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Appendix 16

Treated Wastewater for Golf Course Irrigation

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INTRODUCTION

One of the most critical objectives in wastewater reclamation and reuse is to assure protection of public health. Special emphasis is placed on reducing concentrations of pathogenic organisms including bacteria, parasites, and enteric viruses in reclaimed wastewater. The need for research, especially on the efficacy of enteric virus inactivation/removal in wastewater reclamation and reuse, has been recognized because of their low-dose infectivity, long-term survival in the environment, difficulty of monitoring, and low removal efficiency in conventional wastewater treatment (Dryden, *et al.*, 1979; Asano and Sakaji, 1990; Gerba and Rose, 1993).

The possibility exists that failure may occur with wastewater treatment systems, and that enteric viruses may be detected even in tertiary treated effluents. Thus, operational reliability of wastewater treatment is of importance in wastewater reclamation and reuse. Risk estimation based on grab samples from tertiary treated effluents, whose enteric virus concentrations are almost always below the detection limit, can not be used to quantify the safety of wastewater reclamation and reuse.

The objective of this paper is to investigate: (1) methods that can be used to evaluate the reliability of wastewater reclamation and reuse, considering the variability of virus concentrations to meet a given annual infection risk; and (2) the comparative assessment of the safety of different wastewater treatment systems, using the U.S. Environmental Protection Agency's Surface Water Treatment Rule (SWTR) for domestic water supply as a reference (U.S. EPA, 1989). Assessing the appropriateness of the 10^{-4} infection risk implied in the EPA SWTR criteria document as a safety criterion was beyond the scope of this paper. Two concepts related to the safety of wastewater reclamation and reuse are presented. The first is *reliability* defined as the probability that an infectious risk from enteric viruses in reclaimed water does not exceed an acceptable risk. The second is based on the *expectation* of an annual risk in which the exposure to enteric viruses may be estimated stochastically by numerical simulation.

Thus, central to the safety of wastewater reclamation and reuse is the ability to estimate the reliability of operation as well as the expectation of annual risk under varying enteric virus concentrations. To this end, first, enteric virus monitoring data for unchlorinated secondary effluents from four wastewater treatment plants in California are analyzed using a lognormal distribution. The assumption that observed data follow the lognormal distribution was tested by the Kolmogorov-Smirnov's goodness-of-fit test. Second, the reliability of wastewater reclamation and reuse is discussed with respect to enteric virus inactivation/removal meeting the SWTR. Third, using Monte Carlo methods(MCM), the expectation of annual risk was simulated and compared with the results of the virus inactivation/reuse calculations using four different wastewaters. The wastewater reuse applications and exposure scenarios examined included golf course irrigation, food crop irrigation, unrestricted recreational impoundments where swimming may take place, and groundwater recharge. Finally, the safety of wastewater reclamation and reuse is evaluated using two scoring systems derived from the reliability assessment and the expectation estimates of meeting the SWTR for enteric viruses.

ENTERIC VIRUS CONCENTRATIONS IN SECONDARY EFFLUENTS

The enteric virus database used in this study included 377 unchlorinated secondary effluent samples in which 242 samples (64 %) were reported as positive. These data were obtained from the published reports from the County Sanitation Districts of Los Angeles County, the Orange County Water District, and the Monterey Regional Water Pollution Control Agency in California. Because of the small number of positive samples found in the chlorinated tertiary effluents reported in the earlier study (Asano, *et al.*, 1992) and some uncertainty associated with their detection, the following analyses were conducted using enteric virus concentrations reported in the unchlorinated secondary effluents as given in Table 1. The main purpose of the virus monitoring at the four facilities was to assure virtually no enteric viruses could be found in the tertiary effluents to be used for unrestricted water reuse. The effluents were to be in compliance with the most stringent requirements for the total coliform group of bacteria specified in the California Wastewater Reclamation Criteria (often referred to as the Title 22 regulations) (State of California, 1978).

Table 1 Summary of the Enteric Virus Data Used for the Analysis (Unchlorinated Secondary Effluents)

California agency	Facility	Study period	Type of secondary treatment	No. of samples	No. of positive samples
Orange County Water District (OCSD TF)	County Sanitation Districts of Orange County, Plant No.1	1975-78	Trickling Filter	145	109
Orange County Water District (OCSD AS)	County Sanitation Districts of Orange County, Plant No.1	1978-81	Activated Sludge	105	53
County Sanitation Districts of Los Angeles County (Pomona AS)	Pomona	1975	Activated Sludge	60	27
Monterey Regional Water Pollution Control Agency (MRWPCA AS)	Castroville	1980-85	Activated Sludge	67	53
Total				377	242

Quantifying virus concentrations is necessary for estimating the risk of infection due to exposure to reclaimed municipal wastewater. All of the observed data from the California agencies shown in Table 1 are plotted in Fig. 1.

The statistical model used in this study was the lognormal distribution. The data reported as negative values were estimated as they are below the detection limits. Although these data points cannot be plotted on the graph, they were used for the calculation of the empirical cumulative density function (CDF). The goodness-of-fit of the hypothesized distribution was evaluated using the nonparametric Kolmogorov-Smirnov test (Benjamin and Cornell, 1970; Niku and Schroeder, 1981; Hogg and Tanis, 1988).

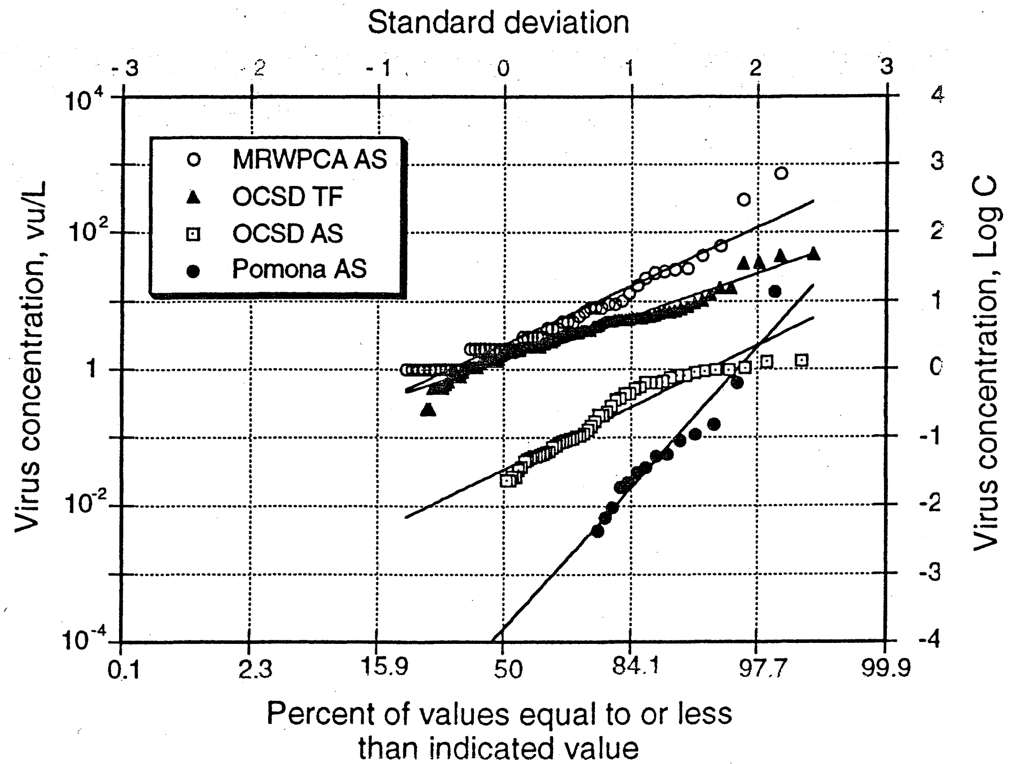

Figure 1 Cumulative Distribution Function of Virus Concentrations in Unchlorinated Secondary Effluents

The estimated parameters for the lognormal distribution model for the enteric virus concentrations obtained using regression analysis are reported in Table 2. The lognormal distribution was determined to be a reasonable approximation for the enteric virus distribution in the unchlorinated secondary effluents.

Based on the analysis presented above, it can be concluded that the virus concentrations vary over a wide range in unchlorinated secondary effluents. Furthermore, virus concentrations among different plants varied widely. For example, the geometric means ranged over four orders of magnitude (10^{-4} to 10^{0} vu/L) and the spread factors range approximately from 4 to 115. Thus, characterizing the variability of enteric virus concentrations in unchlorinated secondary effluent is extremely important in virus risk assessment.

PERFORMANCE AND RELIABILITY ANALYSES

As noted in the previous section, the variability of virus concentrations in the unchlorinated secondary effluent is large; thus, it becomes difficult to select an appropriate virus concentration to use in the subsequent risk calculations. The geometric mean of the observed virus data have been reported in several studies (McCarty, *et al.*, 1978; Haas, 1983; Olivieri, *et al.*, 1989). However, the 50 percentile value in the probability analysis may not be acceptable in case of public health protection, knowing that any risk of infection derived from this value will be exceeded 50% of time. The risk estimated from the observed maximum concentration would be conservative; but, in this case, the maximum value may be dependent on a sample size and time of observation.

Table 2 Estimated Parameters for the Lognormal Distribution of the Virus Concentrations in the Unchlorinated Secondary Effluent[1]

Estimated Parameters	Symbols	California Agencies[1]			
		OCSD TF	OCSD AS	Pomona AS	MRWPCA AS
Arithmetic mean[2] of log C	μ	0.12	-1.47	-3.81	0.37
Standard deviation of log C	σ	0.63	0.91	2.06	0.86
Geometric mean[3] of C	m_g	1.4	0.034	0.0002	2.32
Spread factor[4] of C	S	4.27	8.13	114.82	7.24
Correlation factors	R^2	0.963	0.962	0.934	0.940
Number of samples used for regression analysis		99	52	14	53
Number of samples used for calculation of empirical CDF		135	105	60	67
Estimated C in given percentile	50%	1.4	0.034	0.0002	2.3
	90%	8.9	0.5	0.34	29
	95%	15	1.1	3.0	59

[1] Refer to Table 1.
[2] C denotes enteric virus concentrations expressed as viral units per liter (vu/L).
[3] Geometric mean, m_g, is defined as $m_g = 10^{\mu}$.
[4] Spread factor, S, is defined as $S = 10^{\sigma}$.

Estimation of Reliability

Several researchers have attempted to estimate the effectiveness of pathogen inactivation/removal in water and wastewater treatment processes and the fate of pathogens in environment using risk assessment methodologies (Hutzler and Boyle, 1980 and 1982; Haas, 1983; Gerba and Haas, 1988; Olivieri *et al.*, 1989; Asano and Sakaji, 1990; Rose and Gerba, 1991; Asano, *et al.*, 1992; Gerba and Rose, 1993).

One method of determing the relative safety of wastewater reclamation and reuse practices is to estimate the time that a risk from reclaimed water does not exceed an acceptable risk. In this context, the reliability of wastewater reclamation and reuse is defined as a probability that an infectious risk due to the ingestion of enteric viruses in reclaimed water does not exceed an acceptable infectious risk. To estimate the reliability of wastewater reclamation and reuse, it is first necessary to determine the maximum concentration of enteric viruses that constitute an acceptable risk in the use of reclaimed water. If the acceptable risk is given as an annual risk of infection, an acceptable daily risk can be calculated from Eq. (1) where n denotes number of exposure events in a year and Pa an acceptable annual risk.

$$Pa = 1-(1-Pa^*)^n \quad (1)$$

where Pa* is acceptable daily risk

$$Pa^* = 1-(1-Pa)^{1/n} \quad (2)$$

When a person ingests a volume, V, of reclaimed water containing the enteric virus concentration, C, a single exposure dose, D, for this event is:

$$D = CV \quad (3)$$

The dose-response relationships often cited where an acceptable virus concentration, Ca* can be determined using Eqs. (4) or (5).

Single-hit exponential model

$$Ca^* = 1\text{-}Pa^*/\gamma V \qquad (4)$$

Beta-distributed probability model

$$Ca^* = \beta/V\,[(1\text{-}Pa^*)^{-1/\alpha} - 1] \qquad (5)$$

where α, β, and γ are model parameters estimated from actual infectious doses.

A similar methodology was used to estimate *Giardia* cyst density in domestic water supply systems complying with the SWTR (Gerba and Haas, 1988; Rose and Gerba, 1991; Regli, *et al.*, 1991; Gerba and Rose, 1993). The beta-distributed probability model was chosen for use in this paper because it best represented the frequency distribution of infection for pathogen of concern (Haas, 1983a; Asano and Sakaji, 1990; and Rose and Gerba, 1991)

Second, the probability that the daily risk due to exposure to wastewater reuse activities satisfies the acceptable daily risk can be estimated. When the virus concentration in secondary effluent is Cs, the ingested virus concentration C* is

$$C^* = Cs\ 10^{-R}\ E \qquad (6)$$

where R denotes a log-removal efficiency during tertiary treatment and E denotes the environmental reduction, i.e., the fraction of enteric viruses remaining after environmental exposure. Because Cs follows the lognormal distribution described in Table 2, the probability, p that C* does not exceed Ca* is:

$$p = \Phi\,[\{(\log Ca^* - \mu)/\sigma\} + R - \log E] \qquad (7)$$

where Φ is the standardized normal function.

Third, a basis for acceptable risk must be selected. An appropriate reference used in this paper is the EPA's Surface Water Treatment Rule for domestic water supply. If the reliability of wastewater reclamation and reuse is the same as the reliability of domestic water supply in meeting the enteric virus removal criteria and the infectious risk, wastewater reclamation and reuse is deemed to be as safe as drinking water.

Required Virus Removal Efficiency With Tertiary Treatment

If reclaimed wastewater is to be as safe as using domestic water supply, with respect to enteric virus infection, the required virus removal efficiency in tertiary treatment is determined in the reverse way that reliability is calculated. The first step involves the determination of the maximum virus concentration which satisfies an acceptable annual risk, Ca*. Rearranging Eq. (7) and solving for R yields:

$$R = \Phi^{-1}(p) + \log E - [(\log Ca^* - \mu)/\sigma] \qquad (8)$$

The environmental inactivation/removal efficiency of enteric viruses, E, is given by the environmental factors and the different exposure scenarios, and μ and σ are dependent upon the characteristics of the distribution of virus concentrations in secondary effluent. When the reliability of domestic water supply systems is p, the required inactivation/removal efficiency for satisfying the acceptable risk at a reliability, R, can be determined by using Eq. (8).

RELIABILITY IN WASTEWATER REUSE APPLICATIONS

To assess potential risks associated with the use of reclaimed wastewater in various reuse applications, four exposure scenarios developed by Asano, *et al.* (1990 and 1992) were tested: golf course irrigation, food crop irrigation, recreational impoundments, and groundwater recharge. An exposure dose (intake volume and enteric virus concentration in the ingested water), frequency of exposure, and environmental decay/fate are assessed for each exposure scenario. The four exposure scenarios examined are summarized in Table 3.

Table 3 Summary of Exposure Scenarios Used in Risk Assessment[1]

Application purposes	Risk group receptor	Exposure frequency	Amount of water ingested in a single exposure	Reduction in the environment
Scenario I Golf course irrigation	Golfer	Twice per week	1 mL	Irrigation one day before playing
Scenario II Crop Irrigation	Consumer	Every day	10 mL	Stop Irrigation two weeks before harvest and shipment. Viral reduction due to sunlight
Scenario III Recreational Impoundment	Swimmer	40 days per year - summer season only	100 mL	No virus reduction
Scenario IV Groundwater recharge	Groundwater consumer	Every day	1000 mL	3 m vadose zone and 6 month retention in aquifer. Virus inactivation coefficient = 0.69/d

1. Adapted from Asano *et al.* (1992)

Virus Inactivation/Removal Efficiency Required in Tertiary Treatment

If the acceptable annual infectious risk from enteric viruses in wastewater reclamation and reuse is on the order of 10^{-4} (less than or equal to one infection per 10,000 population per year) at least 95 % of time, an acceptable virus concentration, Ca* can be calculated using Eqs. (2) and (5). The rotavirus model, developed by Rose and Gerba (1991), with dose-response model parameters ($\alpha = 0.232$, $\beta = 0.347$) was used. If wastewater reclamation and reuse should be as safe as the domestic water supply meeting EPA's SWTR for enteric viruses, the required virus inactivation/removal in tertiary treatment can be calculated using Eq. (8). A summary of calculations for which the reliability requirement for domestic water supply is met at 90 and 95% reliability is presented in Table 4.

Reliability of Meeting California's Wastewater Reclamation Criteria (Title 22)

In the Pomona Virus Study (CSDOLAC, 1977; Miele, *et al.*, 1977; Dryden, *et al.*, 1979), tertiary treatment processes consisting of coagulation, flocculation, sedimentation, filtration, and disinfection (designated as full-treatment in this paper) and its alternative, contact filtration, removed 5.2 logs of seeded poliovirus when the residual chlorine concentration was 10.0 mg/L. When residual chlorine was about 5.2 mg/L, the full-treatment still removed 5.2 logs, but contact filtration removed 4.7 logs. When secondary effluent was chlorinated, the inactivation/removal

Table 4 Required Log Removal of Enteric Viruses by Tertiary Treatment (Filtration and Disinfection) if One Enteric Virus Infection per 10,000 Population per Year is Met at 90 or 95 Percent Reliability

	Scenario I Golf Course Irrigation		Scenario II Crop Irrigation		Scenario III Swimming		Scenario IV Groundwater Recharge	
	Reliability, % of time							
Treatment process	90	95	90	95	90	95	90	95
OCSD: Trickling filter	3.7	3.9	1.3	1.6	5.6	5.8	0.0	0.0
OCSD: Activated sludge	2.4	2.7	0.1	0.4	4.3	4.6	0.0	0.0
Pomona: Activated sludge	2.3	3.3	0.0	0.9	4.1	5.1	0.0	0.0
MRWPCA: Activated sludge	4.2	4.5	1.8	2.1	6.1	6.4	0.0	0.0

efficiency of secondary treatment alone was 3.9 logs at a 9.0 mg/L residual chlorine dose (CSDOLAC, 1977). In all cases, the chlorine contact time was two hours (cf. Systems I, II, and III in Table 5).

If these inactivation/removal efficiencies are applied to the secondary effluents reported in Table 2, the distribution of virus concentrations in reclaimed water after full-treatment and contact filtration can be predicted. The reliability of wastewater reclamation and reuse when the specific inactivation/removal capabilities of the Pomona Virus Study tertiary treatment are simulated assuming that the exposure scenarios remained the same is reported in Table 5 . For golf course irrigation (Scenario I), food crop irrigation (Scenario II), and groundwater recharge (Scenario IV), the reliability of wastewater reclamation and reuse is such that more than 95 percent of time the criterion of one infection per 10,000 population per year is met for all effluents studied. However, for recreational impoundments (Scenario III), the reliability of wastewater reclamation and reuse is not always as high as with the use of domestic water supply systems complying with the SWTR. It is noted that maintaining a high quality secondary effluent equivalent to the OSCD AS and the Pomona AS is necessary in this application. Otherwise, full treatment or contact filtration system with high chlorine dose may be necessary. In contrast to the recreational impoundments where full body contact may take place, infectious risk from enteric viruses in the groundwater recharge application is still negligible even if secondary effluent without chlorination is used.

VARIATION IN VIRUS CONCENTRATIONS AND EXPECTED INFECTIOUS RISK

The preceding risk assessment method was used to assess reliability compliance with different exposure scenarios (Tables 4 and 5) using field data from various water and wastewater agencies in California (Table 1). The risk evaluation method, however, does not describe the extent of risk associated with wastewater reclamation and reuse when the risk actually exceeds the accepted annual risk.

Theoretically, high risk might occur even if the reliability of wastewater reclamation and reuse is extremely high because the virus concentrations in reclaimed water can take any values between zero and infinity due to the characteristics of lognormal distribution. Although the likelihood of events exceeding the established acceptable annual risk or reliability might be very small, the risk might be extremely high compared to the acceptable risk. In other words, the annual risk might exceed the established acceptable annual risk in a large extent in spite of a small number of the extraordinary events.

To assess the effects of variations in virus concentrations, an expected value (expectation) is computed using MCM to quantify how often and to what extent infectious risk from enteric viruses associated with wastewater reclamation and reuse exceeds the acceptable annual risk. Because concentrations of enteric viruses in unchlorinated secondary effluents, Cs, follows a lognormal distribution (Fig. 1 and Table 2), virus concentrations in secondary effluents are simulated using MCM and the expected values of the annual risk are computed.

The Expectation of Annual Risk

The expectation in this case means an average value of the risks in many exposure events considering their frequencies; and can be calculated by using MCM computer simulations. As previously defined in Table 2, the lognormal distribution of enteric virus concentrations in unchlorinated secondary effluents was determined with parameters μ and σ. By generating random numbers that follow a lognormal distribution, a daily virus concentration in unchlorinated secondary effluent, Cs, can be computed, which can give a single exposure infection risk caused by enteric viruses, P*(D), from Eqs. (3) and (6), and the following beta-distributed dose-response relationship (Haas, 1983a):

$$P^*(D) = 1 - (1 + D/\beta)^{-\alpha} \quad (9)$$

An annual risk, Pa, is calculated with variable daily risks when Di represents the dose ingested in the i th exposure event in the same fashion as Eq. (1).

$$Pa = 1 - \prod_{i=1}^{n} (1 - P^*(D_i)) \quad (10)$$

The expected value of Pa changes depending on the single exposure infection risk caused by enteric viruses, P*(D), and the exposure frequency, n, used in the simulation as given by Eq. (11).

$$E[Pa] = E\left[1 - \prod_{i=1}^{n} (1 - P^*(D_i))\right] = 1 - E\left[\prod_{i=1}^{n} (1 - P^*(D_i))\right] \quad (11)$$

where n = frequency of exposures in a year.

Using MCM, the expected annual risk is calculated in the following steps: (1) simulate an enteric virus concentration in reclaimed water by random number generation, (2) calculate a single exposure risk caused by the reclaimed wastewater using the dose-response curve, (3) repeat above two steps as many time as the given exposure frequency in a year, (4) calculate annual risk based on the above single exposure risk, (5) repeat the above steps in a number of different sets and take an arithmetic mean of Pa. The generated virus concentrations using a random number generator and MCM (500 trials were run for each wastewater treatment plant) are plotted in Fig. 2. As an example, the result for golf course irrigation using tertiary treatment effluent from OCSD TF is plotted in Fig. 3 in which the frequency distribution for annual infectious risk is shown.

The expectations of annual risk from wastewater reclamation and reuse in various exposure scenarios are summarized in Table 6. If the reliability of wastewater reclamation and reuse is assessed by whether the expectation of annual risk is equal to or less than 10^{-4}, 95 percent of the time as reference to the SWTR, the wastewater reuse practices are deemed as safe as using domestic water supply. The expectation of annual risk with full treatment/contact filtration and high chlorine dose (System I) are less than 10^{-4} in golf course irrigation, food crop irrigation, and groundwater recharge (Exposure Scenarios I, II, and IV) regardless of different reclaimed

Table 5 Reliability of Wastewater Reclamation and Reuse When Pomona Virus Study Results Are Applied to Various Unchlorinated Secondary Effluents

Treatment process	Secondary effluent	Reliability, %			
		Scenario I	Scenario II	Scenario III	Scenario IV
System I					
Full-treatment/	OCSD TF	100	100	76	100
contact filtration	OCSD AS	100	100	99	100
with high chlorine	Pomona AS	100	100	98	100
(5.2 Logs)	Monterey AS	99	100	61	100
System II[1]					
Direct chlorination	OCSD TF	95	100	9	100
of secondary	OCSD AS	100	100	80	100
effluent	Pomona AS	99	100	93	100
(3.9 Logs)	Monterey AS	83	100	11	100
System III					
Contact	OCSD TF	100	100	47	100
filtration with	OCSD AS	100	100	96	100
low chlorine	Pomona AS	100	100	97	100
(4.7 logs)	Monterey AS	97	100	38	100

[1] System II is an application of chlorinated secondary effluents in various wastewater reuse application where 3.9 logs of enteric viruses are inactivated/removed.

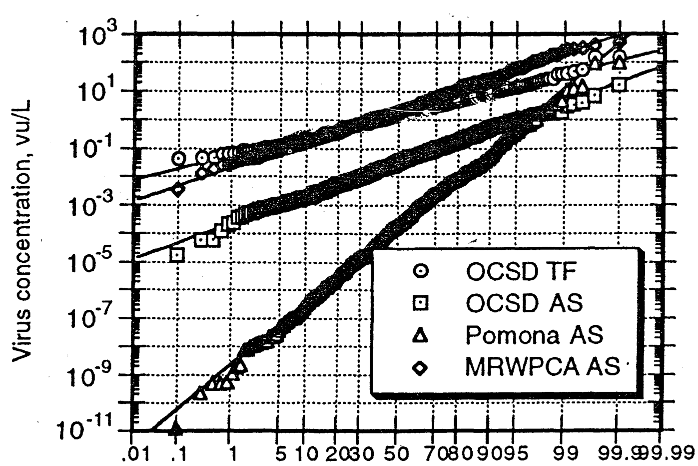

Figure 2 Generated virus concentrations using a random number generator and MCM (Based on 500 trials)

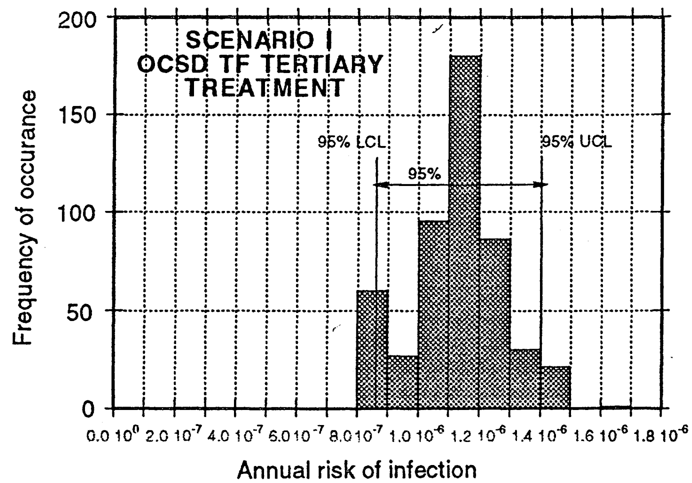

Figure 3 Frequency Distribution Diagram for Annual Infection Risk for Golf Course Irrigation Using Tertiary Treatment Effluent (Based on 500 Trials)

wastewater sources. For unrestricted recreational impoundment where swimming may take place, the expectation of annual risk slightly exceeding the reliability requirement imposed in this paper may exist, as shown in Table 6. If unchlorinated secondary effluent without any further treatment is used for variety of wastewater reuse applications, the expected annual risk is, as might be expected, much higher than acceptable reliability except for groundwater recharge.

DISCUSSION

From the results of the analyses presented in Tables 5 and 6, the reliability or relative safety of wastewater reclamation and reuse can be assessed from a combination of scoring systems derived from the reliability measures and the expectation estimates of annual infection risk from enteric viruses. Such a scoring system is shown in Table 7. If the acceptable annual risk of infection from enteric viruses in reclaimed wastewater is one infection per 10,000 population (10^{-4}), the reliability of four different exposure scenarios can be evaluated by using a simple scoring system consisting of very good, O; good, Ø; unsatisfactory, Δ; and risky, X, corresponding to reliability values of more than 95, 90, 85, and less than 85 percent, respectively. For the annual expectation estimates simulated by MCM, the scoring system consisting of expectation estimates less than 10^{-5} infection risk denoted with O; 10^{-4} denoted with Ø; up to 5×10^{-4} denoted with Δ; and more than 10^{-4} denoted with X.

When the full treatment effluent from OCSD TF and the chlorinated secondary effluent from Pomona AS are used for recreational impoundment (Scenario III), assessments based on the reliability and the expectation estimates resulted in different conclusions. For unrestricted recreational impoundments (Scenario III) using System I effluents, evaluations for the reliability based score for the OCSD TF effluent and the MRWPCA AS effluent, and evaluations for the expectation based score for the MRWPCA AS effluent show unattainability of the acceptable risk criterion (Table 7).

In comparing the reliability of wastewater reclamation and reuse, reference is made in this paper to the EPA's SWTR. Although there was no clear definition of reliability requirement in the SWTR for domestic water supply regarding the inactivation/removal of *Giardia* and enteric viruses, the turbidity requirement in finished water is stated to be below the maximum

Table 6 Expectations of Annual Infection Risk Simulated by the Monte Carlo Method (n=500 trials)

Tertiary treatment		Treatment system: OCSD TF	OCSD AS	Pomona AS	MRWPCA AS
System I					
Full Treatment	Scenario I	1.13E-06	7.77E-08	2.86E-07	4.34E-06
(5.2 log inactivation/	Scenario II	5.03E-09	3.47E-10	1.27E-09	1.94E-08
removal)	Scenario III	8.67E-05	5.95E-06	2.20E-05	3.32E-04
	Scenario IV	1.07E-56	7.47E-58	2.18E-57	4.18E-56
		8.32E-10[1]	5.81E-11[1]	1.69E-10[1]	3.25E-09[1]
System II					
Direct chlorination	Scenario I	2.83E-05	1.95E-06	7.19E-06	1.09E-04
of secondary	Scenario II	1.26E-07	8.71E-09	3.20E-08	4.86E-07
effluent (3.9 log	Scenario III	2.17E-03	1.49E-04	5.50E-04	8.24E-03
inactivation/removal)	Scenario IV	2.69E-55	1.88E-56	5.46E-56	1.05E-54
		2.09E-08[1]	1.46E-09[1]	4.25E-09[1]	8.17E-08[1]
System III					
Unchlorinated	Scenario I	1.60E-01	1.22E-02	3.82E-02	4.39E-01
secondary effluent	Scenario II	7.96E-04	5.50E-05	2.02E-04	3.06E-03
(0 log inactivation/	Scenario III	9.96E-01	4.61E-01	3.20E-01	1.00E+00
removal)	Scenario IV	1.70E-51	1.18E-52	6.82E-52	8.56E-51
		1.32E-04[1]	9.21E-06[1]	2.68E-05[1]	5.15E-04[1]

[1] Virus inactivation/removal coefficient of 0.1/d is assumed in this case, instead of 0.69/d.

concentration at least 95 percent of time. Thus, the reliability criterion of meeting the less than 10^{-4} annual infection risk meeting at least 95 percent of time was used in this paper to assess the safety of reclaimed water application in a given exposure scenario. It may be argued, however, that the reliability criterion used in this paper, that is, EPA's Surface Water Treatment Rule, is too stringent for wastewater reclamation and reuse. Regli, *et al.* (1988), for example, reported that the annual risk of infection from swimming in natural waters ranged from 8×10^{-4} to 1.5×10^{-2}.

SUMMARY AND CONCLUSIONS

Based on the study reported in this paper, the following summary and conclusions are provided.

1. Methods of evaluating the reliability of wastewater reclamation and reuse has been investigated, considering the variability of virus concentrations to meet a given annual infection risk, and the comparative assessment of the safety of different wastewater treatment systems with respect to domestic water supply systems. Two concepts related to the safety of wastewater reclamation and reuse are presented. The first is *reliability* defined as the probability that an infectious risk from enteric viruses in reclaimed water does not exceed an acceptable risk. The second is based on the *expectation* of an annual risk in which the exposure to enteric viruses may be estimated stochastically by numerical simulation. To assess potential risks associated with the use of reclaimed wastewater in various reuse

Table 7 Scoring System for the Safety of Reclaimed Water Uses When Full Treatment or Contact Filtration is Used (System I), and Chlorinated Secondary Effluent is Used (System II)[1]

		Scenario I Golf Course Irrigation		Scenario II Crop irrigation		Scenario III Recreational impoundment		Scenario IV Groundwater Recharge	
		A, reliability; B expectation							
Treatment system	Secondary effluent	A	B	A	B	A	B	A	B
System I									
Full Treatment or contact filtration with high chlorine (5.2 Logs)	OCSD: Trickling filter	O	O	O	O	X	Ø	O	O
	OCSD Activated sludge	O	O	O	O	O	O	O	O
	Pomona: Activated sludge	O	O	O	O	O	Ø	O	O
	MRWPCA: Activated sludge	O	O	O	O	X	Δ	O	O
System II									
Chlorinated secondary effluent with high chlorine (3.9 Logs)	OCSD: Trickling Filter	O	Ø	O	O	X	X	O	O
	OCSD: Activated sludge	O	O	O	O	X	Δ	O	O
	Pomona: Activated sludge	O	O	O	O	O	Δ	O	O
	MRWPCA: Activated sludge	X	Δ	O	O	X	X	O	O

1. Assessment based on (A) the reliability equal to or less than 10^{-4} annual infection risk at 95 percent of time, and (B) the expectation estimates of not exceeding the 10^{-4} annual infection risk criterion using the Monte Carlo methods.

applications, four exposure scenarios were tested: golf course irrigation, food crop irrigation, recreational impoundments, and groundwater recharge.

2. Past monitoring data on the enteric virus concentrations in unchlorinated secondary effluents in California were analyzed in this paper. Enteric viruses were detected in 64 percent of the 377 samples evaluated. The enteric virus concentrations in unchlorinated secondary effluents were found to vary over a wide range. For example, the geometric mean virus concentrations ranged over four orders of magnitude (10^{-4} to 10^{0} vu/L). Thus, characterizing the variability of enteric virus concentrations is extremely important in the virus risk assessment.

3. To evaluate the safety of wastewater reclamation and reuse, reference was made to the U.S. Environmental Protection Agency's Surface Water Treatment Rule. The safety of wastewater reclamation and reuse was assessed by reliability, that is, the meeting the 10^{-4} infection risk criterion at least 95 percent of time, as well as the expectation estimates using Monte Carlo methods. For golf course and food crop irrigation, and groundwater recharge, the reliability of wastewater reclamation and reuse is such that more than 95% of the time the criterion is met for all of the effluents examined. However, for recreational impoundments, the reliability of wastewater reclamation and reuse is not always as high as the use of domestic water supply specified in the EPA Surface Water Treatment Rule.

4. This paper should be viewed as a first step in the application of quantitative microbiological risk assessment as applied to wastewater reclamation and reuse. The methodology should be refined using a larger enteric virus database developed using standardized field and laboratory protocols.

ACKNOWLEDGMENTS

Special credit goes to Japan International Cooperation Agency and the Japan Ministry of Construction for the opportunity given to the senior author's study abroad at the University of California at Davis. Mr. Richard A. Mills, Dr. Richard H. Sakaji, and Dr. Rafael Mujeriego provided valuable advice and suggestions for this paper.

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FACT SHEETS

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Reclaimed Water

- "Reclaimed water" refers to recycled wastewater treated to improve its quality. Reclaimed water can serve in many capacities where it is unnecessary to use high- quality potable (or drinkable) water. Nonpotable uses include: irrigation, wetland restoration, industrial washing and cooling, fire protection, geothermic energy production and car washing.
- Using reclaimed water is known as "water reuse".
- AWWA supports responsible water reuse for nonpotable uses.
- Water reuse for nonpotable purposes has been a widely accepted practice around the world for decades.
- Water reuse eases pressure on water supplies and conserves potable water reserves.
- The use of reclaimed water for irrigation at a single California golf course has saved 1.2 billion gallons of potable water in 6 years.
- Increased population and development have led some communities to supplement their potable water resources with appropriately treated reclaimed water.
- Supplementing potable water supplies with reclaimed water is known as "potable water reuse".
- There are two kinds of potable water reuse, direct and indirect.
- Direct potable water reuse refers to the merging of potable and reclaimed water supplies in the distribution system after both supplies have left their respective treatment plants. Direct potable water reuse is not currently used anywhere in the U.S. and no plans currently exist for its implementation.
- Indirect potable water reuse refers to the insertion of reclaimed water resources into existing natural resources, like rivers, lakes, streams or aquifers. Indirect reuse projects have been initiated in Los Angeles, California, Fountain Valley, California, Centreville, Virginia, and El Paso, Texas.
- Indirect reuse projects are being developed in San Diego, California and Tampa, Florida.

- AWWA does not oppose indirect reuse in cases where reclaimed water is used as a supplement to existing natural water resources and after appropriate treatment occurs.

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EPA United States Environmental Protection Agency

Water Programs

Region 9

Water Recycling and Reuse: The Environmental Benefits

The Experience at Koele Golf Course, on the Island of Lanai, has used recycled water for irrigation since 1994. The pond shown is recycled water, as is all the water used to irrigate this world-class golf course in the state of Hawaii.

"Water recycling is a critical element for managing our water resources. Through water conservation and water recycling, we can meet environmental needs and still have sustainable development and a viable economy."

—*Felicia Marcus, Regional Administrator*

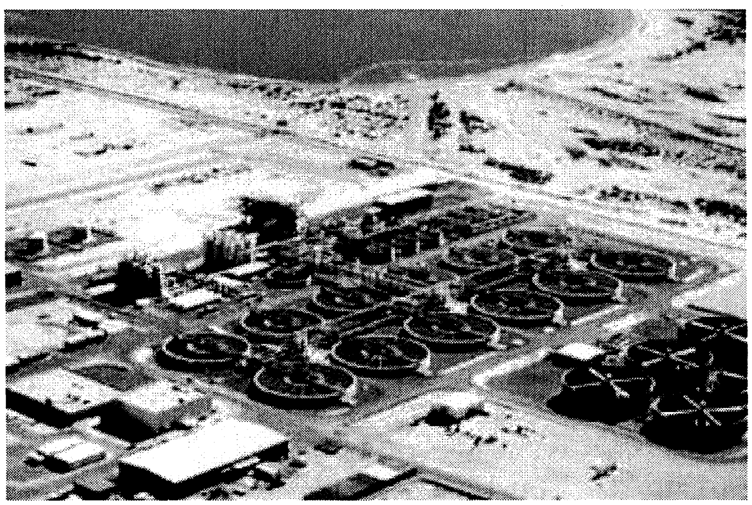
Water Division Region IX - Publication Number: EPA 909-F-98-001

What Is Water Recycling?

Recycle: verb 1.a. To recover useful materials from garbage or waste, b. To extract and reuse.

While recycling is a term generally applied to aluminum cans, glass bottles, and newspapers, water can be recycled as well. Water recycling is reusing treated wastewater for beneficial purposes such as agricultural and landscape irrigation, industrial processes, toilet flushing, and replenishing a ground water basin (referred to as ground water recharge). Water is sometimes recycled and reused onsite; for example, when an industrial facility recycles water used for cooling processes. A common type of recycled water is water that has been reclaimed from municipal wastewater, or sewage. The term water recycling is generally used synonymously with water reclamation and water reuse.

Through the natural water cycle, the earth has recycled and reused water for millions of years. Water recycling, though, generally refers to projects that use technology to speed up these natural processes. Water recycling is often characterized as "unplanned" or "planned." A common example of unplanned water recycling occurs when cities draw their water supplies from rivers, such as the Colorado River and the Mississippi River, that receive wastewater discharges upstream from those cities. Water from these rivers has been reused, treated, and piped into the water supply a number of times before the last downstream user withdraws the water. Planned projects are those that are developed with the goal of beneficially reusing a recycled water supply.



The Palo Verde Nuclear Generating Station, located near Phoenix Arizona, uses recycled water for cooling purposes.

How Can Recycled Water Benefit Us?

Recycled water can satisfy most water demands, as long as it is adequately treated to ensure water quality appropriate for the use. Figure 1 shows types of treatment processes and suggested uses at each level of treatment. In uses where there is a greater chance of human exposure to the water, more treatment is required. As for any water source that is not properly treated, health problems could arise from drinking or being exposed to recycled water if it contains disease-causing organisms or other contaminants.

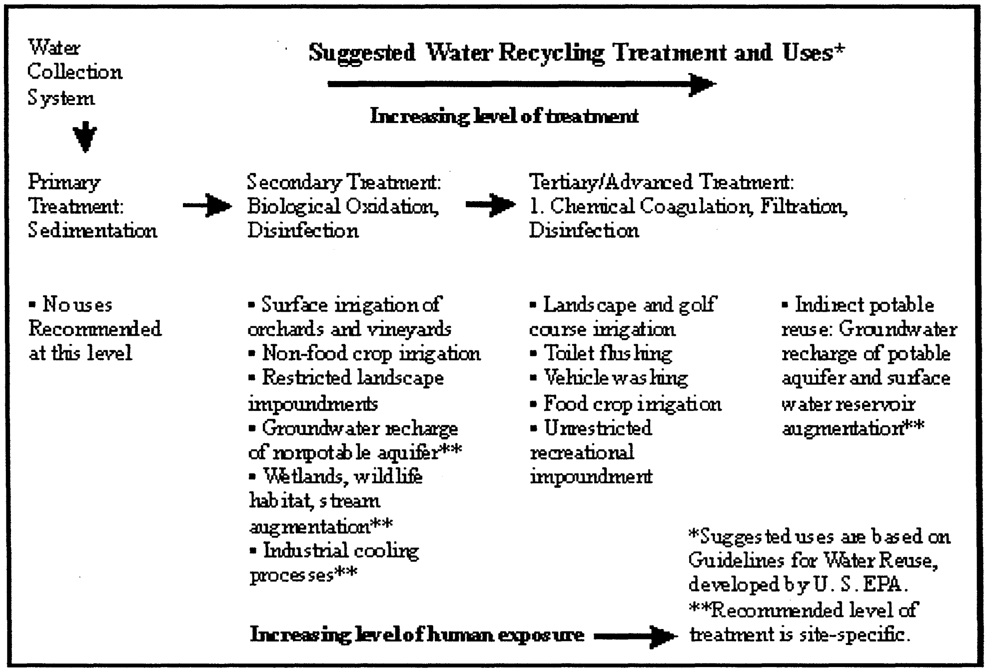


Figure 1: While there are some exceptions, wastewater in the United States is generally required to be treated to the secondary level. Some uses are recommended at this level, but many common uses of recycled water such as landscape irrigation generally require further treatment.

The US Environmental Protection Agency regulates many aspects of wastewater treatment and drinking water quality, and the majority of states in the US have established criteria or guidelines for the beneficial use of recycled water. In addition, in 1992, EPA developed a technical document entitled "Guidelines for Water Reuse," which contains such information as a summary of state requirements, and guidelines for the treatment and uses of recycled water. State and Federal regulatory oversight has successfully provided a framework to ensure the safety of the many water recycling projects that have been developed in the United States.

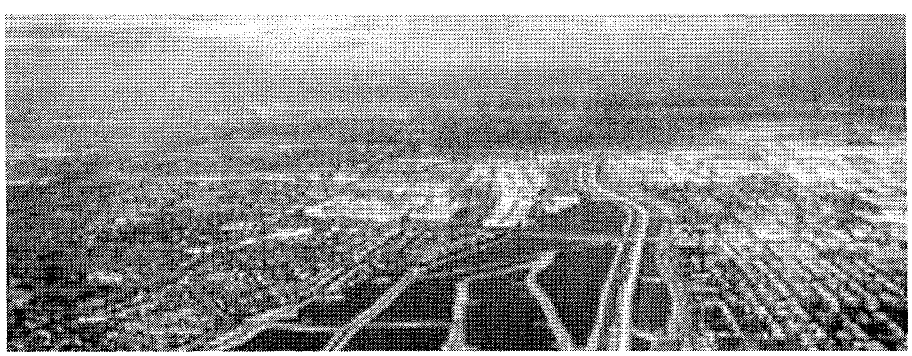
The Irvine Ranch Water District provides recycled water for toilet flushing in high rise buildings in Irvine, California. For new buildings over seven stories, the additional cost of providing a dual system added only 9% to the cost of plumbing.

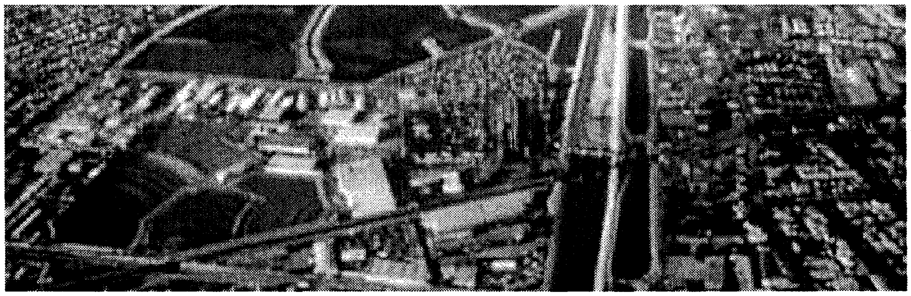
Recycled water is most commonly used for nonpotable (not for drinking) purposes, such as agriculture, landscape, public parks, and golf course irrigation. Other nonpotable applications include cooling water for power plants and oil refineries, industrial process water for such facilities as paper mills and carpet dyers, toilet flushing, dust control, construction activities, concrete mixing, and artificial lakes.

Although most water recycling projects have been developed to meet nonpotable water demands, a number of projects use recycled water indirectly[1] for potable purposes. These projects include recharging ground water aquifers and augmenting surface water reservoirs with recycled water. In ground water recharge projects, recycled water can be spread or injected into ground water aquifers to augment ground water supplies, and to prevent salt water intrusion in coastal areas. For example, since 1976, the Water Factory 21 Direct Injection Project, located in Orange County, California, has been injecting highly treated recycled water into the aquifer to prevent salt water intrusion, while augmenting the potable ground water supply.

[1]*Indirect potable reuse refers to projects that discharge recycled water to a water body before reuse. Direct potable reuse is the use of recycled water for drinking purposes directly after treatment. While direct potable reuse has been safely used in Namibia (Africa), it is not a generally accepted practice in the US.*

While numerous successful ground water recharge projects have been operated for many years, planned augmentation of surface water reservoirs has been less common. However, there are some existing projects and others in the planning stages. For example, since 1978, the upper Occoquan Sewage Authority has been discharging recycled water into a stream above Occoquan Reservoir, a potable water supply source for Fairfax County, Virginia. In San Diego, California, the Water Repurification Project is currently being planned to augment a drinking water reservoir with 20,000 acre-feet per year of advanced treated recycled water.





For over 35 years, in the Montebello Forebay Ground Water Recharge Project, recycled water has been applied to the Rio Hondo spreading grounds to recharge a potable ground water aquifer in south-central Los Angeles County.

What are the Environmental Benefits of Water Recycling?

In addition to providing a dependable, locally-controlled water supply, water recycling provides tremendous environmental benefits. By providing an additional source of water, water recycling can help us find ways to decrease the diversion of water from sensitive ecosystems. Other benefits include decreasing wastewater discharges and reducing and preventing pollution. Recycled water can also be used to create or enhance wetlands and riparian habitats.

Water recycling can decrease diversion of freshwater from sensitive ecosystems.

Plants, wildlife, and fish depend on sufficient water flows to their habitats to live and reproduce. The lack of adequate flow, as a result of diversion for agricultural, urban, and industrial purposes, can cause deterioration of water quality and ecosystem health. Water users can supplement their demands by using recycled water, which can free considerable amounts of water for the environment and increase flows to vital ecosystems.

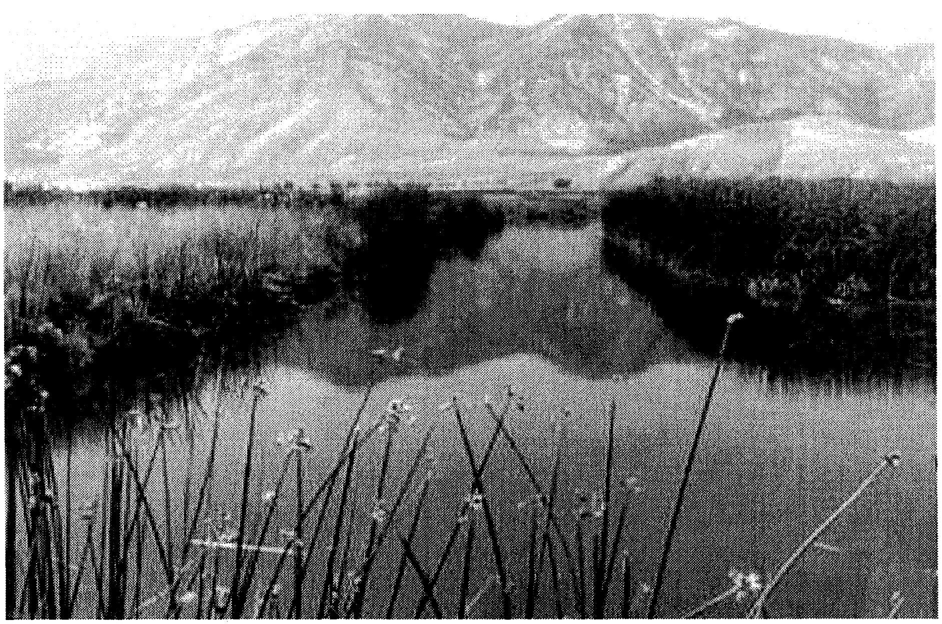
In California, Mono Lake's water quality and natural resources were progressively declining from lack of stream flow. In 1994, the Los Angeles Department of Water and Power was required to stop diverting one-fifth of the water it historically exported from the basin. The development of water recycling projects in Los Angeles has provided a way to partially offset the loss of Mono Basin water, and to allow the restoration of Mono Lake to move ahead.

Water recycling decreases discharge to sensitive water bodies.

In some cases, the impetus for water recycling comes not from a water supply need, but from a need to eliminate or decrease wastewater discharge to the ocean, an estuary, or a stream. For example, high volumes of treated wastewater discharged from the San Jose/Santa Clara Water Pollution Control Plant into the south San Francisco Bay threatened the area's natural salt water marsh. In response, a $140 million recycling project was completed in 1997. The South Bay Water Recycling Program has the capacity to provide 21 million gallons per day of recycled water for use in irrigation and industry. By avoiding the conversion of salt water marsh to brackish marsh, the habitat for two endangered species can be protected.

Recycled water may be used to create or enhance wetlands and riparian (stream) habitats.

Wetlands provide many benefits, which include wildlife and wildfowl habitat, water quality improvement, flood diminishment, and fisheries breeding grounds. For streams that have been impaired or dried from water diversion, water flow can be augmented with recycled water to sustain and improve the aquatic and wildlife habitat.



Incline Village, Nevada, uses a constructed wetland to dispose of wastewater effluent, expand the existing wetland habitat for wildlife, and provide an educational experience for visitors.

Water recycling can reduce and prevent pollution.

When pollutant discharges to oceans, rivers, and other water bodies are curtailed, the pollutant loadings to these bodies are decreased. Moreover, in some cases, substances that can be pollutants when discharged to a body of water can be beneficially reused for irrigation. For example, recycled water may contain higher levels of nutrients, such as nitrogen, than potable water. Application of recycled water for agricultural and landscape irrigation can provide an additional source of nutrients and lessen the need to apply synthetic fertilizers.

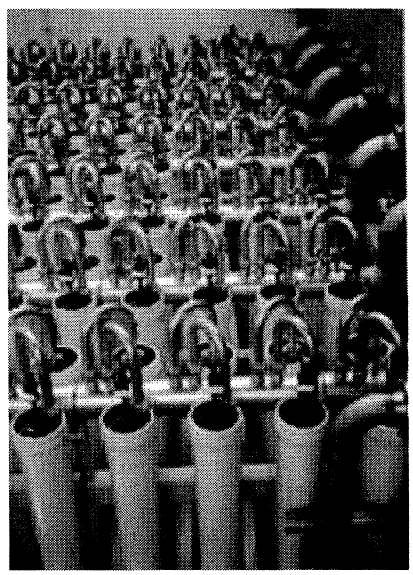
Recycled water has been used for a number of years to irrigate vineyards at California wineries, and this use is growing. Recently, Gallo Wineries and the City of Santa Rosa completed facilities for the irrigation of 350 acres of vineyards with recycled water from the Santa Rosa Subregional Water Reclamation System.

What Is The Future Of Water Recycling?

Water recycling has proven to be effective and successful in creating a new and reliable water supply, while not compromising public health. Nonpotable reuse is a widely accepted practice that will continue to grow. However, in many parts of the United States, the uses of recycled water are expanding in order to accommodate the needs of the environment and growing water supply demands. Advances in wastewater treatment technology and health studies of indirect potable reuse have led many to predict that planned indirect potable reuse will soon become more common.

While water recycling is a sustainable approach and can be cost-effective in the long term, the treatment of wastewater for reuse and the installation of distribution systems can be initially expensive compared to such water supply alternatives as imported water or ground water. Institutional barriers, as well as varying agency priorities, can make it difficult to implement water recycling projects. Finally, early in the planning process, agencies must implement public outreach to address any concerns and to keep the public involved in the planning process.

As water demands and environmental needs grow, water recycling will play a greater role in our overall water supply. By working together to overcome obstacles, water recycling, along with water conservation, can help us to conserve and sustainably manage our vital water resources.



At West Basin Wastewater Treatment Plant in California, reverse osmosis, an advanced treatment process, is used to physically and electrostatically remove impurities from the wastewater.

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EPA Material:

Guidelines for Water Reuse. US EPA Office of Technology Transfer and Regulatory Support. EPA/625/R-92/004. September 1992.

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Layperson's Guide to Water Recycling and Reuse, published in 1992 by the Water Education Foundation, Sacramento, California.

Video, entitled *Water from Water: Recycling,* produced in 1995 by National Water Research Institute, Fountain Valley, California.

Video, entitled *Water in an Endless Loop,* produced in 1997 by WateReuse Foundation, Sacramento, California.

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FINAL

September 1999

USE OF RECYCLED WATER TO AUGMENT POTABLE SUPPLIES: AN ECONOMIC PERSPECTIVE

INDIRECT POTABLE REUSE - THE INTRODUCTION OF RECYCLED WATER INTO A COMMUNITY'S DRINKING WATER SUPPLY – CAN BE A COST-EFFECTIVE MEANS OF SUPPLEMENTING A COMMUNITY'S WATER SUPPLY

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FINAL DRAFT

September 1999

USE OF RECYCLED WATER TO AUGMENT POTABLE

SUPPLIES: AN ECONOMIC PERSPECTIVE

INDIRECT POTABLE REUSE - THE INTRODUCTION OF RECYCLED WATER INTO A COMMUNITY'S DRINKING WATER SUPPLY – CAN BE A COST-EFFECTIVE MEANS OF SUPPLEMENTING A COMMUNITY'S WATER SUPPLY

INTRODUCTION

Maintaining a reliable water supply is one of the most important issues facing California. Many regions of California rely on diverting water from rivers and streams located in other parts of the state or from the Colorado River, a practice that lacks reliability due to droughts and is becoming less acceptable due to our growing awareness of the environmental impacts of these practices.

Recognizing water's importance to the state's economic prosperity and the quality of life enjoyed by its citizens, the California Water Plan focuses on developing a mix of complementary water resources. The state legislature enacted the Water Recycling Act of 1991, acknowledging that recycled water is an integral part of the state's water supply mix and that water recycling should be adopted wherever appropriate. According to the most recent edition of the California Water Plan (Bulletin 160-98), recycled water use in 1995 was 485,000 acre-feet, less than half of the State's goal of 1 million acre-feet per year by 2010.

The majority of municipal wastewater produced statewide continues to be disposed of to the ocean or other saline water body. This untapped resources represents one of the largest potential sources for "new water" in California. Communities throughout the state are planning new or expanded water recycling programs.

Definitions:

Recycled Water – Municipal wastewater that has been subjected to an array of biological, physical, and chemical treatments as necessary depending on the end use.

Indirect Potable Reuse – A particular application where the recycled water (generally having received a substantial degree of treatment) is blended into a community's water supply (via groundwater recharge or surface water augmentation) prior to final treatment and distribution to the customer in the existing water distribution system.

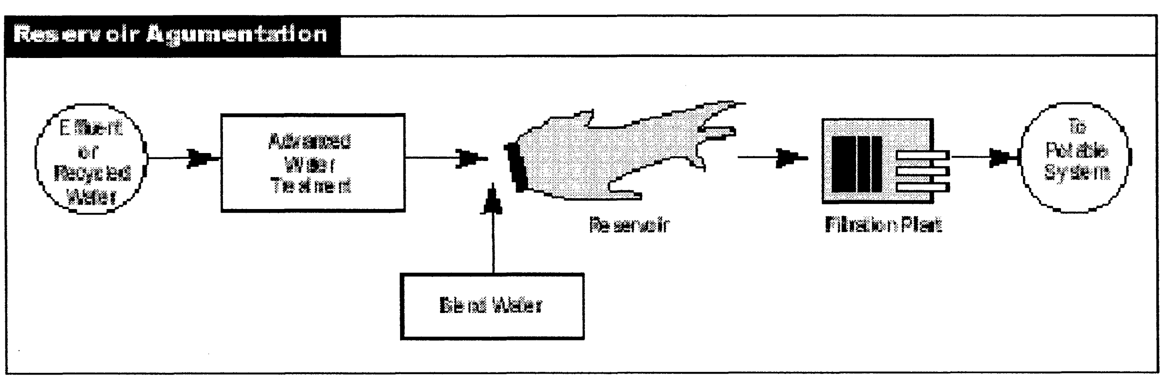
Recycled water is used for a myriad of non potable uses including industrial process, cleaning and cooling water, commercial toilet flushing, aesthetic water features, dust control and fire suppression. Agriculture and landscape irrigation are the predominant non potable uses of recycled water. Urban water recycling projects that rely on landscape irrigation and other non-potable uses often are limited due to the seasonal nature of the demand.

Alternatively, indirect potable reuse – which involves, blending recycled water with other water supplies (groundwater or reservoir) that feed a community's potable water supply system - enables a community to improve recycled water production efficiency and maximize year-around benefits. This use of existing seasonal storage water supply infrastructure enables a community to avoid construction of a separate water storage and delivery system; otherwise needed to provide a customer base and economic viability to a non-potable recycled water project.

Indirect potable reuse projects are in operation in Los Angeles and Orange Counties. And other projects are being considered in the Bay Area and Southern California.

INDIRECT POTABLE REUSE MECHANISMS

Recycled water quality and treatment requirements vary depending on the mechanism used to introduce recycled water into the potable system. Tertiary treated and disinfected (conventional) recycled water is a safe and reliable source for irrigation and industrial applications and some applications that may result in body contact (swimming), but may contain some contaminants that pose a risk to human health if ingested. Conventional tertiary treated recycled water may be used to recharge groundwater supplies if applied via surface spreading and treatment is provided as the water percolates through the soil/aquifer system. To "inject" the recycled water directly into the groundwater basin, or to introduce it directly into a water supply reservoir (upstream of a water treatment plant), additional treatment beyond tertiary is required.



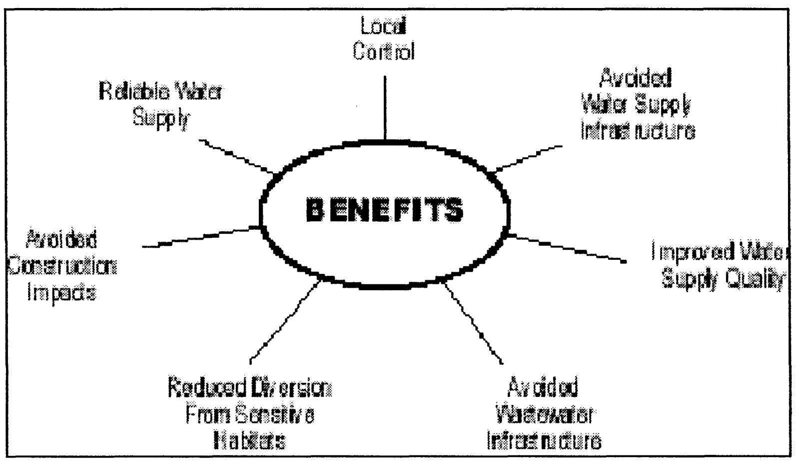
BENEFITS OF INDIRECT POTABLE REUSE

Indirect potable reuse projects provide an array of benefits, some consistent with conventional nonpotable applications and others unique to indirect potable applications.

- Common Recycled Water Benefits

- Provides a reliable local water supply, which serves a ledge against future droughts and potential uncertainty associated with traditional water supplies.
- Enables some warm suppliers to reduce imports during average and above-average years, and "bank" this imported water for use during dry years.
- Provides economic benefits by retaining businesses, and by attracting new businesses with a reliable water supply, (lower cost?).
- May improve environmental conditions by reducing the need to divert additional supply from sensitive watersheds.
- Reduces the quantity of treated wastewater discharged into the environment.
- May reduce the cost of wastewater treatment and disposal.
- Recycled water projects that include a demineralization step provide a significant enhancement to water quality.

- The yield of indirect potable reuse optimizes a recycled water project through the use of the existing water supply infrastructure, including seasonal storage and distribution facilities.

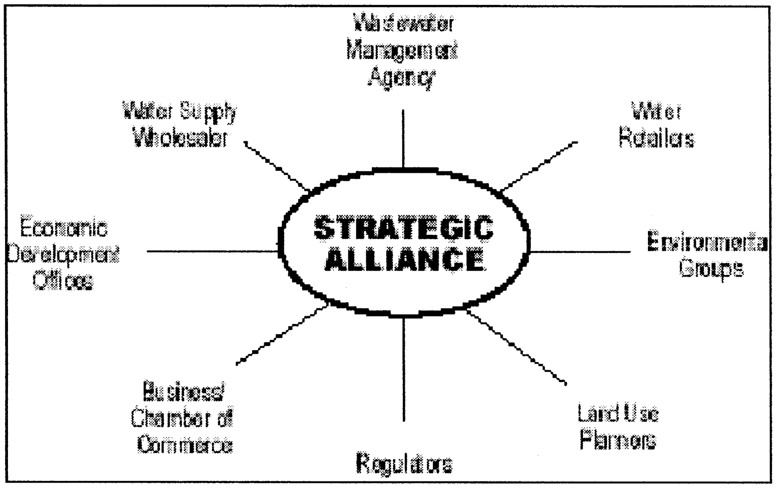


REALIZATION OF ECONOMIC SUCCESS

The economic value of water recycling projects is a function of the potential project benefits and their associated value. A recycled water project is analyzed by comparing the cost of producing and conveying the recycled water to the cost of other new water supply options. Important considerations include reduced or delayed infrastructure costs, improved reliability, savings in treatment costs and environmental benefits. When viewed from this perspective, recycled water projects often are found to provide cost effective new water supplies.

To accurately depict the cost-effectiveness of an indirect potable water recycling project, all potential benefits of the project should be considered. The beneficial effects of a indirect potable reuse project often extend beyond the sponsoring agency, providing regional benefits and in many cases the benefits extend state-wide and beyond. A broad spectrum of stakeholders is needed to provide valuable, consensus-driven input to accurately evaluate indirect potable reuse projects. By venturing outside the sponsoring agency and focusing on institutional relationships, regional and statewide benefits are more likely to be realized. An alliance between the water supply agencies, the wastewater agency, economic development offices, chambers of commerce, environmental interests, state and federal interests such as the CALFED Bay Delta Program, and other stakeholders should be created early in the development of a indirect potable reuse project so that all potential benefits can be considered.

In certain settings, indirect potable reuse projects provide a mechanism for large-scale beneficial use of recycled water with relatively modest additional infrastructure requirements. With a broad spectrum of stakeholders identifying the full array of economic and environmental benefits, indirect potable reuse can provide a cost-effective path for a community to follow in pursuing its recycling ethic.



Three indirect potable reuse projects have been proposed that would exemplify this critical mix of size and breadth of benefits: the East Valley Water Recycling Project, the Orange County Groundwater Replenishment System, and the San Diego Water Repurification Project. These three projects represent varying stages of planning and implementation. The East Valley project is nearing completion of construction. The Orange County project is under design, and the San Diego Repurification project has proceeded to 30% design, but is currently on hold due to unresolved policy and public perception issues.

I. East Valley Water Recycling Project

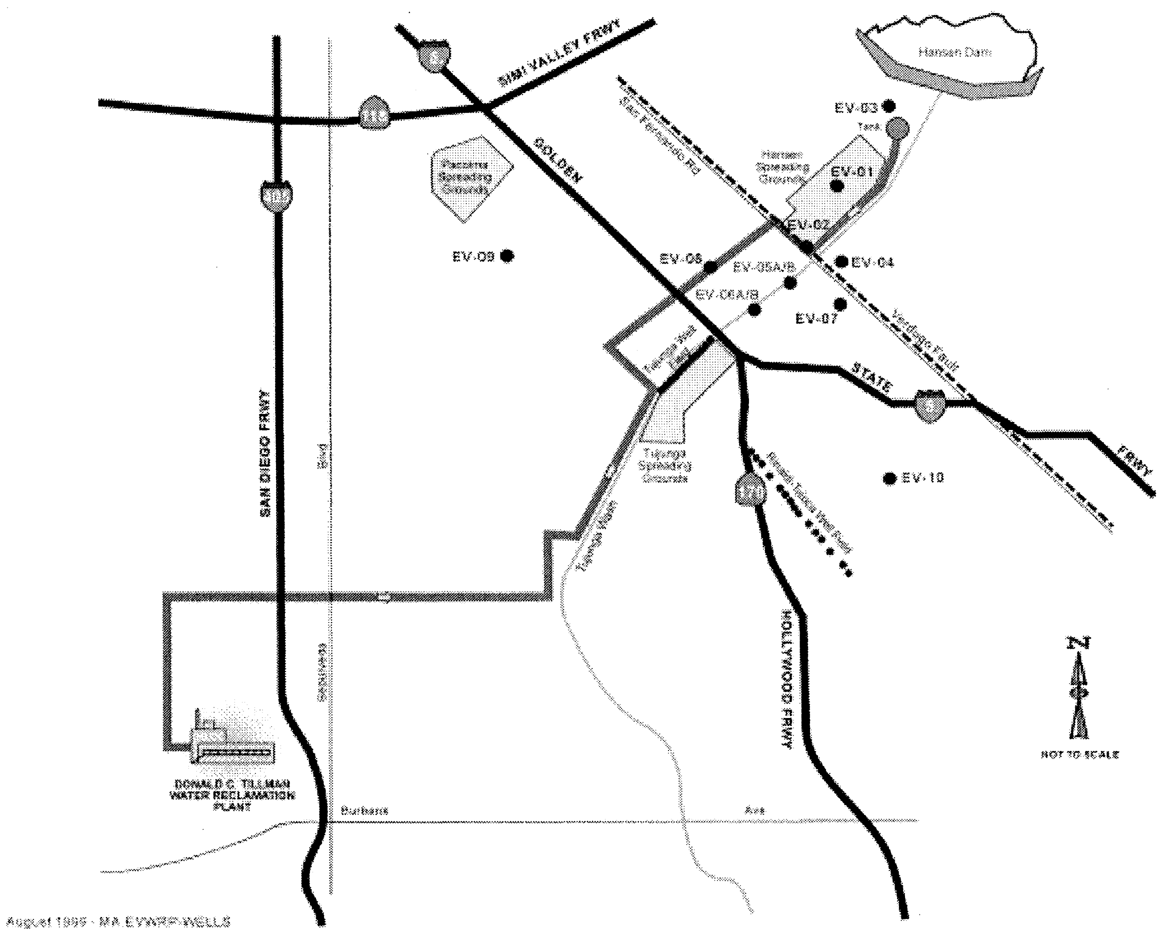
In June 1990, the Los Angeles City Council adopted a goal of reusing about 40% of the City's wastewater by 2010. In response to this goal, the City's Department of Water and Power (DWP) began development of the East Valley Water Recycling Project (EVWRP), which is the cornerstone water recycling project for the City. The EVWRP will ultimately provide up to 35,000 acre feet of recycled water per year for groundwater recharge at the Hansen and Pacoima Spreading Grounds in the San Fernando Valley, and for industrial and irrigation uses along the pipeline route. The EVWRP has received strong local, state, and national political support due to its regional and state importance.

Once completed, the EVWRP will lessen the City's demand on imported water supplies, and will replace a portion of the Mono Basin water no longer available for export. The EVWRP will also reduce the likelihood of severe water conservation measures in the future on residents and businesses in the event of a drought, as the overall reliability of the City's water supply will be improved.

Project Description

Phase IA of the EVWRP includes approximately ten miles of 54-inch diameter pipeline and a pumping station to deliver tertiary treated recycled water from the Donald C. Tillman Water Reclamation Plant to the Hansen Spreading Grounds. Phase IA of the EVWRP also includes an extensive monitoring well network designed to track the recycled water as it travels through the San Fernando Groundwater Basin from the spreading grounds to domestic production wells. Phase IA of the EVWRP will initially deliver up to 10,000 acre feet per year to the Hansen Spreading Grounds. Phase IB of the EVWRP will include construction of additional pipeline to deliver recycled water to the Pacoima Spreading Grounds. Phase II will include construction of additional facilities such as a tank and a booster pump station needed to deliver recycled water to irrigation and industrial customers.

FIGURE 1: EAST VALLEY WATER RECYCLING PROJECT



DWP is the lead agency for the EVWRP. The City's Bureau of Sanitation (Sanitation) and Los Angeles County Department of Public Works (Los Angeles County) have participated in the development of the EVWRP and are identified as responsible parties in the permit for operation of the project. Sanitation owns and operates the Donald C. Tillman Water Reclamation Plant which is the source of the recycled water for the EVWRP. Los Angeles County owns and operates the Hansen and Pacoima Spreading Grounds and will spread recycled water delivered by the EVWRP.

DWP staff worked closely with staff from the Regional Water Quality Control Board (Regional Board) and the State Department of Health Services (Health Department) to evaluate the EVWRP and develop appropriate operational and monitoring criteria. After review of the Groundwater Recharge Engineering Report by the Regional Board and the Health Department, Water Reclamation Requirements (permit) were issued on September 18, 1995. This permit allows for groundwater recharge of up to 10,000 acre feet per year at the Hansen Spreading Grounds for a three-year demonstration period. Groundwater modeling results, as well as the geologic and hydrogeologic features in the groundwater basin, indicate that this project is very conservative when evaluated using the proposed regulations for groundwater recharge upon which the approval for the EVWRP was based. An extensive groundwater monitoring and modeling program will track actual changes in water quality and recycled water movement within the groundwater basin, which will provide data for determining appropriate future project operations. The monitoring well system will also provide additional safeguards to the water supply by serving as an early warning system.

Economics

Phase IA of the EVWRP, which is scheduled to begin operation in 1999, has cost approximately $52-million. Up to 25% of this cost is being funded by the federal government through the Federal Reclamation Projects Authorization and Adjustment Act of 1992. Up to 50% of the total cost is being funded by the State of California through the Environmental Water Act of 1989. The remaining 25% of the total cost is being funded by ratepayers through special conservation and reclamation rate adjustments.

ESTIMATED CAPITAL AND OPERATION AND MAINTENANCE COSTS FOR PHAS IA

Without federal and state reimbursement

Capital Costs	$52,000,000
Amortized annual cost (6% interest for 30 years)	$3,777,743
Operation & Maintenance cost per acre-foot (AF)	$100
Annual delivery	10,000 AF
Cost of delivered water	$478 per acre-foot

With 25% federal and 50% state reimbursement

Capital Costs	$52,000,000
State Reimbursement (50%)	$26,000,000
Federal Reimbursement (25%)	$13,000,000
Net DWP capital expenditure	$13,000,000

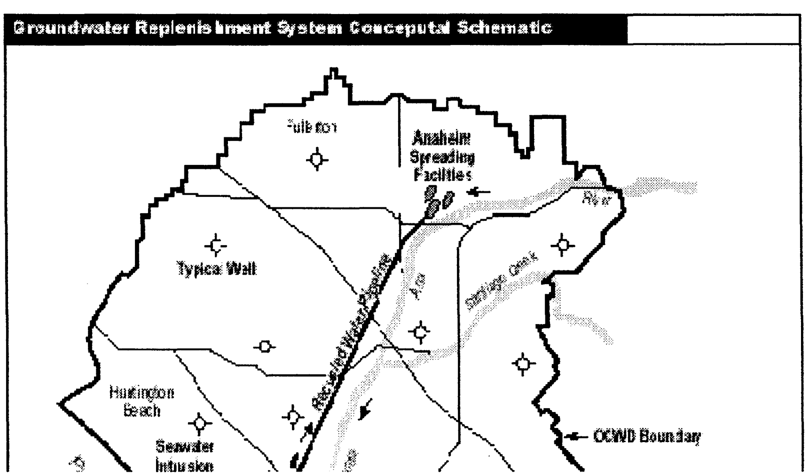
Amortized net capital expenditure (6% interest for 30 years)	$944,436
Operation & Maintenance cost per acre-foot (AF)	$100
Annual delivery	10,000 AF
Cost of delivered water	$194 per acre-foot

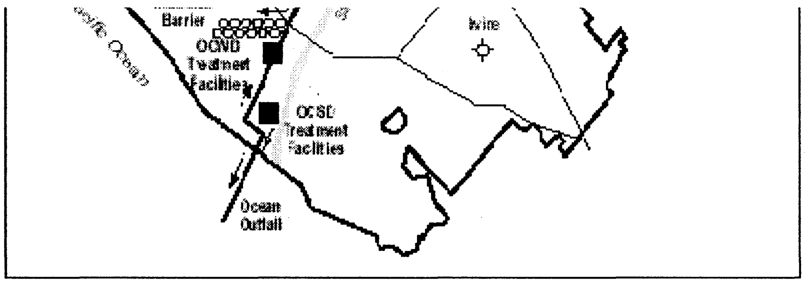
Phase IA of the EVWRP will provide water at an estimated cost of approximately $478 per acre-foot, with a net cost to DWP of approximately $194 per acre-foot when state and federal funding is considered. Even if state or federal funding had not been available, the EVWRP would still provide a new reliable source of water at a cost comparable to other water supplies, and significantly less expensive than other new supply options. According to the City Of Los Angeles Department of Water and Power Urban Water Management Plan Fiscal Year 1997-1998 Annual Update, seawater might be desalinated using new technology which has produced desalted ocean water at a cost of about $800 per acre-foot in pilot tests, or approximately $2000 using current technology. Furthermore, the EVWRP has other benefits which have not been quantified such as the reduction of water imported from the Mono Basin, and improved water system reliability resulting from a new local supply of water.

II. Groundwater Replenishment System

The Groundwater Replenishment System is being developed jointly by the Orange County Water District (OCWD) and the Orange County Sanitation District (OCSD). After five years of planning and analysis, the Groundwater Replenishment System was determined to be the most economical and feasible new water supply for the region.

With OCSD secondary treated effluent as its source, the Groundwater Replenishment System would provide additional treatment including reverse osmosis and ultraviolet disinfection. The advanced treated recycled water would then be pumped to either: 1) existing spreading basins where it would percolate into and replenish the groundwater supply or 2) a series of injection wells that act as a seawater intrusion control barrier. The Groundwater Replenishment System would be implemented in three phases, providing roughly 68,000 afy of new water by the year 2003, 95,000 afy by 2010, and up to 120,000 afy by 2020.





Capital and Operation and Maintenance Costs

The cost of the water produced by the Groundwater Replenishment System is dependent on many factors including regulatory permit requirements, equipment and construction costs, power costs, operation and maintenance costs, system on-line reliability requirements, interest rates, and grants received from outside agencies. The following is a conservative preliminary estimate of the costs for the most probable alternative for Phase I of the Groundwater Replenishment System.

Capital Costs	$267 Million
Operation & Maintenance	$17.3 Million/year
Grant Receipts	$25 Million
Interest	6% amortized over 25 years
Power Cost	$0.06/kwh
Capacity Utilization	100% Barrier; 82% Spreading
Cost of Product Water	$565/AF

The utilization factor – the percentage of time that the system produces recycled water – significantly affects product water cost. It is anticipated that recycled water would be produced continuously for both the barrier and the spreading basins, with the exception of approximately 70 days during the winter months when the basins may not be able to accept water due to peak storm flows.

The estimated annual cost of the Phase I Groundwater Replenishment System, including capital amortization, operation, and maintenance totals approximately $38.2 million per year.

Value of Project Benefits

An explanation of project benefits and their economic values (avoided costs) are described below.

1. Alternative Water Supply

If the Groundwater Replenishment System is not implemented, one of a variety of alternatives would need to be implemented to make up the anticipated water supply shortfall. OCWD conducted an analysis of three alternatives to meet the Groundwater Replenishment System production capacity. Each alternative would rely on continued imported water availability at non-interruptible rates, and two of the three alternatives would include some level of expansion or modification of Water Factory 21, OCWD's existing advanced recycled water treatment system. Based on the analysis, the following alternative represents the least-cost alternative to the Groundwater Replenishment Project.

Water Factory 21 would be expanded to provide all the water needed for seawater intrusion control via groundwater injection. Additional water needed for spreading would be purchased from the

Metropolitan Water District of Southern California (MWD) and would require the construction of a pipeline from MWD's Diemer by-pass pipeline to the spreading facilities located in Anaheim. OCWD would avoid $ 27.4 million in annual costs, including expansion of existing treatment facilities, reduction in operation and maintenance costs, pipeline construction, and imported water costs, by implementing the Groundwater Replenishment System instead of this alternative water supply. Provided that imported water is available, the equivalent unit cost to implement this alternative would be $695/AF.

2. Salinity Management

The Groundwater Replenishment System service area receives water from the Santa Ana River and imported water from the Colorado River Aqueduct and the State Water Project. The first two of these sources have relatively high salinity levels, potentially causing both agricultural and urban customers economic impacts. Agricultural water users suffer economic damage through reduced crop yields, added irrigation labor management costs, and added drainage requirements. Urban customers may incur additional costs due to more frequent replacement of plumbing and water using appliances. Estimated normalized costs for these replacements range from $100 to $150 per household each year.

The reverse osmosis-treated product from the Groundwater Replenishment System would lower the overall TDS content of the groundwater basin by at least 12.5 percent, saving the average household approximately $12.50 per year (or $25/AF). Industries and other large water users also could realize significant savings. With an average projected water use of approximately 675,000 AFY over the next 25 years, this provides an annual benefit of $16.9 million.

3. Reliability

Allocations from imported water supplies are already overextended. Drought worsens the situation. And the population in north and central Orange County is increasing. It is currently projected that approximately 186,000 AFY of additional water would be required by the year 2020 to satisfy OCWD's service area demands.

The water supplied from the Groundwater Replenishment System would be available during times of drought, relieving the region of its dependence on imported water supplies. In addition, the Groundwater Replenishment System would protect the existing groundwater from further seawater intrusion and contamination. The value of this benefit is dependent on both drought frequency as well as other factors and is difficult to assess. No attempt to quantify the value of this benefit has been made.

4. Delay/Avoid Ocean Outfall Construction

Implementation of the Groundwater Replenishment System would divert up to 100 million gallons per day (mgd) during Phase I from the Sanitation Districts Ocean Outfall Disposal System. During peak wet weather events, peak discharges of about 750 mgd are projected while the ocean disposal system capacity is approximately 480 mgd. To make up for this shortfall, OCSD is considering a variety of options including use of existing standby disposal facilities, retarding flows (peak shaving), and inflow reduction techniques to delay the near term cost of constructing a second ocean outfall. The most significant and economical way to reduce the peak is the diversion of 100 mgd through the Groundwater Replenishment System.

The estimated $150 million cost of a new ocean outfall can be delayed at least ten years by application of several peak reduction methods including this project. Assuming that half of this delay is due to the Groundwater Replenishment System (5 years) the savings at 6% interest spread over 25 years yields a $5 million per year benefit.

5. Section 301 (h) Waiver

OCSD currently has a waiver under Section 301 (h) of the Clean Water Act from the requirement to discharge strictly secondary treated effluent thanks to a comprehensive source control program (in the wastewater collection system) and the relatively good quality of their effluent. OCSD's waiver is the largest granted by the United States Environmental Protection Agency (EPA) and in 1989 was estimated to save over $50 million per year in capital, operation, and maintenance costs. Protection of this waiver is OCSD's highest priority, and commitment to water reclamation could complement future waiver requests. However, the degree to which waiver savings can be attributed to the Groundwater Replenishment System is difficult to assess. If for example, the Groundwater Replenishment System accounted for 20% of the savings, the project could be credited with $10 million per year in cost avoidance. However, no credit was taken for this project benefit.

6. Revised Discharge Permit

OCSD's 1998 ocean discharge permit allows a discharge of 20,000 metric tons per year of suspended solids and, thanks to a condition in the permit, would be re-opened if the Groundwater Replenishment System were built. The Regional Water Quality Control board could then consider an increase in solids loading discharge to 25,000 metric tons per year, potentially delaying construction of new secondary facilities (10 years). The savings in operation and maintenance (including solids disposal), amortized at 6% interest over 25 years, is $9.9 million per year. However, these savings were not included in the evaluation of this project.

Economic Summary

The annual cost to implement the Groundwater Replenishment System including capital, operation and maintenance, engineering, administration, and contingencies, at 6% interest and amortized over a 25-year period, would be approximately $38.2 million. Totaling the avoided costs presented above, including Alternative 2 as the next lowest cost water supply solution, the total annual benefits are as follows:

Item	Total Annual Cost Avoidance (Millions $)
OCWD Cost Avoidance	$27.4
Salinity Management	$16.9
Reliability	Not Counted
OCSD, Delay in outfall	$4.9
OCSD, Waiver Support	Not Counted
OCSD, Secondary Savings	Not Counted
TOTAL BENEFITS	$49.2

This results in a maximum Benefit to Cost Ratio of 1.288 ($49.2/$38.2), not including estimates for reliability, waiver support, and secondary treatment savings. Based on this analysis, OCWD and

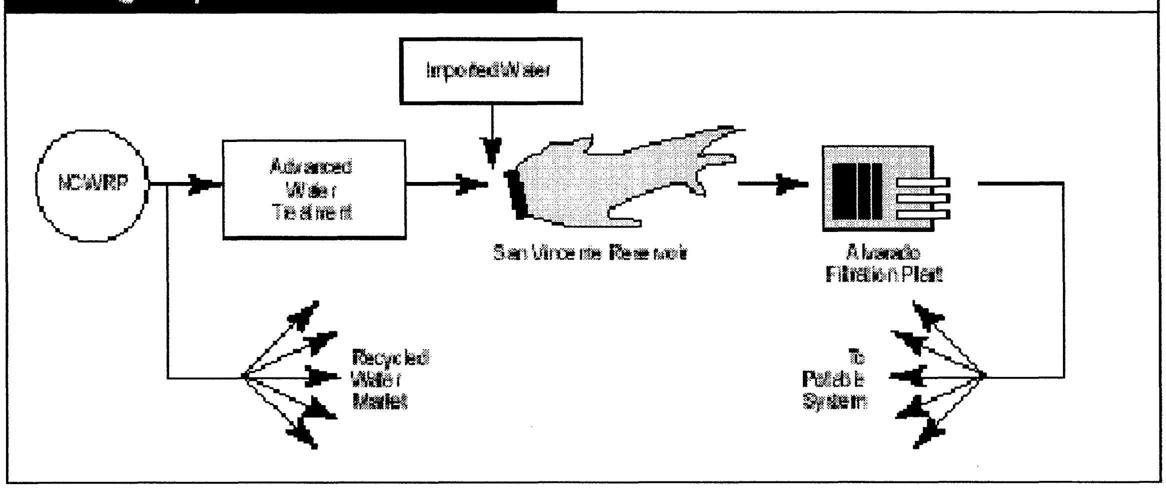
OCSD have decided to move forward with the implementation of this project.

III. San Diego Water Repurification Project

The City of San Diego, in conjunction with the San Diego County Water Authority (SDCWA), the Metropolitan Water District of Southern California (MWD), and the U.S. Bureau of Reclamation, has proposed a surface water augmentation project to achieve indirect potable reuse of reclaimed water from the City's North City Water Reclamation Plant (NCWRP). The Water Repurification Project would provide a renewable, reliable, local source of raw water that would expand the City's total available raw water supply under its direct control. In a region in which 90% of its water supply is imported from the Colorado River and northern California, this project is not only resource-efficient, but it also improves the cost-effectiveness of the NCWRP.

The proposed project, designed to produce between 15-20,000 AFY of repurified water, consists of a 20 million gallon per day (MGD) advanced water treatment plant (co-located with the NCWRP) and a 23-mile pipeline to deliver the repurified water to the City's San Vicente water supply reservoir in eastern San Diego County. The advanced treatment plant (AWTP) would treat tertiary effluent from the NCWRP using a treatment process train including microfiltration, reverse osmosis, Ion exchange, and ozonation. The repurified water would be introduced into San Vicente Reservoir, where it would blend with imported water. Raw water from San Vicente Reservoir would be pumped to the Alvarado Filtration Plant prior to being introduced into San Diego's potable water distribution system.

San Diego Repurification Schematic



The City has been conducting research into the advanced treatment and ultimate use of repurified water as a supplement to potable supplies since the early 1980's. Since 1993, the City has worked closely with the California Department of Health Services (DHS) to develop a project that meets the department's strict standards for public health and reliability, while maintaining its cost-effectiveness. DHS has approved the project for design, which commenced in early 1997 but was put on hold in late 1998 due to policy and public perception issues.

Capital and Operation and Maintenance Costs

The following is a preliminary estimate of the costs for the San Diego Water Repurification project.

Capital Costs	$168 Million
Operation & Maintenance	$4.1 Million/year
Interest	5.75% amortized over 30 years
Power Cost	$0.05/kwh
Capacity Utilization	83%
Gross Cost of Product Water	$1060/AF
Title IX Funding	($38/AF)
SRF Loan (0%, 30 yrs)	($94/AF)
MWDSC Incentive	($250/AF)
SDCWA Incentive	($100/AF)
Cost of Product Water	$578/AF

The above unit cost is based on 1) estimated repurified water production of 15,000 AFY, grant funding of $8 million, and a State Revolving Fund $50 million zero interest loan, with $7 million (13%) contributed by City.

Value of Project Benefits

An explanation of project benefits and their economic values are described below.

1. Alternative Recycled Water Supply

The City and the SDCWA have committed to incorporating water recycling into the water supply mix. At a production capacity of 30,000 AFY, NCWRP is the largest water recycling plant in the region, and provides the best opportunity for large-scale reuse. A recycled water distribution system currently serves roughly 5,000 AFY of NCWRP product to local non potable customers. If the water repurification project is not built, the City would expand the non potable distribution system to serve an additional 5,900 AFY.

The value of the Water Repurification project includes the avoidance of construction and operation of this expanded distribution system. The estimated capital cost of this distribution system expansion is $83 million. Estimated annual operations and maintenance costs to distribute the additional 5,900 AFY are $450,000.

2. Additional Avoided Wastewater Costs

Wastewater flows that are not treated at NCWRP and beneficially reused must be conveyed to the Point Loma Wastewater Treatment Plant. These unused flows would cause increased operation of the City's collection system Pump Station No. 2, and would undergo re-treatment at the Point Loma plant. The City has estimated that annual operations and maintenance costs associated with accommodating this 5,900 AFY are $236,000 at Pump Station No. 2 and $855,000 at Point Loma.

Economic Summary

The City commissioned an independent study of the cost-effectiveness of the Water Repurification project. Considering the estimated construction and operations and maintenance costs of the project, and considering the avoided costs as discussed above, San Diego expects this project to fully recover 100% of its capital costs, debt service and operation and maintenance costs within fifteen years after it commences operations.

CONCLUSIONS

Recycled water represents a safe and reliable new water supply that provides insurance against future droughts or shortages of imported water supplies, and provides a stable foundation for maintaining and improving California's economic prosperity and quality of life.

The East Valley Water Recycling Project, Groundwater Replenishment System, and San Diego Water Repurification Project exemplify how indirect potable reuse projects, when compared to other water supply and wastewater management options, can offer the greatest benefits for the least cost. The ultimate success of these projects would be attributable to project sponsors reaching out and forming alliances with the full array of beneficiaries. Public involvement and education also would be instrumental in successful project development.