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Article

State Regulations and Guidelines for Wastewater Reuse for Irrigation in the U.S.

William Ritter

University of Delaware, Newark, DE 19716, USA; writter@udel.edu

Abstract: The objective of this paper is to present an overview of state regulations and guidelines for wastewater reuse for irrigation. Land application of wastewater in the U.S. began in the 19th century when it was considered the safest and best method for wastewater disposal. According to the Environmental Protection Agency (EPA), 27 states have regulations for wastewater reuse and 11 states have guidelines for reuse. Some states have no regulations or guidelines for wastewater reuse. For urban wastewater reuse for irrigation where public access is not restricted and for irrigation of food crops, many of the states require additional levels of treatment beyond secondary treatment, which may include oxidation, coagulation, and filtration and high levels of disinfection. California, Arizona, Texas, and Florida were the earliest states to establish water reuse programs and account for the majority of wastewater reuse for irrigation in the U.S. Several of the challenges to increase wastewater reuse are water rights in the western states and a lack of funding for new projects.

Keywords: wastewater treatment; irrigation; regulations; wastewater reclamation; water quality; California

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1. Introduction

Land application of wastewater in the U.S. began in the 1800s. The first land application system in the U.S. was constructed in 1872 in Augusta, Maine, at the State Insane asylum to irrigate hay and a vegetable garden. Land application in the 1800s was considered the safest and best method for wastewater disposal [1]. George Rafter of the U.S. Geological Survey reported in 1899 that there were a total of 143 wastewater treatment plants in the U.S. and Canada, and most of them used land application [2]. New wastewater treatment plants were being constructed in the 1920s and 1930s using trickling filters and activated sludge, and the philosophy was changing in wastewater management to partially treating the wastewater and using stream discharge instead of land application. Hutchins reported that there were 125 communities using land application in the western states in 1939 [3]. In the early 1960s, Pennsylvania State University started pioneering work on land application that was designated as the "Living Filter" [4]. This research became a model for the design and management of a number of land application sites that served a population of 6.6 million [5].

With the passage of PL92-550 (later known as the Clean Water Act) in 1972, the U.S. Environmental Protection Agency (EPA) established a new policy, that all wastewater construction projects must consider land treatment. It was considered innovative technology and was eligible for 85 percent Federal funding [4]. During the 1970s and early 1980s, there was a renewed interest in land application. The Muskegon County wastewater plant was built in 1974 in Michigan as a land application demonstration project on 4455 ha of sandy unproductive soil, and today is the largest land application system in the U.S. EPA funded a number of research projects, contracted a number of reports, sponsored a number of conferences and workshops, and promoted technology transfer, because state regulatory people were not trained in land application [6]. By the late 1980s, interest in land application declined. Although there have been sessions on land treatment at a few conferences, there has not been a national conference or symposium entirely devoted to land treatment systems in the past 25 years. In 1977, EPA published the first design manual on land treatment [7]. It was revised in 1981 [8], and EPA released a new revised version in 2006 [9]. Reid and Crites [9] published a handbook on land treatment in 1984. Crites et al. [10] published a revised version of the book in 2000.

The major objective of the paper is to present an overview of the state regulations and guidelines for wastewater reuse by irrigation for agriculture crops and landscaping and golf courses in the U.S.

2. State Irrigation Wastewater Reuse Statistics

The U.S. Geological Survey (USGS) [11] estimated that the reclaimed wastewater used for irrigation was 2.53×10^6 m^3/d in the U.S. in 2015. California was the leading state for wastewater reuse with 1.09×10^6 m^3/d, followed by Florida with 7.38×10^5 m^3/d, Arizona with 4.01×10^5 m^3/d, and Texas with 1.71×10^5 m^3/d. These four states accounted for 95% of the wastewater reuse for irrigation. There were 10 states that reported reclaimed wastewater use for irrigation. Besides California, Florida, Arizona, and Texas, the other states included, in order of reducing reuse volume, were Utah, Nevada, New Mexico, Colorado, Kansas, and Illinois. In 2010, the estimated volume of reclaimed wastewater used for irrigation was 1.79×10^6 m^3/d. Up-to-date state wastewater reuse data for irrigation is limited.

The state of California published wastewater estimates for reuse for agriculture irrigation, which decreased from 2001 to 2019, while urban wastewater reuse increased steadily from 1970 to 2015. The total wastewater reuse in California in 2015 was estimated to be 880×10^6 m^3 (Table 1). Agriculture irrigation was the largest category of reuse at 31%, followed by landscape irrigation at 18% (Table 2). In 2019, total wastewater reuse was 846×10^6 m^3.

Table 1. Wastewater reuse for irrigation in California from 1970 To 2019 [12,13].

Year	Agriculture Irrigation ($m^3/yr \times 10^6$)	Urban Irrigation ($m^3/yr \times 10^6$)
1970	40.9	35.1
1977	145.8	41.1
1987	207.0	50.9
2001	297.1	171.3
2009	271.2	192.3
2015	270.0	224.4
2019	175.1	198.5

Table 2. Wastewater reuse in California and Florida [14,15].

Source	California (%)	Florida (%)
Agriculture Irrigation	31	8
Landscape Irrigation (Public Access)	26	57
Groundwater Recharge	24	12
Industrial Uses	9	17
Wetlands and Other Uses	10	6

Florida has been using treated wastewater for agriculture irrigation for over 50 years. As of 2017, there were 118 systems irrigating agriculture crops with treated wastewater and 17 systems were for edible crops. About 79% of the agriculture wastewater reuse is used for citrus [16]. Florida's total wastewater reuse from 1986 to 2019 is shown in Figure 1, and the utilization rate for different sources for 2019 is shown in Table 2 [15]. Total wastewater reuse increased from 1.08×10^6 m^3/d in 1986 to 3.10×10^6 m^3/d in 2019. In 1990, agriculture irrigation accounted for 28% of the reuse, while public access irrigation accounted for 31% of the reuse flow. In 2019, public access areas accounted for 57% of the wastewater reuse, while agriculture accounted for only 8%. Groundwater recharge wastewater reuse is important to prevent saltwater intrusion to the Florida aquifers. It is likely that some of the urban irrigation wastewater ends up as groundwater recharge.

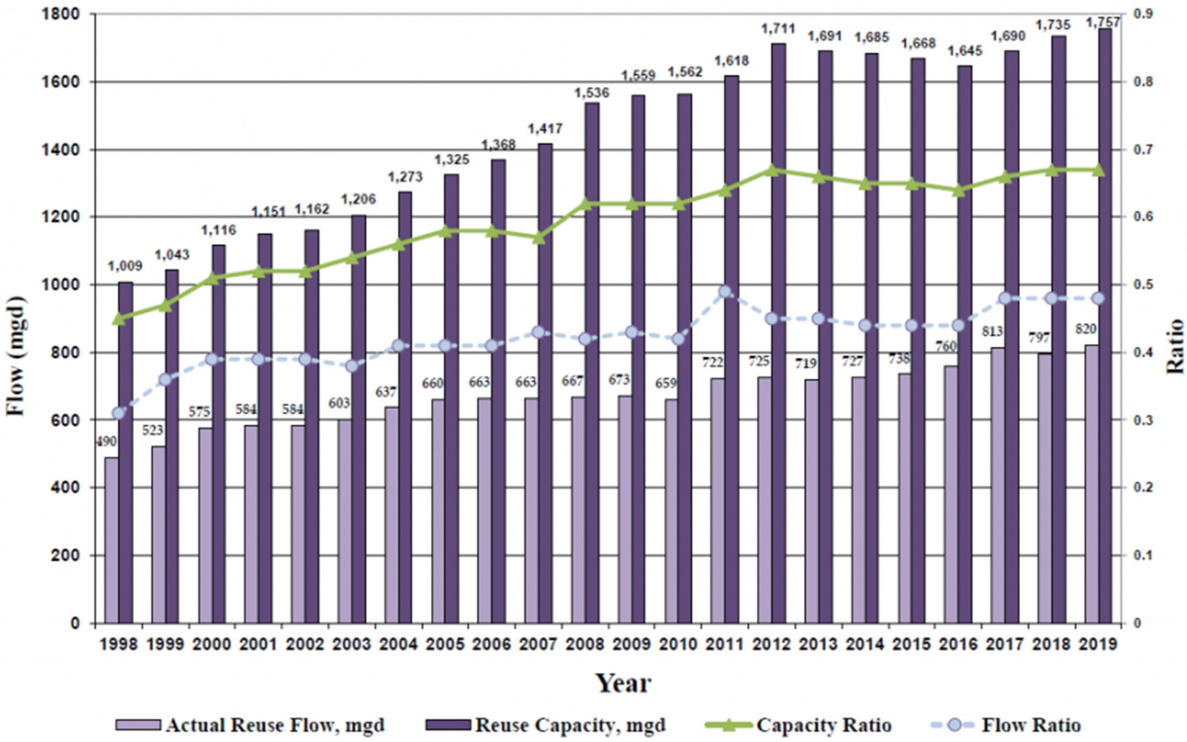

Figure 1. Florida wastewater reuse from 1986 to 2019 [16].

3. State Regulations and Guidelines

This section is a discussion of state regulations and guidelines. Eight states with long-term reuse programs are discussed in detail. There are no Federal regulations for wastewater reuse in the U.S. Setting regulations or guidelines for wastewater reuse is up to each individual state. According to EPA, as of August 2012, 22 states have regulations and 11 states have guidelines for wastewater reuse [17]. The states of Connecticut, Kentucky, Maine, New Hampshire, and New York have no regulations or guidelines for wastewater reuse. Forty-three states have regulations or guidelines for non-food crops and processed food crops for irrigating with reclaimed wastewater, while 27 states have regulations or guidelines for food crops. Thirty-two states have regulations or guidelines for unrestricted urban use and 40 states have regulations and guidelines for restricted urban use. Most of the states allow irrigation on parks, public landscaping, athletic fields, and golf courses. A few states, such as Florida, allow irrigation on homeowners' lawns and other landscapes. Most regulations or guidelines for irrigation with reclaimed wastewater include permitting and monitoring requirements, treatment technology requirements, water quality requirements, and other items, such as construction requirements, reporting requirements, access control and use area requirements, operation and maintenance requirements, and education and notification requirements [17]. Some of these requirements listed may not be included in the regulations and guidelines but included in the permit issued by the state for the operation.

In the northeastern states, wastewater reuse has not been widely implemented. As a result, regulations or guidelines have not been developed in all states. Massachusetts, Vermont, and New Jersey are the only states with wastewater reuse regulations. New Jersey first passed regulations in 2009. Both New Jersey and Massachusetts have restricted and non-restricted urban use and food crop irrigation. Vermont only has regulations for restricted urban reuse irrigation [17]. There is very little data available on irrigation wastewater reuse in the northeast.

In the Mid-Atlantic states, Delaware and Virginia have regulations, while Pennsylvania and Maryland have guidelines. Delaware and Pennsylvania have agriculture irrigation reuse regulations that were adopted in the 1970s. Pennsylvania has 11 industrial plants and 14 municipal plants that have irrigation wastewater reuse [17].

In the southeastern states Alabama, Georgia, and Tennessee have guidelines for wastewater reuse, while Florida, South Carolina and North Carolina have regulations. North Carolina allows wastewater reuse on food crops and nonfood crops. With Type 2 reclaimed water that is highly treated, the potential for increasing agriculture irrigation reuse is great, since supplemental irrigation is needed to increase crop yields. The main reuse in Tennessee is for golf courses, followed by pastureland irrigation, residential irrigation reuse and parkland irrigation [17].

In the Midwest and Great Lake states, Illinois, Indiana, Iowa, Michigan, Missouri, and Nebraska have regulations for reuse, while Kansas, Minnesota, and Ohio have guidelines. Wisconsin does not have any guidelines or regulations for wastewater reuse. Minnesota and Illinois have guidelines or regulations for agriculture nonfood crops and unrestricted and restricted urban irrigation. Iowa and Missouri only have guidelines for agriculture nonfood crops and restricted urban irrigation [17]. Kansas has guidelines for agriculture nonfood crops. Kansas has 140 facilities permitted for agriculture spray irrigation. All of the projects serve small populations [18].

In the Pacific Northwest states, Washington, Oregon and Idaho have well established wastewater reuse regulations. In Oregon, irrigation wastewater reuse is part of a facility's NPDES permit, and is required to manage and operate reuse projects under a water reuse management plan. Washington pasted their Reclaimed Water Act in 1992. Today, irrigation wastewater reuse includes golf courses, agriculture irrigation, and forestland irrigation. The driving forces for wastewater reuse include strict discharge limits, impaired water bodies, and new facilities with advanced wastewater treatment technologies [17]. Idaho started supporting wastewater reuse in 1988. The major forces driving wastewater reuse in Idaho have been strict discharge limits, water supply needs, and the need to reduce stream discharge volumes. Today, Idaho has 141 active reuse projects. Colorado began wastewater reuse in the 1960s with projects in Colorado Springs and Aurora. In 2015, the state developed the Colorado Water Plan. The plan integrated water conservation and water reuse into its long-term water strategy. Colorado has regulations for restricted and nonrestricted urban reuse. In 2012, there were 28 wastewater treatment plants supplying water for reuse. Water rights limit the use of wastewater reuse in some areas. Some of the drivers for increasing wastewater reuse are drought conditions, costs for treating lower-quality water sources, and regulatory requirements [18].

Oklahoma has been permitting wastewater reuse projects since the 1990s. The Oklahoma Department of Environment developed regulations for wastewater reuse in 2012. Reclaimed water can be used for crops, golf courses, and landscaping complexes. Four classes of wastewater are listed for non-potable reuse. Category 2, which requires the highest level of treatment, can be used for orchards and vineyards. Wastewater reuse will become more important in the future in Oklahoma, since in 2012, the Water for 2060 Act was passed. The goal of the Act was to consume no more fresh water in 2060 that was used in 2012 [18].

Utah passed regulations for wastewater reuse in 2006 with the Wastewater Reuse Act. Only public agencies are granted wastewater reuse project permits. The regulations specify two classes of reuse water. Class I can be used for public access irrigation and requires secondary treatment plus filtration. Class II requires secondary treatment with limited public access. Two challenges that limit wastewater reuse in Utah are water rights and the cost of the projects. There is concern that if a water reuse project is developed it may impact the flow downstream for the water rights holders. Utah has 36 wastewater reuse projects.

EPA has developed suggested regulatory guidelines for different categories of wastewater reuse they recommend should be used in the U.S. The guidelines are summarized in Table 3 for agriculture reuse and urban reuse. The guidelines include recommendations for wastewater treatment, water quality requirements, monitoring requirements, and setback distances. For unrestricted urban reuse and agriculture food crops, EPA recommend secondary treatment plus filtration and disinfection plus a BOD_5 of 10 mg/L and no detectable fecal coliform. For restricted urban irrigation and agriculture processed food crops and non-food crops secondary treatment and disinfection is recommended, with maximum BOD_5 and TSS concentrations of 30 mg/L and a 200 fecal coliform limit of 200/100 mL in the effluent [17].

3.1. California

The California State Water Quality Board (CSWRQB) and the nine Regional Water Quality Control Boards (RWQCBs) in the California Environmental Protection Agency regulate agencies involved in irrigation water recycling. The nine RWQCBs are divided by regional boundaries based upon major watersheds. The RWQCBs make water quality planning and regulatory decisions in their region. The CSWQCB sets statewide water quality policy and regulations [19].

California has a long history of wastewater reuse and regulations for wastewater reuse. The first regulations for wastewater reuse in California for crop irrigation were developed in 1918 [20]. The latest regulations for reclaimed water were adopted 1 October 2018. The first regulations prohibited the use of raw wastewater and septic tank and Imhoff effluent for the irrigation of food crops. The regulations adopted in 2018 in California Code of Regulations, Title 22, Section 60304, specify levels of treatment for recycled water for different non-potable applications [21]. The four levels of treatment described in the regulations are disinfected tertiary treatment, disinfected secondary treatment 2.2, disinfected secondary treatment 2.3, and undisinfected secondary treatment. Tertiary treated disinfected water must be filtered and have a total coliform limit of 2.2/100 mL or a CT (total coliform and contact time) of 450 mg-min/L, and no more than one sample exceeding 23/100 mL of total coliform in any 30-day period. Disinfected secondary 2.2 effluent must have a no more than 2.2/100 mL of total coliform the last 7 days. Disinfected secondary 2.3 effluent must have a total coliform of no more than 23/100 mL the last 7 days. California has the most restrictive microbial standards of any state in the country for agriculture wastewater reuse. A major drawback of the requirement is that it is expensive and may not improve public health outcomes.

Recycled wastewater used for the irrigation of food crops where the recycled water encounters the edible part of the crop, and for non-restricted public access such as golf courses, parks, playgrounds, and residential landscaping, requires disinfected tertiary treated water. For food crops where the edible portion of the crop is above ground and does not come in contact with the recycled water, at least disinfected secondary treatment 2.2 water must be used. For uses such as freeway landscaping, restricted access golf courses, ornamental nursery stock, and non-edible vegetation with controlled access, disinfected secondary treatment 2.3 water must be used.

California has several large projects that irrigate vegetables with highly treated recycled water. In Monterey County, disinfected tertiary treated recycled water has been used since 1998 to irrigate 4860 ha of vegetables. The irrigated vegetables include artichokes, broccoli, cauliflower, celery, and lettuce [12]. The City of Watsonville in neighboring Santa Cruz County provides recycled water to 2025 ha of vegetable farms. The city's treatment plant was specifically designed to produce highly recycled water for the area's vegetable farms.

Table 3. EPA suggested regulatory guidelines for irrigation wastewater reuse [17].

Reuse Category	Treatment	Water Quality	Monitoring	Setback Distances
Unrestricted Urban Reuse	Secondary + Filtration + Disinfection	pH 6.0–9.0 BOD_5 10 mg/L Turbidity 2 NTU Fecal coliform 0/100 mL Cl_2 residual 1.0 mg/L (min)	pH weekly BOD_5 weekly Turbidity continuous Fecal coliform daily Cl_2 residual continuous	15 m from potable water supply wells
Restricted Urban Reuse	Secondary + Disinfection	pH 6.0–9.0 BOD_5 30 mg/L TSS 30 mg/L Fecal coliform 200/100 mL Cl_2 residual 1.0 mg/L (min)	pH weekly BOD_5 weekly TSS daily Fecal coliform daily Cl_2 residual continuous	90 m from potable water supply wells 30 m to public access areas
Agriculture Food Crops	Secondary + Filtration + Disinfection	pH 6.0–9.0 BOD_5 30 mg/L TSS 30 mg/L Fecal coliform 0/100 mL Cl_2 residual 1.0 mg/L (min)	pH weekly BOD_5 weekly Turbidity continuous Fecal coliform daily Cl_2 residual continuous	15 m from potable water supply wells
Agriculture Processed Food Crops Non-Food Crops	Secondary + Disinfection	pH 6.0–9.0 BOD_5 30 mg/L TSS 30 mg/L Fecal coliform 200/100 mL Cl_2 residual 1.0 mg/L (min)	pH weekly BOD_5 weekly TSS daily Fecal coliform daily Cl_2 residual continuous	90 m from potable water supply wells 30 m to public access areas

3.2. *Arizona*

Arizona has a well-established program in recycling wastewater. The Arizona Department of Environmental Quality is responsible for regulating wastewater reuse and setting policy for its use. Arizona first adopted regulations for wastewater reuse in 1972 [19]. The latest regulations were adopted in 2012. Wastewater water quality standards for reuse are regulated under Arizona Administrative Code (AAC) Title 18, Chapter 11, Article 3 and reuse applications are described under AAC, Title 18, Chapter 9, Article 7 [22].

Arizona has five classes of recycled water. Class A+ recycled water requires secondary treatment plus filtration and nitrogen removal and disinfection. Fecal coliform must be non-detectable in four out of the last seven daily samples and a maximum of 23/100 mL. The five-sample geometric mean for total nitrogen must be less than 10 mg/l. The average 24 h turbidity must be 2 NTU or less and a maximum of 5 NTU. Class A recycled water requires secondary treatment plus filtration and disinfection. It has the same turbidity and microbial requirements as Class A+ recycled water [23]. Neither Class A+ or Class A specify a limit for BOD_5. Arizona allows wastewater reuse on food crops and nonfood and processed food crops and unrestricted and restricted urban irrigation. Both Class A+ and Class A recycled water can be used on agriculture food crops and unrestricted urban use areas [24]. If the total nitrogen concentration is above 10 mg/L on Class A water, Class A+ water will probably be needed for irrigation.

Class B+ recycled water requires secondary treatment plus nitrogen removal and disinfection. Class B recycled water requires secondary treatment plus disinfection. The Class B+ recycled water must have a maximum fecal coliform concentration of 200/100 mL in four out of the last seven daily samples and a maximum of 800/100 mL. The five-sample geometric mean for nitrogen must be less than 10 mg/L. Class B recycled water must also have a maximum fecal coliform concentration of 200/100 mL in four out of the last seven daily samples and a maximum of 800 cfu/100 mL. No limits are specified for turbidity or BOD_5 for Class B+ or Class B recycled water. Class B+ and Class B recycled water can be used for processed food crops and nonfood crops and restricted urban area irrigation. If the total nitrogen concentration is above 10 mg/L, Class B+ water will probably need to be used for irrigation. Arizona limits total nitrogen to 10 mg/L to protect groundwater.

In 1989, Arizona established an aquifer protection program (APP) to protect groundwater quality. In 2001, the ADEQ set stringent APP standards that required all new and expanding wastewater treatment plants larger than 946 m^3/d must employ high-performing tertiary treatment including nitrogen removal, which must achieve a pathogen-free effluent, total nitrogen concentration below 10 mg/l, and turbidity of not more than a 24 h average of 2 NTU and a maximum of 5 NTU [25]. In other words, all new and expanding wastewater treatment plants had to produce a Class A+ effluent. By 2011, 72% of the reclaimed wastewater being used was Class A+ effluent.

3.3. Florida

Florida began using wastewater in the 1960s to irrigate agriculture crops from Tallahassee. In 1986, Orlando and Orange County Water Conserve II started the irrigation of citrus groves and groundwater recharge with reclaimed wastewater. Agriculture irrigation is allowed on edible crops and food and fiber crops. Florida has 118 systems that irrigate agriculture crops, with 17 systems irrigating edible crops. Citrus is the largest crop using reclaimed wastewater for irrigation, with approximately 79% of the agriculture reuse flow [15].

In the 1980s, Florida established regulations that prohibited direct contact with crops that are not processed and eaten raw. Micro irrigation is used to irrigate citrus with recycled water. Use of recycled water has increased greatly from the 1980s. From 1986 to 2016, recycled water use increased form 780 tm^3/d to 2877 tm^3/d. Agriculture irrigation decreased, but public access landscape irrigation increased dramatically. In 1990, recycled wastewater used for agriculture irrigation was 341 tm^3/d and public access irrigation was 375 tm^3/d. In 2016, agriculture irrigation declined to 245 tm^3/d and landscape irrigation increased to 1661 tm^3/d [15].

Florida's wastewater reuse regulations are outlined in Chapter 62-610 FAC of the Florida Administrative Code [26]. The chapter is titled "Reuse of Reclaimed Water and Land Application". The regulations have been revised in 1989, 1996, 1999, 2007, and 2021. Treatment and disinfection for wastewater are outlined in Rules 62-600.530 and 62-600.440 [27].

Florida regulations for wastewater used on food crops must have secondary treatment plus filtration and high-level disinfection, with an annual average of BOD_5 of 20 mg/L and a TSS of 5 mg/L. Fecal coliform concentrations must not be detected in 75% of the samples and have a maximum concentration of 25/100 mL. For nonfood crops and processed food crops, secondary treatment and disinfection is required. The annual average BOD_5 and TSS concentrations must be 20 mg/L or lower. The average fecal coliform concentration must be 200/100 mL or less and a maximum of 800/100 mL. For unrestricted urban landscape irrigation, the wastewater treatment levels are the same as for food crop irrigation. There is nothing in the regulations for restricted access urban use [17].

3.4. Nevada

The Nevada Division of Water Resources (NDWR) within the Nevada Department of Conservation and Natural Resources regulates wastewater reuse in Nevada. The regulations are under Nevada Administrative Code Chapter 445A.274 to 445A.280 [28]. The State also has guidelines for reuse in two Water Technical Sheets, which are WTS 1A General Design Criteria for Reclaimed Water Irrigation Use [29] and WTS 1B General Criteria for Preparing a Reclaimed Water Management Plan [30].

Nevada has five different categories of water reuse that may be used for irrigation. All five categories require at least secondary treatment. Category A may be used for unrestricted urban irrigation and food crops [28]. The BOD_5 and TSS must be 30 mg/L or less. The 30-day geometric mean total coliform must be 2.2/100 mL or less and a maximum of 23/100 mL [28]. The regulations only specify secondary treatment for Class A reuse effluent but requires a high level of disinfection. Categories B and C can be used for landscape irrigation where public access is controlled. Category B has the same coliform limits as Category A. For Category C, the 30-day monthly geometric total coliform must be 23/100 mL or less and a maximum of 240 cfu/100/mL. Category C also requires a 30 m buffer zone. Categories B and C can also be used for agriculture non-food crops along with Categories D and E. Category D requires a 30 geometric mean total coliform concentration of 200/100 mL or less and a maximum concentration of 400/100 mL. There is no total coliform limit for Category E effluent but it requires a 244 m buffer zone. Category D requires a buffer zone of 122 m. Categories B, C, D, and E require a BOD_5 and TSS concentration of 30 mg/L or less.

3.5. Virginia

Wastewater reuse is regulated in Virginia by the Virginia State Water Control Board in the Virginia Department Environmental Control under the Virginia Code Title 9 Environment, Chapter 740 Water Reclamation and Reuse Regulations [31]. Virginia has regulations for Level 1 and Level 2 reclaimed water. Level 1 reclaimed water requires secondary treatment plus filtration and a higher-level disinfection. The BOD_5 must be 10 mg/L and a monthly average of 8 mg/L. The 24 h average turbidity must be 2 NTU [32]. The monthly fecal coliform geometric mean must be 14/100 mL or less. Level 2 reclaimed water must have secondary treatment and standard disinfection. The BOD_5 and TSS monthly average must be less than 30 mg/L and have a maximum weekly concentration of 45 mg/L. The monthly geometric mean fecal coliform concentration must be 200/100 mL or less.

Level 1 reclaimed water is required for unrestricted urban use, such as golf courses, parks, school yards and athletic fields, and agriculture food crops [32]. Level 2 reclaimed water may be used for restricted urban use and agriculture nonfood crops and processed food crops. Depending upon the size of the irrigation area, a nutrient management plan is required if the total N concertation is greater than 8 mg/l or the total P concentration is above 1.0 mg/L. Level 1 wastewater must have a setback distance 30 m from potable water supply wells of 30 m, and Level 2 water must have a setback distance of 60 m from potable water supply wells and 30 m from property lines.

3.6. Delaware

Delaware's regulations for wastewater reuse by irrigation are covered in their on-site wastewater regulations under 7 Delaware Code Chapter 6 [33]. The regulations are administered by the Delaware Department of Natural Resources and Environmental Control (DNREC)'s Division of Water Groundwater Discharge Section. The regulations were first adopted in 1985 and have been amended a number of times, with the latest amendments dated 11 January 2014.

Spray irrigation for wastewater reuse has been used in Delaware since the 1960s, when food processing companies stated applying treated wastewater to grassland [34]. In the 1970s, the largest spray irrigation site in the State was developed when Townsend, a poultry processing company, started using recycled wastewater on corn. In 2002, Townsend was sold to Mountaire Farms, which still operates the processing plant and applies the wastewater to 405 ha of corn and soybeans. It was not until the 1990s that municipal wastewater was recycled by spray irrigation to any extent. A number of municipal wastewater recycling projects were proposed in the 1970s and 1980s but were abandoned because of strong public opposition. Today, there are 24 sites permitted for spray irrigation. The sites include private systems, individual systems, industrial systems, and municipalities [34]

Under Delaware regulations, wastewater can be applied to agriculture nonfood crops, golf courses, nursery stock, forestland, parkways, roadway medians, and cemeteries. For public access areas, tertiary treatment is required. The BOD_5 and TSS concentration must be no greater than 10 mg/L, and the average fecal coliform concentration must be 10/100 mL. For agriculture reuse where public access is restricted, the average BOD_5 and TSS concentration must be below 50 mg/L and the fecal coliform concentration must be 200/100 mL or less. Buffer zones must be 45 m [33]. Loading rates for spray irrigation are either limited by the hydraulic loading rate or the amount of nitrogen. In most cases, nitrogen is the limiting loading rate factor. Food crops cannot be grown on wastewater reuse sites.

3.7. Maryland

Maryland has guidelines for wastewater reuse [35]. The guidelines for land application were last revised in 2010. The Maryland Department of the Environment regulates the development and operation of wastewater land application systems through the Groundwater Discharge Program. Maryland has four classes of reclaimed wastewater that may be used for irrigation. Class I has a maximum monthly average BOD_5 of 50 mg/L and maximum monthly average TSS solids of 90 mg/L. The Class I effluent must have buffers of 60 m from property lines and roadways and 153 m from residential properties and areas where the public may congregate. Class I effluent may be used for agriculture nonfood crops. By Maryland standards, Class I effluent is not classified as reclaimed wastewater [35]

Class II effluent must have monthly maximum average BOD_5 and TSS concentrations of 10 mg/L and a monthly geometric mean fecal coliform of 3/100 mL or less. Class II effluent can be used to irrigate golf courses, forestland, and agriculture nonfood crops with limited public access. Class III effluent must have a maximum monthly average BOD_5 of 10 mg/L and an average daily turbidity of 2 NTU and a maximum of 5 NTU. Class III effluent can be used to irrigate public access areas such as golf courses, cemeteries, parks, and other non-residential irrigation [36].

Class IV effluent must have a maximum monthly average BOD_5 concentration of 10 mg/L and a daily average turbidity of 2 NTU and a maximum of 5 NTU [36]. The monthly maximum median fecal coliform concentration is 2.2fu/100 mL and a maximum fecal coliform concentration of 23/100 mL. Class IV effluent must also have a total chlorine residual from 0.5 to 4 mg/L. It is the only effluent class that requires a chlorine residual and can be used for residential irrigation.

3.8. Texas

Texas has a long history of irrigation wastewater reuse. San Antonio started using sewage for agriculture irrigation in the late 1890s in land south of the city. In 1925, Lubbock started applying all their wastewater (2.64×10^5 m^3/d) to a 729 ha site growing cotton and grasses. By 1955, they were applying 2.2×10^6 m^3/d. In 1986, Lubbock purchased additional land and switched from furrow irrigation to center pivot irrigation. In 1999, they purchased an additional 1620 ha. Today, they mostly apply wastewater to cotton, wheat, sorghum, and alfalfa [35].

During the 1920s, Amarillo started providing primary treated wastewater to local ranchers and in the 1960s, Abilene started supplying treated wastewater for agriculture irrigation. In the late 1990s, they started suppling reclaimed wastewater to municipal users and in 2011, installed a regional wastewater reuse system that provides treated wastewater to irrigate golf courses, athletic fields, parks, and other open space [37].

In the 1940s, the city of Odessa stated supplying primary treated wastewater for a local landowner to irrigate alfalfa. In the 1980s, they expanded their wastewater reuse program to irrigate university grounds, golf courses, highway right of way, and a residential subdivision.

El Paso started using reclaimed wastewater for municipal irrigation in the 1960s. Today, El Paso uses reclaimed wastewater for irrigating golf courses, parks, school grounds, cemeteries, zoo grounds, street parkways and medians, a city tree farm and other landscaping areas [37].

During the 1950s, Texas had a severe drought, which resulted in the release of the first statewide water planning document in 1961 by the Texas Board of Water Engineers. In 1962, the Texas Water Pollution Control Board adopted the first rules for water quality and wastewater treatment. In 1968, the Texas Water Plan presented basic wastewater reuse principles. In 1990, the first official policy for use of reclaimed water was established by the Texas Legislature [37]. In 1997, wastewater reuse policy was incorporated into chapters 210, 295, and 297 of the Texas Administrative Code.

Wastewater reuse in Texas is regulated by the Texas Commission on Environmental Quality (TCEQ). The regulations for reuse are in Title 30 Texas Administration Code, Chapter 210 [38]. Texas regulations specify water quality criteria for Type I and Type II reclaimed wastewater. Type I reclaimed water can be used to irrigate food crops and irrigate pastures which are grazed by milking cows, golf courses, athletic fields, and individual landscaping. Type II reclaimed water can be used to irrigate areas where access is controlled and where human contact is unlikely. It can be used to irrigate animal food crops and other crops where the irrigation does not touch the edible part of the crop.

Water quality standards for Type I reclaimed wastewater must have a 30-day average BOD_5 of 5 mg/l or less and a turbidity of 3 NTU or less. The 30-day geometric mean for fecal coliform must be 20/100 mL or less and the maximum concentration of any seven samples must be less than 75/100 mL. For Type II reclaimed water, the 30-day average BOD_5 concentration must be 20 mg/l or less. The 30-day geometric mean for fecal coliform must be 200/100 mL or less and a maximum of a single sample must be 800/100 mL. The water quality standards were adopted in 2009.

4. Challenges and Opportunities for Wastewater Reuse for Irrigation in the U.S.

There are 14,748 public-owned wastewater treatment plants serving 238 million people in the U.S. It is estimated that about 7% is recycled for non-potable use. There is a great opportunity to increase wastewater reuse significantly in the U.S. [39]. Israel recycles almost 90% of their wastewater for reuse. Most of it is used to irrigate agriculture crops [40].

In some places, the public is skeptical about the health risk of reuse projects. This is especially true with new emerging contaminants such as pharmaceuticals. Enhanced monitoring and education and outreach will be required to convince the skeptical public that the recycled water is safe to use to irrigate crops and public access areas such as golf courses [18].

In the western states, water rights may limit wastewater reuse for a facility. In these states, prior appropriation water laws apply, while in the eastern states exist riparian rights water laws. Under prior appropriation rights, water is allocated based on when the water right was given. When water shortages occur, water is allocated in the order water rights were granted for a stream. Under riparian rights, water rights are given to landowners bordering a stream where they may use a reasonable amount of water from the stream. In some states, legislation has been passed that specifically addresses water reuse and clarifies legal questions that could arise [41]. Additionally, wastewater treatment plants must discharge enough effluent to assure minimum instream flow to protect aquatic life.

The Colorado River basin has been in such a long-term drought that Lake Mead and Lake Powell are at the lowest water levels since the dams have opened. The U.S. Bureau of Reclamation announced on 30 August 2021 that cuts in water allocations will occur in 2022. Arizona stands to lose 512,000 ac ft or 18% of their allocation and Nevada will lose 8% of their allocation. If levels keep dropping in Lake Mead, California will face cuts to their allocation in 2023 [42]. In Arizona and California, a large volume of the Colorado River water is used for irrigating agriculture crops. Farmers will take a large part of the mandatory cuts being proposed. Since both Arizona and California have a long history of wastewater reuse, this will be an opportunity to initiate new reuse projects.

Most reuse projects are funded through the Federal Clean Water State Revolving Fund (CWSRF) program. In most cases, states do not have state or local funds to finance reuse projects. Over 90% of reuse projects are funded through the CWSRF program. There is a need for increased Federal funds to finance reuse projects in order to increase wastewater reuse. This is especially true in the western states, which have seen continuous drought. In 2020, two of the states had record low precipitation [18].

Very few states have personnel dedicated to reuse projects. Most reuse programs are integrated into the existing permitting program. In many states, reuse projects involve multi jurisdictions and require multi agency approval. Lack of personnel dedicated to reuse projects may create challenges in obtaining approval for projects [18].

In 2020, EPA released their National Water Reuse Plan (WRAP) [43]. EPA worked with stakeholders and other Federal agencies and released a draft of the Action Plan in

September 2019, followed by a 60-day public comment period. The WRAP has 11 strategic themes, which are as follows:

1. Integrated watershed action plans;
2. Policy coordination;
3. Science and specification;
4. Technology development and validation;
5. Water information availability;
6. Financial support;
7. Integrated research;
8. Outreach and communication;
9. Workforce development;
10. Metrics of success;
11. International collaboration.

The Action Plan was a cooperative effort of EPA, Army Corps of Engineers, U.S. Department of Interior, U.S. Department of Energy, and U.S. Department of Agriculture. Many state agencies who implement water resource programs, along with water associations such as the American Water Works Association, WateReuse Association, and the Water Research Foundation, had input in developing the Action Plan. EPA also launched the WRAP online platform, which provides a repository to house and gain access to the full spectrum of actions in the plan. It is also intended to foster partnerships and collaboration across the water user community. The WRAP online platform is also intended to communicate the progress toward the implementation of various actions that enhance water reuse consideration within the scope of the WRAP. It also aims to help interested parties identify opportunities to join in collective action and contribute their expertise to the effort. With many stakeholders involved in implementing the Plan, it should provide opportunities for increased wastewater reuse for irrigation in many areas of the U.S.

5. Final Considerations

California, Arizona, and Florida have long-established programs in wastewater reuse for irrigation. California and Florida are recognized as the leaders in wastewater reuse for irrigation in the U.S. Their programs are innovative and have a long history. California developed the first regulations for wastewater reuse in 1918, and today have the most restrictive microbial standards of any state for agriculture wastewater reuse. The states of California, Arizona, Florida, and Texas account for 90% of the wastewater reuse in the U.S. Forty-three states have regulations or guidelines for non-food crops and processed food crops for irrigating with reclaimed wastewater, while 27 states have regulations or guidelines for food crops. Thirty-two states have regulations or guidelines for unrestricted urban use and 40 states have regulations or guidelines for restricted urban use irrigation. There are a number of states that do not have regulations or guidelines and do not have a wastewater reuse program. The Federal government has no regulations for wastewater reuse but have developed suggested guidelines that the states could use to set regulations. For irrigation of food crops or unrestricted urban irrigation, numerous states require an average maximum BOD_5 of 10 mg/L, an average daily turbidity of 2 NTU, and a 30-day geometric mean for fecal coliform of 2.2/100 mL. Tertiary treatment and enhanced disinfection is required to meet these limits. Some states have developed different categories of reclaimed wastewater in their regulations with different water quality standards.

There are a number of challenges that can limit the growth of wastewater reuse in some states. In the western states, water rights may limit new projects. Lack of federal, state, or local funding for projects is a problem in many states. Many states do not have personnel dedicated to water reuse projects.

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