total phosphorus was calculated by multiplying the flow rate in MGM, nutrient concentration in mg/L, and 8.34, the standard method for conversion [170].

Statistical analyses for total nitrogen and phosphorus discharge and concentration for nonpotable-NC recycling were conducted using a generalized linear model with gaussian family and identity link function and Newey-West standard errors [169].

Paired t-tests were used to determine whether there was a statistically significant mean difference between discharge of total nitrogen and total phosphorus into the environment before (formula 1) and after (formula 2) the SWIFT Research Center became operational. D_T and D_R are the levels of discharge from the SWIFT Research Center's wastewater treatment facility and aquifer recharge facility respectively and C_T and C_R are the concentrations from these facilities. Additionally, we compared the nutrient discharge into the surface water location before SWIFT operations (formula 1) to the SWIFT discharge (formula 3).

[1] $(D_T + D_R) * C_T$

[2] $(D_T * C_T) + (D_R * C_R)$

[3] $D_T * C_T$

A paired t-test was also run to determine whether there was a statistically significant mean difference between discharge of total nitrogen and total phosphorus into the initial source from the wastewater treatment plant with and without the SWIFT aquifer recharge Center. Cohen's d test for effect size were used for all paired t-tests.

Energy use

Nonpotable-NC recycling energy use was tested using a generalized linear model with gaussian family and identity link function, and Newey-West standard errors [169]. Comparisons included total treatment train, total pump, drinking water, and wastewater energy use. Energy use statistics could not be run on either indirect potable-VA or direct potable-TX recycling due to data unavailability.

RESULTS

Water withdrawals, discharges, and water depletion

There was no significant decrease in water withdrawals with nonpotable-NC recycling from (df=45, p=0.59, Figure 4.2). Direct potable-TX recycling generated an average 29.92 MGM of reclaimed water which was routed to the drinking water treatment facility and therefore not withdrawn from the environment.

There was a significant decrease in water discharges from the wastewater treatment facility for nonpotable-NC recycling into the environment after implementation of recycling from a monthly average of 239 to 188 million gallons, a decrease of approximately 33% (df=38, p<0.001). There was a significant decrease in total discharge into the environment, assumed to be net change for indirect potable-VA recycling due to no change in withdrawals, an average of 577.50 MGM before recycling to 535.7 after recycling with a significant change of 7.24% (95% CI, 3.5 and 10.98, Figure 4.3). There was an approximate 67% decrease in water discharges from the wastewater treatment plant due to direct potable-TX recycling.

There was a no change in water depletion for nonpotable-NC recycling (Figure 4.4). There was a loss of 31% (13.42 ± 4.46 MGM) of the inflow into the recycling facility with direct potable-TX recycling.

Indirect potable-VA recycling generated an average of 14.0 MGM of reclaimed water which was released into the Potomac Aquifer. It appears that the indirect potable-VA recycling system is positively impacting aquifer depth, and thus water sustainability, or the ability of future generations to have access to water in the aquifer (Figure 4.5). The slopes of the regression lines decreased as depth and distance from the discharge point increased with the upper aquifer 50 feet from the discharge point having the strongest relationship between average daily discharge and aquifer depth.

Nutrient concentration and discharges

Total phosphorus discharge was significantly lower with nonpotable-NC recycling, decreasing 28% with a difference in average monthly discharge of 212 pounds (df=38, p=0.03, Figure 4.6) however the concentration of phosphorus was not significantly different (df=45, p=0.17, Table 4.4). There was significant variation in phosphorus discharges both before and after implementation, ranging from 15 to 2885 pounds per month. The concentration of phosphorus was significantly lower in the effluent of the SWIFT facility than the influent (df=37, p=0.03, Table 4.4). Total phosphorus discharge into the environment decreased after the implementation of SWIFT (1382.23 ± 350.8 lbs) compared to before (1424.68 ± 377.45 lbs); a statistically significant increase of 42.45 lbs/month (95% CI, -76.79 to -8.12 lbs/month, t(7) = -2.92, p =0.022, *d* = 1.03, Figure 4.6). Total phosphorus discharge into the surface water was also lower after the implementation of SWIFT (1368.76 ± 356.8 lbs/month) than before (1424.68 ± 377.45 lbs/month); a significant decrease of 55.93 lbs/month (95% CI, -81.98 to -29.87 lbs/month, t(7) = -5.08, p = 0.001, *d* = -0.15). The total phosphorus discharges from the wastewater treatment plant for direct potable-TX recycling decreased significantly after implementation of recycling (p<0.001, df=22, Figure 4.6).

There was a significant decrease in total nitrogen discharged after implementation of nonpotable-NC recycling, with an average difference of 8572 pounds per month or 32% (df=38, p<0.001). The concentration of nitrogen significantly decreased (df=45, p=0.029, Table 4.4). There was no significant change in the concentration of nitrogen from inflow to outflow of the SWIFT Research Center (df=53, p=0.99, Table 4.4). Total nitrogen discharge into the environment was lower before the implementation of SWIFT (15192.47 ± 1683.95 lbs) than after (15222.6 ± 1661.12 lbs); a non-statistically significant decrease of 30.13 lbs/month (95% CI, -63.23 to 2.96 lbs/month, $t(17) = -1.92$, $p = 0.072$, $d = 0.45$, Figure 4.7). Total nitrogen discharge into surface water was lower after the implementation of SWIFT (14746.16 ± 1712.61 lbs/month) than before (15192.47 ± 1683.95 lbs/month); a significant decrease of 446.31 lbs/month (95% CI, -549.13 to -343.49 lbs/month, $t(17) = -9.15$, $p < 0.001$, $d = -0.26$).

Energy use

There was no significant impact on energy use from the drinking water treatment plant, pump stations, or the total treatment train (df=45, $p>0.05$). The monthly average energy use increased by 0.56% for the wastewater treatment plant but decreased by 1.61% for the pump stations and drinking water plant (Figure 4.8). The additional energy use from the VA-indirect potable reclamation facility averaged approximately 119,762 (±3276.0) kW/hr per month. No energy data for direct potable-TX recycling were available.

DISCUSSION

The results from this analysis show variation in environmental impacts between the nonpotable-NC, indirect potable-VA, and direct potable-TX recycling systems (Table 4.4). All three recycling systems provided environmental benefits compared to traditional treatment except in the arena of energy use. Water depletion decreased in the nonpotable-NC recycling system and indirect potable-VA recycling shows a positive impact on aquifer sustainability though it appears to increase water depletion. Direct potable-TX recycling showed sizeable losses during recycling treatment. All three systems decreased nutrient discharge. There was no significant change in total energy from adoption of the nonpotable-NC recycling system but use shifted between parts of the treatment chain. However, energy use increased for both VA-indirect and direct potable-TX recycling systems due to the addition of treatment facilities. The variability in these results demonstrate the trade-offs utilities must consider depending on their individual goals.

Water sustainability implications

Water recycling increases human water availability by adding treated wastewater back into the supply instead of it leaving the system through discharge. Despite this increase in human water resources for human use, the impact of water recycling on water available in the environment for instream uses is variable. Water losses in the human water system occur through consumption during human use such as irrigation, but also during treatment. Leaks during distribution and transportation of water coupled with evaporation during treatment and losses through sludge disposal create a net loss of water during human water use [171–174]. The additional transportation and treatment of wastewater for reuse was expected to generate additional water loses that result in increased water depletion, or the water that is removed from the environment and not returned through discharge, compared to the traditional human water use system. This increase in water depletion would therefore result in decreased water in the environment which is necessary for ecosystem health. However, the lack of significant change in water depletion for nonpotable-NC recycling suggests that increased water losses may not be inevitable. As with much of the southern U.S., increasing sustainability, longevity, and dependability of water resources was an imperative for the nonpotable-NC recycling system as the program was initiated in part due to a significant drought in 2001 and 2002 [175]. As the prevalence of drought is expected to increase, the potential for nonpotable recycling to meet human water needs, while not increasing total water demand, may contribute to water resilience.

An important factor in the nonpotable-NC recycling system is that reclaimed water users pay for the construction and maintenance of the distribution pipes. However, many nonpotable recycling programs use a system commonly referred to as ‘purple pipe’ which allows users to tap into a separate distribution system, built and maintained by the utility, from their potable water without a permit. In many cases, the utility does not actually pass the full cost on to the consumer and it is possible that this easy access and lower cost for uses such as residential irrigation might incentivize increased water depletion [176]. The utility should take this into account in making pricing decisions. Whether there is a difference in nonpotable water use based on the direct-to-consumer design compared to ‘purple pipe’ needs to be investigated.

Data to determine the change in water depletion due to direct potable recycling was not available, however, sizeable losses were observed during the recycling treatment process with additional technology of microfiltration and reverse osmosis. Research shows that losses of feed water ranging from 15-20% are expected with reverse osmosis treatment, indicating there is limited potential to increase treatment efficiency to decrease water losses [177]. With no decreased losses during another stage of treatment, such as the movement of withdrawn water to the drinking water facility, to compensate for the increased water loss from recycling treatment, the system will result in net water depletion. For future direct potable recycling design,

As was expected for all recycling systems, indirect potable-VA recycling did result in increased water depletion because the total amount of water entering the environment from a combination of the wastewater treatment plant discharge and the aquifer recharge facility was significantly less than the amount discharged from the wastewater treatment facility prior to the initiation of recycling. More research is needed to understand the cause of water loss, but it is possibly the result of losses occurring during transport or incidental to the additional treatment at the aquifer recharge facility. Despite the additional water loss, the data showed that aquifer depth increased with the increasing discharge of reclaimed water. Impacts diminished with greater distance from the discharge point. It is expected that the total discharge into the aquifer will increase as additional discharge sites are added in the third stage of the SWIFT program. In addition to groundwater aquifers, surface water bodies are often utilized as the environmental buffer in indirect recycling systems. A one-year post-implementation monitoring of the indirect potable water recycling system in Wichita Falls, Texas showed an increase in reservoir depth, indicating the benefit to the environmental water sources is likely consistent across environmental buffer types [178]. The results from indirect potable-VA recycling emphasize the importance of looking beyond the impact of indirect potable recycling systems on discharges into one environmental source, and instead assess total water availability. While discharge into the Potomac Aquifer increased, the discharge into the James River decreased which has the potential to create problems. This potential tradeoff of shifting water discharges between locations must be considered during the decision-making process to incorporate not just the benefits to the recycling discharge location, but the losses to the initial reclaimed water discharge source.

Protection of nutrient polluted water sources

Nutrient discharges, with their potential to contribute to impairment and eutrophication, decreased with recycling across all three study sites. For nonpotable-NC recycling, the decrease in nutrient discharges from the wastewater treatment plant into Morgan Creek is critical given the impaired status of numerous waters in the area. Previous biological assessment of taxonomic richness showed a decrease downstream of the discharge from the wastewater treatment plant into Morgan Creek compared to upstream of the discharge location. Additionally, Morgan Creek is a tributary of Jordan Lake, a reservoir impaired by excess nutrient loading [179]. While the decrease in wastewater discharge into the surface water is clearly beneficial for water quality, there is no measure in this study of the nutrients leaving the system in the form of recycled water, shifting the discharge from a point source to a nonpoint source via irrigation. The path of nutrients in nonpotable water, especially if used for irrigation, is significantly different than with traditional treatment where the nutrients are either captured in the sludge and taken to the landfill or released into surface water through discharge. In the case of nonpotable water used for irrigation, further nutrients are likely removed through plant uptake and soil percolation. Additionally, nutrient presence in the nonpotable water may benefit irrigation users, as it decreases the need for fertilizer purchase and application. Therefore, while the discharge of nutrients in the nonpotable-NC water was not included in the analysis, it is likely that further removal during agricultural use before the water enters groundwater or surface waters occurs.

In the absence of direct potable-TX recycling, all the wastewater from the Big Spring Wastewater Treatment Plant is discharged into Beals Creek, a tributary of the Colorado River. Reports from the Lower and Upper Colorado River authorities indicate that both Beals Creek and the Colorado River downstream of the confluence point are classified as water quality concerns due to chlorophyll and nutrients [180]. Therefore the shift of a portion of the wastewater discharge from the WWTP to the Raw Water Production Facility for further treatment and reuse is expected to decrease the negative impacts of nutrient discharge in the area and further downstream. However, Beals Creek is also the discharge location of the brine concentrate from the reverse osmosis treatment at the Raw Water Production Facility.

Reverse osmosis is widely used in advanced water treatment, including for direct potable recycling, due to its effectiveness at treating a variety of pollutants, including emerging contaminants [37]. Waste from this treatment technique is highly concentrated, however, and is often difficult to dispose of, representing a tradeoff that utilities must consider [181]. The direct potable-TX recycling facility's reverse osmosis concentrate discharge into Beals Creek required an industrial discharge permit that was allowed due to the brackish nature of the creek. Disposal of brine concentrate that cannot be discharged into the environment, due to unavailable discharge locations, can be cost-intensive and must be weighed against the benefits of reverse osmosis. Research shows that alternative and less expensive treatment processes that do not result in the discharge of brine are likely to be successful at treating wastewater to potable water standards [91,178]. As more research and implementation of these systems increase, there is the potential for removing the negative environmental impact of brine contaminant release as a constraint of direct potable recycling.

While there was no impact on total nitrogen, there was a significant decrease in the concentration and total quantity of phosphorus released into the environment with the implementation of indirect potable-VA recycling. Nutrient impacts on surface water from the Nanesmond WWTP are particularly important due to its discharge of treated wastewater into the James River, a tributary of the heavily impaired Chesapeake Bay. A consortium of federal, state, and local government and nongovernmental agencies aim to decrease nitrogen and phosphorus discharge in the tributaries by 100 percent by 2025 to protect the bay, a federally designated national treasure [182,183]. The shift of a portion of the WWTP discharge to the SWIFT aquifer recharge facility not only decreases the release of nutrients into the James River, but also the total nutrients discharged into the environment through the additional water treatment the SWIFT Research Center provides. Once injected into the aquifer, there is evidence that the water is treated even further as it moves through the sediments in the aquifer, shown by a decrease in contaminants as water moves away from the discharge point [184,185]. Travel time for contaminants from the discharge well to the monitoring station 50 feet away is as rapid as three days but increases to months or years in travel time to the stations 340 feet or further away [185,186]. Based on this evidence and previous research, it is likely that negative impacts of contaminants in the aquifer will be localized to areas near the injection sites with positive impacts from increased water quantity seen on a larger scale throughout the aquifer. The additional decrease in contaminants in groundwater is important due to the negative impact on human health of well water intake from excess nitrogen that can cause sickness and even death in infants [187].

Energy implications of technology and facility decisions

There are many benefits of decreasing energy consumption including decreasing greenhouse gas emissions and operational costs and independence from fossil fuels, particularly in times of political tension. Decisions on water recycling system design can have significant impacts on energy consumption and therefore costs and negative environmental impacts such as greenhouse gas emissions. Indirect-VA and direct potable-TX recycling both resulted in increased total energy consumption due to the operation of an additional treatment facility. Additionally, the Raw Water Production Facility for direct potable-TX recycling uses the same treatment technology as that for desalination, described as ‘full advanced treatment.’ This combination of microfiltration, reverse osmosis, and ultraviolet disinfection is shown to be responsible for up to 98% of system energy use [188]. Utilizing this system is both energy intensive and expensive which can make it a barrier to implementing recycling, especially for small inland communities [189]. Previous research suggests, however, that without additional drinking water treatment, the energy required for direct potable recycling will be less than that required to use other water sources such as desalinization or transportation of alternative supplies over significant distances. Direct potable recycling has the potential to be the most energy efficient system of expanding potable water supplies [181].

The nonpotable-NC recycling system did not involve additional facilities or treatment technologies and showed no significant change in total energy use after recycling began. However, studies show that water distribution accounts for 65% of the total energy consumption in nonpotable recycling systems [190]. Therefore, nonpotable recycling systems that add significant additional distribution systems to increase access to recycled water along-side potable water, may see a significant increase in energy consumption. For the nonpotable-NC system, however, unlike both indirect-VA and direct-TX potable recycling, there was no change in total energy consumption.

Limitations

There are several important limitations of this study to consider when interpreting these results. First, it does not consider the environmental impacts of infrastructure such as new pipes and facilities required to implement a water recycling system. This can be a major factor depending on the infrastructure design and is especially important when considering the differences between adding recycling technologies at an existing plant compared to constructing a new facility. While a new facility might allow for more recycling capacity and treatment quality, the environmental impacts may be significant as a result of construction impacts and additional operational impacts such as energy use and increased use of chemical additives for treatment. Secondly, this study utilizes case studies which provide a narrow view of potential recycling facility impacts. Factors unique to each community such as quality of source water, alternative water sources, hydrology and current infrastructure must be considered [181,190].

Assessing the impacts from multiple facilities would allow for a demonstration of the effects of site variation, however, it is not currently possible with all forms of recycling due to the limited number of facilities which use direct potable recycling.

CONCLUSION

Despite these limitations, the results of this study demonstrate that all three major systems for water recycling (nonpotable, indirect potable and direct potable) have the potential to benefit the environment in some ways. Those impacts vary depending on the type of recycling employed. Nonpotable-NC resulted in no change in water depletion indicating the absence of significant impacts on water loss by additional water transportation. Even though nonpotable recycling does not increase the amount of water available in the environment for instream uses, it does not decrease this amount and utilities benefit from increased water supply for human use because wastewater that was previously discharged downstream is now integrated into the human water system by adding volume to the water supply. Indirect potable-VA recycling resulted in increased water depletion, but also shows positive impacts on sustainability of the Potomac Aquifer. Results for water depletion with direct potable-TX recycling were not comprehensive due to incomplete data but indicate substantial losses during additional recycling treatment. Increased water depletion is an important, yet previously undiscussed, impact of water recycling that should be considered in project implementation, especially when protecting instream uses for aquatic health is a major utility goal. All three recycling systems have the potential to decrease the discharge of nutrients into the environment, thereby decreasing the potential for eutrophication and dead zones. Energy use varied among the recycling systems with indirect potable-VA and direct potable-TX showing increased consumption due to the implementation of additional treatment facilities and nonpotable-NC recycling showing no change. More research is needed to evaluate the consistency of these results across recycling sites to account for variation in environmental impacts.

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FIGURES AND TABLES

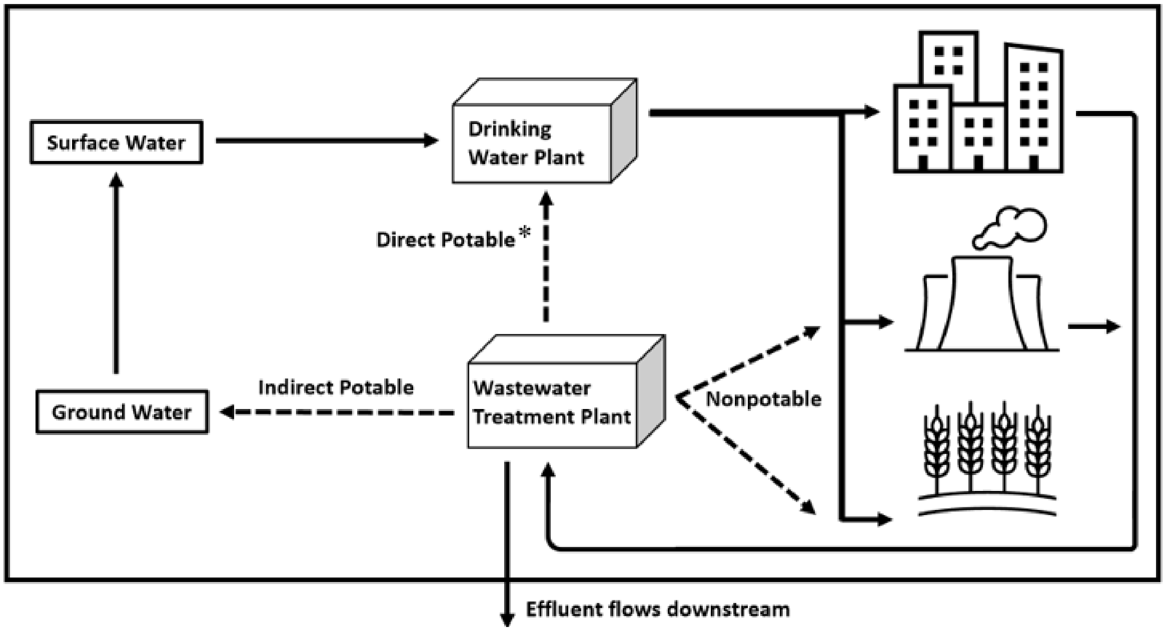

Figure 4.1. Traditional water treatment and use system versus water recycling. Dashed lines indicate additional distribution lines likely with water recycling. Asterisk represents recycling systems that are likely to require additional treatment.

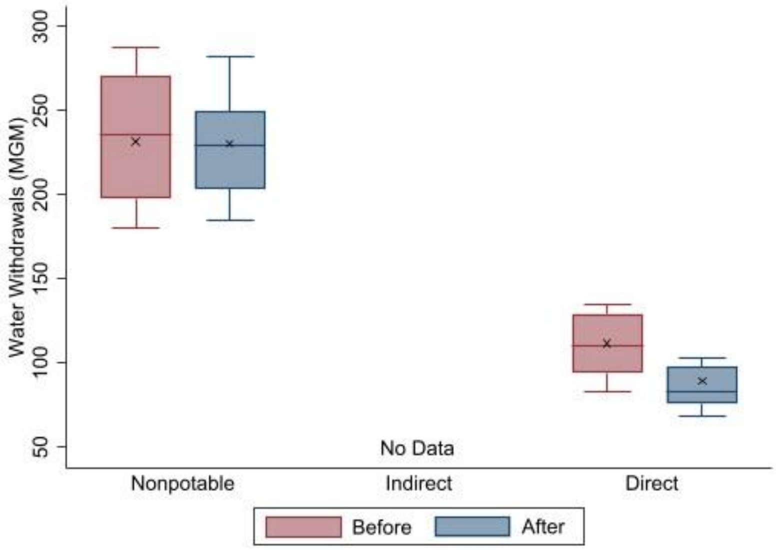

Figure 4.2: Water withdrawals before and after implementation of nonpotable-NC and direct potable-TX recycling. No data was available for indirect potable-VA recycling. Boxes represent 25th and 75th percentiles. The midline and x represent median and average respectively. The upper and lower lines off the boxes represent the spread of the data.

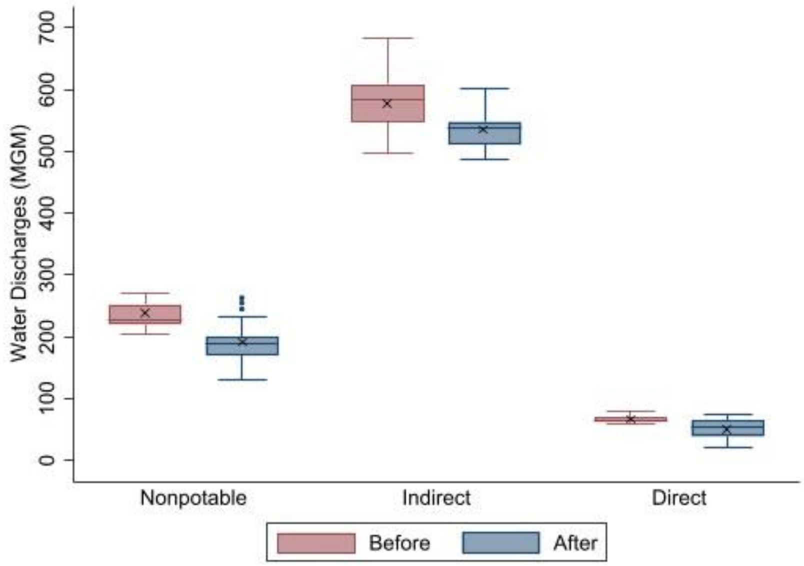

Figure 4.3: Water discharges before and after implementation of nonpotable-NC, indirect potable-VA, and direct potable-TX recycling. Boxes represent 25th and 75th percentiles. The midline and x represent median and average respectively. The upper and lower lines off the boxes represent the spread of the data. Points represent outliers.

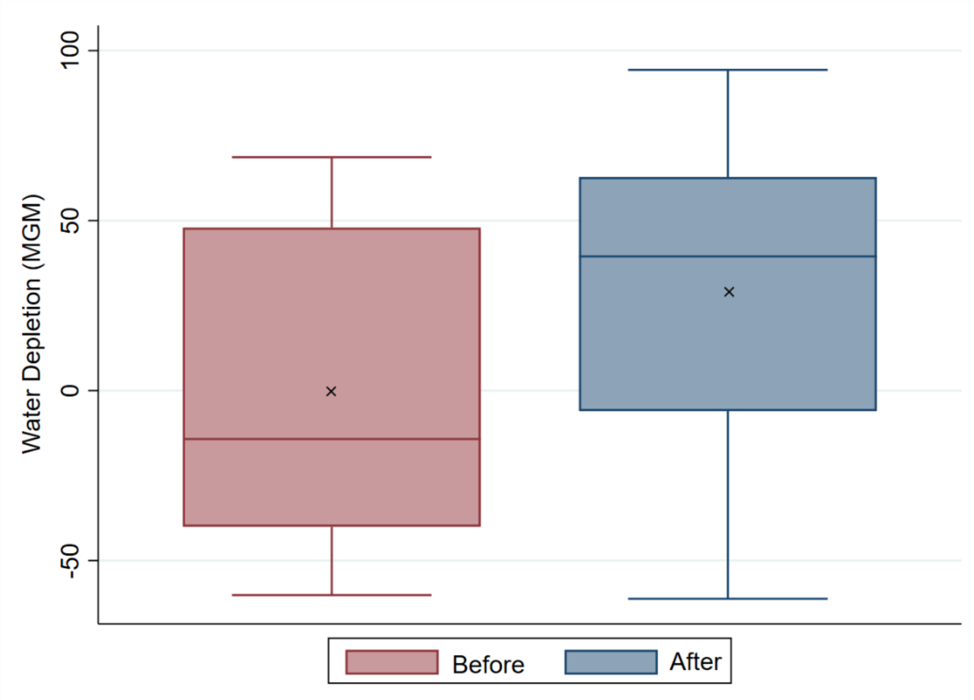

Figure 4.4: Water depletion before and after implementation of nonpotable-NC recycling. Boxes represent 25th and 75th percentiles. The midline and x represent median and average respectively. The upper and lower lines off the boxes represent the spread of the data. Points represent outliers.

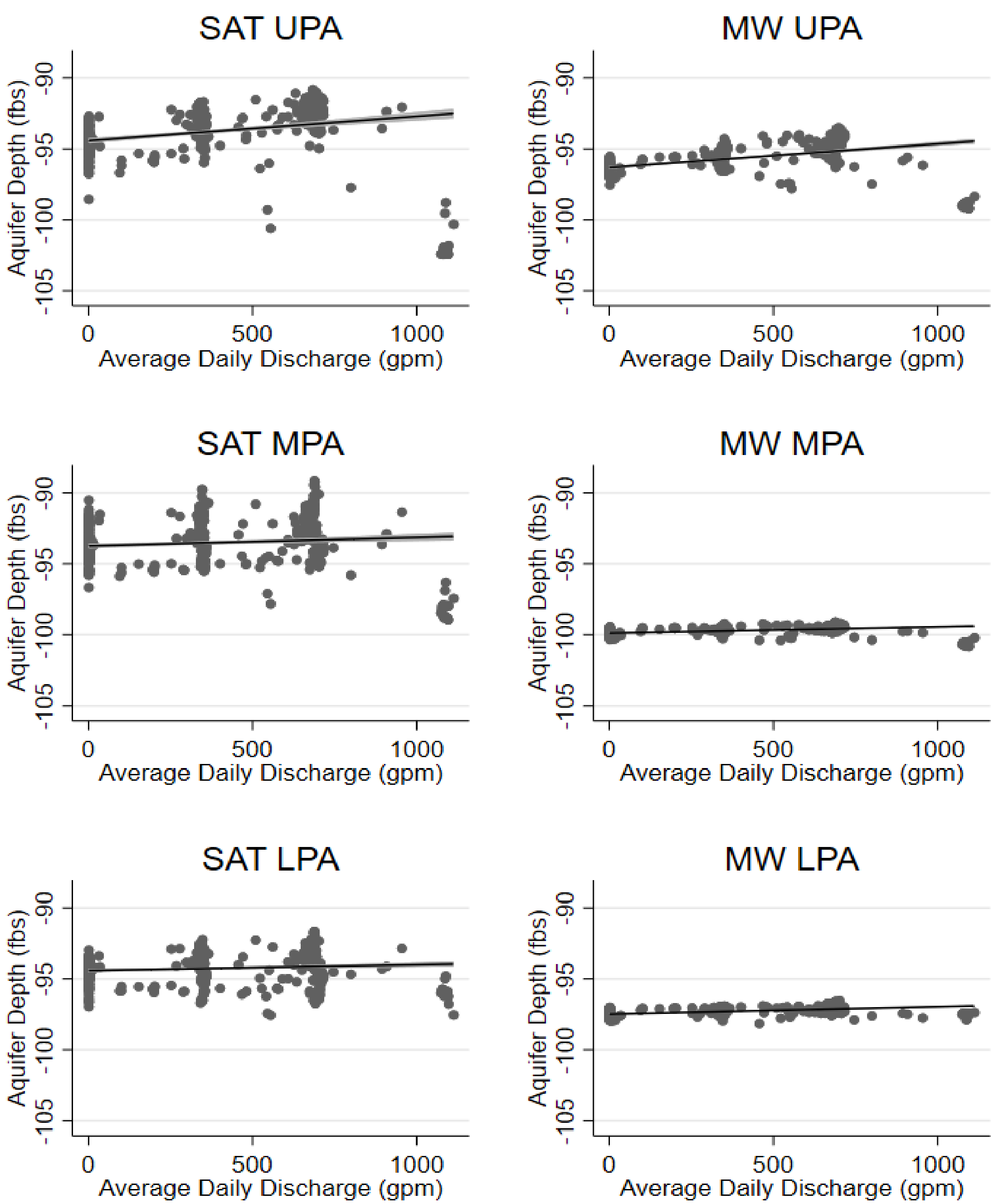

Figure 4.5: Aquifer depth and discharge from the indirect recycling facility-VA at six sampling sites. SAT sites were located 50 feet from the discharge point in the upper (UPA), middle (MPA), and lower (LPA) aquifer regions. The MW upper (UPA), middle (MPA), and lower (LPA) regions were located 340, 390, and 440 feet from the discharge point respectively.

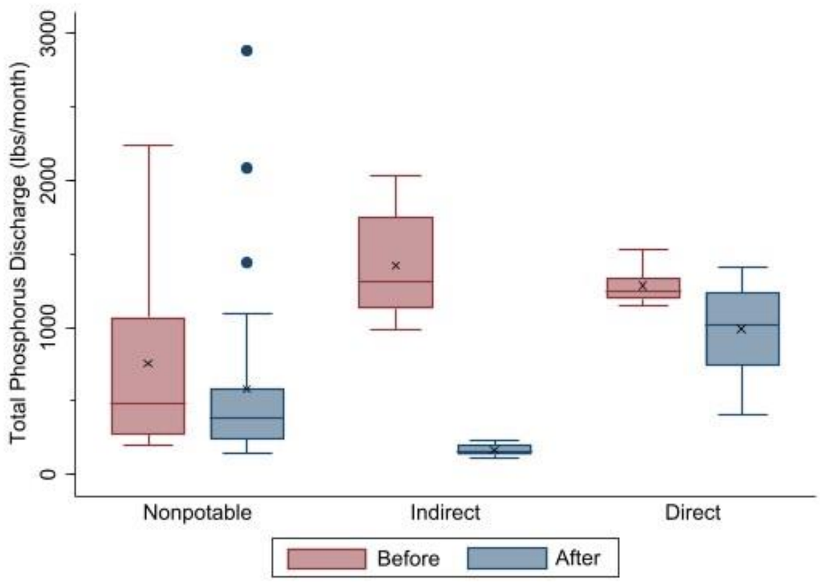

Figure 4.6: Comparison of total phosphorus discharge before and after implementation of nonpotable-NC, indirect potable-VA, and direct potable-TX recycling. Boxes represent 25^{th} and 75^{th} percentiles. The midline and x represent median and average respectively. The upper and lower lines off the boxes represent the spread of the data. Points represent outliers.

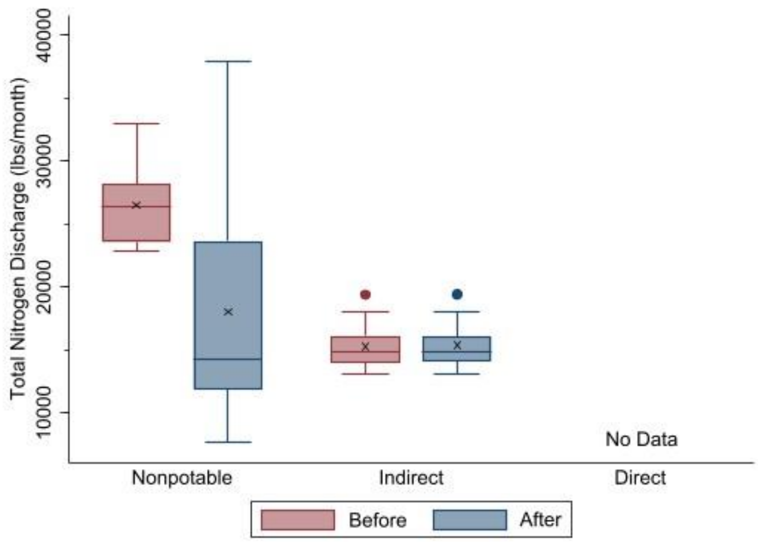

Figure 4.7: Comparison of total nitrogen discharge before and after implementation of nonpotable-NC and indirect potable-VA recycling. No data was available for direct potable-TX recycling. Boxes represent 25th and 75th percentiles. The midline and x represent median and average respectively. The upper and lower lines off the boxes represent the spread of the data. Points represent outliers.

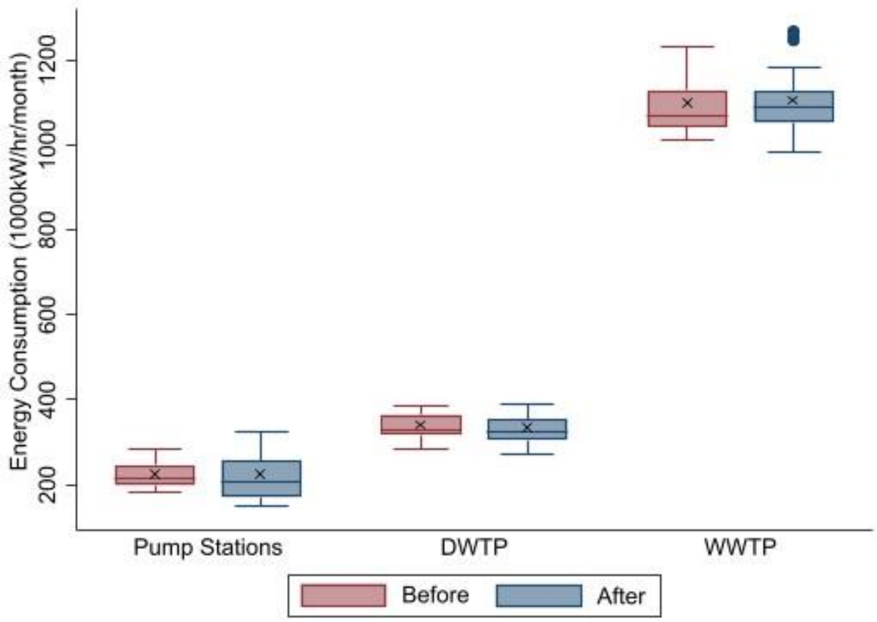

Figure 4.8: Change in energy consumption before and after implementation of nonpotable-NC water recycling for water withdrawal pump stations, drinking water treatment plant (DWTP), and wastewater treatment (WWTP). Boxes represent 25th and 75th percentiles. The midline and x represent median and average respectively. The upper and lower lines off the boxes represent the spread of the data. Points represent outliers.

Table 4.1: Terms, benefits, and barriers for water recycling [90,143,181,191–193].

Terms	**Definition**		
Nonpotable Water	Water treated for uses other than drinking, mostly for landscape irrigation and agriculture, and therefore held to lower quality requirements than potable water		
Potable Water	Water suitable for human consumption (drinking)		
DeFacto Recycling	A community's withdrawal of water that includes wastewater discharged by an upstream community		
Recycling Type	**Definition**	**Benefits**	**Barriers**
Nonpotable	Water is used, treated, and piped to consumers for nonpotable uses such as irrigation and cooling	-Rarely requires additional treatment -Widely accepted by consumers -Often the least expensive way to increase availability of water resources -More acceptable by the public -Well established process	-Requires additional infrastructure to move recycled water to consumers -Use based on available consumers and water quality -Potential for overall increase in water use given cost signals
Indirect Potable	Water is used, treated, and released into an environmental buffer such as a lake, river, or groundwater aquifer before being withdrawn and used again for drinking water	-Rarely requires additional treatment -Environmental buffer increases public acceptance of potable recycling -Widely used, creates more than 200 MGD of water in the US	-Requires appropriate water body for use as the environmental buffer
Direct Potable	Water is used, treated, and then used again for drinking and other purposes by the same utility without the use of an environmental buffer	-Increased water reliability in drought situations	-Significant negative public perception -Often requires additional treatment and infrastructure upgrades, which can be costly -Uncertainties involving emerging contaminants -Minimally used in the United States

Table 4.2: Study site system information for water treatment, wastewater treatment, and water recycling.

	NC-Nonpotable	**VA-Indirect Potable**	**TX-Direct Potable**
Drinking Water			
Source(s)	Cane Creek Reservoir, University Lake, and Quarry Reservoir	Numerous sources, including Potomac Aquifer	Lake J.B. Thomas, E.V. Spence Reservoir, O.H. Ivie Reservoir, and two groundwater well field
Tertiary Treatment	Filtration and disinfection utilizing chlorine and chloramines	Not applicable	No tertiary treatment
Capacity	20 MGD	Not applicable	16 MGD
Wastewater			
Tertiary Treatment	Disinfection, oxygenation	Phosphorus recovery, aeration, disinfection	Aeration, disinfection
Capacity	14.5 MGD	30 MGD	3.8 MGD
Discharge Location	Morgan Creek	James River	Beals Creek
Water Recycling			
Additional Facility	Not applicable	Sustainable Water Initiative for Tomorrow (SWIFT) Research Center	Raw Water Production Facility
Additional Treatment	Not applicable	Ozone-biologically active filtration and ultraviolet disinfection	Microfiltration, reverse osmosis, and ultraviolet disinfection
Recycled Water Use	Energy generation and irrigation	Aquifer recharge (Potomac Aquifer)	Drinking water plant inflow
Capacity	3 MGD	1 MGD	1.5 MGD

Table 4.3: Collected data for analyses of environmental impacts from nonpotable-NC, indirect potable-VA, and direct potable-TX. Comparisons were made between before and after recycling for each environmental impact indicator based on data collected from drinking water plants (DWTPs), wastewater treatment plants (WWTPs), and recycling facilities (RFs).

	NC-Nonpotable	**VA-Indirect Potable**	**TX-Direct Potable**
Withdrawals	Before: DWTP inflow January 2008- March 2009 After: DWTP inflow May 2009-December 2011	No data collected; assumed to be no change	Before: DWTP inflow January 2012- December 2012 After: DWTP inflow January 2014- December 2014 reduced by average inflow recycled water composition in 2020 (26%)
Discharges	Before: WWTP discharge January 2008- March 2009 After: WWTP discharge May 2009-December 2011 (not including recycled water)	Before: WWTP discharge May 2016-May 2018 After: Sum of WWTP and RF discharge June 2018-March 2020	Before: WWTP discharge January 2012- December 2012 After: WWTP discharge January 2014- December 2014
Water depletion	Difference between water withdrawals and water discharges	Assumed to be the change in water discharges	Difference between water withdrawals and water discharges
Total Phosphorus	Before: WWTP discharge concentration multiplied by WWTP discharge January 2008-March 2009 After: WWTP discharge concentration multiplied by WWTP discharge May 2009-December 2011	Before: RF inflow concentration multiplied by the sum of RF and WWTP discharge After: Sum of RF inflow concentration multiplied by the WWTP discharge and RF outflow concentration multiplied RF discharge All from June 2018-March 2020	Before: Average RF nutrient inflow concentration for 4 samples from 2013-2021 multiplied by WWTP discharge January 2014- December 2014 After: Average RF nutrient inflow concentration for 4 samples from 2013-2021 multiplied by WWTP discharge January 2012- December 2012
Total Nitrogen	Before: WWTP discharge concentration multiplied by WWTP discharge January 2008-March 2009 After: WWTP discharge concentration multiplied by WWTP discharge May 2009-December 2011	Before: RF inflow concentration multiplied by the sum of RF and WWTP discharge After: Sum of RF inflow concentration multiplied by the WWTP discharge and RF outflow concentration multiplied RF discharge All from June 2018-March 2020	Data not available
Energy	Before: Monthly energy total for pump stations, DWTP, and WWTP January 2008- March 2009 After: Monthly energy total for pump stations, DWTP, and WWTP May 2009-December 2011	Before: Data not available After: Monthly energy total for RF May 2018 - August 2021	Data not available

Table 4.4: Total phosphorus and total nitrogen concentration (mg/L) before and after implementation of nonpotable-NC and indirect potable-VA recycling. Asterisks indicate a significant difference in concentration. No data for direct potable-TX recycling was available.

	Nonpotable-NC			Indirect Potable-VA		
	Before	**After**	**Difference**	**Before**	**After**	**Difference**
Total Phosphorus (mg/L)	0.39±0.12	0.35±0.06	0.034±0.13	0.52±0.11	0.2±0.11	0.31±0.12*
Total Nitrogen (mg/L)	13.45±0.55	11.11±0.33	2.33±0.2*	3.42±0.14	3.57±0.17	-0.15±0.06

*Statistically significant ($p<0.05$)

Table 4.5: Water recycling environmental impact variable qualitative comparisons.

Recycling Type	**Nonpotable-NC**	**Indirect Potable-VA**	**Direct Potable-TX**
Water withdrawal volume	No change	No data	Decrease†
Water source depth	No data	Increase*	No data
Water depletion	No change	Decrease*	No change
Wastewater discharge volume	Decrease*	Decrease	Decrease†
Total Nitrogen			
Pounds	Decrease*	No change	No data
Concentration	Decrease*	No change	No data
Total Phosphorous			
Pounds	Decrease*	Decrease*	Decrease*
Concentration	Decrease	Decrease*	Decrease†
Energy use	No change	Increase†	Increase†

*Statistically significant ($p<0.05$)
†Statistical significance not assessed (see methods section)

CHAPTER 5

CONCLUSIONS

Water scarcity is increasing across the globe, including many regions of the United States. Climate change and drought are decreasing supply; simultaneously human water demand is rising [106,194]. To protect water resources for humans and the environment, the consideration of water recycling to expand water supply has increased in communities worldwide. Despite the potential to increase access to water resources beyond what conservation alone can provide, water recycling is limited. When decision makers are considering the adoption of water recycling projects, they must take into account many interconnected factors including public support, state and local policies, implementation costs, infrastructure and technology requirements, and environmental impacts. As part of Chapter 3, respondents in the United States were asked to select the factors that impact their willingness to use recycled water, and the most common choices were health, cost, and the environment. Each chapter of my dissertation focuses on overcoming barriers related to each of these factors to increase recycling projects and protect the future of water resources.

Risk to human health, distrust in utilities to protect consumers from that risk, and disgust at the idea of consuming treated wastewater (called the ‘yuck’ factor), are all negative perceptions associated with consuming recycled water [27,62]. The analysis in Chapter 2 was initiated in response to a request by the water reuse committee of an organization of water utilities in the state of Georgia who believe that comprehensive state water recycling legislation will help overcome these negative perceptions. A summary and analysis of all comprehensive state water recycling policies in the U.S. was completed. Recommendations were then made for future policy design including clearly communicating the public health and environmental goals of the policy, involving both the state health and environmental agencies in developing and implementing recycling legislation and regulations, appointing a diverse group of stakeholders to contribute to legislative and regulatory drafting, holding public listening sessions during the drafting process, streamlining and simplifying the permitting process to combine wastewater treatment and reuse permits, requiring utilities to develop outreach programs for consumers of recycled water, requiring utilities to consider reuse as a supply option in their ongoing planning, and providing state resources to help offset costs of planning and building recycling infrastructure. Implementing these recommendations can help overcome negative perceptions and assure the public that water recycling is safe.

To further understand consumer perceptions, Chapter 3 surveyed 1000 individuals across various cities in the United States. Using a consumer choice experiment, I evaluated consumer willingness to pay for potable recycled water considering the impact of terminology and the likelihood of recycling to decrease future water restrictions. I found that consumer willingness to pay for potable recycled water is impacted by terminology, as individuals were not willing to pay as much for water that was labeled in terms other than ‘the same water you receive now.’ Of the terms I tested, ‘purified water’ was the most preferred term and generated the highest willingness to pay scores, followed by ‘reclaimed water’. Shifting from the commonly used terminology ‘recycled water' towards ‘purified water’ has the potential to increase both consumer acceptance and willingness to pay, enhancing successful project implementation and contributing to the future protection of water resources.

The final of the three factors most important to the respondents surveyed in Chapter 3 was the environment. Therefore, Chapter 4 investigated the differences in environmental impacts between the three main forms of water recycling (nonpotable, indirect potable, or direct potable), using case studies. Comparing data before and after implementation at all three sites for the environmental variables of water depletion, nutrient discharges, and energy consumption, I found that there were considerable differences depending on the type of recycling. The additional transportation and treatment of wastewater for reuse was expected to increase water depletion, or the water that is removed from the environment and not returned through discharge. This increase in water depletion would therefore result in decreased water in the environment which is necessary for ecosystem health. However, water depletion only increased for indirect potable recycling, and did not change for nonpotable recycling. Direct potable recycling showed substantial increased water loss during recycled water treatment. All three study sites decreased the release of total nitrogen and total phosphorus into the environment. There was no significant change in total energy after adoption of the nonpotable recycling system, but there were total energy increases for both direct and indirect potable recycling due to the implementation of additional water treatment facilities. Despite study limitations, this research indicates substantial variation in environmental impacts requiring evaluation of tradeoffs by stakeholders during recycling project consideration. Utility specific goals such as increasingly stringent nutrient discharge standards will assist stakeholders in valuing the variable environmental impacts found in these results.

Overall, my dissertation investigated barriers and recommended solutions to promote water recycling. Potable water recycling projects have failed in the past due to negative public perceptions [59]. Communication regarding the safety of water recycling consumption, potential economic benefits, and opportunities for environmental protection are all key factors to increase community acceptance [50]. Adoption of state recycling policy and use of purposeful terminology have the potential to increase consumer acceptance of recycled water. Additionally, consumer willingness to pay can be equal to costs of current water use, indicating that utilities may not need to decrease water cost to offset negative perceptions. Finally, while all recycling systems have the potential to benefit the environment, these benefits vary and should be evaluated during project design. Many factors must be considered in deciding whether to recycle water in a community, but the many potential benefits to humans and the environment necessitate its consideration.

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APPENDIX A

CHAPTER 2 SUPPLEMENTARY MATERIALS

Arizona

Responsible Agency

The Arizona Department of Environmental Quality has authority over water recycling (Ariz. Admin. Code R18-9).

Categories of Recycled Water and Water Quality Criteria/Permitting System

General permits for recycled water fall into three categories: Types 1-3 (AZ Admin. C. R18-9-A704). Type 1 and 3 address permitting for greywater, wastewater from residential, commercial and industrial bathroom sinks, tub and shower drains, and clothes-washing equipment, that is recycled onsite for non-potable purposes, typically for landscape irrigation. Type 2 general permits are for the use of reclaimed water other than greywater. Type 3 recycled water general permits allow for blending reclaimed water with other water (AZ Admin Code R 18-9-B709). Type 2 permits require that one of five categories of water quality be met, depending on the intended use of the recycled water; these categories are assigned alphabetical letters with "A+" being the highest quality and "C" being the lowest quality. Each of the categories has corresponding allowed uses, water quality criteria, and treatment requirements. The categories of recycled water that include the "+" require nutrient monitoring as well as the other requirements of that category. For example, "A+" and "A" recycled water must undergo the same treatment and meet the same water quality standards but "A+" water also requires monitoring of total nitrogen. The "+" designation does not allow the recycled water to be used for additional purposes, meaning that "A" water and "A+" water have the same approved uses, but the "A+"

title is designed to indicate that the water is of higher quality than “A” water due to the additional required nutrient monitoring. Uses that are not assigned to a category, including direct reuse, can be approved on a case-by-case basis if the agency determines the use does not endanger public health or the environment (AZ Admin Code R18-11-309).

Blue Ribbon Stakeholder Committee

In 2009, the Governor of Arizona convened a Blue Ribbon Panel on Water Sustainability to address the conservation and recycling of water resources. The panel recommended changes in existing policy and practices to optimize water recycling in their state. These included decreasing redundancies in permitting, creating a state training and certification program for the operation of reuse systems, increasing stakeholder participation, increasing incentives for recycling through tax exemptions and tax credits, and providing education and outreach (Blue Ribbon Panel 2010). Listening sessions for the committee’s recommendations were completed in 2015 and 2016 which led to the rulemaking in January 2018 that removed the prohibition on direct potable reuse (D. Dunaway, personal communication, July 13, 2018). The Arizona Department of Environmental Quality is taking steps to secure primacy on underground injection which is currently exercised by the federal Environmental Protection Agency (EPA).

Indirect Potable Reuse

Aquifer storage and recovery in Arizona allows reclaimed water dischargers to be given credits to allow for withdrawal of the discharged water at a later date outside of their other withdrawal permits (AZ Rev. Stat. § 45 Ch.3). These credits can be traded and sold between groups.

Direct Potable Reuse

Effective January 2018, Arizona permits direct potable reuse systems (AZ Admin Code R18-9-E701). The permit application for reuse, not including greywater, must be accompanied by a design report by a professionally-certified engineer and results from a pilot treatment system or an analogous system demonstrating the treatment efficiency of the source water; these permits are approved on a case-by-case basis.

Funding

Financing water recycling in Arizona falls on the municipalities, utilities, and end users (Bracken 2012). However, the Water Infrastructure Finance Authority of Arizona is authorized to finance the construction and updating of water facilities or projects, including water reclamation and recycling facilities, through the utilization of loans with below-market interest rates.

California

Legislative Goals and Mandates

The state of California encourages the use of reclaimed water in several statutes including Water Code §461, 462, and 463. The most general of the codes, Code §461, declares that the conservation of water resources is critical to this drought-susceptible state and that it requires the reclamation and reuse of water whenever possible: "It is hereby declared that the primary interest of the people of the state in the conservation of all available water resources requires the maximum reuse of reclaimed water in the satisfaction of requirements for beneficial uses of water." Code §462 and §463 promote investigation into the availability and quality of water resources for recycling and into the technology for reclamation. Code §10633 requires urban water suppliers to evaluate the potential for water recycling in their urban water management plans which must be updated every five years. Beginning in 2010 the plans must include descriptions of the current water recycling programs occurring in the service area, the amount of treated water that meets recycled water standards, the potential for water recycling based on technical and economic feasibility, and actions that may be taken to encourage and optimize the use of recycled water.

Responsible Agencies

California Code §13521 (Uniform recycling criteria; establishment) tasked the State Department of Public Health with establishing statewide criteria for different types of recycling that have the potential to impact human health. These regulations specifically discuss the use of recycled water containing domestic sewage (Cal. Code Regs. Tit. 22 § 60302). The State Water Resources Control Board and nine Regional Water Quality Control Boards regulate water reuse quantity and issue permits. A Memorandum of Agreement was issued in 1996 between the Department of Health Services, the State Water Resources Control Board and the Regional Water Quality Control Boards to define their responsibilities and to promote future collaboration and coordination (M.O.A. CA. 1996).

Categories of Recycled Water and Water Quality Criteria/Permitting System

Any person or group that recycles water or uses recycled water must file a report with the State Water Resources Control Board; failure to do so is a misdemeanor (Cal. Water Code § 13522.5, Cal. Water Code § 13522.6). California uses a categorization system similar to Arizona’s which assigns specific water quality criteria and treatment requirements to particular uses. There are four categories: Disinfected Tertiary Recycled Water, Disinfected Secondary 2.2 Recycled Water, Disinfected Secondary 23 Recycled Water and Undisinfected Secondary Recycled Water. All categories must meet the criteria for total coliforms. California also regulates the proximity of recycled water to domestic water supplies, impoundments, and locations where public exposure is likely (Cal. Code Regs. Tit. 22, § 60310).

California has separate regulations for surface applications and subsurface applications of recycled water but uses the same application process for both. Approval for indirect potable recycling projects through groundwater replenishment is determined by the Department of Health Services and the Regional Water Quality Control Boards, and only after a public hearing is held. Surface water and subsurface applications must meet the standards for disinfected tertiary recycled water with additional criteria for nitrogen, pathogenic microorganisms, lead, copper, and other contaminants (Cal. Code Regs. Tit.22 § 5.1).

Funding

Financial assistance for water recycling in California is provided by the Water Recycling Funding Program operated by the State Water Resources Control Board (Water Recycling Program). This program provides loans and planning grants for water recycling projects. Additionally, the Clean Water Revolving Fund Program offers low-interest loans to public agencies for planning, design and construction of water recycling projects.

Colorado

Legislative Subcommittee Provided Leadership

The population of Colorado is expected to double by 2050 to between six and eight million people. These projections combined with a series of droughts led the Colorado legislature to take steps to encourage water reclamation and reuse in their state. A presentation to the Water Quality Control Commission by the American Water Works Association and the Water Environment Association in 1998 addressed the need for and potential for enacting regulations to address the use of recycled domestic wastewater for landscape irrigation (5 Colo. Code Regs. § 1002-84). As a result, a legislative subcommittee was created in 1999 that successfully proposed amending the

Colorado Water Quality Control Act to give the commission the authority to oversee and implement a water recycling program. Regulations were subsequently adopted over time.

Legislative Goals and Responsible Agency

Colorado's regulations were enacted to "protect public health and the environment while encouraging the use of reclaimed water" to meet the growing water needs of the state (Colo. Code Regs. § 5-1002-84). The Colorado Water Quality Control Act charges the Water Quality Control Commission under the Colorado Department of Health and the Environment with developing water recycling regulations; this is the same department that regulates drinking water quality. (Colo. Rev. Stat. § 25-8-202).

Permit System

A letter of intent must be submitted to the Commission and if approved, the Commission will issue a notice of authorization for the recycling project (amounting to a permit) which includes water quality criteria, monitoring and reporting requirements and approved uses. Colorado uses a categorization system for water recycling similar to the preceding states; Category 1, 2, and 3 have associated water quality criteria and allowed usages.

Liability

The user of the recycled water is required to submit a User Plan to Comply which designates the person legally responsible and the best management practices planned to reduce unintended negative environmental impacts, such as ponding during surface application (Colo. Code Regs. § 5-1002-84). Liability for failing to comply with the regulation may be imposed on the user, the treater or both. The treatment entity is responsible for ensuring the quality of water meets requirements while the user is responsible for using the recycled water only for designated uses. If either are aware of the other's violation and fail to report it, they may be subject to penalties.

Additionally, the entity treating the recycled water is required to implement a public education program for those that may come in contact with the water (such as firefighters or plumbing contractors) on how to safely work with the recycled water (Colo. Code Regs. § 5-1002-84).

Local Government Authority for Greywater Systems

Colorado provides local governments the authority to regulate the use of greywater for non-drinking water purposes within their jurisdictions (Colo. Code Regs §1002-86). Local governments must adopt the state's minimum criteria for particular uses and submit their ordinances to the Water Quality Control Division.

Florida

Legislative Goals and Responsible Agency

Florida's statutes encourage the use of water reclamation and reuse as a crucial element in meeting the state's water supply needs. The legislature proclaims that state agencies and facilities should use recycled water for nonpotable uses and "should take a leadership role in using reclaimed water in lieu of other water sources" (Fla. Stat. § 403.0645). The Department of Environmental Protection oversees wastewater facilities and issues water recycling permits (Fla. Admin. Code § 62-620.410).

Categories of Recycled Water and Water Quality Criteria/Permitting System/Liability

Permits for recycling and land application of reused water for the purpose of spray irrigation are combined with the permit for the wastewater treatment plant; a separate permit is required only if the user receives water from more than one wastewater treatment facility (Fla. Admin. Code § 62-610). Liability for the use of recycled water for spray irrigation remains with the treatment plant unless the irrigator was negligent or improperly managed the operation (Fla. Stat. § 403.135). Water quality criteria differ based on uses of the recycled water. The strictest water quality criteria are for groundwater recharge and indirect potable reuse; this criterion requires the water to meet drinking water standards and be monitored for contaminants (Fla. Admin. Code § 62-610).

Required Reuse Feasibility Studies in Water Resource Caution Areas and Mandated Use

The state has designated Water Resource Caution Areas where existing water sources are not sufficient to meet the projected demand in 20 years. The Florida Water Management District Governing Board is required to conduct regional planning in these areas and the plans must evaluate the feasibility of water recycling (Fla. Stat. § 403.064). As of May 2018, any wastewater treatment plant that operates in, treats water of people living in, or discharges into Water Resource Caution Areas are required to submit a feasibility study with their permit application (Fla. Stat. § 403.064). The studies must evaluate the financial costs and benefits for several levels and types of recycling, potential water savings, environmental and water resource benefits, constraints, and an implementation schedule which considers phased implementation. If the study determines that recycling is feasible, the wastewater treatment plant must give "significant consideration to its implementation." Additionally, water management districts have the jurisdiction to require water users to utilize recycled water instead of surface water or groundwater when it is available, feasible, and is sufficient quality and quantity for the user's needs (Fla. Stat. § 373.250).

Funding

The Florida Water Management District Governing Board created a Water Protection and Sustainability Program Trust Fund to provide financial assistance for water recycling initiatives and other alternative water sources (Fla. Stat. § 373.707). Sixty-five percent of the $100 million allocated funded the implementation of alternative water supply, including recycling, which generated 842 million gallons of “new” water per day. The program terminated via a sunset provision in 2009.

Hawaii

Responsible Agency

In the island state of Hawaii, drinking water and wastewater regulations are overseen by the Hawaii State Department of Health (DOH). DOH oversees the approval and oversight of water reuse and recycling projects. To construct or use a recycled water system the owner must have written approval from the DOH (Haw. Admin. Rules § 11-62-27). The policy states that the director’s decisions regarding recycled water should be guided by the “Guidelines for the Treatment and Use of Reclaimed Water” which was published by the DOH and revised in 2016. Each county is required to include in their mandatory water use and development plan, the status of their water, including reuse, reclamation, and recharge (Haw. Admin. Rules § 13-170-41).

Categories of Recycled Water and Water Quality Criteria

There are three categories of recycled water with varying treatment requirements, R-1 Water is the highest quality followed by R-2 Water and R-3 Water being the lowest quality recycled water. Turbidity and disinfection requirements vary depending on the category and treatment technology used.

All wastewater treatment system effluent must meet the same minimum water quality criteria requirements for BOD_5 and total suspended solids whether the water is to be reused or discharged (Haw. Admin. Rules § 11-62-26).

Funding

Funding for water recycling in Hawaii is available through grants from the director of the DOH to counties or agencies for the construction of wastewater treatment facilities and recycled water projects (Haw. Rev. Stat. § 342 D-54).

Idaho

Responsible Agency

The Idaho Department of Environmental Quality (DEQ) oversees water recycling in the state (Idaho Admin. Code r. 58.01.17.000).

Permit System

A permit from the director of DEQ is required before construction, modification, or operation of a water recycling facility (Idaho Admin. Code r. 58.01.17.300). The permit requires a map of the facility and the surrounding area, the volume and quality of water to be treated, and the impact on groundwater. Permits for the recycling of industrial wastewater often require additional information about contamination and potential impacts on human health (Idaho Admin. Code r. 58.01.17.603).

Categories of Recycled Water and Water Quality Criteria

DEQ has designated five categories of recycled water: Classes A through E. Each category has associated water quality criteria and treatment requirements for total coliforms, turbidity, total nitrogen, pH, and BOD_5.

Idaho allows for indirect potable water recycling through groundwater recharge of Class A recycled water (Idaho Admin. Code r. 58.01.17.614). Groundwater quality may not fall below the baseline standards, designed to protect public health, at any time (Idaho Admin. Code r. 58.01.11.200). The groundwater recharge facility must own the land down-gradient of the impact area to prevent other drilling that could allow for the removal of the recycled water before it has been mixed into the groundwater. In addition to the DEQ permits required for the recycled water facility, a permit is required from the Idaho Department of Water Resources (DWR) for groundwater injection wells. DEQ is responsible for groundwater quality while DWR is responsible for groundwater quantity (Idaho Admin. Code r. 58.01.17.614).

Massachusetts

Responsible Agency/Permitting System

The Massachusetts agency that oversees recycled water use, quality, and regulation is the Department of Environmental Protection (DEP). Permit requirements vary based on whether the reclaimed water is discharged into surface water, groundwater, or reused directly but the application for each of these are submitted to DEP for review and approval (Code Mass. Regs. § 314-3.00; Code Mass. Regs. § 314-5.00; Code Mass. Regs. § 314-20.00). In addition, groundwater discharge and direct reuse require a Reuse Management Plan approved by DEP; the application must include information about the volume and class of the recycled water, distribution method and the plan to inform the public about the use (Code Mass. Regs. § 314-20.03). The public education program is required to inform residents, users, and contractors that may come in contact with recycled water about the use of the water and any relevant safety concerns (Code Mass. Regs. § 314-20.13).

For reuse that will be distributed, sold, or used by an entity other than the treatment facility, a DEP-approved Service and Use Agreement between the entity and treatment is required; this includes the class and use of the water and the use sites. Reuse also requires an engineering report which includes the quality of the incoming water, the proposed class of the water, and the quality of the water to be treated and recycled. Facilities are required to be designed in accordance with the latest version of “Guidelines for the Design of Wastewater Treatment Facilities” from the New England Interstate Water Pollution Control Commission.

Categories of Recycled Water and Water Quality Criteria

Massachusetts has three categories of recycled water with associated allowed uses and water quality criteria. The classes from highest to lowest quality are Class A, Class B, and Class C.

Nevada

Responsible Agency

Nevada does not specifically define recycled water; however, it does state that effluent that is discharged from a wastewater treatment facility is considered water that is subject to appropriation and beneficial use (NV Rev. Stat. § 533.440). Water recycling in Nevada is managed by the Division of Environmental Protection, NDEP, of the State Department of Conservation and Natural Resources, DCNR. To recycle water, a management plan must be approved by NDEP and to discharge water into waters of the state for indirect reuse, a permit must be obtained from DCNR. NDEP establishes buffer zones around the site of use, such as spray irrigation for crops, that must be kept free from recycled water for safety purposes (NV Admin. Code § 445A.2756).

Categories of Recycled Water and Water Quality Criteria

All recycled water must meet the requirements for secondary treated water. There are five categories of recycled water with corresponding approved uses and water quality criteria: Reuse Categories A through E. The only difference between the water quality criteria for each of these categories is the bacteria limits. Based on these differences, the categories are approved for specific uses and for any additional use approved by NDEP.

New Mexico

Legislative Goals, Responsible Agency, and Permitting

Aquifer storage and recovery is stated by the legislature to have the potential to conserve water resources and protect groundwater sources (NM Stat § 72-5A-2). Groundwater storage and recovery permits are overseen by the New Mexico Office of the Sate Engineer and the New Mexico Environmental Department on a case-by-case basis (N.M. Code R. § 20.6.2.5000).

North Carolina

Legislative Goals and Responsible Agency

The North Carolina legislature proclaims that the use of recycled water and greywater are "critical to meeting the existing and future water needs of the state" (NC Gen. Stat. Ann. §143-355.5). Permitting responsibilities for reuse rest with the Division of Environmental Management of the North Carolina Department of Natural Resources and Community Development (NC Admin. Code § 15A-02U).

Categories of Recycled Water and Water Quality Criteria

Recycled water falls within one of two categories: Type 1 and Type 2 (NC Admin. Code § 15A-02U). Type 2 recycled wastewater can be used as potable water if it is mixed with raw source water, is added to a pretreatment basin for mixing, and meets the additional pretreatment requirements (NC Gen. Stat. Ann. §143-355.5). However, the regulations specifically state that reclaimed water cannot be directly reused as a raw potable water supply (NC Admin. Code § 15A-02U). Type 1 and Type 2 water may also be used for industrial and irrigation purposes as specified in the regulations (NC Admin. Code § 15A-02U). The regulations also differentiate between conjunctive and non-conjunctive systems for facility design requirements. In a conjunctive system, not all wastewater can be recycled and other methods may be used, whereas in non-conjunctive systems, reusing water is sufficient to dispose of all of the facility's wastewater (NC Admin. Code § 15A-02U).

Oklahoma

Responsible Agency and Permitting System

The Department of Environmental Quality, DEQ, oversees water recycling in Oklahoma. Permits from DEQ are required to construct or modify water recycling systems; permit applications must include an engineering report (Okla. Admin. Code 252:627-1-3, Okla. Admin. Code 252:656-3-4). DEQ also reviews permit applications for discharges into water bodies for indirect reuse projects (27A Okl. St. Ann § 2-2-105). The recycled water supplier is responsible for assuring that the users of the recycled water comply with regulations and thus are given reasonable access to all user sites for monitoring purposes (Okla. Admin. Code 252:627-1-3).

Blue Ribbon Stakeholder Committee

The "Water for 2060 Advisory Council" was created in 2012 to recommend incentives to increase water conservation, including the use of water recycling and reuse systems (Okl. St. Ann § 82-1088.11). The 15 council members included the executive director of the Oklahoma Water Resources Board, four members appointed by the governor, five members appointed by the Speaker of the Oklahoma House of Representatives, and five members appointed by the President Pro Tempore of the Oklahoma State Senate. The council submitted their findings to the Governor, Speaker of the House of Representatives, and President Pro Tempore of the Senate in October 2015 (Bachmann et al., 2015). The council had the ambitious end goal of consuming no more freshwater in 2060 than they did in 2010.

Categories of Recycled Water and Water Quality Criteria

Oklahoma has denoted six categories of recycled water with corresponding allowed uses, water quality criteria and treatment requirements. Category 1 is "reserved" with no criteria and Category 6 does not require a permit as the only allowed usage is on site of treatment facilities (Okla. Admin. Code 252:627-1-6). Categories 2-5 are the recycled water categories and therefore require permits from DEQ and monitoring.

Funding

Funding for recycling projects is provided by the Oklahoma Water Conservation Grant Program. The Oklahoma Water Resources Board solicits proposals and gives grants for pilot programs to implement water conservation projects that are innovative and will serve as models for other communities (Okla. St. Ann § 82-1088.13). The projects may include recycling and reuse.

Oregon

Responsible Agencies

The Environmental Quality Commission encourages "beneficial purposes in a manner which protects public health and the environment of the state" (Or. Admin. Rules § 340-055-0007). The Oregon Department of Environmental Quality, DEQ, is responsible for regulating recycled water use in Oregon. The wastewater treatment system may not provide recycled water for use unless it is authorized to do so by either a National Pollutant Discharge Elimination System (NPDES) permit or a Water Pollution Control Facility (WPCF) permit, or it receives approval from DEQ for a recycled water use plan (Or. Admin. Rules § 340-055-0016). Before approving a plan for Class C, Class D, or nondisinfected recycled water (see below) DEQ submits the plan to the Oregon Department of Human Services for comment. Recycling projects approved through NPDES or WPCF permits are required to submit a recycled water permit application to DEQ within a year.

Categories of Recycled Water and Water Quality Criteria

Oregon's five categories of recycled water (listed from lowest quality to highest quality) are nondisinfected recycled water, Class D recycled water, Class C recycled water, Class B recycled water, and Class A recycled water. Each of the categories is assigned water quality criteria for specific beneficial purposes, and site management requirements (Or. Admin. Rules § 340-055-0012). Blending recycled water with other water or using it as potable water for human consumption are not forbidden but must be approved on a case-by-case basis by DEQ. A potable reuse application must be approved by DEQ, the Environmental Quality Commission, and the Oregon Department of Health Services, and a public hearing is required (Or. Admin. Rules § 340-055-0017). The DEQ may authorize additional uses for any category of recycled water.

Required Evaluation of Recycling

The water conservation element of the Water Management and Conservation Plan required of each municipal water supplier applying for a new water use permit or permit extension compels some suppliers to investigate the potential for water recycling. If the supplier serves a population greater than 7,500 or if it serves a population of over 1,000 and proposes to expand a diversion of water it is required to include a description and timeline with 5-year benchmarks to implement water reuse, recycling and non-potable water opportunities or document why these strategies are not appropriate or feasible (Or. Admin. Rules § 690-086-0150).

Funding

Funding for water recycling is provided by several sources in Oregon. The Water Resources Department established a grant program to pay for up to $500,000 for studies that evaluate the feasibility of developing a water conservation or storage project (Or. Rev. Stat. § 541.561). Funds for this grant program comes from the Water Conservation, Reuse and Storage Investment

Fund that was established from $2 million in lottery bonds (O.R.S. § 541.576, 2015 Oregon Laws Ch. 812 (H.B. 5030)). Additionally, through the Clean Water State Revolving Fund Loans, public agencies, municipalities, or state agencies may receive a loan for up to 100 percent of the cost of a project to reuse or recycle water (Or. Admin. Rules § 340-054-0015).

Texas

Responsible Agency and Permit System

Water recycling in Texas is governed by the Texas Commission on Environmental Quality, TCEQ. This agency regulates permits and water quality for both direct and indirect reuse in the state. To receive approval for recycling, the water provider is required to notify the executive director of TCEQ and include information about the quality, intended use, operation and maintenance plan, and the source of the recycled water (TX Admin. Code § 30-210.4). The producer is the person(s) who treats the used water to adequate quality to be recycled and the provider is the person(s) who transports the recycled water from the source to the user (TX Admin. Code § 30-210.3); the two can be different entities. The transfer of water from the provider to the user is required to be done on-demand to avoid providing more water that can be utilized beneficially (TX Admin. Code § 30-210.7).

Liability

The duties and liabilities for the producer, provider, and user are outlined in the state code (TX Admin. Code § 30-210.6). The producer is responsible for the quality of water up to the point of delivery while the provider is responsible for the construction and maintenance of delivery infrastructure and transport of the water. The user is responsible for using the water in compliance with regulations. The producer and provider are both required to notify the executive director within five days of obtaining knowledge of unauthorized use of the recycled water. The producer is not liable for misapplication of the recycled water by the user.

Categories of Recycled Water and Water Quality Criteria

Texas recognizes two categories of recycled water: Type I and Type II. Type I water is of higher quality and can be used when the public may directly encounter the water, for example in indirect potable reuse (TX Admin. Code § 30-210.32). While Texas does not have specific regulations regarding indirect or direct water reuse, these projects may be approved on an individual basis. TCEQ has approved multiple recycling facilities including those in San Antonio, Wichita Falls, and Big Spring. Indirect reuse requires additional permitting to discharge water into state waters.

Virginia

Responsible Agencies and Status of Regulations

The state of Virginia began addressing water recycling through legislation in 2008, authorizing the Virginia Department of Environmental Quality, DEQ, to regulate water reclamation and reuse (VDEQ, 2013). Policies that may impact small businesses must undergo periodic reviews which requires an analysis of alternative strategies to minimize impacts and allows a period for public comment (Va. Admin Code § 2.2-4007.1). Water reclamation regulations fall under the purview of that requirement.

The Virginia State Water Quality Control Board, in consultation with the Department of Health, establishes requirements for the reclamation and recycling of wastewater (Va. Admin. Code § 62.1-44.15, Va. Admin. Code § 9-25-740-20).

Prohibitions on Recycling

Direct potable reuse; the use of reclaimed water to fill swimming pools, hot tubs, or wading pools; the incorporation of water into food for human consumption; and the reduction of discharge into receiving waters that decreases other beneficial uses are generally prohibited (Va. Admin. Code § 9-25-740-50). In times of drought, the State Water Control Board can issue emergency authorization for the production, distribution, or reuse of reclaimed water or uses the board determines are necessary (Va. Admin. Code § 9-25-740-45). The Virginia Department of Health must be provided time to submit comments or recommendations on the application for emergency reuse authorizations.

Categories of Recycled Water and Water Quality Criteria

Virginia has two categories for the treatment and use of recycled water: Level 1 and Level 2 (Va. Admin. Code § 9-25-740-70). Level 1 is higher quality water than Level 2 but both must undergo secondary treatment and disinfection. Additional parameters or treatments can be determined on a case-by-case basis for industrial wastewater recycling or based on the intended use of the recycled water.

Washington

Legislative Goals and Responsible Agencies

In 2007, the Washington legislature declared that the state and its people “have an interest in the development of facilities to provide reclaimed water to replace potable water in nonpotable applications, to supplement existing surface and ground water supplies, and to assist in meeting the future water requirements of the state” (RCWA 90.46.005). The Department of Health and the Department of Ecology were directed to collaborate and develop processes for the use of recycled water. The Department of Ecology consulted with an advisory committee composed of stakeholders including the Department of Health and the Department of Agriculture to provide technical assistance for the development of regulations and guidelines (Rev. Code WA. § 90.46.050).

To coordinate the collaboration between the Department of Ecology and the Department of Health, there are designated lead agencies and nonlead agencies for specific situations. The Department of Ecology is the lead agency responsible for issuing permits when the reclaimed water facility source is effluent from a water pollution control facility permitted by the Department of Ecology or when the reclaimed water is released to water bodies regulated by the Department of Ecology (WA Admin. Code § 173-219). The Department of Health is the lead agency responsible for issuing permits when the source of the recycled water is effluent from an on-site sewage system with flow of less than or equal to 100,000 gallons per day and there is no discharge of water into state waters. They are also the lead agency when the recycled water permit is dependent or supplemental to an on-site sewage treatment system operating permit or the only release of the treated water is to an on-site sewage treatment plant. The lead agency is responsible for coordinating with the nonlead agency, monitoring compliance with the permit, collecting fees, and responding to appeals (WA Admin. Code § 173-219). The nonlead agency is responsible for assisting the lead agency with appeals and attending meetings set up by the lead agency while also commenting on all permits and reports and submitting them to the lead agency. Regardless of lead designation the Department of Ecology develops all permit requirements to protect state waters and issues all decisions about the impairment of water rights downstream of reclaimed water discharge points and the Department of Health is responsible for developing permit requirements necessary to protect public health (Rev. Code WA. § 90.146.130).

Permit Process

To use or distribute reclaimed water permit from the lead agency is required (WA Admin. Code § 173-219). Prior to submitting an application, a long-term feasibility study that shows the financial, legal, technical, and management ability to design, construct, and operate the facility must be approved (WA Admin. Code § 173-219). An application for the water reclamation facility must be accompanied by an operations and maintenance report and an engineering report that shows the technical design of the facility (WA Admin. Code § 173-219). Both departments have streamlined their permit systems to require only one permit. Notice is provided to the public of the application. The public has a minimum of thirty days to comment on the draft of the permit and the lead agency must consider and respond to all comments received. During the comment period, the public may request a public hearing which the lead agency will hold if they determine there is sufficient public interest.

Categories of Recycled Water and Water Quality Criteria

There are two categories of recycled water in Washington: Class A Reclaimed Water and Class B Reclaimed Water. Class A is of higher quality and therefore is required to meet stricter water quality criteria. Each category has associated approved uses with A being appropriate for all of the listed uses. Additionally, Class A+ water requirements can be established by the Department of Health to allow for direct potable reuse (WA Admin. Code § 173-219).

Funding

Funding for water recycling projects is available through Department of Ecology grants or loans because recycling projects are characterized as water pollution control facilities which are eligible for funding (Rev. Code WA. § 70.146.030).

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