Water Reuse Treatment Technologies

Subjects: Engineering, Environmental

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Treating water for water reuse typically involves treating wastewater in several steps consisting of preliminary treatment, primary treatment, and secondary treatment. Tertiary treatment and advanced treatment may be needed for water reuse purposes.

Keywords: water reuse ; Water recycling ; Wastewater treatment ; Sustainability

1. Introduction

Most residential and industrial activities generate wastewater containing harmful pollutants [1]. Before this wastewater can be safely and sustainably reused, it must undergo treatment to remove these pollutants to an appropriate degree. This plain fact is important to consider since water reuse is increasingly being recognized as a sustainable solution for global water management issues. By addressing the issue of harmful pollutants in wastewater, we can ensure that it can be effectively treated and safely reused. Ensuring water quality is an essential aspect of water reuse, as the suitability of the water for a given purpose can depend on its quality. The challenge rests in implementing water reuse technologies that are cost-effective, robust, and safe for human health and the environment [2].

The goal of water reuse treatment is to produce water that meets the quality of the intended use and is safe for public health and the environment. Producing water viable for particular uses while maintaining safety standards is known as a "Fit-for-Purpose" model that can be customized to a particular purpose. In determining quality thresholds, treatment goals (e.g., salt reduction for irrigation or industrial reuse) are specifically tailored to end user needs, safe for the public and the environment while being cost-effective. This is a frequently used strategy in developing various solutions for water reuse [3].

During preliminary treatment, large objects that may damage the treatment process are removed. In primary treatment, some suspended solids and organic matters are removed from wastewater. The removal process is done by sedimentation of floating and settleable matter. In secondary treatment, most of the organic matter is removed using biological and chemical processes. Additionally, tertiary treatment and advanced treatment may be added to the system train for water reuse purposes. In tertiary treatment, disinfection and nutrient removal occurs, and the remaining suspended solids are removed using granular medium filtration or micro screens. Remaining suspended solids and other constituents that are not removed by secondary treatment are then removed by a combination of unit operations and processes in advanced treatment [4].

Wastewater treatment systems can use a variety of different technologies to treat effluent for water reuse. **Table 1**a,b provide an overview of the various technologies and their applications [5][6]. The various technologies fit under one or more of the following five categories:

Table 1. (**a**) Unit operations and process used for the removal of different constituents in water reuse applications. (**b**) Treatment technologies and capabilities.

(a)

Constituent Class	Secondary Treatment	Secondary with nutrient removal	Depth filtration	Surface filtration	Microfiltration	Ultrafiltration	Dissolved Air Flotation	Nano filtration	Reverse Osmosis	Electro dialysis
Suspended Solids	✓	-	✓	✓	✓	✓	✓	-	-	-
Colloidal Solids	-	-	-	-	✓	✓	✓	-	-	✓
Particulate Organic Matter	-	-	-	✓	✓	✓	✓	✓	-	-
Dissolved Organic Matter	✓	✓	-	-	-	-	-	✓	✓	-

Nitrogen	-	✓	-	-	-	-	-	-	✓	-
Phosphorous	-	✓	-	-	-	-	-	-	✓	-
Trace Constituents	-	-	-	-	-	-	-	✓	✓	-
Total Dissolved Solids	-	-	-	-	-	-	-	✓	✓	✓
Bacteria	-	-	✓	✓	✓	✓	-	✓	✓	-
Protozoan Cysts and Oocysts	-	-	✓	✓	✓	✓	✓	✓	✓	-
Viruses	-	-	-	-	-	✓	✓	✓	✓	-

(b)

Overall Treatment Objective	Unit Processes	TOC	TSS	TDS	Trace Ch
Removal of Suspended Solids	Media Filtration, Microfiltration and ultrafiltration	Partial removal	High removal	None	
Reducing the Concentration of Dissolved Chemicals	NF/RO	90% removal	High removal	High removal	H
	ED/EDR	None	None	High removal	
	PAC	High removal	None	None	Pa
	GAC	40–60% removal	High removal	None	40
	Ion exchange	None	None	High removal	Pa
	Biofiltration	High removal, High degradation [2]	High removal	None	Hig
	Ozone	None	None	None	Hig
Disinfection and Removal of Trace Organic Compounds	UV	None	None	None	Parti
	Free Chlorine	None	None	None	Parti
	Chloramines [4]	None	None	None	
	PAA [5]	None	None	None	Parti
	Pasteurization [5]	None	None	None	Part
	Ozone	None	None	None	Hig
	Chlorine dioxide	None	None	None	Parti
	Advanced oxidation processes (UV/H_2O_2, O_3/H_2O_2, UV/Cl_2)	None	None	None	Hig

Notes: * Contact time and concentration dependencies. [1] Some chemical constituents may have Reverse Osmosis (RO) removal efficiencies less than 90%, such as NDMA, 1,4-dioxane, and flame retardants. Additionally, Reverse Osmosis (RO) likely has greater removal efficiency than Nanofiltration (NF). [2] BAC is effective at removing trace chemical constituents, but BAC will result in higher TOC levels than RO. [3] MF and UF membranes can remove bacteria and protozoa. MF is not considered an effective barrier against viruses, while UF can remove viruses to a certain extent. [4] Extended chloramine contact times are required for virus inactivation, but no Giardia or Cryptosporidium inactivation should be anticipated with chloramine disinfection. [5] Currently used only in wastewater treatment.

- Removal of suspended solids;
- Reducing dissolved chemical concentrations;
- Removal or disinfection of trace organic compounds;
- Stabilization;
- Aesthetics (taste, odor, color correction).

In instances where stringent effluent disposal standards apply, implementing water reuse may require upgrading technologies used at wastewater treatment plants (WWTP) to incorporate tertiary treatment technologies to treat contaminants that remain in the effluent [5][6]. Typical WWTPs use coagulation, flocculation, and sedimentation to remove suspended particles, while medium filtration and micro/ultrafiltration can improve effluent quality by enhancing the removal of solids and microorganisms. Media filtration uses gravity or pressure differentials to pass water through porous mediums, removing solids via adsorption and separation by size. Micro/ultrafiltration use a porous polymer film acting as a selective barrier and operate under size exclusion [6].

Reverse osmosis, electrodialysis, electrodialysis reversal, nanofiltration, granulated activated carbon, ion exchange, and biologically active filtration can be used to degrade dissolved compounds. Typically, a membrane is used to separate dissolved chemical elements such as road salts or pesticides from wastewater influents [6].

Disinfection and removal of trace organic compounds come after the removal of dissolved chemicals to eliminate pathogens in wastewater. This is accomplished through UV, free chlorine/chloramines, peracetic acid, pasteurization, chlorine dioxide, and advanced oxidation processes. These methods neutralize microorganisms through inactivation processes but are dependent on contact time, pH, and temperature [6].

Certain approaches for reducing corrosion, such as reverse osmosis and nanofiltration, must be followed by stabilization. Mineralization may involve decarbonation, or addition of sodium hydroxide, lime, calcium chloride, or mixing. The desired Langelier Saturation Index (LSI) should be close to zero, and thus should produce a final product that will not corrode metal pipelines or concrete tanks [6].

Though aesthetics may appear unimportant, public opinion has a significant impact on the feasibility of wastewater recycling. Therefore, some qualities, such as flavor, odor, and color, must be treated prior to the distribution of water to public systems or agricultural systems. Activated carbon, UV, and chlorination are efficient ways of treating taste and odor. All aesthetic issues are adequately remedied with the help of ozone and biologically activated carbon [6].

Table 2 lists all treatment technologies from various case studies that were collected for this research. As the need for higher water quality increases, the degree of treatment increases. For instance, a more complex treatment process is required when the intended use of the recycled water is for indirect potable reuse (IPR) or direct potable reuse (DPR).

Table 2. Treatment technologies used existing water reuse projects.

Category	Tertiary Treatment Process		Reuse Purposes	Location
	Pre-Treatment-Filtration	Disinfection		
Urban Reuse	Flocculation Media Filtration	Chlorination	Non-potable irrigation (residential, commercial, industrial)	El Segundo, CA, SUA
Agriculture	Flocculation Multi-media Filters	Chlorination	Raw-eaten vegetables and fruits	Monterey One, CA, USA
	None (Membrane Bioreactor effluent)	Ultraviolet	Vineyards	American Canyon, CA, USA
	Coagulation Flocculation Cloth Media Filter	Ultraviolet	Raw-eaten fruits	Pajaro Valley, CA, USA
Industrial	Microfiltration	Reverse Osmosis (Single Pass) Decarbonation	Industrial—Boiler Feed (BF) water	El Segundo, CA, USA
	Microfiltration	Reverse Osmosis (Single Pass) Ozone Decarbonation	Industrial—Low-Pressured Boiler Feed	El Segundo, CA, USA
	Microfiltration	Reverse Osmosis (Double Pass) Ozone Decarbonation	High-Pressure Boiler Feed	El Segundo, CA, USA
	Sand Filter	Addition of corrosion inhibitors, sodium hypochlorite, acid, and antifoaming agents (at power plant)	Cooling towers	Denver, CO, USA
	Media Filtration	Oxidized Coagulation Disinfected (UV or Chlorine)	Pulp and paper (newspaper)	Los Angeles, CA, USA
	Gravity Filter	Chlorination	Textile (carpet dyeing)	Santa Fe, CA, USA
	Granular Coal	Ultraviolet	Geyser recharge for electricity	Santa Rosa, CA, USA
	Lime Softening Filtration	Chlorination	Cooling towers	Baltimore, MD, USA

Category	Tertiary Treatment Process		Reuse Purposes	Location
	Pre-Treatment-Filtration	Disinfection		
Environmental	Automatic Backwash with Sand Media	Chlorination	Wetlands	Orlando, FL, USA
Indirect Potable Reuse	Microfiltration	Reverse Osmosis UV with Hydrogen Peroxide Lime Treatment	Groundwater recharge	Orange County, CA, USA
	Lime Clarification Media Filtration	Granulated Activated Carbon Ion Exchange Chlorination		Fairfax, VA, USA
	Media Filtration	Reverse Osmosis Ultraviolet with Advanced Oxidation Process Chlorination	Groundwater recharge via riverbank filtration	Arapahoe County, CO, USA
Potable Reuse	Flocculation Biologically Active Carbon Filtration Microfiltration Ozonation Granular Activated Carbon	Ultraviolet Chlorination	Drinking Water (preliminary approval)	Castle Rock, CO, USA
	Granular Activated Carbon Filtration	Reverse Osmosis Ultraviolet with Advanced Oxidation Process	Drinking Water (Undergoing regulatory approval)	El Paso, TX, USA
Combination	Granular Coal	Ultraviolet	Farmlands Vineyards Public urban landscaping	Santa Rosa, CA, USA
	None	UV	Agricultural Irrigation (Vineyards) Landscape Irrigation (excludes golf courses) Industrial use Other—Construction site dust control Other—In-plant use at City WRF	American Canyon, CA, USA
	Microfiltration	Chlorine/Dechlorination Reverse Osmosis Ultraviolet	Irrigation Industrial Streamflow Augmentation (future direction) Groundwater Recharge (future direction)	Santa Clara, CA, USA

Crini and Lichtfouse (2019) gave an outline of various wastewater treatment processes and analyzed the pros and cons associated with each, considering factors such as cost, effectiveness, practicality, reliability, environmental impact, sludge production, operational complexity, pre-treatment needs, and the potential for generating hazardous byproducts (**Table 3** and **Table 4**) [7][8][9][10][11][12][13][14][15][16][17][18][19][20][21][22][23][24][25][26][27]. Based on the variability of choices, advantages, and disadvantages of wastewater treatment processes and technologies, engineers, stakeholders, and people partaking in water reuse projects can select the most appropriate treatment method and technologies to achieve the desired water quality (**Table 3**).

Table 3. Advantages and disadvantages of various water treatment processes.

Process	Advantages	Disadvantages
Advanced oxidation processes (AOP) **Photolysis** **Heterogeneous and homogeneous photocatalytic reactions** **non-catalytic wet air oxidation (WAO)** **Catalytic wet air oxidation (CWAO)** **Supercritical water gasification**	• Local production of reactive radicals; • Chemicals are not necessary; • Pollutant mineralization; • Rapid degradation; • Efficient for color removal; • Efficient in chemical and total oxygen demand reduction; • WAO is efficient for effluent that is too dilute or toxic for biological treatment, phenol removal, and insoluble organic matter conversion.	• Lab-scale technologies; • Economically ineffective for small and medium-sized industries; • Technical issues; • Generate byproducts; • Low production capacity; • WAO is energy-intensive.
Adsorption/filtration **Commercial activated carbons (CAC)** **Commercial activated alumina (CAA)** **Sand** **Mixed materials** **Silica gel**	• Simple technologies; • Widely available; • Adsorption targets various contaminants; • Effective with fast kinetics (Adsorption); • Produce high-quality effluent; • Universal elimination depending on adsorbent (CAC); • Efficient in removing chemical oxygen demand; particularly when paired with coagulation to minimize suspended particles, chemical oxygen demand, and color (CAC); • Sand effectively removes turbidity and suspended solids; • Alumina effectively removes fluoride.	• High cost overall (CAC); • High-cost material (CAC, CAA); • Material dependency performance (CAC); • Multiple adsorbents needed; • Derivatization of chemical increases adsorption capacity; • Costly regeneration when clogged; • Complex adsorbent elimination.
Biological methods **Bioreactors** **Biological activated sludge (BAS)** **Microbiological treatments** **Enzymatic decomposition** **Lagoon**	• Simple mechanism of removal; • Cost-effective; • Widely accepted; • Eliminates organic materials, NH_3, NH_4^+, iron; • Efficient in color removals; • BAS is effective in biological oxygen demand (BOD) and suspended solids (SS) removal; • Future treatment systems for emerging contaminants removal will rely heavily on microbial activities.	• Required a suited environment; • High maintenance; • Kinetics problems are present; • Poor dyes biodegradability; • Thickening and foaming of sludge (BAS); • Generation of byproducts; • Change of mixed cultures' composition; • Complex mechanisms of microbiology.

Process	Advantages	Disadvantages
Coagulation/flocculation	• Simple process; • Widely available chemicals; • Low capital cost; • Efficient for suspended solids, colloidal particles, and insoluble contaminants removal; • Efficient in chemical oxygen demand, biochemical oxygen demand, and total organic carbon reduction; • Lower precipitation time.	• Arsenic removal rates are low; • Complex dosing; • Requires non-reusable chemicals; • Requires pH monitoring; • High sludge volume generation.
Dialysis **Electrodialysis (ED)** **Electro-electrodialysis (EED)** **Emulsion liquid membranes (ELM)** **Supported liquid membranes** **Membrane filtration** **Microfiltration (MF)** **Ultrafiltration (UF)** **Nanofiltration (NF)** **Reverse osmosis**	• Widely available (with a multitude of applications and module combinations); • Large space is not required; • Efficient even at high concentrations; • Produce a high-quality effluent; • Chemicals are not necessary; • Reduce soil waste production; • Eliminates all salts, mineral concentrations, and colors; • MF, UF, NF, and reverse osmosis are efficient in removing particles, suspended solids and microorganisms; • NF and reverse osmosis are efficient in removing volatile and nonvolatile organics; • ED and EED are efficient for dissolved inorganic matter removal; • ELM is efficient for phenols, cyanide, and zinc removal.	• Requires more energy; • Diverse membrane filtration system design; • High O&M costs; • Frequent clogging problems; • Specific membranes for different applications; • Not as efficient at low solute feed concentrations.
Ion exchange **Chelating resins** **Selective resins** **Microporous resins** **Polymeric adsorbents** **Polymer-based hybrid adsorbents**	• Vast selections of products available; • Simple technology; • Easy maintenance; • Integrates well with various methods and is simple to use; • Efficient process; • Generate high-quality effluent; • Considered cost effective for metal removal compared to other technologies; • Effective for recovering valuable metals.	• High columns require for large volumes; • Frequent clogging problems; • Performance is affected by the pH of the effluent; • Removal of certain contaminants are ineffective; • Resins are not selective; • Removal of resins; • Beads are easily damaged by particles and organic matter.

2. Non-Potable Reuse Treatment Technologies

The most widely implemented and accepted water reuse practice is non-potable water reuse. It has been successfully implemented in many states in the US, particularly California, Texas, Arizona, and Florida. Due to the variety of non-potable water reuse, treatment goals and processes are based on specified non-potable reuse, and the requirements/guidelines to ensure the protection of public health. Water quality goals for industrial reuse are often site-specific and different from water reuse for irrigation. To achieve industrial water quality standards for cooling and boiler water applications, nutrient (e.g., nitrogen, phosphorus) and ion (e.g., chloride, hardness) removal may be necessary. Typically, tertiary treatment and disinfection are needed for agricultural and crop irrigation reuse. Several filtration technologies may be used to remove suspended particles and pathogens, including granular media filters, moving bed sand filters, cloth filters, and membrane filters. The state of California, California Title 22, maintains a list of permitted filtering methods for non-potable reuse applications. This list is helpful for those designing tertiary filtration [2].

Figure 1 provides some examples of agricultural water reuse and their treatment technologies. Treatment requirements vary depending on the intended use, though water quality restrictions for chloride, TDS, ammonia, TSS, and bacteria are regularly considered for scaling and corrosion in boiler feed and cooling towers. Industrial end-user-specified water quality standards might also alter treatment strategies. Depending on the needs of the system, no extra treatment beyond the tertiary non-potable treatment system may be required, or an independent advanced system may be required to produce higher water quality. If an advanced treatment system is required, it is normally installed by the industrial user at the point of use [2].

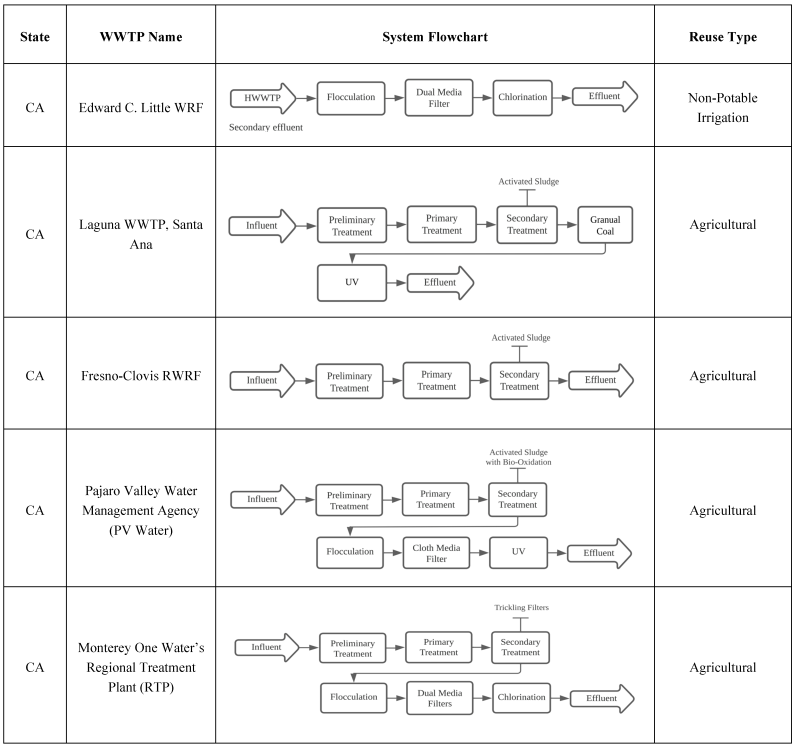

Figure 1. Wastewater treatment technologies for agricultural purposes based on various case studies in the US.

3. Potable Reuse Treatment Technologies

Potable reuse can be divided into two categories, which are direct potable reuse (DPR) and indirect potable reuse (IPR). Typically, complex treatment processes are used to remove organics, pathogens, and other impurities to fulfill potable water requirements. IPR refers to a system in which recycled effluent or advanced treated effluent is delivered to an environmental buffer prior to withdrawal for potable uses [28]. Direct potable reuse (DPR) refers to a system in which there is no environmental barrier between recycled effluent and potable water; nevertheless, mixing processes can be employed and still be classified as DPR [2]. Different treatment systems for IPR and DPR are depicted in **Figure 2**. In 2017, the EPA published the Potable Reuse Compendium which serves as a supplement to the 2012 guidelines and highlights current practices and treatment technologies in potable reuse.

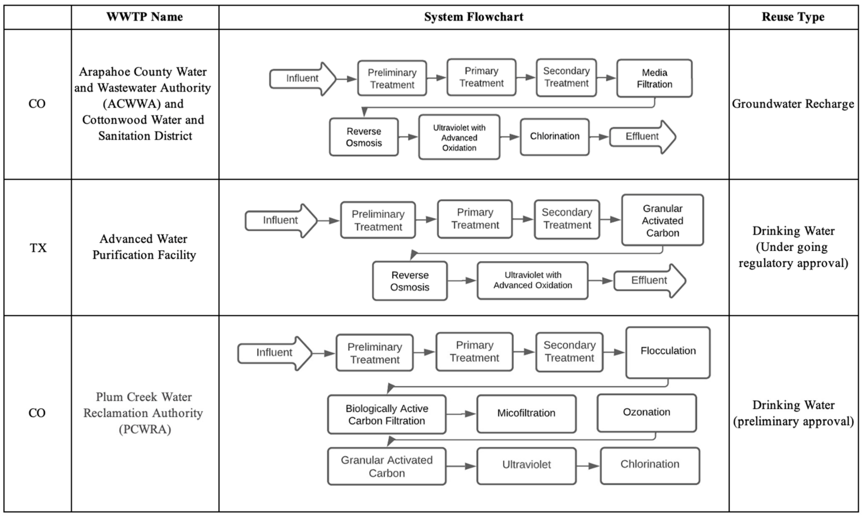

Figure 2. Wastewater treatment technologies for IPR and DPR purposes based on case studies in the US.

4. Costs of Treatment Technologies

As recycled water is a relatively new source of supply, the water sector has not yet adopted a pricing strategy for recycled water. Moreover, the assessment and distribution of costs associated with the production of recycled water are inherently complicated, reflecting both water and wastewater functions and necessitating judgments regarding the optimal management of shared costs [29]. **Table 4**a provides approximate costs using information from previous water reuse projects in 2009 USD [30], along with a comparison of reclaimed (recycled) water rates for various communities in the US (**Table 4**b) [3].

Table 4. (**a**) Water reuse projects financial costs. (**b**) Comparison of reclaimed (recycled) water rates [3].

(a)

Capacity (million gallons per day, MGD)	Treatment Technologies	Total Capital Cost (USD /kgal per year)	Annualized Capital Cost (USD /kgal)	Capital Cost (USD /kgal)	Annual Capital Cost + O&M Cost (USD /kgal)	End Uses	Facility
5	Secondary treated water–Filtration–UV	5.73	0.5	0.35	0.85	Landscape irrigation	Desert Breeze, NV, USA
10	Secondary treated water–Filtration–UV	4.23	0.37	0.68	1.05	Landscape irrigation	Durango Hills, NV, USA
16.4	Advanced Activated Sludge Treatment	1.14	0.1	0.05	0.15	Landscape irrigation, amenity reservoir	Trinity River Authority, TX, USA
30	Biologically aerated filters–Flocculation–Sedimentation–Filtration–Disinfection	13.57	1.18	1.06	2.24	Landscape irrigation, Industrial cooling, zoo	Denver Water, CO, USA
40	Biological Nutrient Removal (BNR) secondary treated water–Filtration–Chlorine Disinfection	18.75	1.63	1.02	2.65	Irrigation, industrial cooling, laundry, paper processing	West Basin, CA, USA
12.5	Microfiltration-Reverse Osmosis (RO)–Advanced Oxidation	30.72	2.68	2.38	5.6	Indirect Potable Reuse	West Basin, CA, USA
10	Activated Sludge Secondary Treatment with Denitrification–Anaerobic Digestion–Lime Treatment–Sand Filtration-Ozonation-Biologically Active Granular Activated Carbon Filtration–Final Disinfection	23.46	2.05	0.33	2.38	Indirect Potable Reuse	El Paso Water, TX, USA

20	Biological Nutrient Removal (BNR) secondary treated water–Filtration–Chlorine Disinfection–Soil Aquifer Treatment	11.26	0.98	1.18	2.16	Indirect Potable Reuse	Inland Empire, CA, USA
24	Biological Nutrient Removal (BNR) secondary treated water–Sodium Hypochlorite Disinfection–Treatment Wetlands	3.92	0.34	0.35	0.69	Indirect Potable Reuse	Casey WRF/Huie Wetlands Clayton Co., GA, USA
70	Enhanced Primary Treatment–Activated Sludge and Trickling Filter Secondary Treatment–Microfiltration (MF)–Reverse Osmosis (RO)–Advanced Oxidation (ultraviolet light and hydrogen peroxide)	20.0	1.74	1.16	2.90	Indirect Potable Reuse	Orange Co. GWRS, CA, USA

(b)

Community	Potable Water Rates (First Tiers Only)		Reclaimed Water Rates	
	Rate per 1000 gal	Use	Rater per 1000 gal	Use
Tucson, AZ, USA	2.19	1–15 ccf	2.45	Variable on all use
	7.82	16–30 ccf		
Dublin San Ramon Services District, CA, USA	3.28	Tier 1 Volume charge, first 22,440 gallons	3.19	Flat rate volume charge
	3.48	Tier 2 Volume Charge over 22,440 gallons		
Eastern Municipal Water District, CA, USA	2.07	Tier 1 Indoor use	0.8	R-452 Non-Ag, Secondary, Disinfected-2009
	3.79	Tier 2 Outdoor use	0.88	R-452 Non-Ag, Tertiary, Disinfected, Filtered-2009
Glendale Water and Power, CA, USA	3.18	Commercial Rate	2.39	Non-potable purposes
Irvine Ranch Water District, CA [1], USA	1.62	Residential Detached Base Rate 5–9 ccf	1.44	Landscape Irrigation Base Index 41–100% ET
	3.34	Residential Detached Inefficient Rate 10–14 ccf	3.01	Landscape Irrigation Inefficient Index 101–110% ET
	5.78	Residential Detached Excessive Rate 15–19 ccf	5.2	Landscape Irrigation Excessive Index 111–120% ET
Orange Country, FL, USA	1.04	0–3000 gal	0.74	Variable on >4000 gal/month
	1.39	4000–10,000 gal		
St. Petersburg, FL, USA			17.63	Unmetered–First acre
	3.45	0–5600 gal	10.1	Unmetered > 1 acre
			0.5	Metered
El Paso, TX, USA	1.94	Over 4 ccf	1.24	Variable on all use

Notes: ccf = 100 cubic feet; [1] Irvine Ranch Water District employs a steep inclined rate based on watering in excess of the evapotranspiration (ET) rate.

5. Water Reuse Distribution Infrastructure

According to Asano and Mills (1990), the network of the reclaimed water distribution system comprises all pipeline routes, storage reservoir locations, sizes, types, and pumping station locations and their capabilities. When elevation changes exist, it may be essential to divide the distribution system into two or more pressure zones; each pressure zone should be able to meet peak water demands. Therefore, redundant infrastructures are needed [31]. **Figure 3** depicts a conceptual diagram of several distribution system configurations. Asano et al. (2007) discussed the distribution system types of loop, grid, and tree systems (**Table 5**). With a grid or loop system, each major reuse area is supplied from multiple directions, ensuring that all demands will be met even if a portion of the distribution system is disrupted. While in a tree system, a failure in the main supply line will interrupt service to all or a portion of the users. A tree system is generally not advised to be used for the distribution of water reuse due to the possibility of odors developing in the dead-end outlets [5].

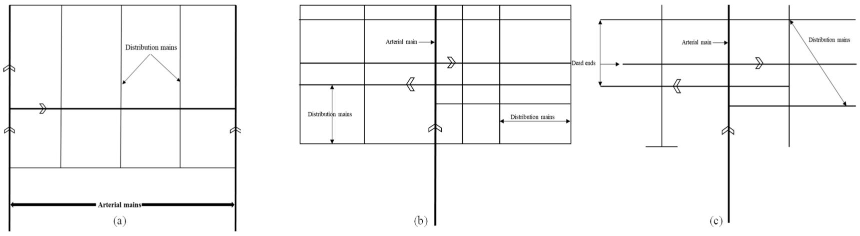

Figure 3. Pipelines distribution configurations: (**a**) loop, (**b**) grid, (**c**) tree.

Table 5. Types of distribution systems.

System Type	Description	Notes
Loop	**The areas that are going to be served are surrounded by large feeder mains, and smaller cross feed lines are connected to the main loop.**	**Reclaimed water is distributed from two directions to the main reuse area. Looped systems have less head loss than tree system.**
Grid	**The piping is set out in a checkerboard arrangement, and the size of the pipe typically decreases as the distance from the source increases.**	**Pipe size reduction will reduce material costs and has similar advantages as the loop system.**
Tree	**It utilizes a single main that decreases in size the further away it is from the source.**	**Usually used for systems that do not need the higher level of reliability that loop and grid systems offer. The accumulation of build-up in dead ends can be avoided with regular line flushing.**

The majority of states mandate that recycled water distribution pipelines to be purple; Pantone 512 or 522 is typically preferred for this purpose. Reclaimed water piping should be identified in accordance with state design guidelines, which may include labeling, tagging, and signs along the piping's alignment. PVC is a popular material for constructing reclaimed water pipes, as it is easy to infuse color during the manufacturing process. Reclaimed water distribution systems will contain all components characteristic of potable water distribution systems. Most standard system components are now available in purple, to facilitate the expanded installation of reclaimed water systems with purple color coding [3].

6. Water Reuse Planning Model

Planning a rational project requires well-defined objectives. The conventional framework for analysis begins with determining if a project has a single-purpose or multi-purpose, i.e., designed to serve two or more fundamental functions. The typical wastewater reclamation projects are intended for control or water supply. Water reuse planning generally consists of three stages [31]:

1. Conceptual level planning;

2. Preliminary feasibility investigation;

3. Facilities planning.

According to Asano and Mills (1990), a proposed project is drawn out during conceptual planning, then approximate costs are assessed and a potential market for recovered water is identified. If the conceptual planning seems viable, a preliminary feasibility analysis is conducted. Preliminary feasibility includes the following steps:

- Performing a market evaluation, i.e., identifying a market for recycled water and specifying the criteria that must be met (e.g., user needs for water quality and pricing);

- Evaluating the current water supply and wastewater facilities and creating some preliminary options that might service the entire market, in parts or in full, while meeting its technical and water quality needs;

- Comparing a wastewater reclamation and reuse option with other non-reclamation facilities, such as wastewater treatment for stream discharge or the construction of a reservoir for water supply;

- Considering technical needs, economics, financial advantages, marketability of recovered water, and other restrictions such as health protection of recycled water.

If wastewater reclamation and reuse look feasible, and desired based on the previous preliminary feasibility research, deeper planning may be explored, revised facilities options can be produced, and a final facilities' designs can be suggested [30]. The Water Environment Federation (WEF) also highlights the importance of holistic planning and decision-making frameworks, including but not limited to triple-bottom-line, "one water", and life cycle analysis. The WEF defines three components of water reuse planning, such as establishing a long-term vision for integrated water resource; setting strategic planning goals to create an integrated, reliable, resilient and sustainable water supply; and lastly, mapping the water resource supply/demand and infrastructure capacity [2].

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