

HOW SAFE IS THE WASTEWATER REUSE?

Takashi Asano

Despite a long history of wastewater reuse in many parts of the world, question of *safety* is still difficult to define and *acceptable* health risks have been hotly debated. In this article, a comparative assessment of the safety of wastewater reuse is discussed based on the recent findings on enteric virus risk assessment.

Reclaimed municipal wastewater has been used in agricultural and landscape irrigation, industrial purposes, groundwater recharge, recreational and environmental uses, nonpotable urban uses such as toilet flushing, and indirect potable reuse. When treated municipal wastewater effluents are used in the urban environment resulting direct contact with humans, considerable health concerns may be justified. The potential health hazards inherent in the use of reclaimed municipal wastewater must always be guarded against in such reuse applications.

In the industrialized countries with the high health standard, these health concerns are specifically directed to the presence of enteric viruses in wastewater because of their low-dose infectivity, long-term survival in the environment, difficulty of monitoring, and low removal and inactivation efficiency in conventional municipal wastewater treatment facilities. Thus, this article will focus on potential public health risks associated with enteric viruses in wastewater reuse.

ENTERIC VIRUS CONCENTRATIONS IN MUNICIPAL WASTEWATER

The enteric virus data assembled by Asano, *et al.* (1992) included 424 unchlorinated secondary effluent samples in which 283 samples (67 %) were virus positive and 814 chlorinated tertiary (filtered) effluent samples with 7 positive samples (1 %). The database was obtained from the published reports from the water and wastewater agencies in California. Quantifying the virus concentration (expressed as viral unit, vu, per liter) in the treated effluent is the first step for estimating the risk of virus infection upon exposure to reclaimed municipal wastewater. The statistical model used was the lognormal distribution and the goodness-of-fit of the hypothesized distribution was evaluated.

The virus concentrations vary in a wide range in the unchlorinated secondary effluents. Furthermore, the virus concentrations among different treatment plants show

distinctively different characteristics; for example, the geometric means ranged four orders of magnitude (10^{-4} to 10^0 vu/L) and the spread factors range from 4 to 115. The geometric mean values of unchlorinated secondary effluent samples ranged from 0.0002 to 2.3 vu/L and 90 percentile concentrations ranged from 0.34 to 29 vu/L. The virus concentration of 0.01 vu/L is considered to be the reasonable estimate of limit of detection. Thus, characterizing the variability of enteric virus concentrations in municipal wastewater is extremely important in virus risk assessment.

Two set of virus concentrations were used for the risk analysis: the data derived from the unchlorinated activated sludge effluents and the chlorinated tertiary filtration effluents. For the first run, the geometric mean and the 90 percentile values for enteric viruses found in unchlorinated activated sludge effluents were used, and the 5-log removal (99.999 %) of viruses was assumed, based on the well-operated wastewater reclamation plants, in tertiary filtration and chlorine disinfection. For the second run, two computer simulations used the virus concentrations of 0.01 vu/L and 1.11 vu/L from the chlorinated tertiary filtration effluents, which are the reasonable estimate of limit of detection for enteric viruses and the maximum concentration found in tertiary effluents.

VIRUS RISK ASSESSMENT

To analyze potential risks associated with the use of reclaimed wastewater, the exposure scenarios, as shown in Table 1, are developed for landscape irrigation, spray irrigation of food crops, recreational impoundments where swimming may take place, and groundwater recharge.

The beta-distributed probability model, based on Haas (1983), was chosen for use in risk calculations because it best represented the frequency distribution of virus infection. Infectious models based on echovirus 12, and poliovirus 1 and 3 were used by Asano, et al. (1992) and the rotavirus model, based on Rose and Gerba (1991), was used in the study by Tanaka, et al., (1993).

Results of the annual risk calculations are shown in Table 2, using the virus concentrations of 0.01 vu/L and 1.11 vu/L from the chlorinated tertiary filtration effluents. The estimates of risk of infection shown in Table 2 present a range of risks associated with annual exposures encountered in different wastewater reuse applications. The overall probability of infection due to ingestion of viruses is a combination of virus removal and inactivation by wastewater treatment, die-off in the environment, and dose-response for infection. For each exposure scenario presented, the range of risks covers 2-3 orders of magnitude. This reflects the differences in infectivity among different viruses. For groundwater recharge with reclaimed wastewater, with an effluent virus concentration of 0.01 vu/L, the annual risk of infection ranges from 5×10^{-10} to 5×10^{-11} .

When virus concentration is increased to 1.11 vu/L which is the maximum virus concentration found in the chlorinated tertiary effluent in the California database, the risk of infection increased by 2 to 3 order of magnitude (6×10^{-8} and 5×10^{-9}). Similar trends are noted in the other exposure scenarios.

Table 1. Summary of Exposure Scenarios Used in Risk Analysis (Asano, et al., 1992).

Reuse Application	Risk Receptor	Exposure Frequency	Amount of Water Ingested in a Single Exposure	Decay/Fate in the Environment
Scenario I Golf Course Irrigation	Golfer	Twice per week	1 mL	Irrigation one day before playing
Scenario II Food Crop Irrigation	Consumer	Every day	10 mL	Stop irrigation before harvest and shipment. Viral reduction due to sunlight
Scenario III Recreational Impoundments	Swimmer	40 days per year - summer season only	100 mL	No virus reduction
Scenario IV Groundwater Recharge	Ground-water consumer	Every day	1,000 mL	3 - meter vadose zone and 6 month retention in aquifer

Of the remaining three categories, the highest potential exposure to reclaimed wastewater is recreational impoundments where water contact sports such as swimming may take place. In all cases, regardless of the starting virus concentrations, the use of reclaimed wastewater for unrestricted recreational impoundments

allows the highest exposure to enteric viruses. The relatively high probability of infection is attributed to the fact that no dilution or virus die-off in the environment were included in the risk calculations, assuming the worst possible case.

Landscape irrigation for golf courses posed the second most exposure to reclaimed wastewater, and spray irrigation of food crops ranked third being two orders of magnitude lower in relative risk. The lower risks of infection in the cases of spray irrigation of food crops and groundwater recharge can be attributed to environmental factors such as use area controls. In both cases, the exposure scenarios developed include virus die-off in the environment. These risk analyses, however, do not account for the variability of enteric viruses in the environment. Seasonal fluctuations in the endemic virus populations will affect the quantity and species present in the wastewater at any given time.

Table 2. Annual Risk of Contracting at Least One Infection from Exposure to Reclaimed Wastewater Based on Two Different Enteric Virus Concentrations (Asano, *et al.*, 1992)

Viruses	Exposure Scenarios			
	Landscape Irrigation for Golf Courses	Spray Irrigation for Food Crops	Unrestricted Recreational Impoundments	Ground-water Recharge
1. Maximum virus concentration of 1.11 vu/L enteric viruses in chlorinated tertiary effluent				
Echovirus 12	1E-03	4E-06	7E-02	6E-08
Poliovirus 1	3E-05	2E-07	3E-03	5E-09
Poliovirus 3	3E-02	1E-04	8E-01	2E-08
2. Minimum virus concentration (the concentration limit of detection) of 0.01 vu/L enteric virus in chlorinated tertiary effluent				
Echovirus 12	9E-06	4E-08	7E-04	5E-10
Poliovirus 1	3E-07	1E-09	2E-05	5E-11
Poliovirus 3	2E-04	1E-06	2E-02	2E-10

The lack of positive samples indicates that the chlorinated tertiary effluent is essentially virus free; however, none of the monitoring has produced enough positive samples to establish a measure of process reliability with respect to virus removal. Since a wastewater treatment process rarely produces a constant

quality effluent, due to daily and seasonal water quality variations, flow fluctuations, or process variability, the effluent produced should be expected to vary. Indeed, the positive samples in tertiary effluents reported in Table 2 were associated with the operational difficulties. These could be detected by real time monitoring of effluent water quality such as with continuous turbidity measurement.

In the seven positive samples out of 841 samples analyzed (roughly 1 % positive), the virus concentration ranged from 2 to 111 vu/ 100 L. Therefore, it might be assumed that the wastewater treatment process produced a virus free effluent 99% of the time. In this circumstance, the assumption of 5-log removal of viruses in tertiary treatment needs close examination in light of treatment process reliability. If a treatment process for wastewater reuse has a reliability of 99 %, the process is expected to meet the performance requirements 99 percent of the time. Thus, the permit limit of virus-free effluent is expected to be exceeded 1 % of the time, or three to four times a year. The question in risk management in wastewater reclamation and reuse, then, becomes one of determining whether or not the presence of enteric viruses in the concentration range of 2 to 111 vu/100 L in approximately 1 % of the time in tertiary-treated reclaimed wastewater is significant to protect public health. Further research is needed to characterize treatment process reliability that contribute to the overall reduction of infectious risks in wastewater reclamation and reuse (Asano, et. al., 1992).

HOW SAFE IS THE WASTEWATER REUSE?

The goal of essentially virus-free reclaimed wastewater should not be interpreted to mean that the practice of using such water is risk-free. As Table 2 clearly shows that there will be always some risk of infection due to exposure to reclaimed wastewater. However, this does not mean that the practice of wastewater reclamation and reuse is unsafe. The "safety" of wastewater reclamation and reuse practice is defined by the acceptable level of risks developed by the regulatory agencies responsible for risk management and endorsed by the public based on the needs for additional water resources.

If the acceptable annual infectious risk from enteric viruses in reclaimed wastewater 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 can be calculated. Tanaka et al (1993) conducted such a study using the rotavirus infectious model developed by Rose and Gerba (1991). If wastewater reclamation and reuse should be as safe as the domestic water supply meeting the U.S. Environmental Agency's Surface Water Treatment Rule for enteric viruses, the required virus inactivation/removal in tertiary treatment is shown in Table 3.

Table 3. Required Log-removal of Enteric Viruses by Tertiary Treatment if One Enteric Virus Infection per 10,000 Population per Year is met at 90 or 95 Percent Reliability (After Tanaka, et al, 1993)

Treatment Process	Scenario I Golf Course Irrigation		Scenario II Crop Irrigation		Scenario III Swimming		Scenario IV Groundwater Recharge	
	Reliability, % of Time							
	90	95	90	95	90	95	90	95
A Trickling Filter	4	4	1	2	6	6	0	0
B Activated Sludge	2	3	0	0	4	5	0	0
C Activated sludge	2	3	0	1	4	5	0	0
D Activated Sludge	4	5	2	2	6	6	0	0

Depending on varying effluent enteric virus concentrations in unchlorinated secondary effluent and different reuse applications, required log-removal by tertiary treatment ranges from 0 to 6 logs removal. The tertiary treatment process consisting of chemical coagulation, flocculation, sedimentation, and chlorine disinfection is capable of removing approximately 5-logs of enteric viruses (Pomona Virus Study, 1977). Thus, no public health problem will be expected when tertiary treated effluent is used for golf course and crop irrigation, and groundwater recharge. However, wastewater application in recreational impoundments where swimming may take place will need careful attention.

For golf course and food crop irrigation, and groundwater recharge, the reliability of wastewater reclamation and reuse shown in Table 3 is such that more than 95 % of the time use of tertiary treated reclaimed water is no different from domestic water supply meeting the U.S. Environmental Protection Agency's Surface Water Treatment Rule for enteric viruses. Further safety measures for nonpotable water reuse applications include (1) installation of separate storage and distribution systems of potable water, (2) use of color coded labels to distinguish potable and nonpotable installation of the pipes, (3) cross-connection and backflow prevention devices, (4) periodic use of tracer dyes to detect the occurrence of cross contamination in potable supply lines, and (5) irrigation during off hours to further minimize the potential for human contacts.

REFERENCES

Asano, T., Leong, L.Y.C., Rigby, M.G., and Sakaji, R.H. (1992): Evaluation of the California Wastewater Reclamation Criteria Using Enteric Virus Monitoring Data, *Water Science & Technology*, 26, 7-8, 1523-1524.

Haas, C.N. (1983): Estimation of Risk due to Low Doses of Microorganisms: A Comparison of Alternative Methodologies. *American J. of Epidemiology*, 118, 4, 573.

Pomona Virus Study - Final Report (1977): Sanitation Districts of Los Angeles County.

Rose, J.B., and Gerba, C.P. (1991): Use of Risk Assessment for Development of Microbial Standards, *Water Science & Technology*, 24, 2. 29-34.

Tanaka, H., Asano, T., Schroeder, E.D., and Tchobanoglous, G. (1993): Estimating the Reliability of Wastewater Reclamation and Reuse Using Enteric Virus Monitoring Data, Presented at the 66th Annual Conference & Exposition, October 3-7, 1993, Water Environment Federation.

Takashi Asano is with Department of Civil and Environmental Engineering, University of California at Davis, Davis, CA 95616.

File Name: Book1 "3Safety." Submitted for possible publication in *Water Environment & Technology* on May 27, 1995.