The City of San Diego's Total Resource Recovery Program: Health Effects Study on Potable Water Reuse

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March 1, 2001

Presented to the Air and Waste Management Association (A&WMA)
West Coast Section
May 3rd, 2001

BACKGROUND

Water reclamation is becoming an increasingly common component of water resource planning. In the past, the driving motivation for water reuse was to provide a means of avoiding effluent disposal into surface waters. With increased demand brought on by drought and increasing population, reclaimed water is now considered an important water resource. Since water demands increase each year, nonpotable and potable use of reclaimed water can provide communities with the option of maximizing and extending the use of limited water resources. We can no longer afford to use water only once.

While this process has been utilized minimally for years, public health jurisdictions have been reluctant to accept the concept of potable reuse (indirect or direct) because of concerns that the proposed water supply could contain infectious and toxic materials. Recently however, a number of water reclamation projects have been examined for the public health implications of potable reuse. These projects include the Denver Potable Reuse Demonstration Project, the Tampa Water Resource Recovery plan, and the San Diego Total Resource Recovery project.

This paper will examine the City of San Diego's Health Effect Study on Potable Water Reuse in an effort to demonstrate the feasibility of a total wastewater recovery system, which would provide a raw water system for potable use. Both the California Water Resource Control Board and the City of San Diego have recognized the importance of a human health risk assessment for the system and therefore conducted the study to be presented as part of the San Diego Total Resource Recovery Project.

The City of San Diego's Health Effects Study (HES) is the result of research to evaluate the potential health risks associated with the reclaimed water as opposed to the existing raw water supply used in the city. This paper will present the study's methodology and an overview of the data for the identification, characterization, and quantification of infectious disease agents,

toxic chemicals, mutagenicity, and bioaccumulation of existing chemicals, in both water supplies. In addition, the study includes an analysis of the effluent quality of the water treated, as well as the probabilities of the effluent meeting specified concentrations.

DESCRIPTION OF WASTEWATER TREATMENT SYSTEM

The initial HES investigations were conducted in a small pilot wastewater system, Aqua II, located in Mission Valley, San Diego, California. The system was unique, utilizing water hyacinth ponds for secondary treatment, followed by solids contact clarification with ferric chloride, plus gravity dual media filters providing tertiary treatment. Ultraviolet disinfection, cartridge filtration, reverse osmosis, air stripping, and granular activated carbon were also used, providing an even more advanced water treatment. The capacity of the hyacinth ponds for this system was approximately 156,000 gal/d and the capacity of the total tertiary and Advanced Water Treatment (ATW) facility was 50,000 gal/d.

After results were collected from the three-year investigation of Aqua II, the Total Resource Recovery Program relocated to the Pasqual Valley. The San Pasqual Facility (Aqua III) was similar to the Aqua II plant in design but on a much larger scale. Aqua III had nominal flow rates of 1 Mgal/d through the water hyacinth treatment facilities, 1 Mgal/d through the chemical coagulation and filtration process, and .5 Mgal/d through the reverse osmosis, activated carbon, and air stripping facilities.

PLANT RELIABILITY

Treatment plant reliability is defined as the probability that a system can meet established performance criteria consistently over extended periods of time. The analysis of plant reliability conducted for the HES study covered the Aqua II plant for approximately two and a half years and Aqua III plant for one year. The study used several methods for evaluating inherent plant reliability, including time

series analysis, probability plots, statistical analysis of process performance, and a critical component analysis.

A summary of the data collected at Aqua II and Aqua III shows the performance of the plants to be high. Significant reductions in CBOD, COD, Total Organic Carbon, Suspended Solids, and turbidity levels were observed in the water hyacinth pond effluent. These parameter reductions were near or below detection limits after tertiary and advanced water treatment. Microbial indicator organisms were consistently below detection levels in product water of the Aqua II and Aqua III plants. When compared to the Denver Potable Water Reuse Project and the Water Factory 21 Advanced Treatment Wastewater Reclamation Project, the performance of the Aqua II and Aqua III plants were approximately equivalent.

While studying the mechanical reliability of the plants, a Critical Component Analysis approach was selected. This process determines the in-service reliability, maintainability, and operational availability of critical components. The reliability study shows that over the two and a half year period for Aqua II and the one year period of Aqua III the critical equipment operated almost 100 percent of the time causing only minor “down times” to each plant. It was concluded that the maximum statistical value for down time of the two plants was once per twenty-one days of operation.

CHEMICAL AGENTS

During the three-year investigation for chemical agents, the first year at the Aqua II plant was used to perform chemical screening, while chemical monitoring and other analysis were done during the last two years. Chemical screening was done to meet the following objectives; (1) to determine which chemicals were present and their concentrations in the raw wastewater Aqua II influent (RWW), the Aqua II treated effluent, and the raw water used for the drinking water plant in the local area (Miramar) and (2) to identify which chemicals present are known to pose a health risk to humans.

Monitoring of the Aqua III plant was done for one year. For the monitoring phase of the investigation, analysis consisted of:

- Routine analysis for ninety-eight volatile and semi-volatile organic compounds using liquid-liquid extraction and Gas Chromatographic Mass Spectrometric analysis (GCMS)
- Determination of twenty-seven inorganic elements by Inductively Coupled Argon Plasma-Atomic Emission Spectroscopy (ICP-AES) and Atomic Absorption Spectroscopy (AA)
- Routine analysis of Total Organic Halogen and Total Organic Carbon
- Quarterly analysis during year two of Pesticide/Polychlorinated Biphenyl (PCB)
- One time analysis of chlorinated dibenzodioxin/dibenzofuran

The screening and monitoring analysis were conducted routinely and in duplicate at two separate facilities. Blank samples were used to monitor the purity of the reagents and the possible carryover from one sample to the next. The same sampling process was used at both the Aqua II and Aqua III facilities to ensure accurate comparisons.

CHEMICAL AGENT MONITORING RESULTS

During the monitoring phase, only a limited number of samples were collected to test for the total organic carbon (TOC) and total organic halogen (TOX) concentrations. In a comparison of the Aqua II Effluent, Aqua III Effluent, and the Miramar water, the Miramar water supply showed the highest concentrations of both TOC and TOX.

A list of the purgeable and extractable organics is located in Table 1. Specific concentration levels could not be found, and therefore only the water with the highest concentration is listed.

Overall the Miramar water showed the highest concentrations of metals, Aqua III the lowest. Cobalt, copper, lead, nickel, and silver showed up in higher concentrations in the Aqua III water, but since the concentrations were all less

than the method quantitation limits, they were deemed insignificant. The results of the Metals analysis are shown in Table 2. The space has been left blank where specific concentration levels could not be found while researching this report.

During the four samplings for Pesticide/ PCB analysis, the only compound found was Heptachlor epoxide measured in the Miramar water near the detection limit.

Table 1. Purgeable and Extractable Organics

Compound	Water with Highest Concentration	Compound	Water with Highest Concentration
2-butanone	Aqua II	chloromethane	Aqua II
4-methyl-2-pentanone	not available	diethyl phthalate	not available
benzene	Aqua II	di-*n*-octyl phthalate	not available
Bis(2-ethyl-hexyl)phthalate	not available	methylene chloride	Aqua II
bromomethane	not available	toluene	Aqua II
chloroform	Aqua II		

Table 2. Metal Concentration Results

Metal	Method	Method Detection Limits	Concentration			Highest Concentration	Lowest Concentration
			Aqua II effluent	Aqua III effluent	Miramar		
arsenic	AA-MS	2.0 ug/L	0.3 ug/L	1.7 ug/L		Miramar	Aqua II
	ICP-MS	0.02 ug/L	0.19 ug/L	2.6 ug/L		Miramar	Aqua III
barium	ICP-AES	0.001-.013 ug/L				Miramar	Aqua III
boron	ICP-AES	0.001-1.25 mg/L				Aqua II	Miramar
calcium	ICP-AES	0.001-.013 ug/L				Miramar	Aqua III
cobalt	ICP-AES	0.001-.013 ug/L	< detection limit	< detection limit	< detection limit	Aqua III	Miramar
copper	ICP-AES	0.001-.013 ug/L	< detection limit	< detection limit	< detection limit	Aqua III	Miramar
lead	ICP-AES	0.001-.013 ug/L	< detection limit	< detection limit	< detection limit	Aqua III	Miramar
lithium	ICP-AES	0.001-.013 ug/L				Miramar	Aqua III
magnesium	ICP-AES	0.001-.013 ug/L				Miramar	Aqua III
manganese	ICP-AES	0.001-.013 ug/L				Miramar	Aqua III
mercury	ICP-MS	0.1 ug/L	0.61ug/L	0.57 ug/L		Aqua III	Miramar
molybdenum	ICP-AES	0.001-.013 ug/L				Miramar	Aqua III
nickel	ICP-AES	0.001-.013 ug/L	< detection limit	< detection limit	< detection limit	Aqua III	Miramar
phosphorus	ICP-AES	0.001-1.25 mg/L				Miramar	Aqua II
selenium	AA-MS	2.0 ug/L	0.1 ug/L	0.7 ug/L		Miramar	Aqua II
	ICP-MS	0.01 ug/L	0.62 ug/L	3.1 ug/L		Miramar	Aqua III
silicon	ICP-AES	0.001-.013 ug/L				Miramar	Aqua III
silver	ICP-AES	0.001-.013 ug/L	< detection limit	< detection limit	< detection limit	Aqua III	Miramar
sodium	ICP-AES	0.001-.013 ug/L				Miramar	Aqua III
strontium	ICP-AES	0.001-.013 ug/L				Miramar	Aqua III

SPIKING STUDY

The San Diego Health Effects Study performed a spiking study to estimate the rate of removal of selected chemicals by the Aqua II facility. This study simulated an event where large amounts of contaminates could potentially enter the plant. To perform the test, certain chemicals representative of industrial chemicals typically found in wastewater streams were added to the primary wastewater influent as it entered the hyacinth ponds. Samples were then collected and analyzed from the hyacinth pond and Aqua II plant effluents. The results showed that the ponds removed 60-99 percent of the spike components and the Aqua II plant removed 98.5 to 99.9 of those chemicals remaining. Overall the system had a removal rate of 99.5 to 99.97 percent of all spiking compounds.

COMPARISON OF HES MIRAMAR AND AQUA II WATER WITH U.S. SUPPLIES

To compare the San Diego test waters with waters in cities throughout the U.S, a comparison was made of the organic and metal concentrations in the waters. The results showed that both the Aqua II and Miramar water were in the lower end of the U.S. average range for ground and surface waters. Mean concentration levels of organics and metals in the San Diego waters did not exceed the federal maximum contaminant levels (MCL) for drinking water except for Bis(2-ethyl-hexyl)phthalate. Bis(2-ethyl-hexyl)phthalate contamination most often results from leaching out of plastics.

BIOASSAY

In addition to the previous chemical agent tests, multiple assays were conducted to compare the Miramar, Aqua II, and Aqua III waters in regard to various types of mutagenicity trends. None of the tests revealed any significant trends.

FISH BIOMONITORING

The last test conducted in the chemical agents section of the HES, was that of fish biomonitoring. For the test, young fathead minnows were placed in either Aqua II effluent, Miramar water, or charcoal filtered San Diego tap water (control water) in flow through aquariums. Under EPA and ASTM standards, three 28-day bioaccumulation experiments were conducted, which tested for bioconcentration of chemical agents, swim speed, and optomotor response.

The results of these tests found that there were no statistically significant differences in chemical agents found in fish exposed to the three waters. Additionally, no differences were determined in survival, growth, or swim speed between fish exposed to any of the three waters.

CHEMICAL RISK ASSESSMENT

A chemical risk assessment was conducted to compare the risk associated with the existing untreated (non-potable) water supply and the treated effluent from Aqua II and Aqua III.

DATA EVALUATION AND CHEMICALS OF POTENTIAL CONCERN

The chemicals seen as potential concerns and their average concentration levels are summarized in Table 3 for the Aqua II and Miramar waters. The results show that the Miramar water had higher concentration levels for all compounds tested, except for Bis (2-ethyl-hexyl) phthalate. Neither the Aqua II nor Miramar water reached the maximum contaminant levels (MCL) for drinking water. A comparison of the Aqua III plant effluent and Miramar water gave similar results.

Table 3. Comparison of Potential Concerns in Aqua II Treated Wastewater and Raw Miramar Waters

Compound	Aqua II (ug/L)	Miramar (ug/L)	MCL (ug/L)
Organics:			
Benzyl butylphthalate	<0.300	0.153	NA
Benzoic Acid	<4.011	0.114	NA
Bis (2-ethyl-hexyl) phthalate	<0.048-7.584	<0.045	4
Bromodichloromethane	<.0400	3.726	100
Bromoform	<.0600	0.957	100
Chloroform	<.0300	2.194	100
Dibromochloromethane	<.0500	3.153	100
Toluene	0.101	0.042	100
Trichlorofluromethane	<0.070	0.389	NA
Metals:			
Aluminum	63	206	1000
Arsenic	<2	1.542	50
Barium	<24	77	1000
Boron	195	<25	NA
Calcium	5082	45740	NA
Iron	13	43	NA
Magnesium	1749	19010	NA
Manganese	9	9	NA
Phosphorous	738	1293	NA
Potassium	<1255	2878	NA
Sodium	23540	69040	NA
Silicon	909	4386	NA
Strontium	46	67.4	NA

RISK ASSESSMENT RESULTS

Risk assessment was divided into two categories; non-carcinogenic and carcinogenic. The assessment was completed for all compounds whose reference dose or unit risk values were listed in the Integrated Risk Information Systems (IRIS) database, which is kept by the EPA. For non-carcinogenic substances, the results were translated to a hazard index, for which the Miramar, Aqua II and Aqua III waters all tested extremely low for possible health risks.

The carcinogenic substance tests estimated the lifetime risks of consuming 2 L/day of water and was conducted for all three waters. The Miramar water was estimated to cause 3 cancers per 1000 people. Most of this risk was associated to levels of arsenic, and trihalomethanes from upstream chlorination, both of which had levels well under the MCL for drinking water. The

risk associated with consumption of the advanced treated wastewater was less than one cancer per a million people for both the Aqua II and Aqua III plants. The risk is associated with Bis (2-ethyl-hexyl) phthalate and Trihalomethanes in the wastewater samples.

INFECTIOUS DISEASE AGENTS

Collecting data sufficient to make judgments as to public health risk of infectious disease from pathogens, which might be present in reclaimed water, was a critical aspect of the city of San Diego's HES. The waters involved were monitored for the presence of microbiological indicators of water quality, enteric viruses, representative pathogenic bacterial genera, and parasites. Monitoring was done on the raw wastewater (RWW), the Aqua II and Aqua III AWT plant effluents, and the Miramar water. Monitoring at the Aqua II plant was conducted for a three-year period, while monitoring at the Aqua III plant was conducted for eighteen months.

MICROBIOLOGICAL INDICATORS OF WATER QUALITY

During the HES at Aqua II, samples were collected from the AWT plant effluent, Miramar raw water, and Raw Waste Water (RWW) from June 1987 through June 1990. At Aqua III, samples were collected from the plant effluent, Miramar raw water, and the RWW over a period from March 1994 to August 1995. The microbiological indicators used in the study to indicate the quality of water were Total Coliform, Fecal Coliform, and Fecal Strep.

As anticipated, the RWW samples yielded the highest Total and Fecal Coliform and Fecal Streptococci counts of the three waters. The Aqua II and Aqua III AWT effluent contained consistently fewer indicator coliform and fecal streptococci bacteria than did the untreated City drinking water supply. Total coliforms were detected in 19% and 7% of the Aqua II and Aqua III samples while the untreated City drinking water detected coliforms 92% of the time.

There were only two occasions each where fecal coliforms were detected in the Aqua II and Aqua III waters. This makes it sixty times as likely to be detected in the Miramar water than in Aqua II or AquaII. Streptococci were never detected in the Aqua II AWT effluent and were detected only twice in Aqua III AWT effluent. This is minimal when compared to the 60% and 79% of finds in trials one and two of the Miramar plant.

Overall, it was observed that the Aqua II and Aqua III treatment plants could reduce the measurable indicators by greater than 99.9999 percent, without any disinfection.

Results are shown below in Table 4.

Table 4. Comparison of Samples Greater Than or Equal to 2MPN/100 mL to Total Number of Samples

Water Source	Sampling Period	Total Coliform	Fecal Coliform	Fecal Strep
AWT Effluent	Aqua III	0.07	0.02	0.02
	Aqua II	0.32	0.004	0.005
Miramar	Aqua III	0.91	0.69	0.79
	Aqua II	0.92	0.51	0.46

ENTERIC VIRUSES

To evaluate the ability of the Aqua II and Aqua III processes to remove measurable human enteric viruses, a series of dosing experiments were carried out. In both plants, a known dose of attenuated vaccine strain of Poliovirus 2 was used as a virus seed. It was observed that the Aqua II ponds removed 88% to 99% of the added Poliovirus Type 2, while the entire treatment plant reduced the seeded virus concentration by more than 6 to 8 logs. None of the seeded viruses were recovered in the final effluent of the Aqua III plant. This indicates a combined tertiary and advanced water treatment process removal of 10 logs. Results are shown in Tables 5 and 6.

Table 5. Virus Removal Efficiency of the Aqua II Plant

Run Number	Virus in Pond Effluent Ecpected (pfu/l)	Virus in Pond Effluent Observed (pfu/l)	Virus Removal in Ponds	Virus in AWT Effluent (pfu/l)	Virus Remaoval (%)
1	4.70E+04	1.90E+02	0.996	NDb	99.9999
2	9.60E+04	1.20E+04	0.875	NDc	99.99999
3	1.00E+05	4.00E+03	0.961	ND	99.99999
4	5.60E+04	3.70E+03	0.935	ND	99.99999

Table 6. Virus Removal Efficiency of the Aqua III Plant

Run Number	Expected Concentration (pfu/L)	Observed Concentration (pfu/L)	Log 10 Removal
1	5.70E+07	<0.002	>10.50
2	8.51E+07	>0.003	>10.40
3	6.42E+07	<0.003	>10.30

ENTERIC BACTERIAL PATHOGENS

Another important public health concern associated with wastewater reclamation and reuse is the potential for transmission of infectious disease. With this in mind, an intensive monitoring program was developed for specific bacterial enteric pathogens. Samples from each of the Aqua plants were examined for the presence of the bacterial pathogens: Salmonella spp., Shigella spp., and Campylobacter spp.. Unfortunately, due to the large number of bacteria present in the RWW, sampling for Shigella and Campylobacter was not effective and after nine month of failure was discontinued. From the results presented in Tables 7 and 8, it can be seen that of the three waters tested, only the raw wastewater (84 samples) was found to contain detectable levels of Salmonella.

Table 7. Summary of Observed Samonella in Aqua II

Water Source	Number of Samples	Volume Filtered (L)	Salmonella Concentration (MPN/l)
RWW	84		
Miramar	55	0.76	12.5
AWT	51	10.1	<3
		10.1	<3

Table 8. Summary of Observed Samonella spp. in Aqua III

Analyte	Source	Median	n	Min	Max
	AWT	<.22	29	<.22	<1.6
Salmonella	MIR	<.22	32	<.22	22
spp. (MPN/l)	RWW	22	32	<22	92

ENTERIC PARASITES

Monitoring programs also concentrated on sampling the waters for two pathogenic parasites: Giardia lamblia cysts and Cryptosporidium oocysts. During the Aqua II sampling period, a large portion of the parasite monitoring was dedicated to methods development. No Giardia spp. Were observed in 55 Aqua II AWT effluent samples or 59 Miramar water samples. Giardia spp. was observed in 49 RWW samples. During the Aqua III sampling period, cryptospridium was only rarely detected with a mean concentration of 2 oocysts/L. During routine monitoring, no Giardia lamblia and Cryptosporidium oocysts were found at a detection limit of <.001 cysts, as shown in Table 9.

Table 9. Summary of Giardia lamblia and Cryptosporidium in Aqua II ATW

Analyte	Source	Median	n	min	max
Giardia lambia	AWT	<.002	29	<.001	<.01
(cysts/l)	MIR	<.002	34	<.001	<.006
	RWW	325	34	<.004	3200
Cryptospridum	AWT	<.002	29	<.001	0.02
(oocysts/l)	MIR	<.002	34	<.001	<.006
	RWW	2	36	<.004	25

HEALTH ADVISORY COMMITTEE CONCLUSION

Based on the investigation performed by the San Diego Health Effects Study, the official conclusion by the Health Advisory Committee was “The health risk associated with the use of the Aqua II ATW water as a raw water supply is less than or equal to that of existing City raw water as represented by the water entering the Miramar water treatment plant.” The results also translated to the Aqua III plant.

LONG TERM RECOMMENDATIONS

To monitor future uses such as this for the treated effluent, the Health Advisory Committee recommended a long term monitoring program to include epidemiology monitoring of the population, ATW plant performance and reliability monitoring, and delivered water quality monitoring.

CONCLUSION

Overall, the study found no evidence of the treated wastewater supply posing an elevated health risk to the general public over the existing raw water supply. Before disinfection, the treated effluent was actually less likely to contain high concentrations of microbial indicators for infectious disease than the existing water supply.

FUTURE USE

The San Diego Health Effects Study concluded that the water quality produced by the Aqua II and Aqua III AWT plants is in compliance with State and Federal drinking water standards, even before drinking water treatment. This opened the doorway to a feasibility study to investigate blending the AWT treated effluent with the existing water supply in a drinking water reservoir.

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