RECYCLED WATER FOOD SAFETY STUDY

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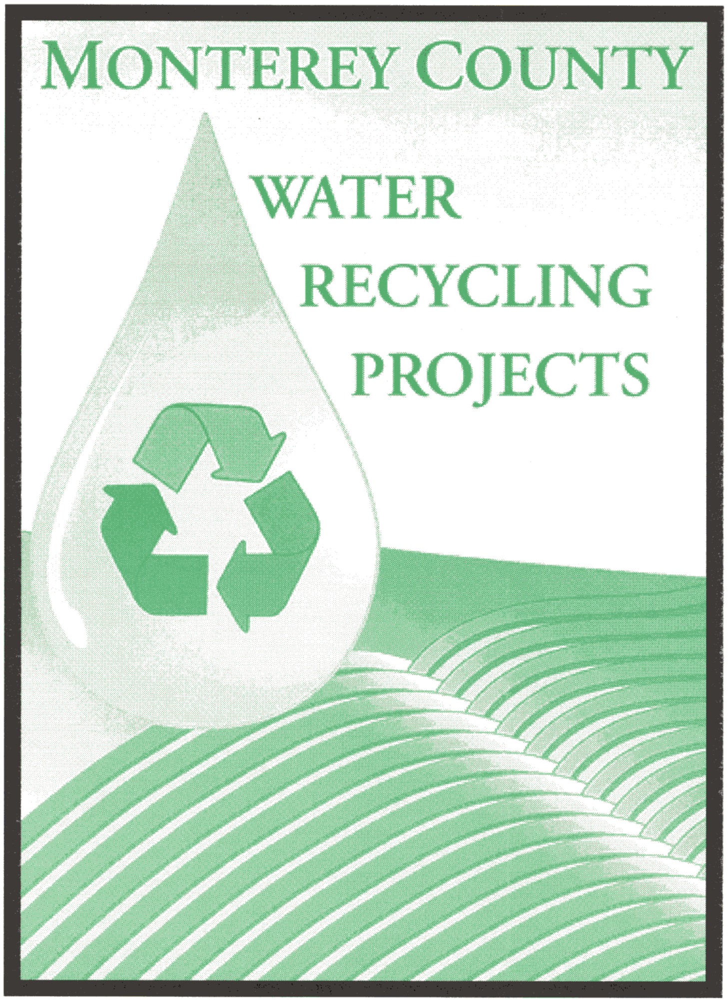

Water Quality and Operations Committee

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sponsored by

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ABSTRACT

During a recent five-year field pilot project conducted in the vicinity of Castroville, California, it was demonstrated that irrigation of raw-eaten vegetable crops with recycled water[1] was as safe as irrigation with other sources of water. No natural virus was detected in the recycled water over the five-year period and virus seeding experiments showed consistent virus removal rates of 99.999 percent or more. In 1997, new questions about food safety (and pathogens that might be in the irrigation water) were raised. Thus, the Recycled Water Food Safety Study was conducted. The study, performed by an independent laboratory at the request of sponsoring agencies, was designed to determine whether or not pathogenic microorganisms of concern to food safety, such as *E.coli* 0157:H7, *Cyclospora,* and *Salmonella* were present in recycled water. Sampling of the recycled water was conducted at intervals over a period of three months. In addition, at the same time, samples were taken from the raw incoming wastewater, from secondary effluent, and from a control source, local well water. This investigation did not detect any *Salmonella, Cyclospora*, or *E. coli* 0157:H7 in any of the samples of recycled water from the Monterey County Water Recycling Projects (MCWRP). The results from samples of recycled water are comparable to those from similar tests at other tertiary recycled water treatment plants and compare favorably with most sources of drinking water supply. Other parasites — of lesser concern to food safety than to drinking water safety — were either absent or were detected at extremely low concentrations of empty, non-viable cysts.

Based on these and earlier findings regarding virus removal capability of the tertiary process, it can be concluded that the MCWRP recycled water is as safe for irrigation of vegetables as are other sources of irrigation water.

INTRODUCTION

The Monterey County Water Recycling Projects (MCWRP) are jointly and cooperatively sponsored by the Monterey County Water Resources Agency (MCWRA)[2] and the Monterey Regional Water Pollution Control Agency (MRWPCA)[3]. These projects will deliver — when operating at capacity — about 19,500 acre-ft per year of recycled water for irrigation of more than 12,000 acres of vegetables. This recycled water (supplemented with groundwater as necessary) is made available in a pressurized distribution network of pipelines, with turnouts at 112 farm irrigation systems.

Safety of the water, as related to food crops irrigated with it, has been a paramount concern of the responsible agencies, growers and landown-

[1] Throughout this report, "recycled water" means **disinfected tertiary recycled water**, as defined and used in the March 1997 draft version of the revised Title 22 Water Recycling Criteria, by the California Department of Health Services.

[2] An agency of the Monterey County government, charged with planning and operation of water resource facilities for the entire county.

[3] A joint-powers agency, providing wastewater collection, treatment and disposal services for a major portion of Northern Monterey County, including the Cities of Del Rey Oaks, Monterey, Pacific Grove, Salinas, Sand City, and Seaside, in addition to Boronda CSD, Fort Ord, Castroville CSA, Marina CWD, Moss Landing CSD and limited portions of unincorporated Monterey County.

ers in the area. Thus, the MCWRP Water Quality and Operations Committee[4] created the Recycled Water Food Safety Study.

The MCWRA and MRWPCA and the members of the Committee had previously relied on a long-term study (completed in 1987) of the comparative safety of irrigating vegetable crops with recycled water. That project, known as the Monterey Wastewater Reclamation Study for Agriculture (MWRSA) (References 1-4), played a significant role in establishing the safety of the proposed recycled water projects and protection of the public health. Based on results obtained from this five-year field pilot study, it had been concluded that recycled water was safe to use for irrigation of food crops. However, given today's emphasis on food safety, Committee members also felt that additional information was needed to assure that the water treatment process would effectively remove certain pathogens of recent concern, such as *Cyclospora* and *E. coli* 0157:H7, that were not included in the 1980-1985 pilot tests of MWRSA.

BACKGROUND

Increased use of water from groundwater sources in Monterey County's Salinas Valley has resulted in an overdraft of coastal aquifers and seawater intrusion. Consequently, the salinity of water in the groundwater wells has increased in an ever-expanding zone along the Coast of Monterey Bay. Many wells have been abandoned as the seawater intrusion front moves farther east toward the City of Salinas.

The economic implications of depletion of groundwater and salinization of an expanding volume of the aquifers for both agricultural and urban sectors in Monterey County are ominous. A local solution to the problem is highly desirable in order to avoid loss of control over the management of the Central Coastal Basin groundwater. Therefore, visionary leaders and planners have looked toward other sources of water to relieve reliance on this diminishing groundwater resource. One such alternative resource is recycled water from the Regional Treatment Plant in Marina, operated by the MRWPCA.

Twenty years of planning, pilot studies, negotiations and lessons learned from many other California water reuse practices have led to the construction of a tertiary treatment plant and distribution system for delivery of recycled water to prime farmlands in the vicinity of Castroville. The treatment process conforms to the very demanding California Title 22 requirements, established by the Department of Health Services. These requirements include coagulation, flocculation, filtration, and disinfection. The treatment and distribution systems were formally inaugurated on October 24, 1997. Actual delivery of recycled water to the farms began in mid-April, 1998. The interim period provided a window of opportunity during which the supplemental testing for pathogenic organisms, reported herein, was conducted.

OBJECTIVE

The main objective of the Recycled Water Food Safety Study was to determine by sampling and analysis, if any viable pathogenic organisms were present in the recycled water produced at the Regional Treatment Plant. A secondary objective was to assess the extent of the ability of the treatment processes to remove pathogens that might be present in the influent wastewater.

[4] The Water Quality and Operations Committee is chaired by Granville Perkins. Other members of the Committee include Tom Erickson, Keith Israel, Allan Jefferson, Marty Johnson, Tony Leonardini, Jim Scattini, Curtis Weeks, and Walter Wong.

MATERIALS AND METHODS

The Recycled Water Food Safety Study was conducted from October 1997 through December 1997. The study was designed on the basis of sampling and analysis for pathogens of concern, and indicators of potential presence of pathogens originating in human or animal waste.

Laboratory personnel of MRWPCA obtained the samples in accordance with detailed procedures and training provided on-site by the principals of BioVir Laboratories. These procedures are documented in various sections of Standard Methods (Reference 5) specifically cited under Methods of Analysis, below. MRWPCA personnel packaged, labeled, chilled, and shipped the samples to BioVir in Benicia, California, using the services of a designated overnight delivery company. BioVir performed analyses in accordance with the most appropriate methods applicable for each parameter, as described further, below.

Quality Assurance Plan

BioVir is a water quality laboratory, certified under the State of California ELAP 1795 (which includes approval for *Giardia* and *Cryptosporidium* analyses), US EPA ICRCA 200 (for *Giardia, Cryptosporidium* and total culturable viruses), and US EPA ICRCA 083 approval for coliform analyses. For *Legionella*, there is no certification or formal approval process. BioVir Laboratories' maintains a comprehensive Quality Assurance Program Plan, which can be accessed by contacting the firm[5]. A team of analytic specialists from the Monterey County Environmental Health Director's Office, headed by Mr. Walter Wong, visited and inspected the Benicia facilities of BioVir Laboratories in December 1997. Further, the Monterey County Health Department performed independent testing of recycled water for selected constituents. Based on these observations, the Department concluded that BioVir Laboratories were operating and performing satisfactorily.

Constituents and Parameters Analyzed: Rationale for Inclusion

The Recycled Water Food Safety Study was aimed toward the acquisition of information needed to respond to the questions raised regarding survivability and viability of certain parasites and other pathogens. Samples were collected from the following four sources:

(1) wastewater treatment plant influent, or raw sewage
(2) secondary effluent,
(3) recycled water, and
(4) a control water source, obtained from a groundwater well storage tank.

These samples were analyzed for *Salmonella*, *E. coli* 0157:H7, *Cyclospora, Cryptosporidium*, *Giardia*, and *Legionella*. Beyond the present study, monthly sampling of recycled water and analyses will continue to be performed for these same pathogens. The purpose of this extended testing is to expand the statistical validity of the sampling program and to provide a longer term data base. It is important to note that these are water-borne pathogens that can produce gastrointestinal diseases in the population when present in drinking water in concentrations exceeding infective doses, which can vary for different individuals. However, the significance of these parameters to food safety is indirect as the irrigation process provides some natural barriers to potential contamination.

In addition to total coliform, turbidity, and chlorine residual — required monitoring analytes for compliance with the Department of Health Services Title 22 regulations — fecal coliform was also monitored during the course of this

[5] BioVir Laboratories may be reached at 685 Stone Road, Benicia, California 94510 and by telephone, at 1/800-GIA-RDIA.

study. Fecal coliform is included because of its significance with regard to indication of potential contamination with animal and/or human waste. Analysis of samples for these indicators continues indefinitely. These routine monitoring efforts will serve to ascertain continuous plant performance in accordance with its design criteria. Over the long term, these performance parameters are the best available indicators of consistent pathogen removal and safety of the irrigation water.

Recycled water from the tertiary plant was sampled for agronomic water quality characteristics: pH, sodium, calcium, magnesium, carbonate, bicarbonate, chloride, boron, total dissolved solids, sodium adsorption ratio, and macronutrients. While these agronomic indicators of water quality have no public health and safety significance, their inclusion in this study was deemed important to the economic interests of the growers. The sampling program is condensed and summarized in Table 1.

Methods of Analysis

Officially referenced standard methods were utilized where available and applicable for specific analyses. In cases of analytes for which no standardized methods were available in the literature, the most commonly accepted procedures and methods used in the profession were selected and utilized. A list of references for the methodologies, which were used for the assay of specific microorganisms, is presented below. Detailed descriptions of the procedures and protocols for sampling and analysis for each constituent and parameter can be found in the given references.

***Cyclospora* spp.** ICR Microbiological Laboratory Manual. USEPA 600/R-95/178, as modified.

***Legionella* spp.** Standard Methods, 18th Ed., APHA/AWWA/WEF Section 9260J, 1992.

Table 1. Sampling Plan for the Monterey County Recycled Water Food Safety Study

Type of Sampling	Analyses	Sampling Locations	Number of Sampling Locations	Number of Samples per Week	Number of Weeks	Total Number of Analyses Planned
Parasites, Bacteria, and Indicators	*Cyclospora* *Legionella* *Salmonella* *E. coli 0157:H7,* *Cryptosporidium* *Giardia*	Influent, Secondary, Tertiary, Control	4	1	7	28
Treatment plant performance	Fecal Coliform, Total Coliform, Turbidity, Chlorine Residual	Recycled Water	1	7	7	49*
Agronomic constituents	Na, Ca, Mg, CO3, HCO3, pH, Cl, B, TDS, N, P, K, SAR (calculated)	Recycled Water	1	1	7	7

* Not including continuous monitoring of turbidity and chlorine residual.

***Fecal* Coliform** Standard Methods, 18th Ed., APHA/AWWA/WEF Section 9221F, 1995.

***Escherichia* coli:** 0157:H7 Membrane filtration. AOAC 997.11, Approved 6/6/97.

Giardia* and *Cryptosporidium ICR Microbiological Laboratory Manual. USEPA 600/R-95/178.

Agronomic constituents Irrigation water quality analytic standards as specified in various Sections in Standard Methods, 18th Ed., APHA/AWWA/WEF, 1992.

RESULTS

Pathogens

Laboratory reports for each sample and each analyte, containing details of analytic techniques, sample identification, chain-of-custody, quality assurance and detection limit documentation are maintained at MRWPCA and at BioVir Laboratories. Summaries of the results of assays for pathogens, and indicators on samples obtained from raw wastewater, undisinfected secondary effluent, recycled water (disinfected tertiary), and a control (well water) are presented in Tables 2 through 5, below.

Table 2. Concentration of Pathogens in Regional Treatment Plant Raw Wastewater (Influent to the Plant)

Sample Date	*E. coli* 0157:H7 (CFU / 100 mL)	*Legionella* (CFU/ mL)	*Salmonella* (CFU / 100 mL)	*Giardia* (/L)	*Cryptosporidium* (/L)	*Cyclospora* (/L)	*Fecal Coliform* (/100 mL)
10/29/97	N. D.*	N. D.	—**	2,000	200	N. D.	7,000,000
11/12- 11/13/97	N. D.	N. D.	N. D.	22,400	143	N. D.	17,000,000
11/17 -11/18/97	N. D.	N. D.	—	6,000	N. D.	N. D.	13,000,000
11/24/97	N. D.	N. D.	2.2	5,218	18	N. D.	30,000,000
12/2 -12/3/97	N. D.	N. D.	16	8,750	N. D.	N. D.	13,000,000
12/8 -12/9/97	N. D.	N. D.	9.2	11,000	N. D.	N. D.	11,000,000
12/15 -12/16/97	N. D.	N. D.	N. D.	17,500	160	330	17,000,000
Average* **	**N. D.**	**N. D.**	**5**	**10,400**	**74**	**47**	**15,000,000**
Range	**—**	**—**	**N. D. – 16**	**2,000 – 22,400**	**N. D. – 200**	**N. D. – 330**	**7,000,000 – 30,000,000**

* N. D. means "none detected" in the collected sample. A discussion of detection limits, is given below.

** — means "not performed".

*** In computing numerical averages, N. D. was set equal to zero and > was set equal to the number.

Table 3. Concentration of Pathogens in Secondary Effluent

Sample Date	*E. coli* 0157:H7 (CFU / 100 mL)	*Legionella* (CFU/ mL)	*Salmonella* (CFU / 100 mL)	*Giardia* (/L)	*Cryptosporidium* (/L)	*Cyclospora* (/L)	*Fecal Coliform* (/100 mL)
10/29/97	N. D.	N. D.	—	0.4	N. D.	N. D.	500,000
11/12- 11/13/97	N. D.	N. D.	—	9.3	0.18	N. D.	—
11/17 -11/18/97	N. D.	N. D.	—	0.4	N. D.	N. D.	230,000
11/24/97	N. D.	N. D.	2.2	8.5	1.8	N. D.	500,000
12/2 -12/3/97	N. D.	N. D.	2.2	5.51	0.45	N. D.	800,000
12/8 -12/9/97	N. D.	N. D.	9.2	12.2	0.10	N. D.	500,000
12/15 -12/16/97	N. D.	N. D.	2.2	6.16	0.14	N. D.	230,000
Average	**N. D.**	**N. D.**	**4.0**	**6.1**	**0.38**	**N. D.**	**596,000**
Range	—	—	**2.2 – 9.2**	**0.4 – 12.2**	**N. D. – 1.8**	—	**230,000 – 800,000**

Table 4. Concentration of Pathogens and Selected Tertiary Plant Operating Parameters for Producing Recycled Water (Disinfected Tertiary)

Sample Date	*E. coli* 0157:H7 (CFU / 100 mL)	*Legionella* (CFU / mL)	*Salmonella* (CFU / 100 mL)	*Giardia* (/L)	*Cryptosporidium* (/L)	*Cyclospora* (/L)	*Fecal Coliform* (/100 mL)	*Turbidity* (NTU)*	*Chlorine Residual* (mg/L)*
10/29-10/30/97	N. D.	N. D.	—	—	N. D.	—	N. D.	1.9	14
11/12-11/13/97	—	N. D.	—	—	—	—	N. D.	1.7	6.2
11/17-11/18/97	N. D.	N. D.	—	N. D.	N. D.	N. D.	N. D.	2.7	—
11/24/97	N. D.	N. D.	N. D.	0.03**	N. D.	N. D.	N. D.	1.2	—
12/2-12/3/97	N. D.	N. D.	—	0.08**	N. D.	N. D.	N. D.	2.3	14
12/8-12/9/97	N. D.	N. D.	N. D.	0.09**	N. D.	N. D.	N. D.	1.6	12
12/15-12/16/97	N. D.	N. D.	N. D.	0.05**	N. D.	N. D.	N. D.	1.5	14
Average	**N. D.**	**N. D.**	**N. D.**	**0.06**	**N. D.**	**N. D.**	**N. D.**	**1.8**	**12**
Range	—	—	—	**N. D. – 0.09****	—	—	—	**1.2 – 2.7**	**6.2 – 14**

* Grab samples

** Determined to be empty or devoid of structure, i. e., non-viable cysts. See section on *Viability of Organisms, Page 9.*

Table 5. Concentration of Pathogens in Well Water (Control)

Sample Date	*E. coli* 0157:H7 (CFU /100 mL)	*Legionella* (CFU/mL)	*Salmonella* (CFU/100 mL)	*Giardia* (/L)	*Cryptosporidium* (/L)	*Cyclospora* (/L)
10/29 -10/30/97	N. D.	N. D.	—	N. D.	N. D.	N. D.
11/12- 11/13/97	—	—	—	—	—	—
11/17 -11/18/97	—	—	—	N. D.	N. D.	—
11/24/97	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
12/2 -12/3/97	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
12/8 -12/9/97	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
12/15 -12/16/97	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.
Average	**N. D.**	**N. D.**	**N. D.**	**N. D.**	**N. D.**	**N. D.**
Range	—	—	—	—	—	—

Detection Limits

Where a sample is assigned "N. D." or "none detected", it means that in the volume of sample collected and analyzed, no (zero) pathogens (for which analysis was performed) were found. A sample is a representation of the content of the entire flow at the time of sampling. The larger the sample volume, the more representative of the entire flow is that sample. It would be impossible to assay the entire flow for pathogens and indicators. Thus, according to accepted scientific methods, sample size was set based on a compromise between practicality and "perfect" accuracy. An indication of the extent to which sample size may reflect the highest possible level of the constituent in the water is a calculated value called "detection limit". The detection limit essentially indicates that a water source with "none detected" (N. D.) in the sample can possibly contain anywhere from zero up to that calculated detection limit — but theoretically no more than that. Within the range of practicality, sample size is often selected to allow for a detection limit that gives an acceptable level of comfort for the safety of the water source, just in case the true concentration of the analyte is actually close to the detection limit. Because sample volume and water quality are not always constant, detection limits can vary widely. Detection limits calculated for all the tests of the various water types are presented in Tables 6 through 9, below.

Table 6. Detection Limits — Raw Wastewater

Sample Date	*E. coli* 0157:H7 (CFU /100 mL)	*Legionella* (CFU/mL)	*Salmonella* (CFU/100 mL)	*Giardia* (/L)	*Cryptosporidium* (/L)	*Cyclospora* (/L)
11/17/97	1,000	1	—	42	42	42
11/24/97	1,000	1	2.2	18	18	18
12/2 - 12/3/97	1,000	1	2.2	74	74	74
12/8 - 12/9/97	1,000	1	2.2	57	57	57
12/15 - 12/16/97	1,000	1	2.2	160	160	330

Table 7. Detection Limits — Secondary Effluent

Sample Date	*E. coli* 0157:H7 (CFU /100 mL)	*Legionella* (CFU/mL)	*Salmonella* (CFU/100 mL)	*Giardia* (/L)	*Cryptosporidium* (/L)	*Cyclospora* (/L)
10/29 - 10/30/97	2	0.1	—	—	—	—
11/17 - 11/18/97	10	0.1	—	0.017	0.017	0.017
11/24/97	10	0.1	2.2	0.082	0.082	0.082
12/2 - 12/3/97	10	0.1	2.2	0.09	0.09	0.09
12/8 - 12/9/97	10	0.1	2.2	0.104	0.104	0.104
12/15 - 12/16/97	10	0.1	2.2	0.14	0.14	0.14

Table 8. Detection Limits — Recycled Water (Disinfected Tertiary)

Sample Date	*E. coli* 0157:H7 (CFU /100 mL)	*Legionella* (CFU/mL)	*Salmonella* (CFU/100 mL)	*Giardia* (/L)	*Cryptosporidium* (/L)	*Cyclospora* (/L)
10/29 - 10/30/97	2	0.1	—	—	—	—
11/17 - 11/18/97	2	0.1	—	0.011	0.011	0.011
11/24/97	2	0.1	2.2	0.034	0.034	0.034
12/2 - 12/3/97	10*	—	—	0.019	0.019	0.019
12/8 - 12/9/97	2	0.1	2.2	0.011	0.011	0.011
12/15 - 12/16/97	2	0.1	2.2	0.0037	0.0037	0.0037

* Sample turbidity limited the volume that could be filtered, hence the higher calculated limit.

Table 9. Detection Limits — Well Water-Control

Sample Date	*E. coli* 0157:H7 (CFU /100 mL)	*Legionella* (CFU/mL)	*Salmonella* (CFU/100 mL)	*Giardia* (/L)	*Cryptosporidium* (/L)	*Cyclospora* (/L)
11/17/97	—	—	—	0.038	0.038	0.038
11/24/97	2	0.1	2.2	0.032	0.032	0.032
12/2 - 12/3/97	1	0.1	2.2	0.005	0.005	0.005
12/8 - 12/9/97	2	0.1	2.2	0.016	0.016	0.016
12/15 - 12/16/97	2	0.1	2.2	0.0096	0.0096	0.0096

Removal Capabilities of Tertiary Process

Based on data presented in Tables 2 through 4, it is evident that *Giardia spp.* is reduced by five to six logs (100,000 to a million-fold) from influent to the plant to the finished recycled water. Because the other pathogens arrive at the treatment plant at much lower concentrations, and because of their absence in the final effluent, it is not as readily possible to calculate a corresponding removal capability for them. However, based on the calculated rates of removal for *Giardia spp.*, it is reasonable to extrapolate similarly high removal rates for the other organisms as well.

Giardia spp. are common in raw sources of water and in wastewaters. The *Giardia spp.* found remaining in the recycled water were empty cysts, hence they were classed non-viable. A discussion of the significance of non-viable cysts found in the recycled water is presented in the following paragraphs.

Viability of Organisms

The analysis for *Giardia spp.* and *Cryptosporidium spp.* included classification of the potential viability of those organisms observed. Four criteria are evaluated when conducting this analysis: the FITC stain, and three classes of organism internal structure. The FITC stain is antibody-based and interacts specifically with *Giardia spp.* and/or *Cryptosporidium spp.* The objects would be a distinctive brightly glowing green. Next, a different type of lighting (differential contrast) is used to reveal the internal structure of a green glowing object. There are two techniques of generating this type of differential lighting. One is called Hoffman Modulation, the other Differential Interference Contrast (DIC). Both techniques were employed. There are three classes of organisms based upon the status of the internal structure. The first is the absence of any internal structure and the object can be classified as "empty". It is generally believed that an empty (oo)cyst is a non-viable shell of the target organism. The next class is assigned to those organisms with no organized internal structure and these are referred to as "amorphous". Again, these may be considered non-viable. The last classification is based upon the presence of obvious internal structure, and can further be described by the degree of internal organization. Conservatively, this latter type of organism may be considered viable.

Giardia spp. and *Cryptosporidium spp.* of all types were observed in the raw influent and to a lesser extent in the secondary effluent. In all of the recycled water samples, 100 percent of the *Giardia spp.* observed were empty, non-viable cysts. It should be noted that the antibody reagent used for the detection of *Giardia spp.* does react with non-human infective forms as well. Therefore, many of the *Giardia spp.* observed may have come from non-human sources.

The Los Angeles County Sanitation Districts have completed an intensive monitoring program at seven water reclamation plants in the County (using similar processes to those employed by MCWRP) to determine the occurrence and viability of protozoan pathogens through the treatment process. Even though *Giardia* cysts were detected in the recycled water, they were established to be non-viable (Reference 6), in the numerous samples analyzed, using similar techniques to those reported above. Findings of this ongoing study are expected to be published by the end of 1998.

Agronomic Characteristics

Samples for analysis of inorganic constituents of concern for agronomic reasons were sent to Delta Environmental Laboratories in Benicia, California. The concentrations of constituents of agronomic significance in the recycled water are summarized in Table 10, shown on the following page.

Table 10. Concentration of Constituents of Agronomic Significance in Recycled Water

Constituent	10/31*	11/14	11/19	11/26	12/4	12/10	12/17	Average	Range
Carbonate	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.	—
Bicarbonate	290	260	280	276	330	257	256	278	256-330
T D S	980	960	970	980	1,060	857	860	952	857-1,060
Chloride	350	330	340	291	340	256	252	308	252-350
.pH	7.4	7.0	7.1	7.5	7.5	6.6	7.3	7.2	6.6-7.5
Total N	37	37	42	34	53	27	28	36	27-53
Ammonia	32	34	39	28	—	—	—	33	28-39
Total P	1.3	0.64	0.84	0.74	0.89	0.43	0.47	0.76	0.43-1.3
Sodium	250	220	220	199	224	200	240	222	199-250
Calcium	54	53	60	57	60	56	61	57	53-61
Magnesium	29	26	28	25	28	26	29	27	25-29
Boron	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.	N. D.	—
Potassium	24	16	18	15	16	14	15	17	14-24
SAR	6.8	6.2	5.9	5.5	6.0	5.5	6.3	6.0	5.5-6.8
Adj. SAR	7.6	7.0	6.8	6.3	7.1	6.4	7.4	6.9	6.3-7.6

* All dates are in 1997.
N. D. = None detected. Detection limit for Carbonate is 10 mg/L and for boron 0.5 mg/L.
— = Not applicable, or test not run.

These values generally fall within ranges considered to be non-problematic for long-term irrigation, given an adequate leaching fraction at each irrigation and well-drained soils and subsoils. The relatively high sodium levels (probably due to water softeners and their regeneration cycles) are cause of some concern and should be closely monitored. If needed, calcium injection or amendment of the soil with gypsum could lower sodium adsorption ratio of the irrigation water and the soil solution.

PLANT OPERATIONS

The tertiary treatment plant was generally operated within normal design and Title 22 parameters during the study period. Key operating parameters included flow rate, chemical dosage, filter loading, and chlorine contact time. However, since the plant was being tested and readied for full-scale operation, certain levels (e. g. chlorine residual) were somewhat elevated. Since this study was completed, operations have been fine-tuned and optimized while still achieving superior pathogen removal and Title 22 compliance.

DISCUSSION

The results presented above can best be viewed in the context of water quality data for a variety of sources commonly used for intimate human contact. Because of the recent concerns about *E. coli* 0157:H7, *Cyclospora, Legionella,* and other pathogens in the food supply, there is not an extensive body of information for comparison. The Florida Department of Environmental Protection Water Reuse Coordinator prepared a compilation of the occurrence of two key protozoa in many high-quality drinking water sources in the United States and Canada (Reference 7). The results are adapted and reproduced in Tables 11 and 12, below, including a summary of the corresponding results from this study:

Table 11. Occurrence and Concentration of Cryptosporidium in Different Water Sources

Water Type Location	Percent Positive	Average Concentration (/100L)	Range	No. of Samples	Notes
Recycled Water					
St. Petersburg, FL	17	0.75	N. D.-5.35	12	
MCWRP, CA*	*0*	*N. D.*	—	*6*	*See Table 4*
Groundwater					
Springs	—	4	—	7	
Well Waters	5.5	0.3	N. D.-4	12	
Well Waters	17	41	—	74	
*Monterey Well**	*0*	*N. D.*	—	*8*	*See Table 5*
High Quality Surface Waters					
Source Water	87	270	N. D.-48,400	151	66 plants in 14 states, Canada
Source Water	52	240	N. D.-6,510	262	from 72 water plants, '91-'93
NW USA	36	1.6	N. D.-5.4	52	
NYC Watersheds					
Catskill	46	1.4	N. D.-17.3		
Delaware	37	0.8	N. D.-15		
Malcolm Br'k	52	1.0	N. D.-43.4		
NYC Source	2	—	N. D.-1.38	203	
W USA Rivers	83	2	N. D.-13	6	Protected watersheds
W USA Rivers	—	8	—	3	Protected watersheds
Pristine Rivers	32	29	N. D.-24,000	59	
Pristine Lakes	53	9.3	N. D.-307	34	
Tampa Canal, FL	43	3.1	N. D.-11	7	
Drinking Water					
Filtered Water	27	1.5	N. D.-48	151	66 plants in 14 states, Canada
Treated Water	13	3.3	N. D.-57	262	from 72 water plants, '91-'93
Treated Water	17	0.1	—	36	
Filtered Water	20	0.1	—	10	Western USA
Non-Filtered	50	0.6	—	4	Western USA

Source: Data were assembled from 13 different sources, mostly by Dr. David York, Florida Department of Environmental Protection Reuse Coordinator, in Proceedings, Water Reuse '98, AWWA/WEF Joint Sponsored Conference, February 1-4, 1998, Orlando, Florida — with adaptation. The Florida DEP is the regulatory agency in charge of enforcing regulations on safe use of all recycled water in that state.

* Data from the Monterey County Water Recycling Projects (MCWRP), the current study, were added to the York compilation for comparison.

Table 12. Occurrence and Concentration of Giardia in Different Water Sources

Water Type Location	Percent Positive	Average Concentration (/100L)	Range	No. of Samples	Notes
Recycled Water					
St. Petersburg, FL	25	0.49	N. D.-3.3	12	
MCWRP, CA*	*80***	*6*	*N. D.-9*	*5*	*See Table 4 (Note different Units)*
Groundwater					
Springs	0	<0.25	—	7	
Wells	0	<0.25	—	12	
Wells	9.5	16	—	74	
*Monterey Well**	*0*	*N. D.*	—	*8*	*See Table 5*
High Quality Surface Waters					
Source Water	81.2	277	N. D.-6,600	151	66 plants in 14 states + Canada
Source Water	45	200	N. D.-4,380	262	from 72 water plants, '91-'93
NYC Watersheds					
Catskill	36	1.2	N. D.-9.3		
Delaware	29	0.7	N. D.-8.2		
Malcolm Br'k	46	1.3	N. D.-23.4		
NYC Source	3.0	—	N. D.-1.38	203	
Portland, OR	19	—	0.34-2.77	Several	Protected reservoir
W USA Rivers	17	0.6	—	6	
W USA Rivers	—	0.9	—	3	
Pristine Rivers	6.8	0.35	—	59	
Pristine Lakes	12	0.5	N. D.-12	34	
3 Seattle Rivers	42	6.3	N. D.-7	222	Pristine river systems in WA
Tampa Canal, FL	14	0.42	N. D.-520		
Drinking Water					
Filtered Water	17.1	4.45	N. D.-64	151	66 plants in 14 states + Canada
Treated Water	4.6	2.6	N. D.-9	262	from 72 water plants, '91-'93
Treated Water	0	<0.25	—	36	

Source: Data were assembled from 13 different sources, mostly by Dr. David York, Florida Department of Environmental Protection Reuse Coordinator, in Proceedings, Water Reuse '98, AWWA/WEF Joint Sponsored Conference, February 1-4, 1998, Orlando, Florida — with adaptation. The Florida DEP is the regulatory agency in charge of enforcing regulations on safe use of all recycled water in that state.

* Data from the Monterey County Water Recycling Projects (MCWRP), the current study, were added to the York compilation for comparison.

** All positives were classed as non-viable: they were either empty cysts or contained no organized internal structure (amorphous). See Section on *Viability of Organisms*.

CONCLUSIONS

Food Safety

This study showed that viable microorganisms of public health concern are not present in the recycled water produced by the MCWRP. This finding corroborates and strengthens the results of the five-year field pilot study near Castroville completed in 1987, which concluded that recycled water was safe for irrigation of raw-eaten food crops. Furthermore, comparison of results obtained from the MCWRP recycled water with those obtained from raw and treated drinking water sources, both for *Cryprosporidium spp.* and for *Giardia spp.* provides an additional indication of safety of the recycled water. Occurrence and concentration of cysts of these protozoa in recycled water is comparable with or lower than in the other waters, some of which are sources of drinking water supply for communities in the United States and Canada.

The Recycled Water Food Safety Study did not detect any *Salmonella, Cyclospora, E. coli* 0157:H7, *Cryptosporidium,* or viable *Giardia* in the MCWRP recycled water. This study augments the Monterey Wastewater Reclamation Study for Agriculture completed in 1987, which detected no natural, *in situ* virus and demonstrated over five-log removal of viruses. Together, these studies assure the safety of recycled water for irrigation of food crops that are consumed without cooking.

Natural Barriers to Pathogens

Besides the treatment processes, there are also natural barriers to the transfer of contaminants — living organisms and organic molecules — from the irrigation water into the plant tissues. The cell walls of plant roots and leaves act to filter the irrigation water. Therefore, microorganisms cannot pass through and into the edible tissues of the crops. A classic work (Reference 8) concluded early on that it was unlikely that viruses would be translocated from the soil water into plant tissues. Furthermore, drying and solar radiation provide further barriers to any organisms that might be still viable in the sprayed irrigation water. The normally dry period prior to harvest affords these mechanisms an opportunity to minimize the presence of any viable microorganisms on plant surfaces after harvest. The combined effect of these natural barriers is to further assure the safety of recycled water.

Agronomic Parameters

Even though the primary focus of this study was on food safety and public health protection, agronomic parameters were also assayed. These assays largely confirmed the suitability of recycled water for long-term irrigation use on the soils of the study area. However, the relatively high sodium levels should be closely monitored to determine if source control or other measures would be needed in the future.

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