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Review

Perspective on Land Treatment and Wastewater Reuse for Agriculture in the Western United States

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Abstract: The practice of irrigation with municipal wastewater has evolved from avoidance of surface water pollution to beneficial reuse of water and nutrients for crop production. The ability of the soil to filter out pollutants and pathogens has been documented, such that groundwater quality is not degraded where recycled water to irrigate crops used for human consumption. The example of successful practice of the Castroville project in Monterey County, California illustrates safe reuse of recycled water for crop growth, marketing of crops grown into the fresh produce market, and groundwater protection. Impediments to the future more widespread reuse of recycled water for agricultural irrigation are also discussed. Many of the same technological advancements that have supported the development of modern agricultural water reuse projects have also improved the feasibility of various competing urban water reuse applications. The effects from increasing water scarcity has also had an impact on the quality and quantity of water available for agricultural water reuse projects. The historical practice of developing centralized and regional wastewater treatment facilities near a suitable surface water discharge location may need to be modified for better consideration of agricultural irrigation in integrated water resources planning.

Keywords: land treatment; agricultural water reuse; case examples; future trends in water recycling

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Citation: Crites, R.; Beggs, R.; Leverenz, H. Perspective on Land Treatment and Wastewater Reuse for Agriculture in the Western United States. *Water* **2021**, *13*, 1822. https://doi.org/10.3390/w13131822

Academic Editor: William F. Ritter

Received: 18 May 2021
Accepted: 28 June 2021
Published: 30 June 2021

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1. Introduction

Wastewater reuse history can provide important context for planning new wastewater reuse projects and policy. Milestones have included design manuals and studies that demonstrated the effectiveness of the land treatment aspect of reuse for protection of water quality, furthering the acceptance of reuse. Evolution of wastewater treatment technology and changing land use patterns have recently become more important drivers for the types of reuse projects implemented. The higher value of water and improved advanced treatment technologies are tending to favor more direct and indirect potable reuse projects. As water conservation measures are increasingly mandated for urban areas, salinity is also becoming a more serious challenge for irrigation water reuse projects. This paper presents examples and a long-term perspective on some of these trends for consideration in policy and planning.

2. Historical Perspective

As far back as the Bronze Age, domestic wastewater has been used for irrigation by a number of civilizations including those in China, Egypt, Mesopotamia, and Crete [1]. In 1531 in Poland the earliest documented "sewage farm" was reported at Bunzlau. Agricultural lands were irrigated and fertilized with municipal wastewater at Edinburgh, Scotland in 1650 [2]. By the 1840s land treatment benefits such as organics and nutrient removal in the soil were reported in England [2]. A chronological listing of selected early municipal wastewater irrigation systems in Europe and the USA is presented in Table 1.

Table 1. Chronological History of Municipal Wastewater Irrigation [1,3,4].

Location	Date Started	Type of System
EUROPE		
Bunzlau, Poland	1531	Sewage farm
Edinburgh, Scotland	1650	Sewage farm
Croydon-Beddington UK	1860	Sewage farm
Paris, France	1869	Irrigation
Leamington, UK	1870	Sewage farm
Berlin, Germany	1874	Sewage farm
Milan, Italy	1881	Irrigation
Wroclaw, Poland	1882	Sewage farm
Braunschweig, Germany	1896	Sewage farm
USA		
Augusta, Maine	1876	Irrigation
Calumet City, Michigan	1888	Irrigation
South Framingham, Massachusetts	1889	Irrigation
Woodland, California	1889	Irrigation
Boulder, Colorado	1890	Irrigation
San Antonio, Texas	1895	Irrigation
Ely, Nevada	1908	Irrigation
Bakersfield, California	1912	Irrigation
Lubbock, Texas	1915	Irrigation

3. U.S. EPA Process Design Manual and Research

By the 1960s the concepts of water recycling and land treatment of municipal wastewater were rediscovered in projects such as Penn State's living filter where agricultural and silvicultural crops were irrigated and the impacts on crops, soil, groundwater and wildlife were studied [5]. EPA and the Army Corps of Engineers (ACE) commissioned state of the art studies of wastewater treatment and reuse by land application [3,6]. EPA and ACE promoted the return of wastewater nutrients to the soil in large-scale projects at Muskegon County, Michigan and Clayton County, Georgia [7,8]. In 1977 and again in 1981 EPA published comprehensive guidance manuals on land treatment technology and practice [9,10]. The concepts of agronomic reuse of water and nutrients were tied together in the manuals.

4. Water Reuse for Agriculture

In the EPA manuals [9,10] the distinction is drawn between agricultural irrigation at agronomic rates (water reuse) and slow-rate land treatment. East of the Mississippi River where precipitation often exceeds evapotranspiration, the percolation of treated water is a significant hydraulic path for slow-rate land treatment.

Municipal wastewater irrigation has historically been accomplished through agency purchase and control of the land. In arid regions, the water reuse concept has developed and most irrigated agriculture procures treated municipal effluent by contract rather than land purchase. For example, in most agricultural water reuse systems the land remains in private ownership and the agencies contract with the landowners for crop irrigation with treated effluent. In Table 2 the two types of land acquisition or control are compared for various sites.

Table 2. Options for Land Acquisition and Management for Agricultural Irrigation [11–14].

Location	Area, ha	Acquisition Option	Management Option
Bakersfield, CA	969	Fee simple	Lease back to farmer
Camarillo, CA	192	Contract	Landowner accepts water
Dickinson, ND	101	Contract	Cash lease for water sale to farmer
Lubbock, TX	1616	Fee simple and contract	Leaseback, farmer owns effluent
Mesa, AZ	64	Fee simple	Leaseback for cash rent
Monterey County, CA	4880	Voluntary acceptance	Managed by agency
Muskegon County, MI	4201	Fee simple	Managed by County
Petaluma, CA	222	Contract	Cash rent for irrigation equipment
Roswell, NM	115	Contract	Cash lease for water sale to farmer
San Antonio, TX	300	Fee simple	Managed by City
Sacramento County, CA	6464	Contract	Managed by agency
Tooele, UT	299	Contract	Cash lease for water sale to farmer
Walla Walla, WA	285	Fee simple	Managed by City

5. Case Study—Monterey County Wastewater Reclamation Study for Agriculture

Monterey County, California is home to a massive agricultural economy, featuring a variety of food crops including broccoli, cauliflower, lettuce, artichokes, celery, and strawberries. By 2016 the value of the produce exceeded $4.2 billion [12]. The crops were historically irrigated with groundwater, but overdrafting of the aquifers along the coast was resulting in seawater intrusion and water quality degradation.

The cities in the Salinas-Monterey peninsula used ocean outfalls to discharge their treated effluent [13]. A regionalization plan for wastewater treatment and water recycling was proposed to avoid expansion of the ocean outfalls and provide recycled water for crop production [14]. The local health officer required a site-specific study of the safety of using recycled water for vegetable crop irrigation.

In 1980 a 5-year study was begun in the Castroville area of Monterey County to evaluate different filtration systems and to demonstrate the removal of viruses prior to irrigation [14]. After the successful conclusion of the Castroville study, a regional wastewater treatment facility was designed and constructed to treat 80,000 cubic meters per day of wastewater and to distribute the recycled water on 4700 ha of row crops [15]. The system has been operating successfully for 20 years and now irrigates 4880 ha of agricultural crops [12]. Over 95 percent of the land used for this project is voluntarily enrolled in the project. Fresh vegetables grown with recycled water have been marketed successfully [12].

6. Case Study—Water Reuse for Irrigation/Groundwater Protection

One issue that has limited the use of recycled water for irrigation has been the fear of degradation of drinking water aquifers. Lands above sole-source drinking water aquifers, such as on Oahu in Hawaii, have been excluded from municipal wastewater irrigation. In 2000 a study was initiated for the Honolulu Board of Water Supply on the safety of irrigating with municipal effluent above a sole-source aquifer [16].

A field research project was operated on Oahu from December 2002 until May 2004 to demonstrate the safety, efficacy, and value of recycled water for turf irrigation. To address potential concerns regarding protection of local groundwater resources, a detailed unsaturated zone monitoring system was designed and implemented on field test plots. Twelve randomized field plots (4.8 m × 4.8 m) were laid out at a representative location in the area where recycled water would potentially be used for irrigation. Experimental design included irrigation with tertiary disinfected recycled water compared with well water as a control. A programmable irrigation system was installed with micro-sprinklers in each corner of plots to provide even irrigation in all plot areas.

The percolating water was collected using suction lysimeters at a depth of 1.5 m. Samples were collected for nutrients, trace organics, metals and pesticides. The trace organics of concern were NDMA, estrone and estradiol. The trace organics were successfully removed through the soil profile. For constituents of concern the percolate quality from the control

(groundwater) irrigated plots and the recycled water irrigated plots were equivalent and safe at the 1.5 m depth [17].

7. New Challenges for Water Reuse in Agriculture

As described above, water reuse for agricultural crop production has the potential to utilize large volumes of irrigation water sourced from treated municipal wastewater. However, expanded water reuse for irrigation is limited currently by a number of logistical challenges. Several of these challenges are summarized in Table 3. Two key considerations that impact the implementation of agricultural reuse are declining water quality and competing uses for recycled water.

Table 3. Summary of key challenges and drivers for agricultural water reuse [18].

Consideration	Challenge	Driver
Water availability	Water conservation reduces potential flows for water reuse; population mostly located on coast, where agriculture is limited	Water scarcity increases demand for water
Water quality	Increasing sodium and chloride concentrations, worsened, in part, by increasing conservation	Increased nutrient/organic content more suitable for irrigation/land treatment than surface water discharge
Regulatory	Administrative and technical requirements can inhibit the implementation of some projects	Mandates for recycled water in some areas
Economic	Capital and operational costs to produce and distribute recycled water to agricultural regions	Government support; revenue from sale of recycled water

7.1. Declining Water Quality

The concentration of salts and other dissolved solids in municipal water supply has a direct impact on the dissolved solids in the effluent from wastewater treatment. Increasing salt concentrations in surface water and groundwater supplies, due in part to overdrafting of aquifers and climatic factors, can have a negative impact on the reuse of wastewater effluent for crop irrigation. Further, reductions in indoor water use also increase the dissolved solids concentration of wastewater effluent.

Impact from source water quality. A strong correlation exists between the quality of the source water used for municipal water supply and the characteristics of the corresponding recycled water produced. In southern California, water received from the Colorado River Aqueduct has a total dissolved solids (TDS) concentration which has varied from around 300 mg/L to nearly 700 mg/L over the last decade [19]. More extreme climate conditions are expected to impact the salinity of many water supply sources due to increased evapotranspiration, discharge of effluent with increased TDS (due in part to water conservation), and less rainfall to replenish reservoirs and groundwater.

Impacts from water conservation and reuse. In areas prone to drought, as is the case in much of California and the western United States, there is a tendency over time for incremental reductions in indoor water usage associated with mandated water conservation measures, and long-term changes in behavior and installed fixtures/appliances. Indoor water use has declined by about 25% over the last decade in southern California, with a net effect of increasing wastewater effluent TDS content by about 50 mg/L on average [19]. The increasing TDS makes the water less suitable for irrigation of sensitive crops. More extreme flow reductions occur under acute dry conditions, such as during the California drought period 2015–2016 when wastewater influent flows were reduced by 10 to 50 percent [20]. Future voluntary and mandated reductions in indoor water use will continue to increase effluent salinity.

The changes in indoor water usage also reduce the flow velocity in wastewater collection systems and reduce the ultimate water available for reuse during the peak irrigation demand. Recent action to divert organics from landfills has also resulted in more co-digestion

projects that impart salts and nutrients into wastewater treatment facilities. The net effect of reduced indoor water use and imported organics for co-digestion is less recycled water available during the irrigation season and with increasing salt concentrations.

7.2. Competing Uses for Recycled Water

Water reuse by irrigation is among the earliest and the most extensively practiced forms of water reuse, but as the value of water increases and technologies for purification of water become more effective and feasible, there will likely be a shift away from irrigation in some regions.

The centralized/regional model of wastewater collection and treatment makes wide spread agricultural water reuse a significant challenge. In large metropolitan regions, much of the urban population is located in coastal areas. Water reuse was not considered when these areas were being planned and developed. Therefore, wastewater effluents are drained to coastal zones for treatment and discharge, far away from agricultural regions. Unfortunately, the proximity is too great between most key agricultural regions and population centers that are producing effluent for reuse to make this type of water reuse feasible.

While early practices may have benefitted from nutrients embodied in urban sewage, modern recycled water, by comparison, is relatively low in nutrients following treatment for nutrient reduction, which is required to meet inland surface water discharge requirements. Agricultural reuse typically does not have stringent nutrient standards compared with surface water discharge, but there is a general trend towards the implementation of biological nutrient removal and tertiary/advanced treatment systems. Because of the discharge standards in the United States, the level of water quality achieved with modern wastewater system designs may exceed that required for irrigation. Therefore, as an alternative water supply, recycled water may be considered for a wider range of potential applications including industrial reuse, groundwater recharge, reservoir augmentation, and potable reuse. Given that the technology and public acceptance of potable reuse has matured, it is expected that more potable reuse projects will be expanding in arid regions in the USA.

The seasonality of irrigation reuse must also be considered when looking to expand and optimize water reuse systems. Applications that have a stable demand throughout the year, such as industrial and potable reuse, will increase the total amount of water that can be reused. Competition with alternative and new types of reuse applications will need to be considered when evaluating the viability of any recycled water projects.

As shown on Figure 1 in California there was a significant increase in agricultural reuse in the 1970s until about 2009. Since 2009, there has been growth in urban and potable reuse (groundwater recharge) applications. Nearly all of the large reuse projects that are in development are focused on potable reuse applications that reduce consumption of potable water use in an effort to adapt to ongoing and worsening water scarcity.

One example of this competitive trend in coastal areas is the indirect potable reuse project for Soquel Creek Water District, which primarily provides water service to municipal clients in the central coast area of California. In an effort to stop seawater intrusion effects on its groundwater production wells, Soquel Creek is implementing advanced treatment of regional wastewater for direct injection of recharge water into aquifers. The advanced treatment includes advanced oxidation and reverse osmosis of tertiary effluent. The high value of water for municipal uses combined with the advanced treatment technology now available out-competes potential agricultural uses of the recycled water.

While there are competing interests for the recycled water, there is a significant opportunity developing for the reuse of agricultural nutrients recovered from urban wastewater. The recovery of nitrogen and phosphate from digestate and other concentrated side-streams can provide a source of locally sourced agricultural fertilizers. As the development of main-stream nutrient recovery processes progresses, the practice of agricultural reuse will grow to include nutrients sourced from wastewater. Thus, while it may not be feasible to

transport water from coastal wastewater facilities to agricultural regions, there is potential to export fertilizers from these urban areas.

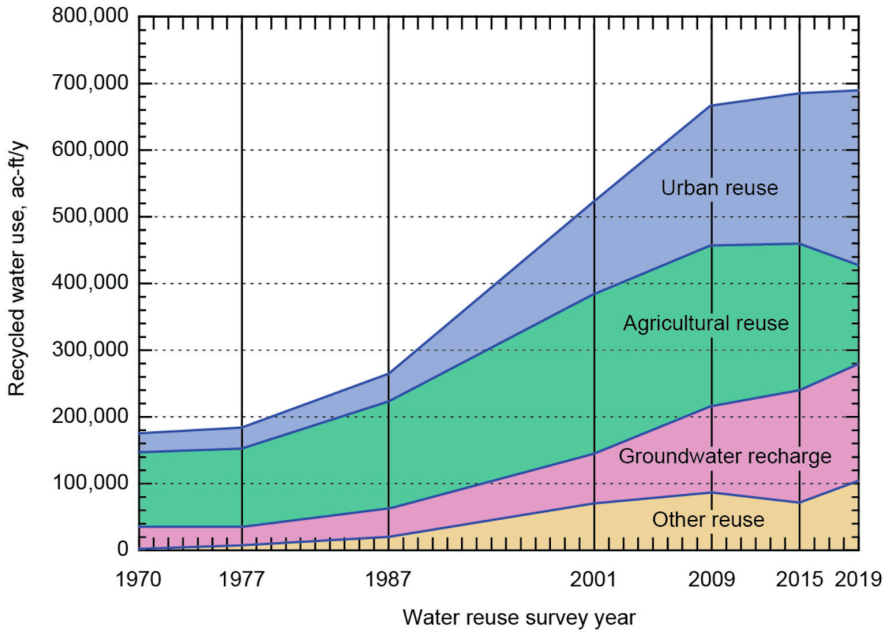

Figure 1. Summary of water reuse activity in California from 1970 to 2019 (adapted from [20,21]).

7.3. Water Availability for Inland Areas

Although recycled water for agriculture use faces increased challenges in coastal areas, the economics can still be favorable in arid inland areas. The City of Lodi in central California continues to irrigate row crops and forage crops on farmland surrounding its wastewater treatment plant. The distribution and treatment costs are low, enabling costs of irrigation reuse that compare favorably with tertiary treatment and river discharge.

The Sacramento Regional County Sanitation District is undertaking a new project to extend pipelines for supplying recycled water to farms south of the regional plant. The project has received supplemental state funding because it helps reestablish sustainable groundwater conditions in an area of historic groundwater overdraft, providing benefits to both agriculture and riparian habitat.

The inland city of Fresno, California continues to direct secondary effluent to percolation ponds that recharge groundwater. The groundwater is then subsequently extracted and discharged into a canal for agricultural use during the growing season. The soil-aquifer system provides economical advanced treatment and seasonal storage to the benefit of local agriculture.

8. Conclusions

Agricultural irrigation use of recycled water has a long history of success. It has developed into a combination of beneficial water reuse for a variety of crops including fresh vegetables and groundwater protection as illustrated in the two case studies presented. It is facing increasing challenges in coastal areas from competition with higher value, more continuous uses. Some other drivers away from agricultural reuse include the increasing value of water, lack of significant irrigation demand near urban areas, and desire to increase the total volume of water being recycled to offset potable water supply demand. In more rural inland areas, agricultural irrigation continues to be economically competitive and provide multiple benefits.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Publicly available datasets were analyzed in this study.

Conflicts of Interest: The authors declare no conflict of interest.

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