APPENDIX I.1 - HUMAN HEALTH RISK ASSESSMENT

Human Health Risk Assessment

SANTA ROSA
INCREMENTAL RECYCLED WATER PROGRAM

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EXECUTIVE SUMMARY

This screening health risk assessment was conducted for the Santa Rosa Incremental Recycled Water Program (IRWP) and updates the risk assessment that was prepared for the Subregional Long-Term Wastewater Project (Long-Term Project) in 1997. It evaluates the theoretical health risks to the public associated with exposure to the chemicals and pathogens that might be present in tertiary treated recycled water from the Laguna Wastewater Treatment Plant (Laguna Plant). It is based on water quality data collected from December 1997 through April 2002.

APPROACH

Many chemicals that were evaluated in the risk assessment for the Long-Term Project have decreased in concentration because of recent upgrades to treatment processes at the Laguna Plant. Nitrification and denitrification have reduced concentrations of ammonia, nitrate and nitrite. Replacement of chlorine disinfection with ultraviolet disinfection has reduced concentrations of disinfection byproducts such as chloroform. Increased aeration capacity has reduced concentrations of volatile organic compounds. Thus, because many chemical concentrations have decreased and because only a few chemicals exceeded the screening criteria used previously for the Long-Term Project, this risk assessment update evaluates only those chemicals that have increased in concentration, that were not detected previously, or that previously triggered a significant impact.

The initial step of the risk assessment employs a method designed to identify and screen out chemicals and microorganisms that do not present a hazard and do not warrant further analysis. The screening is accomplished by using “worst case” assumptions (e.g., maximum detected concentrations, direct exposure to recycled water via a domestic water supply, long-term exposure, etc.). Chemicals and microorganisms that do not present a hazard under these conditions would not present a hazard under more probable conditions (e.g., concentrations less than maximum due to dilution, degradation, or filtration, periodic exposure). Those chemicals and microorganisms that do not pass the screen may or may not present a health hazard and are evaluated further, taking into consideration IRWP-specific information (e.g., the potential for dilution, chemical degradation, volatilization or other mitigating factors that would cause actual exposures to be lower than those used for the screening process).

The chemical and pathogen risk assessments consist of a summary and evaluation of existing chemical and biological analytical data, an exposure assessment, a toxicity assessment, and a risk characterization. The quantitative portion of the risk assessments assume that an exposed human population would use undiluted recycled water as a domestic water supply and would receive additional exposure by consuming fish caught from the surface water bodies that receive recycled water. This approach overestimates the potential health risks posed by exposure to recycled water through the discharge or reuse scenarios of the IRWP. Although long-term exposure to undiluted recycled water is not proposed and is not expected to occur, this approach was selected to screen out chemicals and microorganisms that do not present a significant human health impact.

CHEMICAL AND BIOLOGICAL ANALYTICAL DATA

The data used in this update were collected from December 1997 through April 2002 with the exceptions noted below. December 1997 was used as the beginning date because this was when the Laguna Plant upgraded its wastewater treatment process to include nitrification and denitrification and to increase its aeration capacity. Nitrification and denitrification remove ammonia, nitrate and nitrite while increased aeration capacity results in longer residence times and improved removal rates for many constituents (e.g., volatile organic compounds). Data for trihalomethanes and pathogens were collected from September 1998 (when chlorine disinfection was discontinued and ultraviolet disinfection was implemented) through April 2002.

Total coliform data were collected from December 1997 through April 2002. *Giardia* and *Cryptosporidium* data were collected from May 1996 through January 1997. Although *Salmonella, Shigella, Legionella*, and enteric viruses were assayed for during the Long-Term Project they were not detected in any samples and updated data were not collected. They were not analyzed for during the IRWP because sampling results for indicator organisms (i.e. total coliforms) indicate that it is unlikely that their concentrations have increased to levels that would cause disease.

EXPOSURE PATHWAYS

Screening exposure pathways considered for both the chemicals and microorganisms in recycled water include domestic use of water for drinking and bathing, recreational use, irrigation use, and consumption of fish that have contacted recycled water. The potentially exposed population is assumed to be residents of Sonoma County who may come into contact with the chemicals or microorganisms in recycled water via these exposure pathways. Sensitive subpopulations (e.g., young children, pregnant or nursing women, the elderly, and people with suppressed immune systems) are identified and discussed.

TOXICITY ASSESSMENT AND RISK CHARACTERIZATION

Hazard quotients are used to evaluate the noncarcinogenic health effects of the chemical components. A hazard quotient of less than 1.0 indicates that a chemical would not produce an adverse health effect. Theoretical incremental lifetime cancer risks (ILCRs) are used to evaluate carcinogenic health effects of the chemical components. In general, ILCRs greater than one in a million (1×10^{-6}) to one in one-hundred thousand (1×10^{-5}) are considered by the State of California to pose a significant threat to human health (Title 22, California Code of Regulations, §12703). For this assessment an ILCR of 1.0×10^{-6} is used as a screening level for carcinogenic health effects.

Chemical components that do not pass the screen are examined further and are evaluated as to their environmental fate (chemical or biological degradation), attenuation (loss of viability in the case of pathogens), filtration, dilution by groundwater or surface water, background concentrations, and comparison to State and federal drinking water standards (Maximum Containment Limits, MCLs) and recycled water standards.

The assessment of risk for the microorganisms in Laguna Plant effluent is evaluated by comparing the biological data to a known infective dose (*Giardia* and *Cryptosporidium*), to background concentrations (total coliform bacteria), and to regulatory standards (total coliform).

Noncarcinogenic Chemicals

Of the detected chemicals, the maximum concentrations of ammonia and nitrite in undiluted effluent yield hazard quotients greater than 1.0. The maximum concentration for ammonia exceeded the threshold where it could be detected by smell (but not by taste). The hazard quotients associated with the mean concentrations of these two chemicals are less than 1.0. No other chemical yields a hazard quotient greater than 1.0.

The maximum nitrite (2.3 mg/L) and nitrate (15.5 mg/L) concentrations (as nitrogen) and the combined nitrate and nitrite concentrations in undiluted effluent are greater than the State and federal drinking water standards (1.0 mg/l for nitrite and 10 mg/L for nitrate and nitrate and nitrite combined). Dilution of recycled water with surface water or groundwater upon release and uptake of these chemicals by terrestrial and aquatic plants would reduce the potential human health hazard from nitrate, nitrite, and ammonia, and these chemicals would not present a significant human health hazard via most of the expected exposure pathways. In addition, average concentrations might be more representative of the nitrate and nitrite levels that would be present after storage in reservoirs. Mean concentrations of nitrite (0.18 mg/L) and nitrate (7.3 mg/L) are less than State and federal drinking water standards.

Carcinogenic Chemicals

The ILCR associated with the maximum concentration of chloroform slightly exceeds the screening level of 1.0×10^{-6}. Because the risk is based on the maximum detected concentration in effluent, it overestimates the potential risk from exposure to recycled water via the expected exposure pathways. The concentration of chloroform (one of several disinfection byproducts, or DBPs) is well below the State and federal MCL (0.080 mg/L) for DBPs. Dilution of recycled water with surface water or groundwater, chemical and biological degradation (of organics), and adsorption of chemicals to soils and sediments would further reduce chemical concentrations in recycled water and the actual risk values. Given that the mean concentration does not exceed the MCL and that additional factors (e.g., dilution, volatilization, biological and chemical degradation, changes in treatment plant processes) would reduce chemical concentrations in recycled water it is unlikely that the potentially carcinogenic chemical components of recycled water would present a significant long-term human health risk via the expected exposure pathways.

Fish Consumption

Water quality data and organismal data from the Kelly Farm Pond bioaccumulation study and from the Regional Water Quality Control Board's Toxic Substances Monitoring Program (TSMP) on the Russian River were used to evaluate the potential human health hazard associated with the consumption of fish for the Long-Term Project. Because most chemicals have decreased in concentration since the Long-Term Project was prepared and the newly detected chemicals do not bioaccumulate (i.e., methyl *tert*-butyl ether, MTBE) or have only a low potential to bioaccumulate (i.e., naphthalene) the conclusion of the previous risk assessment—that chemicals detected in recycled water do not present a significant human health hazard via fish consumption—remains valid.

Microorganisms

Total coliforms were detected at a median monthly concentration of <2 most probable number (MPN)/100 mL during the IRWP sampling period from December 1997 through April 2002. The maximum daily concentration during this time was 240 MPN/100 mL. Samples collected from the Russian River for the Long-Term Project varied in concentration from 23 to 240 MPN/100 mL but concentrations as high as 16,000 MPN/100 mL have been reported. *Cryptosporidium* oocysts were detected in one (9.6 oocysts/100 L) of 34 of final fresh effluent samples from the Laguna Plant collected from May 1996 until January 1997. *Giardia* cysts were detected in four (37 cysts/100 L maximum) of 34 final fresh effluent samples. *Cryptosporidium* (2.7 oocysts/100 L) and *Giardia* (13.8 cysts/100 L) have been detected in Russian River samples (CH2M Hill 1993). Given their low concentrations, information on background concentrations in the Russian River, and the expected filtering effects of soils and base materials the microorganisms of recycled water would not present a significant human health hazard via the expected exposure pathways. The inclusion of reverse osmosis treatment as part of the direct and indirect discharge alternatives would further decrease the concentrations of microorganisms.

1.0 INTRODUCTION

This document describes a screening health risk assessment conducted for the Santa Rosa Incremental Recycled Water Program (IRWP). It updates the health risk assessment that was prepared for the Subregional Long-Term Wastewater Project (Long-Term Project) in 1997 (Parsons 1997). It evaluates the potential health risks to the public associated with exposure to tertiary treated recycled water from the Laguna Wastewater Treatment Plant (Laguna Plant) based on recently collected water quality data (generally December 1997 through April 2002). Risks from exposure to chemicals and to pathogens potentially in the treated recycled water are considered.

1.1 SCOPE OF ASSESSMENT

Public health risk assessment, as widely practiced, consists of four steps—hazard identification, exposure assessment, toxicity assessment, and risk characterization (NRC 1983, 1994). The process used for this risk assessment includes the following:

- A hazard identification step that uses the most recently available chemical and biological analytical data to identify chemicals and biological agents in the fresh and stored effluent from the Laguna Plant;
- An exposure assessment that describes the nature, duration, and magnitude of potential human exposures to the chemicals and biological agents in the Laguna Plant's effluent;
- A toxicity assessment that provides dose-response information for the detected chemicals and microorganisms; and
- A risk characterization that integrates the exposure assessment and the chemical and pathogen toxicity information to quantitatively or qualitatively describe the potential carcinogenic and noncarcinogenic health risks due to the chemicals and biological agents in the Laguna Plant's effluent.

The quantitative portion of this risk assessment is based on the theoretical and conservative (health protective) assumption that a human population could be exposed to undiluted recycled water via a domestic water supply and could receive additional exposure to chemicals in recycled water by consuming fish caught from surface water bodies that receive recycled water. Although this is an unlikely scenario and it tends to overestimate the potential health risks posed by exposure to the recycled water through the discharge or reuse scenarios of the IRWP, it was selected to screen out chemicals that present a very low probability of human health impact. All detected chemicals and pathogens are evaluated in the screening process. Chemicals and pathogens that pass the screen would not present a significant human health hazard. Chemicals that do not pass the screen are examined further to consider mitigating factors that would affect their environmental concentrations, and thus exposure, such as their environmental fate (chemical or biological degradation), attenuation (loss of viability in the case of pathogens), and dilution by groundwater or surface water. Detected chemical and pathogen concentrations are also compared to regulatory standards. These factors are considered in the appropriate sections on risk characterization (Sections 2.5 and 3.5).

The risk assessment report is divided into four sections. Section 2 follows this introduction and evaluates the human health risk from exposure to the chemicals contained in the Laguna Plant's effluent. Section 3 evaluates the human health risk from exposure to the biological agents contained in the Laguna Plant's effluent. Section 4 is a list of references.

2.0 RISK FROM CHEMICALS

2.1 CHEMICALS IN LAGUNA PLANT WASTEWATER

The data used in this update were collected from December 1997 through April 2002 with the exceptions noted below. December 1997 was used as the beginning date because this was when the Laguna Plant upgraded its wastewater treatment process to include nitrification and denitrification and to increase the aeration capacity. Nitrification and denitrification remove ammonia, nitrate and nitrite while the expanded aeration capacity results in longer residence times and improved removal rates for many constituents (e.g., volatile organic compounds). Data for trihalomethanes and pathogens were collected from September 1998 (when chlorine disinfection was discontinued and ultraviolet disinfection was implemented) through April 2002.

The data considered for the Long-Term Project were obtained from the Laguna Plant's quarterly water monitoring program (1988-1995) and from data collected as part of the Long-Term Project (1994-1995). Results of the recent IRWP sampling events are compared to data from the Long-Term Project in Table 2.1-1. Fewer chemicals were detected in the recent samples than in the samples collected for the Long-Term Project, although the analyses performed and their detection limits were comparable (Merritt Smith Consulting 1995b, 2002). Lists of chemical analytes and their reporting limits are presented in the *Field Sampling and Quality Assurance Plan* and the *Reclaimed Water Quality Technical Report* for the Long-Term Project and the *Effluent Quality, Reasonable Potential Analysis, and Permit Limits* memorandum prepared for the IRWP (Merritt Smith Consulting 1995a, 1995b, 2002).

The average (mean) concentration for each chemical in Table 2.1-1 was calculated using all quantified values and most non-detect values. Some non-detect values were excluded from the calculation of the average when the reporting limits of the analytical method were several times greater than the highest detected value. The following criteria were applied to non-detects when calculating average concentrations:

- When one-half of the reporting limit for a non-detect was more than twice the maximum detected concentration of any quantified value, that non-detect value was not used to calculate the mean;
- For values reported as non-detect, one-half of the reporting limit was used to calculate the mean.

Table 2.1-1

Chemicals Detected in Tertiary Treated Recycled Water from the Laguna Plant

	1996 Data for Fresh Effluent (1)			2002 Data for Fresh Effluent (2)			Direction of Concentration Change	
Chemical(3)	**Maximum Concentration (mg/L)**	**Mean Concentration (mg/L)**	**Detects/ Total No. Samples**	**Maximum Concentration (mg/L)**	**Mean Concentration (mg/L)**	**Detects/ Total No. Samples**	**Maximum**	**Mean**
Inorganics								
Aluminum	0.15	0.03	20/27	0.15	0.03	75/82	No Change	No Change
Ammonia	40.3	4.1	49/49	12.0	0.60	NR	Decrease	Decrease
Arsenic	0.004	0.002	25/30	0.003	0.002	1/18	Decrease	No Change
asbestos, MFL(4)	0.56	0.25	2/4	NA	NA	NA	—	—
Barium	0.11	0.02	4/27	0.11	0.02	4/27	No Change	No Change
Boron	0.60	0.48	17/18	0.60	0.47	18/18	No Change	Decrease
Cadmium	0.007	0.001	6/89	ND	ND	0/18	Decrease (6)	Decrease
Chromium	0.014	0.002	49/90	ND	ND	0/18	Decrease	Decrease
Copper	0.04	0.01	88/90	0.014	0.0086	16/18	Decrease	Decrease
Fluoride	0.31	0.22	4/4	0.20	0.20	1/1	Decrease	Decrease
Lead	0.012	0.005	19/90	0.0058	0.0019	1/18	Decrease	Decrease
Mercury	0.0002	0.0001	1/91	ND	ND	0/18	Decrease	No Change
Nickel	0.010	0.004	56/90	0.0073	0.0034	10/18	Decrease	Decrease
Nitrate	50.5	16.3	49/49	15.5	7.3	NR(5)	Decrease	Decrease
Nitrite	7.3	0.3	45/48	2.3	0.18	NR	Decrease	Decrease
Silver	0.010	0.001	40/88	ND	ND	0/18	Decrease	Decrease

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Zinc	0.28	0.03	82/90	0.035	0.027	17/18	Decrease	Decrease
Volatile Organics								
Acetone	0.0060	0.0042	2/14	NA	NA	NA	—	—
bromodichloromethane	0.0110	0.0022	22/23	ND	ND	0/15	Decrease	Decrease
bromomethane	0.0014	0.0003	1/19	ND	ND	0/18	Decrease	Decrease
carbon disulfide	0.0370	0.0040	3/14	NA	NA	NA	—	—
chlorobenzene	0.0001	0.0001	1/19	ND	ND	0/18	Unknown (6,7)	Unknown
Chloroform	0.0440	0.0099	23/23	0.004	0.0011	4/15	Decrease	Decrease
chloromethane	0.0050	0.0005	1/19	ND	ND	0/18	Decrease	Decrease
Cyanide	0.03	0.01	6/11	0.016	0.0044	6/18	Decrease	Decrease
dibromochloromethane	0.0021	0.0004	4/22	ND	ND	0/15	Decrease	Decrease
1,4-dichlorobenzene	0.0009	0.0006	10/13	0.0006	0.00034	4/18	Decrease	Decrease
Ethylbenzene	0.0010	0.0002	1/19	ND	ND	0/18	Decrease	Decrease
methyl *tert*-butyl ether (MTBE)	NA	NA	—	0.0018	0.00093	9/12	**New**	**New**
methylene chloride	0.0060	0.0008	5/19	ND	ND	0/18	Decrease	Decrease
Naphthalene	ND	ND	—	0.0075	0.0046	1/18	**New**	**New**
tetrachloroethylene	0.0006	0.0002	2/19	ND	ND	0/18	Decrease	Decrease

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Toluene	0.0004	0.0002	2/19	ND	ND	0/18	Decrease	Decrease
1,1,1-trichloroethane	0.0002	0.0002	1/19	ND	ND	0/18	Decrease	Decrease
Xylenes	0.0002	0.0002	1/18	NA	NA	NA	—	—
Phthalates								
di-n-butyl phthalate	0.0019	0.0012	2/19	ND	ND	0/18	Unknown	Unknown
bis (2-ethylhexyl) phthalate	0.0060	0.0028	5/19	ND	ND	0/18	Unknown	Unknown
diethyl phthalate	0.0070	0.0009	2/19	ND	ND	0/18	Unknown	Unknown
Pesticides								
aldicarb sulfone	0.0018	0.0011	2/4	NA	NA	NA	—	—
aldicarb sulfoxide	0.0019	0.0008	2/4	NA	NA	NA	—	—
Aldrin	0.00003	0.00001	3/19	ND	ND	0/18	Decrease	Decrease
DCPA (Dacthal)	0.0003	0.0002	2/4	NA	NA	NA	—	—
Endosulfan II	0.00001	0.00001	1/19	0.000028	0.00008	1/18	**Increase**	**Increase**

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Chemical(3)	**Maximum Concentration (mg/L)**	**Mean Concentration (mg/L)**	**Detects/ Total No. Samples**	**Maximum Concentration (mg/L)**	**Mean Concentration (mg/L)**	**Detects/ Total No. Samples**	**Maximum**	**Mean**
Pesticides								
α-lindane	0.00003	0.00001	2/19	ND	ND	0/18	Unknown	Unknown
γ- lindane	0.00009	0.00002	8/19	0.000024	0.00002	1/18	Decrease	No Change
Heptachlor	0.00003	0.00001	1/19	ND	ND	0/18	Unknown	Unknown

NA - not analyzed
ND - not detected
— - constituent was not analyzed in the most recent sampling dataset

(1) Data collected between 1988 and 1995.

(2) Data collected between December 1997 and April 2002.

(3) Five inorganic elements (calcium, magnesium, phosphorus, potassium and sodium) that were included in the data summary in 1997 are omitted because they are essential human nutrients and not generally evaluated in risk assessments.

(4) Asbestos values are reported as millions of fibers per liter (MFL).

(5) NR – Not reported, actual number of samples collected each month for this constituent is variable, and the database used for this analysis gives only the monthly average, minimum and maximum..

(6) For analytes that were reported as “not detected” in the 2002 IRWP dataset, median detection limits were compared to 1996 Long-Term Project maximum and mean concentrations and median detection limits, to determine if analyte had increased, decreased or was unchanged.

(7) The detection limits for this constituent are higher in 2002 than the reported maximum and/or mean concentrations and detection limits reported in the 1996 dataset, so it can not be determined whether this compound has increased, decreased or remained unchanged. However, these analytes are not considered further because the changes in detection limits were small (generally two- to five-fold) and the previous risk assessment determined that the constituent did not present a significant cancer risk or non-cancer hazard.

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2.2 POTENTIALLY EXPOSED POPULATION

Components of the IRWP (reservoirs, pipelines, irrigation areas, etc.) that may provide exposure points for people to recycled water are located mostly within central and northeastern Sonoma County (Refer to Figure 2.3 in Chapter 2 Project Description). A small portion of the Geysers steamfield is located in Lake County. Central Sonoma County is characterized by relatively compact cities and communities separated by areas of agricultural use and other open space. About two-thirds of the county population lives in nine incorporated cities or towns and 24 unincorporated communities. Cities within the program area include Santa Rosa, Rohnert Park, Cotati, Sebastopol, Healdsburg and Windsor. Northeastern Sonoma County and the small portion of Lake County within the Program Area are mostly open space with very low density residential or industrial use (i.e., Geysers steamfield).

The density of the cities and communities within the Program Area varies from highly urban to semi-rural. Agriculture occupies a major portion of the county lands outside of the cities and communities with a diversity of operations, including vineyards, orchards, dairies, forage crops, specialty crops and livestock. Major recreation and tourism-related uses occur along the Russian River.

Because of the geographic size and the demographic diversity of the project area, the potentially exposed population is diverse and includes subpopulations (e.g., young children and infants, the elderly, pregnant women) that may be more sensitive to chemical exposures than the general population. These sensitive subpopulations are discussed in the following section. A discussion of subpopulations that may be sensitive to the microorganisms (e.g., people who have suppressed immune systems) in recycled water is included in Section 3.4.

Sensitive Subpopulations

Infants and children are not only particularly sensitive to the toxic effects of many chemicals but also may have elevated exposure rates. Children and infants generally have a greater absorptive capacity than adults, presumably for the enhanced uptake of nutrients to aid in development. This characteristic means that many toxic chemicals are also more readily absorbed. Chemicals that are fat soluble and bioaccumulate may be found in human breast milk. Thus infants may receive elevated doses of chemicals during nursing. Because children have the greatest potential exposure, the exposure equations used in this risk assessment to determine level of hazard were those derived by the DTSC for children. The equations used to calculate theoretical cancer risks account for combined exposure during childhood and adult years averaged over a 70-year lifetime.

Pregnant and nursing women may be more susceptible to the toxic effects of chemicals due to the demands placed on their physiology by fetuses or nursing infants. For example, a woman’s iron reserves may be depleted and this depletion of iron may facilitate absorption of toxic metals such as cadmium. People attempting conception may be susceptible to the toxic effects of certain chemicals, such as organochlorine pesticides which have been shown to affect sperm production and motility (Parsons Engineering Science 1995a, Parsons 2003, and references therein). Elderly people may have increased susceptibility due to decreased function of detoxification and excretory processes, compromised bone integrity, declining cardiovascular and pulmonary function and generally poor health and inadequate nutrition. This risk assessment takes the increased sensitivity of these subpopulations into account by using toxicity values (derived by the USEPA or the DTSC) that have been adjusted to be protective of sensitive subpopulations.

2.3 EXPOSURE PATHWAYS

This section summarizes the potential pathways via which humans could be exposed to the chemicals in recycled water. Recycled water has been proposed for direct and indirect discharge to the Russian River and for several reuse options, including urban and agricultural irrigation, and recharge of the Geyser’s geothermal steamfield. It may be stored in ponds, reservoirs or basins or directed through created wetlands. The potential exposure pathways that may result from these Program components are discussed in the following paragraphs.

Direct and Indirect Discharges to the Russian River

Effluent is currently discharged to the Russian River via outfalls on creeks in the Laguna de Santa Rosa. The IRWP is evaluating an additional direct discharge component that would release recycled water from a new outfall on the Russian River between Healdsburg and Mirabel. A possible exposure pathway from direct discharge into the Russian River includes movement of surface water to groundwater where it could theoretically reach a water supply well or other intake (private or municipal). Domestic use of water from the well could expose people to chemicals or microorganisms in recycled water via inhalation, dermal absorption, or ingestion. People could also be exposed to chemicals in discharges when they eat fish that have been caught in the Russian River (for chemicals that bioaccumulate) or when they use the river for recreation (e.g., via dermal contact and incidental water ingestion during swimming).

The IRWP is also evaluating three indirect discharge options—percolation ponds, infiltration basins, and injection wells. The three indirect discharge options would release recycled water by first discharging it into groundwater through infiltration, and then, from the groundwater it would discharge to the river. Possible exposure pathways that could result from an indirect discharge include movement of recycled water via groundwater to a domestic well where it may be used as a domestic water supply and movement of recycled water via groundwater to a nearby waterway (e.g., Russian River). Thus, the domestic water supply and fish consumption pathways are theoretically complete for the indirect discharge options.

Percolation ponds would be narrow and long in shape (approximately 1,000 feet wide) to reduce groundwater mounding, and would run parallel to the Russian River or Dry Creek. Infiltration basins would have a smaller surface area and be deeper than percolation ponds. Specific locations of percolation ponds and infiltration basins have not been identified. However, in general the areas encompassing the Middle Reach Russian River (from Healdsburg to Windsor), the Alexander Valley along the river between Geyserville and Cloverdale, and portions of the Dry Creek Valley appear to be the most appropriate for development of these facilities. These are areas of suitable soils and underlying geologic formations where there are low densities of existing wells that could be affected by groundwater infiltration.

Injection wells would be constructed to inject recycled water directly into groundwater, from which it would infiltrate to an adjacent waterway. The injection wells would be spaced between 150 and 250 feet apart in a well field. Specific locations for injection well facilities have not been identified. However, like the other Indirect Discharge options, the areas that would be most appropriate encompass the Middle Reach Russian River (from Healdsburg to Windsor), the Alexander Valley along the river between Geyserville and Cloverdale, and portions of the Dry Creek Valley. These areas have sizable areas of suitable soils and underlying geologic formations, and there are low densities of existing wells that could be affected by groundwater infiltration.

Urban and Agricultural Irrigation

The existing water reclamation system distributes recycled water to approximately 6,400 acres of irrigated land (personal communication, Randy Piazza, June 2002). Both agricultural and urban irrigation sites are included in the system, although most are agricultural. During the irrigation season, typically from April through October, recycled water comes directly from the Laguna Plant, supplemented by water stored in ponds. A Winter Irrigation Program can be implemented when weather during the winter season is dry, and less water than expected can be discharged to the Laguna.

The Urban Irrigation component of the IRWP would provide recycled water from the Laguna Plant to urban irrigators as a replacement for either potable City-supplied water or well water used for irrigating turf and landscaped areas. Currently, most urban irrigation with recycled water within the Program Area occurs within the City of Rohnert Park and at Sonoma State University. Within Santa Rosa, irrigation would focus on recycled water use for existing irrigated areas such as the Fairgrounds, Bennett Valley, Fountaingrove and Country Club golf courses, as well as numerous parks and playgrounds throughout the city. In addition, urban irrigation would expand from the existing Rohnert Park urban irrigation system to additional users in both Rohnert Park and Cotati. Replacement of potable water with recycled water potentially could expose people using these facilities to chemicals or microorganisms in recycled water via inhalation, dermal absorption, or inadvertent ingestion of spray irrigation.

The Agricultural Irrigation component of the IRWP would provide recycled water from the Laguna Plant to agricultural lands in the Alexander Valley, Dry Creek Valley, and Russian River Valley and an area east of Rohnert Park. Approximately 57,200 acres of suitable agricultural land are located in these four areas. Most of the land in the Alexander, Dry Creek and Russian River Valleys is currently used for viticulture or is wooded grassland. The area east of Rohnert Park is used for vegetable crops and wholesale nurseries; although recent trends suggest that the long-term crop makeup will most likely consist of wine grape production (viticulture). Most irrigation water in these areas appears to come from groundwater wells. Replacement of groundwater with recycled water potentially could expose people using these facilities to chemicals or microorganisms in recycled water via inhalation, dermal absorption, or inadvertent ingestion of spray irrigation.

Surface Storage and Created Wetlands

Storage facilities are needed to store recycled water that is produced during the winter, for use during summer for irrigation. Ponds or reservoirs could be constructed either by berming on level sites, or in hillside areas, by damming a natural drainage or valley by means of an earth filled embankment dam. Specific locations for storage facilities have not been determined. However, locations would be selected near the end use (e.g., in the Santa Rosa Plain or east of Santa Rosa for urban irrigation). Reservoir properties and ponds would be fenced. Because of the remote siting of the reservoirs and the limited access, the public would not be directly exposed (e.g., via dermal contact) to surface water in the reservoirs and ponds.

There is a small potential for water to migrate from the reservoirs or ponds to groundwater via infiltration and into nearby domestic water supplies. Domestic use of water could expose people to chemicals or microorganisms in recycled water via inhalation, dermal absorption, or ingestion. The amount of recycled water that reaches nearby wells, if any, depends upon the rate of infiltration, other local hydrogeologic conditions, and the pumping rates of the domestic wells. The quality of the water that reaches the domestic wells depends upon the initial quality of the recycled water and groundwater, the dilution of the recycled water with groundwater, and any natural degradation or filtration processes that might occur as water moves through the aquifer. Thus, the domestic water supply pathway is potentially complete for these IRWP components but because the surface storage sites have not been selected, dilution, filtration and other mitigating factors that might reduce exposures cannot be quantified.

Created wetlands may be constructed in association with some reservoirs or ponds (including percolation ponds) for purposes of habitat enhancement. The wetlands could include marsh or open water as well as riparian or upland habitat that could support a variety of plant species valuable to wildlife and ecosystem functions. Locations for these created wetlands have not been determined, and the wetlands could be of a variety of sizes and types. Interpretive trails and viewing points could also be provided at created wetlands. Although the created wetlands would be open to the public, site designs would limit contact with recycled water (e.g., via dermal exposure) and the wetlands would not produce any significant exposure pathways.

Geysers Steamfield Expansion

Additional injection wells would be provided at the Geysers steamfield through conversion of existing steam extraction wells from production to recharge, or by construction of new injection wells. Construction of seven new injection wells would be required in addition to conversion of six existing wells. In addition to the new and converted wells, approximately 37,000 lineal feet of new aboveground pipeline within the Geysers steamfield would be required to convey recycled water to the wells. Because the piping and storage of recycled water for this component is a closed system and because the water is injected at great depth, the geysers expansion would not present any significant exposure pathways.

Summary of Exposure Pathways

Four potentially complete exposure pathways have been identified for direct and indirect discharges, for urban and agricultural irrigation, and for surface storage of recycled (Table 2.3-1 and Figure 2.3-1). The potential exposure pathways include domestic water supply, fish consumption, recreational use and irrigation. The domestic water supply, recreational use and fish consumption pathways would include dilution of recycled water with surface water or groundwater between the release point (e.g., Russian River discharge, reservoir leakage) and the exposure point (e.g., domestic water use, recreational water use). For purposes of screening, however, no dilution or other mitigating factors were considered in the risk assessment. The fish consumption pathway is evaluated only for chemicals that bioaccumulate.

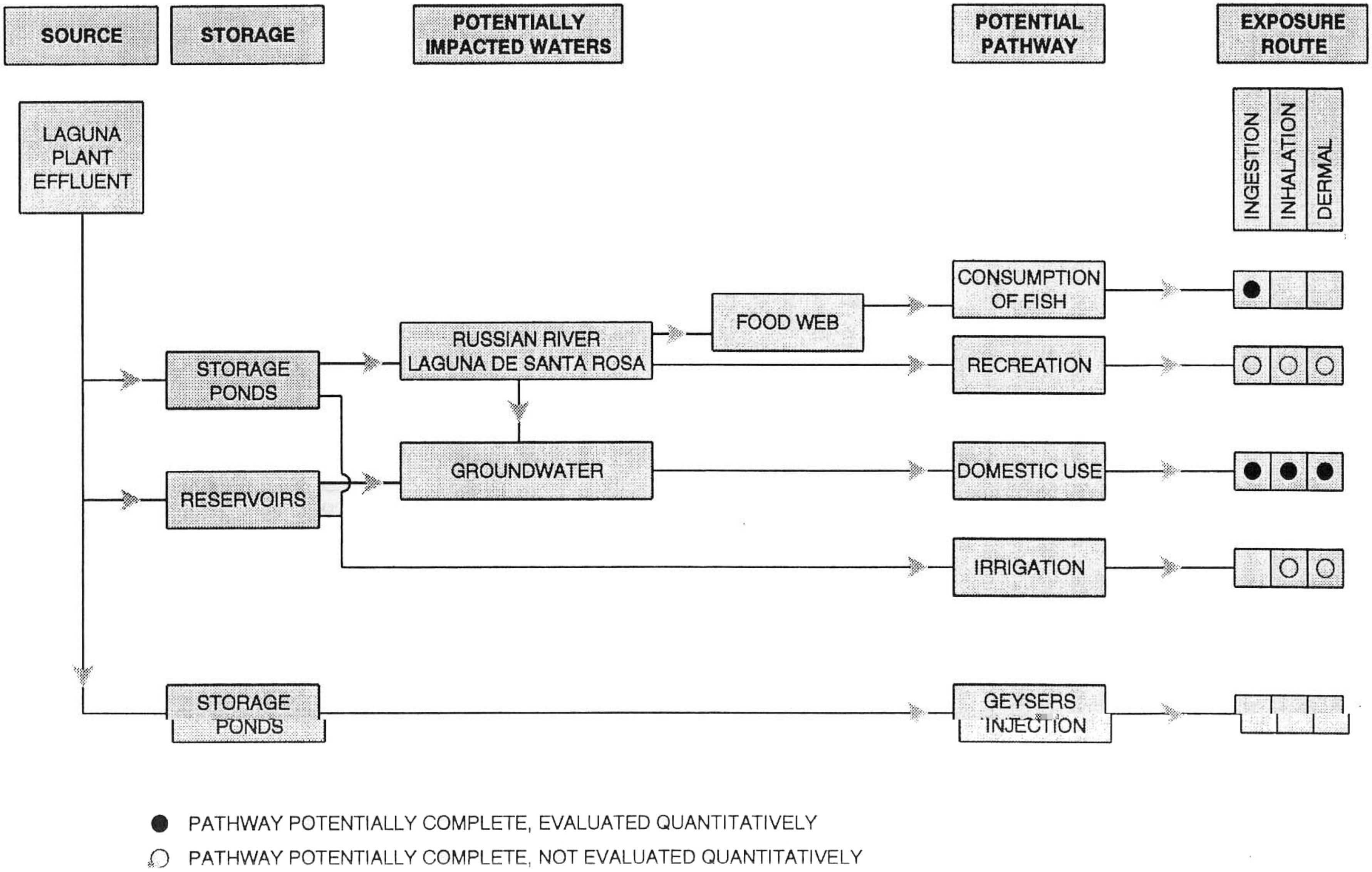
Table 2.3-1

Summary of Potentially Complete Exposure Pathways

Pathway	Comments
Domestic Water Supply	Potentially complete pathway for direct and indirect discharges to the Russian River and for surface water storage components; Russian River flows will dilute discharge and reverse osmosis will remove constituents; Groundwater will dilute discharge; Exposure routes include dermal contact, inhalation and ingestion during domestic use.
Fish Consumption	Potentially complete pathway for direct and indirect discharges to the Russian River for chemicals that bioaccumulate.
Recreational Use	Potentially complete pathway for direct and indirect discharges to the Russian River; Russian River flows will dilute both direct and indirect discharges and reverse osmosis could remove constituents; Groundwater will dilute indirect discharge; Direct discharge occurs during portion of year when swimming and wading uses are low; Clothing (e.g., boots or hip waders) limits direct exposure by fishers; Exposure routes are dermal contact and incidental ingestion, both of which would be at much lower rates than those in the domestic water supply pathway.
Irrigation	Potentially complete pathway for urban and agricultural irrigation; Ingestion discouraged by State-mandated posting of warning signs; Exposure routes are dermal contact and inhalation, which would be at lower rates than those in the domestic water supply pathway.

2.4 TOXICITY ASSESSMENT

This section summarizes toxicity information for chemicals listed in Table 2.1-1 that increased in concentration, that were not detected previously, or that previously triggered a significant impact in the risk assessment prepared for the Long-Term Project (Parsons 1997). The chemicals include nitrate and nitrite, which previously triggered a significant impact and have subsequently decreased in concentration; endosulfan, which increased in concentration; and MTBE and naphthalene, which were not detected previously. Although they did not trigger a significant impact in the Long-Term Project, trihalomethanes (bromodichloromethane, chloroform, and dibromochloromethane) and ammonia are also discussed because their concentrations have declined greatly due to the replacement of chlorine disinfection with ultraviolet disinfection in September 1998 and the introduction of nitrification and denitrification. Toxicity information is summarized in Table 2.4-1. Unless otherwise indicated, the information in this section was obtained from the National Library of Medicine's Hazardous Substances Database (HSDB) and the USEPA's Integrated Risk Information System (IRIS) (USEPA 2003a,b). Both are available on the National Library of Medicine's data network system (TOXNET, http://toxnet.nlm.nih.gov/).



Santa Rosa Subregional
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Incremental Recycled Water Program EIR

CONCEPTUAL MODEL FOR POTENTIAL EXPOSURE PATHWAYS

PARSONS

Figure 2.3-1

One widely held view among toxicologists is that toxic chemicals produce adverse human health effects only when an individual's exposure (via inhalation, ingestion, or dermal contact) exceeds some threshold level. The threshold level is expressed as a chemical dose. The chemical dose at the threshold level is the amount of chemical below which no effect is observed in the exposed individual. Only when the chemical dose exceeds the threshold are adverse health effects expected. Toxicity values information is expressed differently for the carcinogenic and non-carcinogenic health effects as discussed in the following paragraphs.

Toxicity Values for Noncarcinogens

Toxicity values for noncarcinogens are based on toxicological information that has been derived from either animal or human studies. Chemical exposures in these studies may be acute (a brief exposure of a few minutes to a few days), subchronic (a few weeks to months), or chronic (usually includes at least a tenth of the life span of a species, generally six months or more). Chronic exposures generally have the lowest thresholds and are most commonly used to derive toxicity values such as chemical reference doses (RfD) for ingestion or dermal pathways, or reference concentrations (RfC) for inhalation pathways. RfDs are expressed as the weight of chemical ingested or absorbed through the skin per kilogram of body weight of the exposed individual per day (e.g., milligrams/kilogram/day or mg/kg/day). RfCs are expressed as the weight of a chemical per volume of air (e.g., milligram/cubic meter or mg/m^3).

Table 2.4-1

Potential Health Effects of Target Chemicals(1)

Chemical	Target of Potential Health Effects
Inorganics	
ammonia	Eye irritant and respiratory system Screening values in this risk assessment based on odor / taste thresholds, which are lower than toxicity threshold
nitrate	Methemoglobinemia (blue baby syndrome) RfD based on methemoglobenemia in infants
nitrite	Methemoglobinemia (blue baby syndrome) RfD based on methemoglobenemia in infants
Volatile Organics	
chloroform	Cancer (USEPA Group B2), central nervous system, liver, kidneys RfD based on cyst formation in dogs
Methyl tert-butyl ether (MTBE)	Liver, kidneys RfD based on reduced liver and kidney weights and kidney lesions in rats
naphthalene	Central nervous system RfD based on reduced body weight in male rats
Chemical	**Target of Potential Health Effects**
Pesticides	

Table 2.4-1

Potential Health Effects of Target Chemicals(1)

Chemical	Target of Potential Health Effects
endosulfan	Central nervous system RfD based on reduced body weight and blood vessel aneurysms in rats

---

(1) Some of the health effects listed in this table occur only after exposure to elevated chemical concentrations. Reference doses (RfDs) are generally derived from chronic studies that examine health effects which occur at lower concentrations. A discussion of the health effects upon which the RfDs and RfCs are based is presented in Appendix B.

RfDs and RfCs are estimates of the daily intake level or air concentration of a chemical below which adverse health effects are not expected. They incorporate a margin of safety (called an uncertainty factor) and have been calculated by the USEPA to protect the most sensitive members of the population. They are derived from the experimentally determined no-observed-adverse-effect level (NOAEL) or the lowest-observed-adverse-effect-level (LOAEL). The NOAEL is a dose in a toxicity test that does not produce an observable adverse effect. The LOAEL is the lowest dose in a toxicity test that produces an observable adverse effect. The uncertainty factor (usually a number between 1 and 1,000) accounts for intraspecies and interspecies variations, for limited or incomplete data, for evaluating the significance of adverse effects, and for sensitive human subpopulations. In practice, an experimentally derived NOAEL or LOAEL is divided by the uncertainty factor to determine the RfD or RfC. RfDs and RfCs are therefore always equal to or less than the experimentally obtained threshold dose or concentration.

The RfDs and RfCs used in this risk assessment have been derived by the USEPA or the DTSC. An RfD is given for each chemical where information is available. An RfC is given for those organic chemicals that meet criteria for volatile organics set by the USEPA (USEPA 1995). For some volatile chemicals, an RfC is not available, in which case the RfD (adjusted for weight and inhalation rates) was used, as recommended by the DTSC.

Toxicity Values for Carcinogens

Toxicity values for carcinogens are based on available toxicological information that has been derived from either animal or human studies. The DTSC and USEPA consider the weight-of-evidence that a chemical is a carcinogen when developing toxicity values for carcinogens. The weight-of-evidence classification is an objective assessment of each chemical that determines the level or strength of evidence that a substance is a human or animal carcinogen. The USEPA's 1986 Guidelines for Carcinogen Risk Assessment created a five category (A-E) system for classifying carcinogens (Table 2.4-3). The USEPA proposed new guidelines in 1996 that replace this classification system with one that describes the potential carcinogenicity of a compound as "known/likely, cannot be determined, or not likely" (USEPA 1986, 1996). Slope factors or unit risks have generally been calculated for chemicals in Groups A, B1, and B2 and some of the chemicals in Group C - most of which would be categorized in the new system as known/likely carcinogens.

The slope factor is an upper estimate of the probability of a response (the initiation or promotion of cancer) per unit intake of a chemical over a person's lifetime. For the inhalation route, the USEPA does not provide a slope factor, but rather expresses the risk in terms of a unit risk. A slope factor is given for each chemical where information is available. A unit risk is given for those organic chemicals that meet criteria for volatile organics set by the USEPA (USEPA 1995). Slope factors are expressed as the inverse of the dose [(mg/kg/day)$^{-1}$]. The units for the unit risk are risk per 1 microgram/cubic meter, that is, the risk associated with an air concentration of 1 microgram/cubic meter (assuming a 70 kg adult breathes 20 cubic meters/day). Most slope factors and unit risks used in this report were derived by the USEPA. In some cases the DTSC has derived slope factors or unit risks that differ from those derived by the USEPA. The DTSC values have been used in deriving the "no significant risk levels" under the State's Safe Drinking Water and Toxic Enforcement Act of 1986 and the State drinking water Maximum Contaminant Levels (MCLs). DTSC values are used when they differ from the USEPA values.

Table 2.4-2

USEPA Weight-of-Evidence Cancer Classification

Group	Definition
A	Known human carcinogen based on sufficient evidence from epidemiological or other human evidence studies
B1	Probable human carcinogen based on limited evidence of carcinogenicity in humans
B2	Probable human carcinogen based on sufficient evidence in animals and inadequate or no data in humans
C	Possible human carcinogen based on limited evidence of carcinogenicity in animals in the absence of human data
D	Not classifiable as to human carcinogenicity based on lack of data or inadequate evidence of carcinogenicity from animal data
E	No evidence of carcinogenicity from at least two reliable tests in different species of laboratory animals

Summary of Toxicity Assessment

Table 2.4-3 summarizes the toxicity values (RfDs, RfCs, slope factors, and unit risks) for the chemicals listed in Table 2.1-1. Brief descriptions of the data on which the RfDs, RfCs, and slope factors are based are presented in Appendix B. To conduct the risk characterization, one additional set of values is needed, the chemical-specific dermal permeability coefficient from water (Kp). These values are used to account for uptake of chemicals that may occur through the skin and were calculated as described by the USEPA (USEPA, 2001). They are also listed in Table 2.4-3.

Table 2.4-3

Summary of Toxicity Assessment Values

Chemical	**EPA Cancer Class(1)**	**RfD**	**RfC**	**SFo**	**UR**	**Kp**
		mg/kg/day	**mg/m^3**	**(mg/kg/day)$^{-1}$**	**(μg/m^3)$^{-1}$**	**cm/hr**
Inorganics						
ammonia		— (2)	— (2)			
nitrate		1.6				
nitrite		0.1				
Volatile Organics						
chloroform	B2	0.01		0.031(3)	0.0000053(4)	0.0068
Methyl tert-butyl ether (MTBE)			3.0	0.0018 (5)	0.00000026 (5)	0.0033
naphthalene	C	0.02	0.003		(6)	0.046
Pesticides						
endosulfan II		0.006				0.002

RfD Reference dose
RfC Reference concentration
SFo Cancer slope factor, oral
UR Cancer unit risk, inhalation
Kp Dermal permeability coefficient from water

Shading in the columns that list the toxicity values indicates that the toxicity value is not applicable to the chemical (i.e., chemical is not a carcinogen, inhalation or dermal absorption are not significant routes of uptake).

(1) Classifications are based on the USEPA Guidelines for Carcinogen Risk Assessment (USEPA 1986). Shaded boxes indicate that compounds are not classified as carcinogens or have not been evaluated. The 1996 Proposed Guidelines for Carcinogen Risk Assessment no longer use the A-E classification system (USEPA 1996). According to the proposed guidelines, the human carcinogenic potential of naphthalene via the oral or inhalation routes "cannot be determined" at this time based on human and animal data; chloroform is *likely to be carcinogenic to humans by all routes of exposure* under high-exposure conditions that lead to cytotoxicity and regenerative hyperplasia in susceptible tissues; chloroform is *not likely to be carcinogenic to humans by any route of exposure* under exposure conditions that do not cause cytotoxicity and cell regeneration.

(2) Due to its low toxicity, ammonia was evaluated by comparing water concentrations to the taste and odor thresholds as proposed by the World Health Organization (WHO 2002). Odor threshold = 1.5 mg/L; taste threshold 35 mg/L.

(3) DTSC value (DTSC 2003). The USEPA's IRIS database states that a dose of 0.01 mg/kg/day (equal to the RfD) can be considered protective against cancer risk.

(4) DTSC value. The USEPA cancer risk from chloroform inhalation was developed in 1987 and does not incorporate newer data or the 1996 or 1999 USEPA draft cancer assessment guidelines. USEPA is currently working to revise the assessment for inhalation exposure.

(5) DTSC value. The USEPA has not developed cancer risk values for MTBE.

(6) A unit risk estimate for naphthalene was not derived by the USEPA because of the weakness of the evidence (observations of predominant benign respiratory tumors in mice at high dose only) that naphthalene may be carcinogenic in humans.

2.5 RISK CHARACTERIZATION

Theoretical cancer risks and other health hazards were evaluated quantitatively for the chemicals listed in Table 2.4-1 using exposure parameters associated with the domestic water supply pathway described in Section 2.3 and the toxicity values presented in Section 2.4. For screening purposes it was assumed that undiluted recycled water could reach a domestic water supply (e.g., private well) and be used for drinking water and other common household uses. However, see Section 2.6, Uncertainty, for a discussion of how biological, chemical and physical processes (e.g., dilution) would affect the conclusions based on this assumption. Additional environmental fate information for the chemicals is provided in Appendix A.

Calculation of Hazard Quotients

The human health hazard associated with exposure to noncarcinogens is expressed as a hazard quotient. The hazard quotient is the ratio of the estimated dose from exposure to the RfD or RfC. A hazard quotient of less than 1.0 indicates that the chemical is not expected to produce an adverse health effect. Hazard quotients based on maximum detected values are summarized in Table 2.5-1.

The equations used to calculate the hazard quotients for this risk assessment have been derived by the DTSC (DTSC 1994). They are included in Appendix C. These equations have been simplified by the DTSC by incorporating default values to achieve a reasonable maximum estimation of exposure in a residential setting. There are different default values for children and adults and also for different exposure scenarios (i.e., residential and industrial). The water pathway considered in this screening assessment is a summation of ingestion exposure, inhalation of volatile organics from water released indoors, and dermal exposure. The equations are therefore different for volatile and nonvolatile chemicals. The hazard quotients are calculated for the first 6 years of childhood. The default values are such that if the hazard quotient is not exceeded for the first 6 years of childhood, it will not be exceeded for any other age. These equations do not include exposure from ingestion of aquatic organisms in surface water.

Calculation of Incremental Lifetime Cancer Risk

The theoretical human health risk associated with exposure to carcinogenic chemicals is expressed as an incremental lifetime cancer risk (ILCR). The ILCR is a theoretical probability, such as one in a million (1×10^{-6}) or one in ten thousand (1×10^{-4}), of developing cancer over a lifetime as a result of exposure to the potential carcinogen. In general, ILCRs greater than 1×10^{-6} to 1×10^{-5} are considered by the State of California to pose a significant threat to human health (Title 22, California Code of Regulations, §12703; DTSC 1994). In addition, when two or more potential carcinogens are present their ILCRs are added together. If the summed ILCR is less than 1×10^{-6}, the combined effect of the chemicals would not be expected to pose a significant human health risk. ILCRs based on maximum detected values are summarized in Table 2.5-1.

Table 2.5-1

Summary of Hazard Quotients and Incremental Lifetime Cancer Risks Based on Maximum Detected Values (1)

Chemical	Maximum Hazard Quotient	Maximum ILCR
Inorganics		
ammonia	**8.0** / 0.34 (2)	
nitrate	0.62	
nitrite	**1.47**	
Volatile Organics		
chloroform	0.32	**3.0×10^{-6}**
Methyl *tert*-butyl ether (MTBE)	<0.001	9.7×10^{-8}
naphthalene	0.58	
Pesticides		
endosulfan II	<0.001	

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(1) Values in **bold text** indicate a hazard index that exceeds the screening value of 1.0 or an ILCR that exceeds the screening value of 1.0×10^{-6}.
Shading in the "Hazard Quotient" column indicates that no reference doses were available for the chemical. Shading in the "ILCR" column indicates that the chemical is not a carcinogen or that no slope factor was available.

(2) Based on comparison to WHO odor / taste thresholds.

The screening equations used to calculate the ILCRs for this risk assessment have been derived by the DTSC (DTSC 1994). They are included in Appendix C. As with the assessment of noncarcinogenic effects, these equations have been simplified by the DTSC by incorporating default values to achieve a reasonable maximum estimation of exposure in a residential setting. The domestic water supply pathway considered in this screening assessment is a summation of ingestion exposure, inhalation of volatile organics from water released indoors (e.g., volatilization during showering, use of dishwasher, flushing of toilet), and dermal exposure. The equations therefore differ for volatile and nonvolatile chemicals. The equations estimate the ILCR for a combined exposure duration of 6 years as a child and 24 years as an adult. The equations do not account for exposure via fish consumption.

Quantitative Characterization of Noncarcinogenic Effects

The screen for noncarcinogenic effects used maximum reported concentrations and thus generated maximum hazard quotients, which describe a worst-case scenario. Only ammonia and nitrite have maximum hazard quotients greater than 1.0. The mean hazard quotients provide more representative estimates of the potential hazard associated with exposure to chemicals in recycled water. All hazard quotients based on mean concentrations are less than 1.0 (Table 2.5-2).

When two or more chemicals manifest the same toxic effect(s) or target the same organ(s), it may be appropriate to sum their hazard quotients to assess their combined effects. This sum is called a “hazard index.” If the hazard index is less that 1.0, the combined effect of the chemicals is not expected to produce an adverse health effect. Among the chemicals in Table 2.5-1, nitrate and nitrite have similar effects and their combined maximum hazardous quotients yield a hazard index greater than 1.0; their combined mean hazard quotients yield a hazard index that is less than 1.0. No other combination of chemicals with similar effects yields a hazard index greater than 1.0.

Table 2.5-2

Mean Hazard Quotients for Target Chemicals(1)

Chemical	Maximum Hazard Quotient	Mean Hazard Quotient	Basis for RfD
ammonia	**8.0** / 0.34	0.4 / 0.02	Eye irritant and respiratory system; There is no RfD for ammonia, therefore the hazard quotient was based on odor / taste thresholds in humans
nitrate	0.62	0.29	Methemoglobinemia; RfD based on methemoglobinemia in infants

Table 2.5-3

Summary of the Incremental Lifetime Cancer Risks[1]

Chemical	Maximum ILCR	Mean ILCR	EPA Cancer Class	Target Organ(s)[2]
chloroform	**3.3×10^{-5}**	8.3×10^{-8}	B2	kidney
methyl *tert*-butyl ether	9.7×10^{-8}	5.0×10^{-8}	N/A	kidney, lymph, testes

N/A – not available

[1] Values in **bold text** indicate an excess cancer risk that exceeds the screening value of 1.0×10^{-6}.

[2] Target organ in test species identified by the USEPA or DTSC as basis for cancer slope factor or unit risk.

Chemical-Specific Characterizations

Ammonia

Ammonia has a low toxicity and can be detected by taste or smell at concentrations much lower than those that are considered harmful. Therefore, taste and odor thresholds were used to evaluate the concentration of ammonia in recycled water. The maximum hazard quotient for ammonia based on odor is greater than 1.0 while the hazard quotient based on taste is less than 1.0. Hazard quotients based on average ammonia concentrations are less than 1.0 for both the taste and odor thresholds. Ammonia concentrations have decreased in the Laguna Plant's effluent since the treatment process was upgraded to include nitrification and denitrification (Table 2.1-1). Prior to the upgrade, the maximum ammonia concentration yielded a hazard quotient of 2.575 based on the taste threshold in humans (Parsons 1997).

Dilution of recycled water with surface water or groundwater upon release, and uptake of ammonia by terrestrial and aquatic plants would further reduce ammonia levels. Ammonia would not present an unacceptable human health hazard and would not be detectable by taste or smell after a relatively small amount of dilution with groundwater or surface water.

Nitrate and Nitrite

Nitrate toxicity is due primarily to its conversion to nitrite in the body, which oxidizes the Fe(+2) form of iron in hemoglobin to the Fe(+3) state. The resulting form of hemoglobin, called methemoglobin, does not bind oxygen, resulting in reduced oxygen transport from lungs to tissues. Low levels of methemoglobin occur in normal individuals, with typical values usually ranging from 0.5 to 2.0% of total hemoglobin. These levels occur because nitrate is a normal component of the human diet. Over 85% of nitrate intake (or more for vegetarians) comes from the natural nitrate content of vegetables such as beets, celery, lettuce and spinach.

Due to the large excess capacity of blood to carry oxygen, levels of methemoglobin of up to around 10% are not associated with any significant clinical signs. Concentrations above 10% may cause a bluish color to skin and lips (cyanosis). Most cases of infant methemoglobinemia are associated with exposure to nitrate in drinking water used to prepare infants' formula at levels greater than 20 mg/L of nitrate-nitrogen (USEPA 2003b). Cases reported at levels of 11 to 20 mg/L nitrate-nitrogen are usually associated with concomitant exposure to bacteriologically contaminated water or excess intake of nitrate from other sources.

Clinical studies of healthy babies administered controlled doses of nitrate have reported no clinical signs of methemoglobinemia for infants who received water containing up to 34.5 mg/L nitrate-nitrogen. Methemoglobin levels in these infants ranged from about 1% to 3%. Several epidemiological studies of infants exhibiting cyanosis due to methemoglobinemia have reported that no symptoms occurred at concentrations less than 10 mg/L nitrate-nitrogen. A small number of cases (less than 2% of the total) has been reported for water containing 11 to 20 mg/L nitrate-nitrogen, although the diagnosis of methemoglobinemia was considered questionable in some of these cases. Many of the wells in these studies, which were often shallow with inadequate protection from surface water, contained coliform bacteria, which may have been a complicating factor.

The maximum hazard quotients for nitrate and nitrite are greater than 1.0 while the mean hazard quotients are less than 1.0 (Table 2.5-2). Because nitrate and nitrite induce the same adverse health effect, methemoglobinemia in infants, it is appropriate to sum the hazard quotients for nitrate and nitrite. The combined maximum hazard index for nitrate and nitrite is 2.09 while the combined mean hazard index is 0.40.

Dilution of recycled water with surface water or groundwater upon release, and uptake of nitrate and nitrite by terrestrial and aquatic plants would reduce their concentrations to levels that would not present an unacceptable health hazard in most circumstances. In addition, average concentrations might be more representative of the nitrate and nitrite levels that would be present after storage in reservoirs. Mean concentrations of nitrite (0.18 mg/L) and nitrate (7.3 mg/L) are less than State and federal drinking water standards.

Trihalomethanes

Trihalomethanes are disinfection by-products (DBPs) that form when water containing naturally occurring organic matter is chlorinated to inactivate disease-causing microorganisms. Trihalomethanes include bromodichloromethane, bromoform, chloroform, and dibromochloromethane. When chlorine disinfection for tertiary treatment was discontinued at the Laguna Plant, the frequency of detection and the concentrations of trihalomethanes decreased in the treatment plant’s effluent (Table 2.1-1). Only chloroform has been detected in effluent since September 1998. Chloroform is still produced because some chlorine disinfection with hypochlorite (the active chemical in bleach) is used at the headworks for odor control and a chlorine residual is maintained in water pipelines. The average concentration of chloroform (0.0011 mg/L) in the Laguna Plant's effluent is similar to that found in the drinking water supplied by public water systems in the Program area that use chlorine for disinfection.

The maximum and average concentrations of trihalomethanes in undiluted effluent are well below the drinking water standard of 0.080 mg/L. The maximum concentration in undiluted Laguna Plant effluent yields a theoretical ILCR slightly above one in a million (1 X 10^{-6}) while the average concentration yields a theoretical ILCR that is less than one in a million. This level of risk is within (or below) the acceptable cancer risk range (1 X 10^{-4} to 1 X 10^{-6}) that the EPA considers when setting drinking water standards (USEPA 1994c). For these reasons, chloroform in recycled water does not present an unacceptable human health hazard.

MTBE

MTBE was not reported in the dataset that was used to prepare the risk assessment for the Long-Term Project and was rarely analyzed in any water samples prior to the late 1990s. MTBE was detected in 3 of 11 samples of the Laguna Plant's effluent. The theoretical ILCR based on the maximum detection of MTBE was well below one in a million (9.7 x 10^{-8}) and the hazard quotient was well below 1.0 (<0.001) indicating that the concentration of MTBE in recycled water does not present an unacceptable health hazard based on the hazard quotient or theoretical ILCR criteria. In addition, both the mean (0.00093 mg/L) and maximum (0.0018 mg/L) concentrations of MTBE are less than the secondary MCL (0.005 mg/L) for MTBE based on odor and taste, which was adopted by California in 1999, and the primary MCL (0.013 mg/L) based on health effects, which was adopted in 2000.

Endosulfan II

The maximum and average concentrations of endosulfan in the Laguna Plant's effluent are higher than those used in the risk assessment for the Long-Term Project (Parsons 1997). The maximum value is eight times higher and the average is three times higher than reported previously, although the frequency of detection is low (1 of 18 samples). However, both risk assessments concluded that the concentration of endosulfan in recycled water was less than one-thousandth of the threshold concentration that might cause adverse health effects. Thus, the recent increase in endosulfan concentration does present an unacceptable health hazard based on the hazard quotient criterion.

Naphthalene

Naphthalene was not reported in the dataset that was used to prepare the risk assessment for the Long-Term Project. In its pure form it is a white solid. It is found naturally dissolved in fossil fuels (e.g., diesel fuel and gasoline) and is a major component of moth repellents. It is no longer allowed for pesticide use in California, although it is still used in some other states. Naphthalene was detected in 1 of 18 recently collected samples at a maximum concentration of 0.0075 mg/L, which yields a hazard quotient of 0.58. Thus, the concentration of naphthalene in recycled water does not present an unacceptable health hazard based on the hazard quotient criterion.

Fish Consumption

Many pollutants concentrate in fish by accumulating in fatty tissues or muscle (the fillet). Even extremely low concentrations of bioaccumulative pollutants in water or sediments may result in fish tissue concentrations high enough to pose health risks to fish consumers. Some contaminants, particularly pesticides, tend to accumulate in the fatty tissues of fish. Consequently, fish species with a higher fat content, such as carp, bluefish, some species of salmon, and catfish, may pose greater risks from some contaminants than leaner fish such as bass, sunfish, and yellow perch. Although exposure to some contaminants may be reduced by removing the fat, skin, and viscera before eating, other contaminants, such as methylmercury, accumulate in the fillet, and therefore cannot be removed by trimming. In addition, some fish are consumed whole, or used whole in the preparation of fish stock for soups and other foods. Under these conditions the entire burden of bioaccumulative contaminants contained in the fish would be ingested.

In addition to the risks borne by the general population due to consumption of contaminated fish, populations eating higher-than-average quantities of fish are at greater risk of having higher body burdens of contaminants. Those at greatest risk include sport and subsistence fishers. Within these populations, pregnant women and children may be at greater risk of incurring adverse effects than other members of the populations, due to their proportionally higher consumption rates and/or increased susceptibility to adverse health effects.

An assessment of the potential for exposure to chemicals via fish consumption (and other aquatic organisms) was made for the Long-Term Project by comparing the Laguna Plant effluent water quality data to USEPA water quality criteria for the ingestion of aquatic organisms and water; by evaluating data from bioaccumulation/magnification studies performed in 1991 and 1994 at the Kelly Farm Demonstration Wetland; and by applying the USEPA's methodology for fish advisories to data collected for the Toxic Substances Monitoring Program (TSMP). While three chemicals (arsenic, chloroform and γ-lindane) exceeded their respective water quality criteria, the risk assessment concluded that available evidence from all sources (including the Kelly Farm Demonstration Wetland and TSMP data) indicated that the chemicals did not present an unacceptable risk to human health. The concentrations of these three chemicals have decreased since the risk assessment for the Long-Term Project was prepared. Thus, the risk from their current levels would also not present an unacceptable risk to human health.

The two new chemicals that have been detected—MTBE and naphthalene—have a low potential to bioaccumulate and the USEPA has not established water quality criteria for them via the ingestion of aquatic organisms and water. They were not target compounds for the Kelly Pond or TSMP studies, which looked at specific metals and bioaccumulative chemicals. Therefore, no additional data have been collected on which to base an updated evaluation of the hazard associated with consuming fish exposed to recycled water, which is unlikely to have increased (based on the recent decline in most detected chemicals in recycled water).

2.6 UNCERTAINTY

All risk assessment involves the use of assumptions, judgments, and imperfect data to varying degrees. This results in uncertainty in the final estimates of risk. Uncertainties are present in virtually each step of the risk assessment process including the selection of appropriate data, the identification of exposure pathways, the selection of toxicity values, and the characterization of risk. Some of these uncertainties are inherent in the equations and values that are contained in guidance documents and information sources recommended by regulatory agencies. Toxicity values, for example, are often derived from animal data, which must be extrapolated to a human RfD, RfC, slope factor or unit risk. The equations used to characterize risk are based on characteristics of the general population (e.g., food and water intakes, average weights and lifespans). These characteristics may not be appropriate for some subpopulations. Other sources of uncertainty are related to site-specific information. For example, there may be uncertainties associated with the completeness of an exposure pathway or the concentration of a chemical at the potential exposure point. This site-specific uncertainty, as it relates to the IRWP is discussed below.

Data Quality

Quality control samples (e.g., field blanks, trip blanks and method blanks) were not collected or made available for most samples. The lack of such controls precludes an accurate quantitative evaluation of contaminants potentially introduced during sample collection, transport or analysis. Some chemicals may have been introduced during the sample collection and analytical processes. The introduction of these chemicals during sampling and their reporting in the analytical results would result in an overestimation of risk.

Chemicals for which all analyses were below the reporting limit were not included in the quantitative risk assessment. For chemicals that were detected at least once, non-detects were included in the sample mean by assigning a value of one-half the reporting limit. The actual concentration of a chemical that was not detected above the reporting limit may vary between zero and the reporting limit. The omission of these chemicals would underestimate risk if the chemical(s) were present at a concentration greater than zero. To account for some of this risk, reporting limits for this risk assessment were set lower than the drinking water standard for all chemicals for which an MCL has been promulgated (Merritt Smith Consulting 1995a, 1995b). Thus, for these chemicals a non-detect would indicate that the reported value was below the MCL. The use of one-half of the sample reporting limit to calculate the mean may either under- or over-estimate the risk.

Noncarcinogenic hazards and carcinogenic risks were calculated using DTSC guidance (DTSC 1994), which states that maximum reported values should be used. This assumption overestimates risk.

Exposure Pathway Assessment

Recycled water that is discharged to the Russian River or that moves from reservoirs, ponds, or basins to groundwater will be diluted by groundwater and/or surface water before it reaches a potential exposure point. In addition, the chemicals in recycled water will be subject to volatilization (from surface waters), degradation (biological and chemical) and adsorption to soils and sediments. The Direct and Indirect Discharge Alternatives also could include treatment by reverse osmosis before discharge to the Russian River, which would further reduce concentrations of constituents. Therefore, the health hazards and risks predicted by the quantitative assessment, which assumes that water reaching a domestic water intake would consist of 100% recycled water without further reverse osmosis treatment, overestimate the potential health risks posed by exposure to the recycled water through the discharge or reuse scenarios of the IRWP.

For domestic wells near the Russian River, the highest percentage of river water has been predicted to be 35 percent (CH2M Hill et al. 1993). This percentage was predicted to occur during dry weather conditions for a well 50 feet from the river with an average pumping rate of 10 gallons per minute (gpm). For municipal wells, the wells may pump river water almost exclusively under some conditions (e.g., a well located within 100 feet of the river with a pumping rate of 2,000 gpm). The shortest travel time for groundwater between the river and a municipal well 100 feet away was predicted to be 2 days. Infiltration basins, percolation ponds and injection wells would be located in areas that have a low density of water wells that are used for drinking water. Dilution and extended residence times in groundwater (before reaching a domestic water intake) would reduce the exposure concentrations and associated risk.

Volatilization is likely to reduce the mean concentration of volatile organic chemicals in water released to reservoirs, storage ponds, the Laguna de Santa Rosa and the Russian River. The use of effluent data to estimate the concentration of volatile organic compounds in recycled water is likely to overestimate potential health risks from volatile organic chemicals.

Biological and chemical degradation may reduce the concentration of volatile organic chemicals in water released to reservoirs, ponds or the Russian River. The use of effluent data to estimate the concentration of volatile organic chemicals in recycled water stored in ponds or reservoirs, or released to the Russian River, is therefore likely to overestimate potential health risks. Reverse osmosis can reduce the concentration of inorganic ions and many organic chemicals (WEF/AWWA 1998, Asano 1998). Ion removal by reverse osmosis membranes typically varies from 94% to 99%. In addition, large organic molecules are highly rejected, and low-molecular-weight organic compounds are often removed, but some organics, such as phenols, are generally not effectively removed (WEF/AWWA 1998). Implementation of reverse osmosis for the direct and indirect discharge options would reduce the concentrations of inorganic ions and many organic compounds.

The risk equations assume that an individual will be exposed to a chemical for 30 years (6 years during childhood and 24 years as an adult) at an unchanging concentration, an assumption that is useful for screening but which does not accurately describe long-term exposure. For example, the assumptions do not account for operations practices at the Laguna Plant such as the release of water to the Russian River only from 1 October through 14 May. This practice would limit the duration of an individual's exposure and would result in varying dilutions of recycled water with surface water.

Toxicity Assessment

Some uncertainty is inherent in the toxicity values used to assess the noncarcinogenic hazards and carcinogenic risks. These uncertainties, which may lead to either under- or over-estimation of risk, are compounded by the assumption of dose additivity for multiple substance exposures (for example in the case of nitrates and nitrites). The assumption of additivity ignores possible synergisms or antagonisms among chemicals, and assumes similar mechanisms of action and metabolism. If synergistic effects occur the assumption of additivity would underestimate risk, while antagonistic effects would result in an overestimate of risk. Because a margin of safety is built into the toxicity values derived by the USEPA and the DTSC the toxicity values generally overestimate risk.

Current toxicity values that have been derived by the USEPA and DTSC are based on chronic effects and endpoints such as cancer (carcinogens), birth defects (teratogens), and genetic effects (genotoxicity or mutagens) or adverse effects on organ systems such as kidney and liver damage or neurotoxicity. It has recently been suggested that endocrine disrupting chemicals (EDCs) or other xenobiotics may cause developmental, reproductive or other harm to humans at lower concentrations that are not reflected in the current toxicity values (Parsons Engineering Science 1995a, Parsons 2003 and references therein). RfDs based specifically on the primary toxic effects of these compounds, such as developmental and reproductive effects, have not yet been developed by the DTSC and USEPA for most analytes. Because some of these effects may occur at concentrations lower than those considered to establish current RfDs, the current toxicity values may underestimate risk for some chemicals.

Toxicity values for carcinogens are developed using a linearized model and an upper limit of the 95th-percentile confidence interval. These simplified models do not allow use of information on the mechanism of action or cellular repair and are likely to overestimate risk. In addition, a no threshold level (i.e., all concentrations greater than zero are expected to contribute to some incremental increase in cancer risk) is assumed and all carcinogens are assumed to be genotoxic (tumor-inducing). However, some chemicals may produce tumors only after continuous high exposure and may not be carcinogenic at relevant environmental concentrations. There is also evidence that cancer formation is a multistage process involving tumor induction (the genotoxic effect) and subsequent tumor promotion (tumor growth). Some chemicals may be complete carcinogens, that is, capable of both inducing and promoting tumor formation, whereas other chemicals may either induce or promote tumor growth, but not both. The model assumptions may therefore, overestimate risk for chemicals that are not complete carcinogens.

3.0 RISK FROM MICROORGANISMS

This section presents the human health risk assessment for microorganisms in recycled water from the Laguna Plant. It addresses the potential human health risks resulting from discharge of final treated effluent from the treatment plant to surface water and the subsequent use of surface water as a source of potable water as well as other purposes (e.g., irrigation). The risk assessment follows the standard framework used for chemical risk assessment, which consists of:

- Microorganisms in Recycled Water
- Hazard Identification
- Dose-Response Assessment
- Exposure Assessment
- Risk Characterization

3.1 MICROORGANISMS IN LAGUNA PLANT EFFLUENT

Table 3.1-1 presents the data for bacteria and protozoa detected in treated effluent and in the Russian River (for comparison purposes).

Total coliform is an indicator organism for water quality. The term “indicator organism,” as used in water microbiology, means a microorganism whose presence is evidence that pollution (associated with fecal contamination from man or other warm-blooded animals) has occurred. Indicator organisms may be accompanied by pathogens, but do not necessarily cause disease themselves (NRC 1977). Indicators have the following general characteristics: they are absent from unpolluted waters, are present in greater numbers than pathogenic organisms, have greater survival time than pathogens, and their detection is more reliable and less time-consuming.

Total coliform ranged from less than 2 up to 240 most probable number (MPN) per 100 milliliters (mL) during the sampling period from December 1997 until April 2002. The median concentration was less than 2 MPN/100 mL. Total coliform was detected at 280 MPN/100 mL in the one sample taken from Delta Pond of final stored effluent for the Long-Term Project. Delta Pond is an open surface water impoundment. Sheep graze on land adjacent to the pond and ducks and other waterfowl utilize the pond as a stop-over along the Pacific flyway. It is not unexpected that total coliform counts would increase in stored effluent because of the contribution of feces from animals and wildlife. Total coliform was detected in four samples taken from the Russian River, ranging from 23 to 240 MPN/100 mL.

Table 3.1-1

Analytical Data for Bacterial and Protozoa Parameters

Sample Type	Date	Total Coliform (MPN/100 mL)	Giardia lamblia (Cysts/100 L)	Cryptosporidium (Oocysts/100 L)
Final Fresh Effluent	Dec 1997 – April 2002	Range: <2 – 240 Median: <2		
Final Fresh Effluent	May 1996 – Jan 1997		Range: <1.6 – 37 Median: <6.6	Range: <1.6 – 9.6 Median: <6.6
Final Stored Effluent	Nov 1994	280		
Russian River Water	Oct – Dec 1994	Range: 23 – 240 Median: 30 (1)		
Russian River Water	1993 (2)		Range: <1 – 13.8 Median: <1	Range: <1 – 2.7 Median: <1

MPN = most probable number
< indicates the detection limit
Shaded cells indicate that no data were collected for the organism
(1) Four samples were collected. The results were 23, 30, 220 and 240 MPN/100 mL and thus the median falls between 30 and 220 MPN/100 mL.
(2) CH2MHill, 1993

The data also include results for two protozoa, *Cryptosporidium* and *Giardia lamblia*. *Cryptosporidium* oocysts were detected in one of 34 final fresh effluent samples collected from May 1996 until January 1997. *Giardia* cysts were detected in four of 34 final fresh effluent samples. The analyses, which are performed by filtering at least 100 liters of the water and counting the cysts or oocysts, do not distinguish between those that are viable and those that are inactivated. The Delta Pond sample of stored final effluent was not analyzed for these two protozoa. *Cryptosporidium* (2.7 oocysts/100 mL) and *Giardia* (13.8 cysts/100 mL) have been detected in Russian River samples (CH2M Hill 1993).

Microorganisms Reported as Not-Detected for the Long-Term Project

Several microorganisms that were analyzed for but not detected were discussed in the risk assessment for the Long-Term Project (Parsons 1997). These include species of the bacteria *Salmonella, Shigella,* and *Legionella*, and enteric viruses. In addition, data for heterotrophic bacteria were presented but were not used in risk calculations because of the lack of appropriate dose-response information for this broad category of bacteria (data on individual species or genera are needed to identify appropriate dose-response information). No additional data have been collected on these organisms, but based on the results of continued monitoring for indicator organisms it is unlikely that their concentrations have increased to levels that would cause disease.

3.2 HAZARD IDENTIFICATION

Water may contain a wide variety of pathogenic microorganisms. A 1984 comparison of the microorganisms responsible for causing waterborne disease in the U.S. found bacteria caused the greatest number of outbreaks and cases of illness, followed by protozoans then viruses. They also found that the etiological agent had been identified in only half of the outbreaks reported (Lippy and Waltrip 1984). The principal types of microorganisms considered in this risk assessment are those detected in fresh and stored final effluent samples.

Total Coliforms

The coliform group of bacteria is made up of a number of genera including *Klebsiella*, *Escherichia*, *Serratia*, *Erwinia* and *Enterobacteria*. Total coliform bacteria are all gram-negative asporogenous rods and are associated with feces of warm-blooded animals. Although coliforms are usually considered nonpathogenic, enterotoxigenic and enteropathogenic variants of *Escherichia* are responsible for outbreaks of enteritis and gastroenteritis. Studies in different parts of the world have indicated that E. coli is a significant cause of bacterial diarrhea, and food and waterborne outbreaks of E. coli-caused illness have been documented (USEPA 1986).

Giardia lamblia

Giardia lamblia is a flagellated parasitic protozoan. It causes illness by mechanically damaging the microvilous lining of the upper small intestine. The form of *Giardia* that causes the damage is the trophozoite. Trophozoites, shaped somewhat like horseshoe crabs, live and reproduce in the upper part of the small intestine. As they are excreted, they form cysts, a dormant stage which is shed with the feces. Stomach acids activate ingested cysts, releasing new trophozoites into the small intestine. There, the trophozoites act like leaches, attaching to the intestinal epithelium by means of a suction cup-like structure, the ventral disc. As the trophozoites grow in the small intestine, they cause epithelial cells lining the small intestine to slough off. Although the body responds by producing new epithelial cells, these cells are not mature enough to produce digestive enzymes. This prevents digestion of food and leads to diarrhea.

Symptoms of giardiasis include, in addition to diarrhea, flatulence and vomiting. The illness usually continues for about a week, followed by recovery. Patients under stress or with immune deficiency may continue to be ill for months or even years. Severe giardiasis can cause dehydration and weight loss from malabsorption of nutrients. In children, malabsorption of fats and soluble vitamins may slow growth. Because many people can harbor *Giardia* without symptoms, asymptomatic carriers may spread the illness to others (Health & Environment Network 1988).

Cryptosporidium parvum

Cryptosporidium parvum is a coccidian parasitic protozoan. It is an obligate, intracellular parasite, whose life cycle involves both asexual and sexual multiplication. Infection occurs as a result of ingestion of an environmentally resistant stage referred to as an oocyst. Its primary route of transmission from host to host is fecal-oral. When the oocyst, an elliptical sphere 3 to 5 microns in diameter, is ingested by a compatible new host, the oocyst wall breaks down, releasing the four sporozoites contained inside. The sporozoites invade the intestinal epithelial cells of the host, where they undergo stages of asexual and sexual multiplication, finally producing new oocysts, of which 20 percent develop a single wall membrane in the host, while the other 80 percent develop environmentally-resistant, two layer walls and are excreted into the environment, where they are immediately infective (AWWA 1988, Sothern 1994).

Symptoms of cryptosporidiosis (the disease caused by *Cryptosporidium*) in humans appear within 2 to 12 days of exposure and generally include profuse watery diarrhea lasting for up to several weeks. Nausea, abdominal cramps and low-grade fever may accompany the diarrhea. No known drug therapies are effective in treating the disease, but it is self-limiting in immuno-competent individuals. Individuals suffering from a viral illness, particularly measles or chicken pox, may be especially vulnerable to infection, as are malnourished children. The disease can become chronic in immuno-suppressed individuals, for example, in those who have AIDS or are HIV-positive (Sothern 1994).

3.3 DOSE-RESPONSE ASSESSMENT

The dose-response assessment is the process of characterizing the relation between the dose of an agent administered or received and the incidence of an adverse health effect in exposed populations and estimating the incidence of the effect as a function of human exposure to the agent. In this risk assessment, the dose-response assessment identifies the probability of infection as a result of exposure to pathogenic microbial agents and, once infected, the conditional probability that an individual will contract a disease.

Development of disease depends on numerous factors, including the immune status of the host, age of the host, type, strain, and virulence of the microorganism, and route of infection. Uncertainties associated with the dose-response information available in the literature include:

- Experimentation with healthy individuals as opposed to individuals with poorer health status (aged, compromised immune system) and therefore greater susceptibility, and

- Experimentation with well-characterized strains of pathogens as opposed to indigenous pathogens (Glicker and Edwards 1991).

In order to assess the hazards from biological agents in drinking water, it is necessary to know how many viable pathogenic cells are necessary to initiate an infection. Dose-response experiments for microorganisms of concern in drinking water have been conducted with human volunteers using bacteria, protozoans, and viruses. In these experiments, volunteers are typically exposed to dosages of microorganisms that were known to contain certain average concentrations. Then the resulting number of infected and unaffected individuals was determined. The number of infected individuals depends on the probability of the organism's occurrence in the water and the dose-response curve (Regli et al. 1991). The results of some of these dose-response studies are summarized below.

Total Coliforms

The number of bacteria required to produce disease is unknown but can range from 1 to 10^8 per 100 mL or more viable organisms. Total coliform are an indicator of microbial contamination and are usually not pathogenic in and of themselves. The Maximum Contaminant Level for total coliform under the National Primary Drinking Water Regulations is based on the presence/absence of total coliforms in samples, rather than on an estimated coliform density. Community water treatment systems are required to obtain routine total coliform samples at intervals during each month with the number of monthly samples based on the population served. When less than 40 samples per month are required, no more than one sample per month may be positive for total coliform. When 40 or more samples per month are required, no more than 5 percent of all monthly samples may be positive for total coliform (USEPA 1989b). Additionally, under these regulations, filtration of source water is not required if the total coliform concentration in water prior to disinfection is equal to or less than 100/100 mL in at least 90 percent of the samples (USEPA 1989b). The numerical criterion is set based on the premise that the number of coliforms in domestic wastewater far outnumbers the number of pathogenic microorganisms since coliforms are contributed by the entire population while pathogens are contributed only by persons with enteric illnesses. The die-off rate of pathogenic bacteria is greater than the death rate of coliforms outside the intestinal tract, thus, exposure to treatment and residence in water reduces the number of pathogens relative to coliforms. Therefore, the MCL for coliforms is considered statistically safe for human consumption because of the improbability of ingesting pathogenic bacteria.

Giardia lamblia

When the USEPA promulgated the Surface Water Treatment Rule (SWTR), it suggested that water be treated for *Giardia* cyst removal with the goal of ensuring high probability that the population consuming the water would not be subjected to a risk of greater than one infection of giardiasis per 10,000 people per year (1×10^{-4}). This is comparable to other acceptable microbiological risk levels (USEPA 1989a).

Based on a risk analysis by Rose, et al. (1991), which assumed all cysts found were viable and infectious to humans, the incidence of infection from *Giardia* was predicted as a function of exposure to cyst concentrations in drinking water. Table 3.3-1 indicates the annual risk of *Giardia* infection for people consuming water with different concentrations of *Giardia* cysts. From the analysis performed by Rose, et al., a concentration of 7.0×10^{-4} cysts/100 L results in a risk of infection of 1×10^{-4}.

Table 3.3-1

Estimated Yearly Risk of *Giardia* Infections [a]

Yearly Risk [b]	Geometric mean cyst concentration per 100 L
31.6 infections per 100,000 persons (1 x $10^{-3.5}$)	0.002 (2.0 x 10^{-3})
10 infections per 100,000 persons(1 x $10^{-4.0}$)	0.0007 (7.0 x 10^{-4})
3.2 infections per 100,000 persons(1 x $10^{-4.5}$)	0.0002 (2.0 x 10^{-4})
1 infection per 100,000 persons(1 x 10^{-5})	0.00007 (7.0 x 10^{-5})

a Using the exponential risk assessment model of Rose et al. (1991).

b. Risk is a probability and is usually expressed in exponential form (1 x 10-4). Expressing it as the number of infections per population exposed is often easier to understand.

Cryptospordium parvum

Based on a risk analysis by Haas, et al. (1996), which assumed all oocysts found were viable and infectious to humans, the incidence of infection from *Cryptosporidium* was predicted as a function of exposure to oocyst concentrations in drinking water. The oocyst concentration in water predicted to cause infection was based on a study by DuPont, et al. (1995) that determined the infectivity of *Cryptosporidium* in healthy volunteers. From the analysis performed by Haas, et al., a concentration of 3.0 x 10^{-3} oocysts/100 L results in a risk of infection of 1 x 10^{-4}.

Dose-Response Summary

Many of the pathogens present in wastewater are continuing causes of food and waterborne disease in the United States. Although the information on infectious dose for most pathogens is limited, it appears that low numbers (less than 50 organisms) of protozoan cysts are capable of causing infection in a susceptible host. The infective dose of *Giardia* and *Cryptosporidium* by the oral route appears to be as low as between 1 and 10 cysts. Minimum infectious doses for bacteria are generally higher than those for parasites. Virulence of the particular type and strain of microorganism and host factors may play a role in determining the actual number of microorganisms required to cause infection. There appears to be considerable difference in the virulence of various strains of *Cryptosporidium* for example (Teunis et al. 2002). The number of individuals who develop clinical illness will also depend upon the strain and type of organism as well as host factors such as age and immune status.

If the distribution of pathogens in the water consumed by a human population is known and dose-response relationships are established, the risk of infection, morbidity, and mortality can be estimated.

3.4 EXPOSURE ASSESSMENT

This section presents a characterization of the population potentially impacted by the use of treated effluent, an evaluation of exposure pathways, following those identified in Figure 2.3-1, and estimates of potential exposure to microorganisms from the treated effluent.

Population of Potentially Exposed Individuals

Characteristics of populations potentially exposed are discussed in Section 2.3 of this assessment.

Certain population groups are at greater risk of disease from waterborne microorganisms. The infecting dose of microorganisms and disease development varies with the age and general health of the host population. Infants and the aged may be particularly susceptible. Previous exposure to a specific pathogen is important, in that antibodies present in the intestinal tract, associated with immunity to enteric infection, may prevent infection with a strain that is generally present in the population, whereas a new strain introduced into the water supply may present an increased hazard (NRC 1977).

Immunosuppressed individuals are at increased risk of disease from waterborne microorganisms. These populations include the elderly, those who have AIDS, are HIV positive, are organ transplant recipients, are undergoing chemotherapy, or have leukemia. Diseases such as hepatitis may become chronic in these individuals. Among AIDS patients, for example, cryptosporidiosis is regarded as a leading cause of the chronic diarrhea and nutrient malabsorption associated with the wasting syndrome that frequently leads to death (Sothern 1994).

Exposure Pathways

Ingestion is the primary exposure pathway for contact with microorganisms in water. Although direct ingestion of final fresh or stored effluent does not occur, effluent would be discharged directly at a new outfall on the Russian River or indirectly via percolation ponds, infiltration basins or injection wells adjacent to the Russian River or Dry Creek. The Sonoma County Water Agency's (SCWA) intakes (caissons) on the Russian River would probably be several miles downstream from the discharge points, although the locations of discharge points have not been determined.

The National Primary Drinking Water Regulations (Title 40, Code of Federal Regulations §141) require that surface water and "groundwater under the direct influence of surface water" be treated to minimize the risk of disease from pathogenic organisms that may occur in these waters. Groundwater under the direct influence of surface water is defined as groundwater with (1) a significant occurrence of insects or other macroorganisms, algae, or large-diameter pathogens such as *Giardia lamblia*, or (2) significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions. Percolation of water through soil and/or base materials (e.g., sands and gravels) normally filters out macro- and micro-organisms and dampens the magnitude of changes in temperature, turbidity, conductivity and pH. The National Primary Drinking Water Regulations and the Surface Water Treatment Rule require additional treatment (e.g., chlorination or ozonation) of surface water and groundwater under the direct influence of surface water to minimize the risk of exposure to pathogens.

Primarily because of changes in turbidity that correlate with turbidity fluctuations in the Russian River, SCWA’s caisson 5 has been classified as under the direct influence of surface water under certain conditions (Flugum 1995). A 1993 study of this caisson showed that turbidity changes in water withdrawn from caisson 5 correlated with turbidity changes in the Russian River, although the changes in the caisson were at least two orders of magnitude (1×10^{-2}) smaller than the changes observed in the Russian River (CH2M Hill 1993). The report also notes that, in spite of the change in turbidity, the natural filtration system operates well in removing bacteria (only 11 of 60 samples from caisson 5 contained total coliform at 1 to 9 total coliform count) and that no *Giardia* were found in collector water. In contrast, all Russian River samples (62 of 62) were positive for total coliform (16 to 16,000 total coliform count) and two samples of Russian River water were positive for *Giardia* during this time.

Currently, caisson 5 has its own operational controls and is monitored for turbidity. As turbidity increases, the pump is shut down. None of the other four caissons are classified as under the direct influence of surface water. It is therefore unlikely that the microorganisms in recycled water would reach the SCWA’s intakes.

An analysis of the effects of the proposed discharge to the Russian River has reaffirmed that the natural filtration provided by the riverbed will effectively remove coliform bacteria, *Giardia*, *Cryptosporidium*, and viruses (CH2M Hill 1996). The analysis also concludes that implementation of a Russian River discharge upstream of the SCWA collectors would not necessitate additional treatment by the SCWA to comply with the requirements of the Surface Water Treatment Rule, although further analysis of collectors and additional sampling for *Giardia* and *Cryptosporidium* in the effluent and river may be required by the California Department of Health Services.

To provide a simple assessment of the potential risk from ingestion of final treated effluent, this evaluation considers ingestion of final effluent without dilution as the most conservative exposure pathway that could be quantified.

Additional exposure pathways exist from use of effluent as a source of domestic water. During showering, aerosolized microorganisms may be inhaled. Use of water containing microorganisms for irrigating home gardens could result in surface contamination of fruits and vegetables with microorganisms. Eating prior to washing could result in the ingestion of microorganisms along with the skin of the produce. Watering gardens could also generate aerosols that could then be inhaled.

Aerosols can transmit many enteric microorganisms effectively. In fact, the infectious dose by the aerosol route may be lower than the infectious dose for the ingestion route for some organisms. The organisms in aerosols can be transmitted by inhalation or the settling of the organisms onto surfaces with which humans come into contact (USEPA 1986). This exposure route may be important in an urban setting if water is used to irrigate public gardens and lawns.

Recreationists may also be exposed to microorganisms through direct contact with surface water while fishing, swimming or other water sports because of inadvertent ingestion of surface water. Ingestion of inadequately cooked fish caught from water containing pathogens is an indirect exposure pathway for recreationists.

Indirect exposure to pathogenic microbial agents may also occur through person-to-person contact and other means. For example, giardiasis is a fecal-oral disease and can be spread by person-to-person contact. Numerous outbreaks of giardiasis have occurred in daycare centers, and *Giardia* can also be transmitted through sexual contact. Viral and bacterial diseases can also be transmitted indirectly by person-to-person contact.

The agricultural use of treated effluent involves some of the same exposure pathways as domestic use of effluent. As with domestic use of effluent for irrigating home gardens, crop irrigation could result in surface contamination of agricultural products, leading to other indirect routes of exposure. Potential routes of exposure include:

- Inadvertent contact with effluent water during irrigation;
- Handling soil and raw produce from irrigated areas;
- Inhaling microorganisms that become airborne (via aerosols, dust, etc.) during and or after irrigation;
- Contact with dust raised by strong winds or by plowing or cultivating the soil;
- Consumption of pathogen-contaminated crops irrigated with effluent.

The potential for exposure through these pathways diminishes over time as environmental conditions such as heat, sunlight, desiccation, and other microorganisms destroy pathogens that may be present in areas irrigated with wastewater. Table 3.4-1 summarizes the survival rates of bacteria, viruses and protozoan cysts in soil and on plants. Because protozoan cysts are rapidly killed by environmental factors, the public health threat from protozoa in wastewater-irrigated land is minimal. Bacteria and viruses are of greater concern. Some bacteria are unique among pathogens in their ability to regrow. Even very small populations of certain bacteria can rapidly proliferate under the right conditions. Viruses and protozoa cannot regrow outside their specific host organism(s). Once reduced by treatment, their populations stay reduced (USEPA 1989c).

Table 3.4-1

Survival Time of Pathogens in Soil and on Plant Surfaces

	Soil		Plants	
Pathogen	**Absolute Maximum**	**Common Maximum**	**Absolute Maximum**	**Common Maximum**
Bacteria	1 year	2 months	6 months	1 month
Protozoan cysts(1)	6 months	3 months	2 months	1 month
Viruses	10 days	2 days	5 days	2 days

Source: USEPA, 1989c

(1) Little if any data are available on the survival time of *Giardia lamblia* cysts and *Cryptosporidium* oocysts.

Concentrations of Pathogens in Water

In this risk assessment, it is assumed that the final treated effluent is used directly as a drinking water source. Exposure point concentrations of the microorganisms detected are assumed to be equal to the maximum detected concentration in final effluent. However, because there is no mechanism to determine the viability of *Giardia* cysts or *Cryptosporidium* oocysts in a sample, an assumption of viability must be made considering wastewater treatment effectiveness. At the Santa Rosa wastewater treatment facility, the wastewater is disinfected with ultraviolet light, which does not inactivate *Giardia* but may provide 99.9% (3 log-units) or more inactivation for *Cryptosporidium* (Clancy, et al. 2000, Finch, et al. 2002). The ultraviolet disinfection system at the treatment plant is designed to deliver a minimum ultraviolet dose of 85 milliJoules/centimeter squared (mJ/cm^2) at the maximum daily flow. Clancy, et al. (2000) have demonstrated that an ultraviolet dose of 40 mJ/cm^2 provides a 3 log inactivation of *Cryptosporidium* oocysts.

Using the maximum *Cryptosporidium* concentration (9.6 oocysts/100 L) detected in any sample of effluent, the assumption that all oocysts were initially viable, and an inactivation rate of 3 log-units by ultraviolet disinfection, the viable *Cryptosporidium* oocyst concentration would be no more than 9.6×10^{-3} cysts/100 L. For *Giardia*, it is assumed that ultraviolet disinfection does not reduce viability but that only 10 percent of the cysts detected are viable, as stated by Regli et al. (1991). Thus, the concentration of *Giardia* would be 3.7 cysts/100 L.

In addition to reducing concentrations of inorganic ions and many organic chemicals (as noted in Section 2) the semipermeable membranes used in reverse osmosis also exclude microorganisms and thus reduce the concentrations of pathogens in recycled water (Asano 1998). Several types of reverse osmosis systems have been shown to remove 100% of *Cryptosporidium* oocsyts and *Giardia* cysts (Gagliardo 1998). Implementation of reverse osmosis for the direct and indirect discharge options would reduce the concentrations of microorganisms below those used in this risk assessment, which does not consider the effects of reverse osmosis.

3.5 RISK CHARACTERIZATION

This section integrates the information from the hazard identification, dose-response assessment, and exposure assessment to characterize risk.

Total coliform levels have been used for decades as the primary measure of the microbial quality of drinking water. Coliforms are usually present in water contaminated with human and animal feces and are often associated with outbreaks of disease. Although total coliforms are usually not pathogenic themselves, their presence in drinking water indicates that pathogens may also be present. It is generally accepted that treatment that provides total coliform-free water will reduce pathogens to minimum levels (USEPA 1989b).

The sewage treatment facility is required to meet wastewater discharge standards as part of their NPDES permit. This requires them to take daily samples that must be below a concentration of 23 MPN/100 mL, with monthly medians of <2 MPN/100 mL. Data available from December 1997 through April 2002 indicates they have met the monthly requirement for total coliform counts, but had exceedances (maximum of 240 MPN/100 mL) over the daily limit that would be considered above the margin of error for the coliform test (+/-50%) (Merritt Smith Consulting 2002). All exceedances were at or below the concentrations detected in the Russian River upstream of the Laguna de Santa Rosa discharge. For comparison, samples of Russian River water upstream from the Laguna de Santa Rosa discharge point that were collected for the Long-Term Project in 1994 were all positive for total coliform (range 23 MPN to 240 MPN/100 L) and concentrations as high as 16,000 MPN/100 mL have been reported (CH2M Hill 1993).

The estimated maximum concentration of viable *Giardia* cysts in the final effluent, based on the analytical data in Table 3.1-1 and 10 percent viability, is 3.7 viable cysts/100 L. The concentration of *Giardia* cysts that corresponds to an “acceptable” annual risk of infection of 1×10^{-4}, according to the risk analysis of Rose et al. (1991), is 7.0×10^{-4} cysts/100 L when used as a drinking water supply (see Table 3.3-1). Therefore, the estimated maximum *Giardia* concentration in the final effluent exceeds the acceptable average concentration as defined by Rose, et al. However, dilution of effluent with surface and groundwater and filtration by soils and underlying base materials would reduce this risk. In addition, *Giardia* cysts have been reported in the Russian River (CH2M Hill 1993) at a maximum concentration of 13.8 cysts/100 L. Assuming all cysts were viable, this is higher than the viable concentrations calculated for the treatment plant effluent. Reverse osmosis would effectively remove *Giardia* cysts and thus further reduce the risk associated with the Direct and Indirect Discharge Alternatives.

The estimated maximum concentration of viable *Cryptosporidium* oocysts in the final effluent, based on the analytical data in Table 3.1-1 and a 99.9 percent disinfection rate, is 9.6×10^{-3} oocysts/100 L. The concentration of *Cryptosporidium* oocysts that corresponds to an “acceptable” annual risk of infection of 1×10^{-4}, according to the risk analysis of Haas, et al. (1996), is 3.0×10^{-3} oocysts/100 L. Thus, the concentration of viable oocysts in the effluent slightly exceeds the infection risk above what is considered acceptable by USEPA for drinking water. However, dilution of effluent with surface and groundwater and filtration by soils and underlying base materials would reduce this risk. In addition, *Cryptosporidium* has been detected on two testing dates in surface water samples taken from the Russian River at Kaiser Beach at a maximum concentration of 2.7 oocysts/100 L. Assuming all oocysts were viable, this concentration is considerably higher than the viable concentrations calculated for the treatment plant effluent. Reverse osmosis would effectively remove *Cryptosporidium* oocysts and thus further reduce the risk associated with the Direct and Indirect Discharge Alternatives.

Risk Summary

The analysis of microbiological data collected for this study leads to the conclusion that it is unlikely that the treated effluent discharged from the treatment system poses a significant human health risk. However, considering the uncertainty in estimating minimum infectious doses for some pathogens, it is not possible to accurately assess the risk from direct ingestion of treated effluent, let alone the risk through pathways other than ingestion. It is known that waterborne disease occurs as a result of inadequately treated drinking water supplies, and that outbreaks of waterborne diseases have been attributed to bacterial, viral, and parasitic microorganisms. The potential disease risk from exposure to the treated effluent depends on the concentration of the organism in the exposure medium, the virulence of the organism, the health of the receptor, the extent and duration of exposure and the exposure route. The exposure pathway that presents the greatest risk of disease is from use of the treated effluent for potable water without further treatment or dilution. Ingestion of the water would constitute the largest potential dose of microorganisms present in the treated effluent. However, other exposure routes, including inhalation of aerosols and contact with irrigated garden plants and crops would also pose a potential disease risk if pathogenic organisms are present in the treated effluent. Other factors that enter into the determination of risk include survival times of the microorganisms in water and soil, further treatment of the water before its use, and dilution rates.

3.6 UNCERTAINTY

Uncertainties are associated with the collection and analysis of microbial data. Sampling and analytical procedures may or may not have accurately characterized the organisms present and their concentrations. In addition, sample size affects the accuracy of both the identification and quantification of microorganisms. The limited number of samples adds uncertainty to the absence of certain organisms, such as *Shigella* and *Salmonella*, which are responsible nationwide for over 50 percent of waterborne outbreaks and enteric viruses, although the low total coliform count tends to corroborate the lack of these pathogenic bacteria in effluent.

A major uncertainty in the available dose-response data is that human experiments were performed using healthy adult volunteers. The general population has a lower overall health status and a greater susceptibility to adverse effects from infection. The development of clinical illness depends on many factors, including the immune status of the host, age of the host, virulence of the organism, strain of the organism, and route of infection. Because of this, the dose required for infection does not correlate with illness for all receptors. In addition, dose-response data available have been obtained using well-characterized laboratory strains of pathogens. The intrinsic infectivity may differ between laboratory maintained cultures and indigenous viruses; however, the magnitude of these differences is currently not clear.

One major area of uncertainty in the exposure assessment is the assumption of ingestion of effluent without dilution. Although the degree of dilution cannot be adequately predicted on a daily basis, this assumption leads to an over-estimation of the concentration of microorganisms in drinking water. This in turn, over-estimates risk.

The assumption of percent viability for *Giardia* cysts and *Cryptosporidium* oocysts adds uncertainty to the estimate of risk through ingestion. Bracketing the possible viability between 10 and 100 percent allows for a range of estimated risk.

4.0 REFERENCES

American Water Works Association (AWWA) 1988. Roundtable: *Cryptosporidium*. Journal American Water Works Association 80:14-27

Asano, Takashi (ed.) 1998. Wastewater Reclamation and Reuse, Chapter 7, Reverse Osmosis Membranes for Wastewater Reclamation, Water Quality Management Library, Lancaster, PA.

CH2M Hill, Inc. 1993, Final Report, Russian River Demonstration Study. July

CH2M Hill, Inc. 1996, Memorandum from Mr. Mike Price to Mr. Dave Smith/Merritt Smith Consulting. 12 February

Clancy, J.L., T.M. Hargy, M.M. Marshall, and J.E. Dyksen 2000, UV light inactivation of *Cryptosporidium* oocysts. J. American Water Works Association, 90:92-102

DTSC 1994, Preliminary Endangerment Guidance Manual, California Department of Toxic Substances Control. January

DTSC 2003, California Cancer Potency Factors, California Department of Toxic Substances Control, Standards and Criteria Work Group. January

DuPont, H. et al. 1995, Infectivity of *Cryptosporidium parvum* in Healthy Volunteers. New England Journal of Medicine 332:855.

Finch, G.R., and M. Belosevic 2002, Controlling *Giardia* spp. and *Cryptosporidium* spp. in drinking water by microbial reduction processes. J. Environ. Eng. Sci. 1:17-31.

Flugum, J. 1995, Telephone conversation between Mr. Jim Flugum, Sonoma County Water Agency, and Mr. Dennis J. Brown, Parsons ES. 31 October

Gagliardo, P.F. 1998, Comparing the Performance of Various RO Membranes for Water Repurification, Water Reuse Conference Proceedings, February 1-4, 1998, Lake Buena Vista, Florida

Glicker, J.L. and R.A. Edwards 1991, Giardiasis Risk From an Unfiltered, Protected Surface Water Source. American Water Works Association 83:46-51

Haas, C.N., C.S. Crockett, J.B. Rose, C.P. Gerba and A.M. Fazil 1996, Assessing the risk posed by oocysts in drinking water. J. American Water Works Association 88:131-136.

Health & Environment Network 1988, Giardia: A Worldwide Cause of Intestinal Infection. Health and Environment Digest 2:1-2

Howard, P.H. 1990, Handbook of Environmental Fate and Exposure Data For Organic Chemicals, Vol. II: Solvents. Lewis Publishers, Inc. Chelsea, Michigan. 546 pp.

Howard, P.H. 1991, Handbook of Environmental Fate and Exposure Data For Organic Chemicals, Vol. III: Pesticides. Lewis Publishers, Inc. Chelsea, MI. 684 pp.

Lippy and Waltrip 1984, Waterborne Disease Outbreaks - 1946-1980: A Thirty-five Year Perspective. American Water Works Association 76(2):60-67

Merck 1989, The Merck Index, Eleventh Edition. Merck & Company, Inc. Rahway, NJ.

Merritt Smith Consulting, Inc. 1995a, Field Sampling and Quality Assurance Plan. January

Merritt Smith Consulting, Inc. 1995b, Recycled Water Quality Technical Report. September

Merritt Smith Consulting 2002, Technical Memorandum No. 19 Santa Rosa Incremental Recycled Water Program—Effluent Quality, Reasonable Potential Analysis, and Permit Limits.

National Research Council (NRC) 1977, Microbiology of Drinking Water. In Drinking Water and Health, Vol. 1, National Academy of Sciences, Washington, DC

NRC 1983, *Risk Assessment in the Federal Government: Managing the Process.* National Academy Press, Washington, D.C.

NRC 1994, *Science and Judgment in Risk Assessment*. National Academy Press, Washington, D.C.

Parsons Engineering Science, Inc. 1995a, Human Health Effects and Wildlife Effects of Environmental Estrogens. September

Parsons 1997, Environmental Impact Report for the Santa Rosa Subregional Long-Term Wastewater Project, Appendix J-3, Human Health Risks from Chemical and Biological Components of Reclaimed Water. May

Parsons 2003. Human Health Effects and Wildlife Effects of Endocrine Disrupting Compounds and other Xenobiotics.

Piazza, Randy. 2002. Personal communication, June

Prager, J.C. (ed.) 1989, Ammonia. Dangerous Properties of Industrial Materials Report. Van Nostrand Reinhold, New York. Vol. 9(2): 2-6

Regli S., J.B. Rose and C.N. Haas 1991, Modeling the Risk from *Giardia* and Viruses in Drinking Water. Journal of the American Water Works Association 83:76-84

Rose, J.B., C.N. Haas and S. Regli 1991, Risk Assessment and Control of Waterborne Giardiasis. American Journal of Public Health 81:709-713

Sittig, M. 1985, Handbook of Toxic and Hazardous Chemicals and Carcinogens, Second Edition. Noyes Publications, Park Ridge, New Jersey, 950 pp.

Sothern, W. 1994, Protecting Drinking Water from *Cryptosporidium*. The National Environmental Journal. (Sept/Oct) 33-36

State Water Resources Control Board (SWRCB) 2000. Guidelines for Investigation and Cleanup of MTBE and Other Ether-Based Oxygenates. March 27

Teunis, P.F.M., C.L. Chappell, and P.C. Okhuysen 2002. Cryptosporidium Dose-Response Studies: Variation Between Hosts, Risk Analysis 22:475-485

USEPA 1986, Development of a Qualitative Pathogen Risk Assessment Methodology for Municipal Sludge Landfilling. USEPA/600/6-88/006, Office of Health and Environmental Assessment, Washington, DC

USEPA 1989a, National Primary Drinking Water Regulations: Filtration; Disinfection; Turbidity, *Giardia lamblia*, Viruses, *Legionella*, and Heterotrophic Bacteria. Final Rule. Fed. Reg. 54:27486. 29 June

USEPA 1989b, National Primary Drinking Water Regulations: Total Coliforms (Including Fecal Coliforms and E. Coli); Final Rule. Fed. Reg. 54:27544. 29 June

USEPA 1989c, Environmental Regulations and Technology: Control of Pathogens in Municipal Wastewater Sludge. USEPA/625/10-89/006, Center for Environmental Research Information, Cincinnati, OH

USEPA 1991, Guidance Manual for Compliance with the Filtration and Disinfection Requirements of Public Water Systems using Surface Water Sources. Science and Technology Branch, Criteria and Standards Division, Office of Drinking Water, Washington, DC

USEPA 1994c, Drinking Water Regulations and Health Advisories, Office of Water, EPA 822-R-94-001. May

USEPA 1994d, National Primary Drinking Water Regulations: Enhanced Surface Water Treatment Requirements; Proposed Rule. Fed. Reg. 59 (145):38832-38858. Friday, 29 July

USEPA 1995, Region IX Preliminary Remediation Goals, First Half 1995. 1 February

USEPA 1986, Guidelines for Carcinogen Risk Assessment, Office of Research and Development, 51 FR 33992, September 24

USEPA 1996, Proposed Guidelines for Carcinogen Risk Assessment, Office of Research and Development, EPA/600/P-92/003C, April

USEPA 2001, Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment). EPA/540/99/005

USEPA 2003a, Hazardous Substances Data Base (HSDB), Toxnet, National Library of Medicine

USEPA 2003b, Integrated Risk Information System (IRIS), Toxnet, National Library of Medicine

Water Environment Federation and American Water Works Association (WEF/AWWA) 1998. Using Reclaimed Water to Augment Potable Water Resources, Chapter 4, Treatment Technology.

World Health Organization (WHO) 2002. Guidelines for Drinking Water. www.who.int/water_sanitation_health/GDWQ/Chemicals/ammonsum.htm.

APPENDIX A

This appendix describes the natural and artificial sources and the environmental fate of the chemicals whose maximum detected concentration yields a hazard quotient greater than 1.0 or an excess cancer risk greater than 1 x 10^{-6}.

Ammonia

Ammonia occurs naturally in animal waste, primarily urine (Merck 1989). Anthropogenic sources include fertilizers, explosives, fiber and plastic manufacturing, and use as a bactericide.

Ammonia is expected to adsorb readily to soil and to sediment particles in water. Under anaerobic conditions, adsorption to sediments is reduced, resulting in the release of ammonia to water or to an oxidized sediment layer. In water, ammonia is rapidly converted to nitrate via nitrification by bacteria (primarily of the genus *Nitrosomonas*) (USEPA 2003a). Nonionized ammonia (NH_3) is the principal toxic form of ammonia (Prager 1989). It is a lethal toxin at very low concentrations to many aquatic life forms.

Methyl *tert*-butyl ether

MTBE has been added to gasoline to enhance octane ratings and to comply with Clean Air Act mandates. It was approved by the EPA for use in 1979 and was added to gasoline during the 1980s at approximately 2-5% by volume as an octane booster. In 1992, it was blended at 10-15% by volume for use in some areas in the wintertime oxygenated fuel program. In 1996, it began to be used year-round at 11% by volume in the statewide-reformulated gasoline program (SWRCB 2000). California currently intends to ban the use of MTBE in gasoline mixtures by December 31, 2003.

Relative to other fuel hydrocarbons, MTBE has a high solubility in water. The compound has low retardation in groundwater aquifers, and is slow to biodegrade. These properties, combined with a high percentage in gasoline, cause the potential for high source area concentrations, long plumes in groundwater, and long residence times in the subsurface. It also has taste and odor characteristics that can impair water supplies at very low concentrations.

Naphthalene

The primary source of exposure to naphthalene is from air, especially in areas of heavy traffic or where fumes from evaporating gasoline or fuel oil exist or in the vicinity of petroleum refineries. In addition, there are discharges on land and into water from spills during the storage, transport and disposal of fuel oil, coal tar, etc. Naphthalene rapidly photodegrades in the atmosphere (half-life 3-8 hr). Releases into water are lost due to volatilization, photolysis, adsorption, and biodegradation. The principal loss processes will depend on local conditions but half-lives can be expected to range from a couple of days to a few months. When adsorbed to sediment, biodegradation occurs much more rapidly than in the overlying water column. When spilled on land, naphthalene is adsorbed moderately to soil and undergoes biodegradation. However, in some cases it will appear in the groundwater where biodegradation still may occur if conditions are aerobic. Bioconcentration occurs to a moderate extent but since depuration and metabolism readily proceed in aquatic organisms, this is a short term problem.

Nitrate

Natural sources of nitrate include vegetables such as beets, celery, lettuce, and spinach, as well as mineralization of soil organic matter (Sittig 1985). Anthropogenic sources include farm fertilizer and animal wastes, lawn fertilizer, leachate from waste disposal in sanitary landfills and dumps, atmospheric sources, and nitric oxide and nitrite discharges from automobile exhausts (Sittig 1985).

Nitrates may be found in the environment bound with organic and/or inorganic matter. The fate and transport of nitrates, therefore, is dependent upon those properties associated with the nitrate-bound material. Any discussion attempting to encompass all properties of nitrate-bound materials is beyond the scope of this assessment.

Nitrite

Naturally-occurring nitrite is found bound to organic and/or inorganic matter in the environment. Anthropogenic sources include sodium nitrite used in the manufacture of diazo dyes, and in numerous processes involving the manufacture of organic chemicals; textile fabric dyeing and printing; bleaching processes of silk, flax, and linen; photography; and meat curing, coloring and preserving (Merck 1989).

Because nitrites in the environment are generally bound with organic and/or inorganic matter, the fate and transport of nitrites is dependent upon those properties associated with the nitrite-bound material. Any discussion attempting to encompass all properties of nitrite-bound materials is beyond the scope of this assessment.

Chloroform

Natural sources of chloroform include plants. Anthropogenic sources include the chemical industry, chlorination of drinking water, municipal sewage, power plants, auto exhaust, the dry cleaning industry, fumigation, and manufacturing (Howard 1990).

Chloroform will volatilize from soil and water. It is not adsorbed significantly on soils or sediment. Chloroform in soils will leach to groundwater, where it may remain for long periods of time or until discharged. Since it is substantially denser than water, when it occurs as a separate phase it tends to sink to the bottom of the aquifer. Releases to surface soils and water will be dissipated primarily by volatilization. It is subject to significant biodegradation. It is not expected to bioconcentrate in aquatic organisms (Howard 1990). The half-life of chloroform in soil and surface water is one to six months (Howard et al. 1991).

Endosulfan

There are no natural sources of endosulfan. Technical grade endosulfan is composed of α- and β-endosulfan (endosulfan I and II, respectively). It is a pesticide used to control various insects and mites on cereal, cotton, fruits and vegetables (USEPA 2003a).

In soil, endosulfans will most likely biodegrade and hydrolyze, especially under alkaline conditions. Endosulfans on the soil surface may photodegrade. Volatilization and leaching are not expected to be significant because endosulfan adsorbs strongly to soils. In water, endosulfans are expected to hydrolyze readily under alkaline conditions, and more slowly at neutral and acidic pH values (alpha half-lives are 35.4 and 150.5 days for pH 7 and 5.5, respectively; beta half-lives are 37.5 and 187.3 days for pH 7 and 5.5, respectively). Volatilization and biodegradation are also expected to be significant. Photolysis and oxidation may also be important. Bioconcentration of endosulfan is expected to be significant.

APPENDIX B

This appendix describes toxicity data for the chemicals detected in the effluent samples collected from the Laguna Plant. Toxicity data were obtained from the USEPA's Integrated Risk Information System (IRIS) and the National Library of Medicine's Hazardous Substances Database (HSDB) unless otherwise indicated. Both information sources are available on the National Library of Medicine's data network system (TOXNET).

Ammonia

The major targets of ammonia toxicity are the respiratory system and the eyes.

The odor (8 mg/L) and taste (34 mg/L) thresholds for humans were used as screening criteria (WHO 2002).

The USEPA has not placed ammonia in a weight-of-evidence cancer group.

Methyl *tert*-butyl ether

In acute and subacute oral exposure studies, limited effects on the respiratory, gastrointestinal, hematological, liver, kidney, or nervous systems and some minor systemic toxicities have been observed. In subchronic oral exposure, limited effects on gastrointestinal, hematological, liver, or kidney systems and some minor systemic toxicities have been observed. In chronic oral exposure, the main observation is cancer and preneoplastic effects.

A chronic RfC of 3.0 mg/m^3 is based on a NOAEL of 1,453 mg/m^3, which caused increased absolute and relative liver and kidney weights, increased severity of spontaneous renal lesions in female rats and other effects. An uncertainty factor of 10 (to account for interspecies extrapolation and database deficiencies) was used to convert the NOAEL to the RfD.

An oral slope factor of 0.0018 (mg/kg/day)$^{-1}$ and a unit risk of 2.6 x 10^{-7} (µg/m^3)$^{-1}$ have been derived by the DTSC. The USEPA has not derived a slope factor or unit risk for MTBE and has not assigned it a weight-of-evidence group.

Naphthalene

Target organs include the eyes (irritation and cataracts) and kidneys.

A chronic oral RfD of 0.02 mg/kg/day is based on a NOAEL of 100 mg/kg/day that caused decreased mean terminal body weight in male rats. A low incidence of renal lesions was observed in the kidneys and thymus of males and females treated at this level. An uncertainty factor of 3,000 (to account for interspecies extrapolation, sensitive human subpopulations, subchronic to chronic dose extrapolation and database deficiencies) was used to convert the NOAEL to the RfD.

A chronic RfC of 0.003 mg/m^3 is based on a LOAEL of 9.3 mg/m^3 that caused hyperplasia (increased growth of cells) and metaplasia (transformation from one cell type to another) in respiratory and olfactory epithelium, respectively, of mice. An uncertainty factor of 3,000 (to account for interspecies extrapolation, sensitive human subpopulations, LOAEL to NOAEL extrapolation, and database deficiencies) was used to convert the LOAEL to the RfD.

Using the 1996 Proposed Guidelines for Carcinogen Risk Assessment, the human carcinogenic potential of naphthalene via the oral or inhalation routes "cannot be determined" at this time based on human and animal data; however, there is suggestive evidence (observations of benign respiratory tumors and one carcinoma in female mice only exposed to naphthalene by inhalation). Additional support includes increase in respiratory tumors associated with exposure to 1-methylnaphthalene. An inhalation unit risk estimate for naphthalene has not been derived by the USEPA because of the weakness of the evidence (observations of predominant benign respiratory tumors in mice at high dose only) that naphthalene may be carcinogenic in humans.

Nitrate

Nitrate is a normal component of the diet, with a typical daily intake of 75 mg/day (0.2 to 0.3 mg nitrate-nitrogen/kg/day) reported for U.S. adults. Over 85% of the intake comes from the natural nitrate content of vegetables, such as beets, celery, lettuce and spinach.

The primary target of nitrate toxicity is the blood, with methemoglobinemia occurring, especially in infants. Methemoglobinemia occurs when nitrate is converted in the body to nitrite, and the nitrite oxidizes hemoglobin to a form that is unable to transport oxygen. This condition results in reduced oxygen transport to tissues. Methemoglobin (MetHb) concentrations above 10% may cause cyanosis (bluish color to skin and lips). MetHb levels above 25% lead to weakness, rapid pulse and breathing, and levels exceeding 50-60% may be fatal. Infants aged less than three months are most sensitive to this condition because the infant gastrointestinal system has a normally high pH which favors the growth of nitrate-reducing bacteria, and because infants have hemoglobin F, which is more susceptible to oxidation.

A chronic oral RfD of 1.6 mg/kg/day is based on a NOAEL of 1.6 mg/kg/day for methemoglobinemia in infants (dose based upon the amount of nitrogen within the nitrate molecule).

Information regarding the genotoxic potential of nitrate was not located and the USEPA has not placed nitrate in a weight-of-evidence cancer group.

Nitrite

The toxic effects of nitrite are similar to those of nitrate, with the primary concern being methemoglobinemia.

A chronic oral RfD of 0.1 mg/kg/day is based on a NOEL of 1.0 mg/kg/day for methemoglobinemia in infants. A modifying factor of 10 was used to convert the NOEL to the RfD because of the direct toxicity of nitrite.

Information regarding the genotoxic potential of nitrite was not located and the USEPA has not placed nitrite in a weight-of-evidence cancer group.

Chloroform

Chloroform exerts adverse effects on the central nervous system, liver, and kidneys. High doses have been found to cause liver and kidney cancer in experimental animals (ATSDR 1987). Reported fatal oral doses for humans ranged from 212 to 3,755 mg/kg.

A chronic oral RfD of 0.01 mg/kg/day is based on a LOAEL of 12.9 mg/kg/day determined for fatty cyst formation following chronic administration to dogs. An uncertainty factor of 1,000 (to account for interspecies extrapolation, sensitive human subpopulations, and the use of a LOAEL) was used to convert the LOAEL to the RfD. No RfC has been derived by the USEPA, therefore the inhalation RfD is set to the same value as the oral RfD.

The USEPA has placed chloroform in weight-of-evidence Group B2, indicating that it is a probable human carcinogen. An oral slope factor of 0.031 $(mg/kg/day)^{-1}$ and an inhalation slope factor of 5.3×10^{-6} $(\mu g/m^3)^{-1}$ have been derived by the DTSC.

Endosulfan

The primary target of endosulfan is the nervous system.

A chronic oral RfD of 0.006 mg/kg/day is based on a NOAEL of 0.6 mg/kg/day for reduced body weight and adverse effects on the circulatory system in a 2-year feeding study in rats. An uncertainty factor of 100 (to account for inter- and intraspecies variation) was used to convert the NOAEL to the RfD.

Endosulfan has not been placed in a weight-of-evidence cancer group by the USEPA.

APPENDIX C

Table C-1

Derivation of Risk Equation for Non-VOCs in Water

$$\text{Risk}_{\text{water}} = SF_o \text{ x } C_w \text{ x } \frac{IR_{w,adult} \text{ x } EF \text{ x } ED_{adult}}{BW_{adult} \text{ x } AT \text{ x } 365 \text{ day/yr}}$$

$$+ SF_o \text{ x } C_w \text{ x } \frac{IR_{w,child} \text{ x } EF \text{ x } ED_{child}}{BW_{child} \text{ x } AT \text{ x } 365 \text{ day/yr}}$$

$$+ SF_o \text{ x } C_w \text{ x } \frac{SA_{adult} \text{ x } K_p \text{ x } EF \text{ x } ED_{adult} \text{ x } ET_{adult} \text{ x } 1 \text{ L/1000 cm}^3}{BW_{child} \text{ x } AT \text{ x } 365 \text{ days/yr}}$$

$$+ SF_o \text{ x } C_w \text{ x } \frac{SA_{child} \text{ x } K_p \text{ x } EF \text{ x } ED_{child} \text{ x } ET_{child} \text{ x } 1 \text{ L/1000 cm}^3}{BW_{child} \text{ x } AT \text{ x } 365 \text{ days/yr}}$$

Default exposure factors:

BW = body weight (70 kg adult; 15 kg child)
AT = averaging time, 70 yr
EF = exposure frequency, 350 days/yr
ED = exposure duration (24 yr adult; 6 yr child)
IR_w = intake rate (adult = 2 L/day; child = 1 L/day)
ET = exposure time during showering/bathing (adult, 15 min/shower = 0.25 hr/day; child, four 15 min baths/week = 0.14 hr/day)
SA = skin surface area available for contact (adults, 23,000 cm^2; child, 7,200 cm^2)
K_p = chemical-specific dermal permeability coefficient from water, cm^2/hr

Reduced Equation:

$$\text{Risk}_{\text{water}} = (SF_o \text{ x } C_w \text{ x } 0.0149) + (SF_o \text{ x } C_w \text{ x } 0.0325 \text{ x } K_p)$$

Ref: PEA Manual (DTSC 1994a)

Table C-2

Derivation of Risk Equation for VOCs in Water

$$\text{Risk}_{\text{voc,water}} = \text{Risk}_{\text{water}} + \frac{SF_i \times C_w \times IR_{\text{voc,adult}} \times EF \times ED_{\text{adult}}}{BW_{\text{adult}} \times AT \times 365 \text{ days/yr}} + \frac{SF_i \times C_w \times IR_{\text{voc,child}} \times EF \times ED_{\text{child}}}{BW_{\text{child}} \times AT \times 365 \text{ day/yr}}$$

Default exposure factors:

BW = body weight (70 kg adult; 15 kg child)
AT = averaging time, 70 yr
EF = exposure frequency, 350 days/yr
ED = exposure duration (24 yr adult; 6 yr child)
IR_{voc} = intake from inhalation of VOCs from domestic use of water is equivalent to the amount of ingested water

Reduced Equation:

$$\text{Risk}_{\text{water}} = [0.0149 \times ((SF_o \times C_w) + (SF_i \times C_w))] + (SF_o \times C_w \times 0.0325 \times K_p)$$

Ref: PEA Manual (DTSC 1994a)

Table C-3

Derivation of Hazard Equation for Non-VOCs in Water

$$\text{Hazard}_w = (1/\text{RfD}_o) \text{ x } \frac{C_w \text{ x } IR_w \text{ x EF x ED}}{\text{BW x AT x 365 day/yr}}$$

$$(1/\text{RfD}_o) \text{ x } \frac{C_w \text{ x SA x } K_o \text{ x ET x EF x ED x } (1 \text{ L}/1000 \text{ cm}^3)}{\text{BW x AT x 365 days/yr}}$$

Default exposure factors (for childhood exposure from birth to six years of age):

BW = body weight, 15 kg
AT = averaging time, 6 yr
EF = exposure frequency, 350 days/yr
ED = exposure duration, 6 yr
IR_w = daily intake of water, 1 L/day
ET = exposure time, 0.14 hr/day, based on the assumption of four 15 minute baths taken weekly

SA = skin surface area (cm^2) exposed during bathing (child, 7,200 cm^2
K_p = chemical-specific dermal permeability coefficient from water, cm^2/hr

Reduced Equation:

$$\text{Hazard}_{water} = ((C_w/\text{RfD}_o) \text{ x } 0.0639) + ((C_w/\text{RfD}_o) \text{ x } 0.0644 \text{ x } K_p)$$

Ref: PEA Manual (DTSC 1994a)

Table C-4

Derivation of Hazard Equation for VOCs in Water

$$\text{Hazard}_w = (1/RfD_o) \times \frac{C_w \times IR_w \times EF \times ED}{BW \times AT \times 365 \text{ days/yr}}$$

$$(1/RFD_i) \times \frac{C_w \times IR_{w,voc} \times EF \times ED}{BW \times AT \times 365 \text{ days/yr}}$$

$$(1/RfD_o) \times \frac{C_w \times SA \times K_p \times ET \times EF \times ED \times 1 \text{ L}/1000 \text{ cm}^3}{BW \times AT \times 365 \text{ days/yr}})$$

Default exposure factors (for childhood exposure from birth to six years of age):

BW = body weight, 15 kg
AT = averaging time, 6 yr
EF = exposure frequency, 350 days/yr
ED = exposure duration, 6 yr
$IR_{w,voc}$ = intake from inhalation of VOCs ≈ ingestion rate = 1L/day (A chemical is a VOC if it has Henry's Law constant greater than 1×10^{-5} atm-m^3/mole and molecular weight less than 200g/mole). The increased intake for VOCs is to account for the additional exposure via inhalation of volatilized compounds from domestic use of water
ET = exposure time, 0.14 hrs/day, based on the assumption of four 15 minute baths taken weekly
SA = skin surface area (cm^2) exposed during bathing, 7,200 cm^2
K_p = chemical-specific dermal permeability coefficient from water, cm^2/hr

Reduced Equation:

$$\text{Hazard}_{water} = [0.0639 \times ((C_w/RfD_o) + (C_w/RFD_i))] + [(C_w/RfD_o) \times 0.0644 \times K_p)$$

Ref: PEA Manual (DTSC 1994a), Region IX (USEPA 1995)