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Asano T.

in

Bouchet R. (ed.).
Reuse of low quality water for irrigation

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 1

1989
pages 119-132

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There are a number of factors which affect the implementation of municipal wastewater reclamation and reuse projects. Generally, the impetus for water reuse in industrialized countries has resulted from four motivating factors:

1. Increasing cost of freshwater development;

2. Desirability of establishing comprehensive water resource planning, including water conservation and wastewater reuse;

3. Availability of high quality effluents;

4. Avoidance of more stringent water pollution control requirements such as needs for advanced wastewater treatment facilities.

The general factors affecting wastewater reuse decisions include:

1. Local and regional water supply conditions;

2. Water quality requirements for intended water reuse applications;

3. Existing or proposed wastewater treatment facilities;

4. Requirements for degree of treatment process reliability;

5. Potential health risks mitigation and public acceptance; and

6. Financing reuse facilities including sale of reclaimed water.

Along with the facilities planning required for water pollution control projects, additional steps are usually necessary for wastewater reclamation and reuse projects because they involve primary benefits in the area of water supply. Although a wastewater reclamation and reuse projet may be justified on the basis of the least-cost alternative to water pollution control projects, much of the effort in wastewater reclamation and reuse projects is focused on market assessment or actual marketing of reclaimed wastewater. Thus, the facilities planning process for wastewater reclamation and reuse should consist of the following steps:

– Preliminary market assessment

– Engineering and economic analyses

– Detailed market analyses and user contracts

– Implementation plan including financial analyses.

The planning steps should result in the development of a recommended facilities plan for a *given wastewater reclamation and reuse project. By completing the planning steps, the following questions are also addressed (Asano and Madancy, 1982; WPCF, 1983).*

– What local sources of effluent might be suitable for reuse?

– What are the potential local markets for reclaimed water?

– What health risks are associated with water reuse, and how can they be mitigated?

– How would water reuse "fit in" with present and future use of other water resources in the region?

– What are the present and projected user costs of freshwater in the region?

– What existing or proposed laws and regulations affect wastewater reclamation and reuse possibilities in the region?

– What local or central government agencies must review and approve implementation of a wastewater reclamation and reuse projet?

– What are the legal liabilities as a purveyor of reclaimed water?

– What source of funding might be available to support a wastewater reuse project in the region?

– What wastewater reclamation and reuse project would attract the public's interest and support in the region?

I - Wastewater treatment need for irrigation

Although irrigation with wastewater is, in itself, an effective form of wastewater treatment (such as in slow-rate land treatment), some degree of treatment must be provided to untreated municipal wastewater before it can be used for agricultural or landscape irrigation. The degree of preapplication treatment is an important factor in the planning, design, and management of wastewater irrigation systems.

Preapplication treatment of wastewater is practiced for the following reasons (Asamo, *et al.*, 1985):

1. Protection of public health

2. Prevention of nuisance conditions during storage

3. Prevention of damage to crops and soils.

The level of treatment required for agricultural and landscape irrigation uses depends on the soil characteristics, the crops irrigated, the type of distribution and application systems, and the degree of public exposure.

The level of treatment required by regulatory agencies prior to irrigation of many crops is often not greater than, and is sometimes less than, the level of treatment required for discharge to receiving waters. Additional treatment to remove wastewater constituents that may be toxic or harmful to certain crops is technically possible, but normally is not justified economically. To use waters containing such constituents, the crops selected must be tolerant to the wastewater constituents, and systems must be managed to mitigate any harmful effects of these constituents.

1. Wastewater constituents and compositions

The physical properties and the chemical and biological constituents of wastewater are important parameters in the design and operation of collection, treatment, and disposal, and in the engineering management of irrigation facilities. The constituents of concern in wastewater treatment and wastewater irrigation are listed in **Table 1**.

Composition refers to the actual amounts of physical, chemical, and biological constituents present in wastewater. The composition of untreated wastewater and the subsequently treated effluents depends upon the composition of the municipal water supply, the number and type of commercial and industrial establishments, and the nature of the residential community. Consequently, the composition of wastewater often varies widely among different countries. Typical data on the composition of untreated domestic wastewaters in the US are presented in **Table 2**. For comparison, representative composition of night soils in Asia is reported in **Table 3** (Treatment, Disposal and Management of Human Wastes, 1985).

Wastewater quality data routinely measured and reported are mostly in terms of gross, nonspecific pollutional parameters (e.g., biochemical oxygen demand, suspended solids, chemical oxygen demand) that are of interest in water pollution control. In contrast, the water characteristics of importance in agricultural or landscape irrigation are specific chemical elements and compounds that affect plant growth or soil permeability. These characteristics are not often measured or reported by wastewater treatment agencies as part of their routine water quality monitoring program. Consequently, when obtaining data to evaluate or plan a wastewater irrigation system, it is often necessary to sample and analyze the wastewater for those constituents that define the suitability of the water for agricultural or landscape irrigation.

2. Irrigation water quality

Historically, the quality of irrigation water has been determined by the quantity and kind of salt present. As salinity in the reclaimed wastewater increases above a certain level, the probability of soil, water, and cropping problems also increases. Potential problems are related to the total salt content, to the types of salt, or to excessive concentrations of one or more elements. These problems are not different from those caused by salinity or specific ions in fresh water. They are of concern only if they restrict the use of the water or require special management to maintain acceptable crop growth and yields. For irrigation with reclaimed wastewater, the suitability of a water is, therefore, judged against the level of management needed to cope successfully with the water quality related problems that are expected to develop during use.

The approach often used is to present water quality guidelines that stress the management needed to successfully use irrigation water of a certain quality. Such guidelines were developed by Ayers and Westcot (1985) and reported elsewhere (Westoc and Ayers, 1985). The guidelines included potential problems related to salinity, specific ion toxicity, soils permeability, nutrients, and miscellaneous items such as clogging in sprinkler and drip irrigation systems.

Pathogenic microorganisms such as bacteria, viruses, protozoa, and parasitic worms (helminths) are almost always present in untreated municipal wastewater. The number and types of organisms present in wastewater, however, vary from community to community depending on urbanization, population density, sanitary habits, season of the year, and rate of disease in the contribution community.

There is some risk of human exposure to pathogens in every irrigation project with reclaimed municipal wastewater, but the health concern is in proportion to the degree of human contact with the reclaimed water and the adequacy and reliability of the wastewater treatment processes. To protect public health without unnecessarily discouraging wastewater reclamation and reuse, many regulations include water quality standards as well as requirements for treatment process, sampling and monitoring, wastewater treatment plant operations, and treatment process reliability. The management of reclaimed water once it leaves the wastewater treatment facility is also an important facet of the overall wastewater reclamation and reuse operation. In order to minimize health risks and aesthetic problems, tight controls are imposed in California on the delivery and use of the reclaimed water. The regulations of any specific irrigation use are based on the expected degree of contact with the reclaimed water and the intended use of irrigated crops. **Table 4** shows the health criteria for wastewater treatment and water quality applicable to irrigation in California. While the "California Wastewater Reclamation Criteria" require specific treatment unit processes in conjunction with effluent quality requirements, other unit processes may provide equivalent levels of treatment (Crook, 1985; Pettygrove and Asano, 1985).

II - Irrigation of vegetables with treated wastewater effluent – A five year study

The combination of fertile soils and a long growing season makes the lower Salinas Valley in northern Monterey County, California, a rich agricultural region. Artichokes are a major crop, but a variety of annual crops is also grown: broccoli, cauliflower, celery, and lettuce are grown throughout the region. It became evident during the early 1970s that northern Monterey County's groundwater supply was decreasing because of extensive withdrawal of groundwater for irrigation. This overdraft lowered the water tables and created an increasing problem of saltwater intrusion. At the same time, wastewater treatment facilities were reaching full capacity, requiring expansion to meet the growing needs of the region. The water quality management plan recommendations recognized that wastewater reclamation had to be proven safe before regional implementation could be considered. This provided the impetus for the Monterey Wastewater Reclamation Study for Agriculture (MWRSA), which was conceived as a pilot project designed to assess the safety and feasibility of agricultural irrigation with reclaimed municipal wastewater.

Planning for the project was begun in 1976 by the Monterey Regional Water Pollution Control Agency (MRWPCA), the regional agency responsible for wastewater collection, treatment, and disposal. Full-scale field studies began in 1980 and continued through May of 1985. During these five years, a perennial crop of artichokes was grown along with rotating annual crops of celery, broccoli, lettuce, and cauliflower. Extensive sampling and analysis of waters, soils, and plant tissues were conducted throughout the five years by Engineering-Science, a consulting engineering firm; University of California; and State agencies (MWRSA – Monterey Wastewater Reclamation Study for Agriculture, 1987).

1. Description of the Project

The site for the MWRSA field operations was a farm in Castroville, California. The existing 1,500 m^3/d (0.4 mgd) Castroville Wastewater Treatment Plant was selected for modification and upgrading to be used as the pilot tertiary reclamation plan for MWRSA. A portion of the secondary effluent was diverted to a new pilot tertiary treatment plant which consisted of two parallel treatment process trains. The first process Title-22 process (T-22), conformed strictly to the requirements of the California "Wastewater Reclamation Criteria" for irrigating food crops that may be consumed without cooking. The second process produced a treated wastewater designated as filtered effluent (FE). This is a wastewater treated less extensively than T-22 effluent via direct filtration of secondary effluent. Well water from local wells was the control for the study (Kirkpatrick and Asano, 1986).

The 12-ha (30-acre) field site was divided into two parts, demonstration fields and experimental plots. Large demonstration fields were established because farm-scale feasibility of using reclaimed water is of special importance to the growers, farm managers, and operators responsible for day-to-day farming practices.

To investigate large-scale feasibility of using reclaimed wastewater, two 5-ha (12-acre) plots were dedicated to reclaimed water irrigation, using the FE flow stream. On one plot, artichokes, were grown; on the other plot, a succession of broccoli, cauliflower, lettuce, and celery plants were raised during the first three years of the field investigation. The crops were observed carefully for appearance and vigor. At the end of each season, they were plowed under and incorporated into the soil. Normal farming practices of local growers were duplicated on these fields with the exception of harvest, which was not carried out. Because of its experimental nature, the produce from these plots was not marketed. Six field observation days were held, and the local growers and the news media were invited to acquaint the agricultural community with the ongoing MWRSA activities and to obtain feed-back regarding their perceptions, questions, and concerns (Cort, *et al*, 1987).

A split-plot design was chosen for the experimental plots. This design allowed the use of two treatment variables: water type and fertilization rate. Four replicates of three types of main plots were irrigated with T-22 effluent, FE, or well water. These three water types were assigned randomly to main plots within each block or replicate to achieve a randomized complete block (i.e., each block contains all three of the main water type treatments). Each main plot was then divided into four subplots, each of which was randomly assigned a different fertilization rate treatment: the full amount of nitrogen fertilizer used by local farmers (3/3), two-thirds the full rate (2/3), and one-third the full rate (1/3), and no fertilizer (0/3). The full design thus had 48 plots. This process was performed for artichokes and repeated for annual row crops, for a total of 96 plots which occupied 1.2 ha (3 acres). This experimental design allowed comparison of both irrigation with different water types and the effect of varying fertilization rates. The fertilization rates were designed to elucidate the value of the two effluents as a supplement to fertilization (Monterey Wastewater Reclamation Study for Agriculture, 1987).

Five years of field data were collected and analyzed. **Table 5** lists physical and chemical properties of irrigation waters which were used in MWRSA (Bureau *et al.*, 1987). The following results and conclusions were extracted from the Monterey Wastewater Reclamation Study for Agriculture – Final Report, April 1987).

2. Results of public health studies

A - Virus Survival

Monitoring for the presence of naturally occurring animal viruses showed that the influent to the two pilot processes (Castroville unchlorinated secondary effluent) contained measurable viruses in 53 of the 67 samples taken. The median concentration of virus was 2 plaque-forming units per liter (PFU/L): 90% of the samples contained less than 28 PFU/L. During the approximate five-year period, no *in situ* viruses were recovered from the chlorinated tertiary effluent of either process.

No viruses were recovered from any of the crop samples. This was also the case for the soil irrigated with the reclaimed water.

B - Virus seeding of plants and soil

Although no *in situ* viruses were recovered from irrigated plants and soil, it was important that an estimate be made of the ability of virus to survive under these conditions. Virus survival measurements were made in the laboratory and under field conditions. In the laboratory, the times required for a 99% die-off in the viruses (T_{99}) ranged form 7.8 days for broccoli to 15.1 days for lettuce. In field studies in Castroville, the T^{99} values were 5.4 days for artichokes, 5.9 days for romaine lettuce, 7.8 days for butter lettuce.

The survival of virus in Castroville soil was determined both under environmental chamber conditions and under field conditions. The T^{99} values for the decay of virus under environmental chamber conditions were respectively, 5.4, 9.7, and 20.8 days for 60, 70, and 80% relative humidity. In the field the T^{99}s were 5.2 and 4.8 days for runs one and two, respectively. Thus, the rate of virus removal under chamber and field conditions was quite similar. No viruses were recovered from any soil section after 12 to 14 days of exposure.

C - Bacteria and parasites

During the five years of the study, the quality of irrigation waters improved because of the continued improvement in treatment plant operations and storage procedures. All three types of waters, including the well water control, periodically exhibited high coliform levels. No salmonellae, shigellae, *Ascaris lumbricoides*, *Entamoeba histolytica*, or other parasites were ever detected in any of the irrigation waters.

The levels of total and fecal coliform in soils and plant tissue irrigated with all three types of water were generally comparable. No significant difference attributable to water type was observed. No parasites were ever detected in soil samples. Parasites were detected in plant tissue only in Year One, and there were no differences in level of contamination between effluent and well water-irrigated crops.

Sampling of neighboring fields detected no relationship between bacteriological levels and the distance from the field site. The aerosol transmission of bacteria was thus deemed unlikely.

D - Groundwater protection

No discernible relationship existed between the quality of the shallow groundwater underlying the site and the type of applied irrigation water. An examination of all water quality data collected suggests that the groundwater quality trends were associated with trends generally applicable in irrigated areas such as increased TDS and nitrate.

E - Aerosols

It was concluded early in the field operations of MWRSA that aerosol-carried microorganisms from FE sprinklers were not significantly different from those generated by well-water sprinklers. This finding was verified through replications both in daytime and night-time operations to account for die-offs of organisms caused by ultraviolet rays of the sun. Subsequently reported studies by others have corroborated these findings and established the safety of aerosols from an FE spray.

F - Health and field workers

In addition to these studies, the health status of each person assigned to the field tasks in MWRSA was monitored regularly through frequent questionnaires and thorough initial and exit medical examinations administered by qualified medical professionals. One hundred questionnaires were completed by personnel during the five years. No complaints could be related by personnel during the five years. No complaints could be related to contact with treated wastewater effluents. No formal epidemiological investigation was deemed appropriate or necessary for the purposes of MWRSA.

3. Results of agricultural studies

A - Irrigation water quality

As one would expect, the two treated effluents had higher levels of most chemical and metal constituents than did well water. The nutrient value of both effluents was substantial. The salt content of irrigation waters was important because of the potential for deleterious effects on crops and soils. Sodium content of irrigation waters was of particular concern because high levels of sodium along with low salinity can create poor soil physical conditions, which reduce permeability (Westcot and Ayers, 1985).

Salinity of irrigation waters was determined by measuring electrical conductivity (EC) and total dissolved solids (TDS), as well as the concentration of boron, chloride, sodium, bicarbonate, calcium, and magnesium. Concentrations of TDS less than 480 mg/L are recommended for irrigation waters, and levels above 1,920 mg/L are considered to be a severe problem. Levels of EC, TDS, boron, chloride, and sodium in the two treated effluents were comparable and were higher than those in well water. Concentrations of TDS in all three types were below the "severe problem" range, but effluent TDS fell into the range of "increasing problems" (see Westcot and Ayers, 1985). Levels of magnesium and calcium were similar in all three water types. Bicarbonate levels were higher in filtered effluent than in the other two water types, which showed similar concentrations.

The sodium adsorption ratio (SAR) is a measure of the suitability of water for irrigation. Irrigation water data indicate that the reclaimed water is generally in the favorable range for irrigation, because high SAR is accompanied by similarly high salinity (see **Table 5**).

B - Heavy metals in soils

None of the nine heavy metals studied (cadmium, zinc, iron, manganese, copper, nickel, cobalt, chromium, or lead) manifested any consistently significant difference in concentration among plots irrigated with different water types. Furthermore, except in the case of copper, no increasing trends with time over the five years were observed. The gradual increase observed for copper occurred equally for all water types, and at the end of the five years, copper concentrations were still below the average for California soils. Iron was generally measured at higher concentrations in the well water than in either effluent. Zinc, however, was higher in both effluents than in well water, although the actual concentrations were on the order of 0.1 mg/L in the two effluents. At these levels, uptake by plants would be faster than accumulation from irrigation input.

Input of zinc and other heavy metals, from the commercial chemical fertilizer impurities, is far greater and accounts for the large concentration differences observed at the three soil depth sampled throughout the five years. The differences have occured over many decades of continuous farming with regular applications of chemical fertilizers.

C - Heavy metals in plant tissues

The same nine metals studied in the soils were also investigated in samples of the edible tissues of plants collected at harvest at each of the 96 subplots. The most important of the many results is that no consistently significant difference in heavy metal concentrations was observed in plants irrigated with either effluent and with well water in any of the 16 samplings over the five-year field trials.

Analysis of cadmium and zinc in residual tissue produced results very similar to those from edible tissues, i.e., no consistent, significant differences were observed between plants irrigated with well water and with either of the two reclaimed waters. However, consistent differences in the accumulation of zinc and cadmium were observed between edible and residual tissues (higher cadmium in residual tissues and higher zinc in edible tissues for all vegetables studied). This difference in accumulation is in fact fortuitous, because it results in relatively higher zinc to cadmium ratios in the edible portion of the crops, believed to be a safeguard against cadmium bioaccumulation and the resultant health hazards.

D - Soil permeability

Infiltration rates in lettuce field were highest in those plots irrigated with well water, but these levels were not significantly different because of the great variation of infiltration rates within each water type. Infiltration rates in the artichoke field were higher than in the lettuce field. This is probably due to the fact that the artichoke field received less irrigation water and was less frequently compacted by equipment used for field preparation.

E - Crop yields

Artichoke yields were similar for all three water types; in the first two years, the different fertilization rates had no effect on yield. In the last three years, a significant effect of fertilization became apparent. All three fertilization rates showed significantly higher yields than did the unfertilized plots. There were, however, no significant differences in yield among the 1/3, 2/3, and 3/3 rates. The typical full fertilization rate may thus be in excess of the artichoke plants' requirements. The lack of fertilization effect in the first two years may have been due to the presence of residual fertilizer left by previous over-fertilization.

For most vegetables, yield was somewhat higher with irrigation with FE and Title-22 than with well water, and increases in yield with increasing fertilizer tended to level off at the 2/3 fertilizer rate. Yields of all seven lettuce crops were similar for the three different water types. Increases in lettuce yield tended to level off at the 2/3 rate.

F - Crop quality

Field quality assessments and shelf life measurements uncovered no differences between produce irrigated with reclaimed water and that irrigated with well water. Visual inspection of artichoke plants in the field showed no differences in appearance or vigor of plants irrigated with different water types. Occasional problems with mouse damage were not related to water type.

Shelf life and quality of row crops were similar for all water type treatments. No problems with increased spoilage of produce irrigated with effluents were encountered.

4. MWRSA findings

– Based on virological, bacteriological and chemical results from sampled vegetable tissues, irrigation with filtered effluent or T-22 appears to be as safe as with well water.

– After five years of field experimentation (1980 to 1985), results show few statistically significant differences in measured soil or plant parameters attributable to the different water types. None of these differences has important implications for public health. Yield of annual crops is often significantly higher with reclaimed water.

– No virus was detected in any of the reclaimed waters sampled although it is often detected in the secondary effluent.

– The T-22 process is somewhat more efficient than the FE process in removing viruses when influent is artificially inocculated (seeded) at extremely high rates. Both flow streams can remove more than five logs of virus (i.e., removal to below 1/100,000 of the seeded concentration).

– Marketability of produce is not expected to be a problem.

– The cost of producing filtered effluent (after secondary treatment) is estimated to be $0.06/m^3, excluding conveyance and pumping costs.

III - Appropriate wastewater treatment technologies for irrigation

Appropriate technologies are derived from a variety of sources. Most, though not all, technologies are appropriate to the specific time and place in which they are developed. Some can be transferred to other times and places and many can be improved in stages as additional resources become available (Gunnerson and Kalbermatten, 1979).

Technology options for wastewater treatment and disposal are limited by the resources available and the cost considerations of conventional and unconventional alternatives. As discussed in other presentations in this seminar, existing or traditional wastewater treatment facilities are often cost-effective and frequently can be transferred or upgraded in stages as funds become available. In many situations, when the intent of wastewater treatment is to minimize the probability of human exposure to pathogenic organisms (as exemplified in irrigation with wastewater), storage ponds and waste stabilization ponds are often the appropriate technologies. For small communities and/or developing countries, waste stabilization ponds, aquatic treatment systems, and similar low-rate biological processes are usually the most cost-effective method of pretreatment for agricultural irrigation. Where a higher quality effluent is required, such systems as a soil-aquifer treatment system may be appropriate.

1. Selection of appropriate technologies

Important issues in the selection of appropriate technologies for small communities and/or developing countries include:

a) Local health concerns;
b) Required effluent quality;
c) Required treatment plant capacity;
d) Initial capital cost;
e) Operation and maintenance cost;
f) Required energy for treatment.

The order of importance of the above factors will vary with each reuse application and use area control.

For example, aerated lagoons and stabilization ponds can be used to treat municipal wastewater adequately for most irrigation purposes. Pond systems also have the advantage of acting as a storage reservoir for non-irrigating seasons. A major factor to consider when deciding whether to construct stabilization ponds is the amount of land they require. If little land is available near a wastewater source, untreated or treated wastewaster will have to be pumped to stabilization and/or storage ponds in the closest agricultural area. Estimated construction cost for a 379 m^3/day pond system are compared to other forms of biological wastewater treatment in **Table 6**. The land area required for each type of system is also noted. The effect of land value on different wastewater treatment processes is presented in **Table 7**. As shown, although stabilization ponds are often the low-cost option, because they are land intensive, other wastewater treatment options may be more attractive or necessary, particularly for land that carried higher values (Reed and Hais, 1979; Arthur, 1983).

From the data and discussions presented in this section, and other presentations, it can the concluded that low-rate biological processes offer significant economic advantages, especially for small communities. Furthermore, the operation of low-rate systems is not dependent on the availability of highly skilled personnel. Also, because significant reductions in pathogenic organisms can be achieved in pond systems, they are well suited for many developing countries where water is short and resources are limited. Where higher levels of treatment are needed, aquatic and soil-aquifer treatment systems and other more energy intensive systems may be the feasible options.

IV - Summary and conclusions

The quality of reclaimed water to be used for irrigation depends to a great extent on the quality of the municipal water supply, nature of the wastes added during use, and the degree of treatment the wastewater has received. The quality of irrigation water has historically been determined by the quantity and kind of salt present in these water supplies. As salinity increases above a certain level, the probability for certain soil, water, and cropping problems increases. These problems are related to the total salt content, to one or more types of salt, or to excessive concentrations of one or more elements. The problems, however, are not different from those caused by salinity or trace elements in freshwater supplies and are of concern only if they restrict the use of the water or require special management to maintain acceptable yields.

To protect public health without unnecessarily discouraging wastewater reuse, many regulations related to agricultural and landscape irrigation include water quality standards as well as requirements for treatment processes, sampling and monitoring, wastewater treatment plants operations, and treatment process reliability. The management of the reclaimed water once it leaves the wastewater treatment facility is also an important facet of the overall wastewater reclamation and reuse operation. In addition, for irrigation with reclaimed municipal wastewater to be a reasonable alternative for municipalities, financial and economic feasibility for farm owners-operators, landowners, and farm tenants must be shown. In the USA, however, wastewater reclamation and reuse have historically been largely viewed as a means of treatment and disposal of wastewater, primarily through land application. Thus, the economics were approached from a wastewater management perspective by comparing irrigation with reclaimed municipal wastewater with other methods of wastewater treatment and disposal. In this case, the water supply benefits, in the form of usable crops, were generally ingnored in the economic analyses. However, before shifting its water source from fresh water, a prospective reclaimed water user will expect the difference in price between fresh water and reclaimed water to reflect any added costs or savings incurred by the user.

A recently completed agricultural irrigation project, Monterey Wastewater Reclamation Study for Agriculture, was discussed in relation to the California experiences in irrigation with reclaimed municipal wastewater. The five-year field data indicate few statistically significant differences in measured soil or plant parameters attributable to the different water types. None of these differences showed important public health implications.

Acknowledgements

The author is indebted to the State of California for liberal use of many reports and publications which included **Irrigation With Reclaimed Municipal Wastewater** – A Guidance Manual (Pettygrove, G.S., and Asano, T., ed.). In addition, **Monterey Wastewater Reclamation Study for Agriculture – Final Report, April 1987** was the main source of information for the section, Irrigation of Vegetables with Treated Wastewater Effluent. The report was prepared for Monterey Regional Water Pollution Control Agency by Engineering – Science.

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Table 1: Constituents of concern in wastewater and irrigation with reclaimed municioal wastewater

Constituents	Measured parameters	Reason for concern
Suspended solids	Suspended solids, including volatile and fixed solids	Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment. Excessive amounts of suspended solids cause soil plugging in irrigation systems.
Biodegradable organics	Biochemical oxygen demand, chemical oxygen demand	Composed principally of proteins, carbo hydrates, and fats. If discharged to the environment, their biological decomposition can lead to the depletion of dissolved oxygen in receiving waters and to the development of septic conditions.
Pathogens	Indicator organisms, total and fecal coliform bacteria	Communicable diseases can be transmitted by the pathogens in wastewater: bacteria, virus, parasites.
Nutrients	Nitrogen Phosphorus Potassium	Nitrogen, phosphorus, and potassium are essential nutrients for plant growth, and their presence normally enhances the value of the water for irrigation. When discharged to the aquatic environment, nitrogen and phosphorus can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, nitrogen can also lead to the pollution of groundwater.
Stable (refractory) organics	Specific compounds (e.g., phenols, pesticides, chlorinated hydrocarbons)	These organics tends to resist conventional methods of wastewater treatment. Some organic compounds are toxic in the environment, and their presence may limit the suitability of the wastewater for irrigation.
Hydrogen ion activity	pH	The pH of wastewater affects metal solubility as well as alkalinity of soils. Normal pH range in municipal wastewater is 6.5 - 8.5, but presence of industrial waste can alter pH significantly.
Heavy metals	Specific elements (e.g., Cd, Zn, Ni, Hg)	Some heavy metals accumulate in the environment and are toxic to plants and animals. Their presence may limit the suitability of the wastewater for irrigation.
Dissolved inorganics	Total dissolved solids, electrical conductivity, specific elements (e.g., Na, Ca, Mg, Cl, B)	Excessive salinity may damage some crops. Specific ions such as chloride, sodium, boron are toxic to some crops. Sodium may pose soil permeability problems.
Residual chlorine	Free and combined chlorine	Excessive amount of free available chlorine (> 0.05 mg/L CL^2) may cause leaf-tip burn and damage some sensitive crops. However, most chlorine in reclaimed wastewater is in a combined form, which does not cause crop damage. Some concerns are expressed as to the toxic effects of chlorinated organics in regard to ground water contamination

Source: Asano et al., 1985

Table 2: Typical composition of untreated municipal wastewater

Constituent	Concentration range			U.S. average
	Strong	Medium	Weak	
Solids, total	1,200	720	350	-
Dissolved, total:	850	500	250	-
Fixed	525	300	145	-
Volatile	325	200	105	-
Suspended	350	220	100	192
Fixed	75	55	20	-
Volatile	275	165	80	-
Settleable solids, mL/L	20	10	5	-
Biochemical oxygen demand, 5-day 20°C	400	220	110	181
Total organic carbon	290	160	80	102
Chemical oxygen demand	1,000	500	250	417
Nitrogen (total as N)	85	40	20	34
ORG-N	35	15	8	13
NH_3-N	50	25	12	20
NO_3-N	0	0	0	-
NO_3-N	0	0	0	0.6
Phosphorus (total as P)	15	8	4	94
Organic	5	3	1	26
Inorganic	10	5	3	68
Chlorides	100	50	30	-
Alkalinity (as $CaCO_3$)	200	100	50	211
Grease	150	100	50	-
Total coliform bacteria, MPN/100mL	-	-	-	22×10^6
Fecal coliform bacteria, MPN/100mL	-	-	-	8×10^6
Viruses, PFU/100 mL	-	-	-	3.6

(a) All values are expresed in mg/L, except as noted

Table 3: Representative composition of night soils (a)

Constituent	Concentration range (b)
pH	7—9
Biochemical oxygen demand	9,000—22,000
Suspended solids	9,000—26,700
Total solids	18,000—45,000
Chemical oxygen demand	5,000—45,000
Total nitrogen	4,000 — 7,000
NH_3-N	2,000 — 3,500
Kjeldahl-N	3,000 — 4,000
Total phosphorus	600 — 1,600
Chloride	2,300 — 5,600

(a) Data were compiled from the papers presented at the IAWPRC'S First Asian Conference on Treatment, Disposal and Management of Human Wastes, 1-3 October, 1985, Tokyo, Japan

(b) All values are expressed in mg/L, except pH

Table 4: Wastewater treatment and bacteriological quality criteria for irrigation (State of California, 1978)

Treatment level	Coliform limits MPN (a)	Type of use
Primary	- -	Surface irrigation of orchards and vineyards
		fodder, fiber, and seed crops
Secondary and disinfenction	≤ 23/100 ml	Pasture for milking animals
		Landscape irrigation (golf courses, cemeteries, etc.)
	≤ 2.2/100 ml	Surface irrigation of food crops (no contact between water and edible portion of crop)
Tertiary with coagulation clarification, filtration (b), and disinfection	≤ 2.2/100 ml max. = 23/100 ml	Spray irrigation of food crops
		Landscape irrigation (parks, playgrounds, etc.)

(a) See in detail "Wastewater reclamation criteria", State of California, Department of Health Services, 1978

(b) The turbidity of filtered effluent cannot exceed an average of 2 turbidity units (NTU) during any 24-hour period

Table 5: Physical and chemical properties of irrigation waters, August 19, 1980 to June 13, 1985

Parameter	Well water Range	Well water Median	Title-22 water Range	Title-22 water Median	Filtered effluent Range	Filtered effluent Median
	----------------	mg/L, unless otherwise noted			----------------	
pH *	6.9 - 8.1	7.8	6.6 - 8.0	7.2	6.8 - 7.9	7.3
Electrical conductivity †	400 - 1,344	700	517 - 2,452	1,256	484 - 2,650	1,400
Calcium	18 - 71	48	17 - 61.1	52	21 - 66.8	53
Magnesium	12.6 - 6.36	18.8	16.2 - 40	20.9	13.2 - 57	22
Sodium	29.5 - 75.3	60	77.5 - 415	166	82.5 - 526	192
Potassium	1.6 - 5.2	2.8	5.4 - 26.3	15.2	13 - 31.2	18
Carbonate, as $CaCO_3$	0.0 - 0.0	0.0	0.0 - 0.0	0.0	0.0 - 0.0	0.0
Bicarbonate, as $CaCO_3$	136 - 316	167	56.1 - 248	159	129 - 337	199.5
Hardness, as $CaCo_3$	154 - 246	202,5	187 - 416	217.5	171 - 435	226.5
Nitrate as N	0.085 - 0.64	0.44	0.18 - 61.55	8.0	0.08 - 20.6	6.5
Ammonia as N	** -1.04	* *	0.02 - 30.8	1.2	0.02 - 32.7	4.3
Total phosphorus	** -0.6	0.02	0.2 - 6.11	2.7	3.8 -14.6	8.0
Chloride	52.2 - 140	104.4	145.7 - 841	221.1	145.7 - 620	249.5
Sulfate	6.4 - 55	16.1	30 - 256	107	55 - 216.7	84.8
Boron	0.01 - 9	0.08	0.01 - 0.81	0.36	0.11 - 0.9	0.4
Total dissolved solids	244 - 570	413	643 - 1,547	778	611 -1,621	842
Biochemical oxygen demand	0.6 - 33	1.35	0.7 - 102	13.9	** -315	19
Adjusted SAR ††	1.5 - 4.2	3.1	3.1 - 18.7	8.0	3.9 - 24.5	9.9
MBAS †††	** - **	* *	0.095 - 0.25	0.136	0.50 - 0.585	0.15

Source: Burau, R.G. et al., 1987

* Standard pH units
† Micromhos/centimeter
†† Sodium adsorption ratio, no unit
††† Methylene-blue-active substance
Chemical concentration below detection limit

Detection limits are as follows:
Ammonia = 0.002 mg/L
Phosphorus = 0.01 mg/L
Boron = 0.02 mg/L
Biochemical oxygen demand = 1.0 mg/L
MBAS = 0.05 mg/L

Table 6: Estimated costs for 379 m^3/day wastewater treatment facilities (in 1986 U.S. dollars) (a), (d)

System type	Capital costs $ 1,000 (b)	Land area (ha)	Annual energy requirement (1,000 kW.h/year) (c)
1. Low rate biological processes			
Stabilization pond			
Northern climate	531	2.0	0
Southern climate	238	1.2	0
Aerated lagoon	559	0.4	15
2. High rate biological processes			
Oxidation ditch	639	0.4	43
Rotating biological contactors	913	0.6	18

(a) After Reed and Hais with modifications
(b) Does not include raw wastewater pumping, disinfection or land costs
(c) Does not include raw wastewater pumping, preliminary treatment, disinfection or sludge treatment and disposal
(d) Costs are adjusted for 1986 using the Engineering News Record Construction Cost Index

Table 7: Effect of land value on different wastewater treatment processes (a),(b)

System type	Total present value, in U.S. million dollars at given land value		
	$ 10,000/ha	$ 50,000/ha	$ 100,000/ha
1. Low rate biological processes			
Stabilization pond	4.1	5.9	8.2
Aerated lagoon	6.4	8.3	10.8
2. High rate biological processes			
Oxidation ditch	5.5	6.3	7.3
Biological filter (Trickling filter)	7.4	8.4	9.9

(a) After Arthur with modifications
(b) Includes capital and operation and maintenance costs for average wastewater flow of 30,000 m^3/day and present values at 12 percent discount