Appendix G
Science, Technology, and Regulatory Issues

This page intentionally left blank

Science, Technology, and Regulatory Issues

The study of water reuse alternatives for the City of San Diego included an assessment of the science, technology and regulatory issues related to recycled water use. The published literature on recycled water use is extensive representing thousands of articles. This assessment has examined and summarized the key issues. There are four major areas for San Diego's public and policy makers to consider when planning expansion of the City's water reuse program:

1) ***What do we know about recycled water and public health risk?*** Principles of risk assessment and risk management are discussed in **Section 1**. The use of these principles by the U.S. Environmental Protection Agency (EPA) and the State of California to set drinking water regulations that recycled water projects must meet is discussed.

2) ***How is recycled water regulated and used in California?*** The State agencies that set and enforce regulations are discussed in **Section 2** as well as the standards that must be met in order for recycled water to be put to various beneficial uses.

3) ***What water treatment methods are used to protect public health?*** **Section 3** reviews the types of contaminants found in water and how water treatment is used to produce water suitable for recycling. The concept of the "multi-barrier treatment approach" as the basis of recycled water regulation is presented.

4) ***What have public health studies shown? What have been the experiences of other communities?*** Other communities have implemented recycled water projects and addressed risks. The results of some of the key health effects studies are summarized in **Section 4**. **Section 5** summarizes indirect potable (IPR) reuse experiences of other communities.

Section 6 provides conclusions of the assessment and **Section 7** lists references from the literature that were used in the assessment and in this summary.

Section 1 Recycled Water and Protecting Public Health

Risk Assessment, Risk Management and Drinking Water Regulations[1]

To understand how public health is addressed in recycled water use, this section provides background on risk assessment and risk management and how they are used to establish standards for recycled water use. These principles form the basis of regulations that govern how recycled water must be treated and how it can be used.

Risk Assessment

Risk assessment has been defined as "the characterization of the potential adverse health effects of human exposures to environmental hazards" (NRC, 1983).

Health risk assessments are used to determine if a particular chemical poses a significant risk to human health and, if so, under what circumstances. Risk assessment helps regulators develop consistent and realistic goals for reducing exposure to toxics so that priorities can be established, and health threats to the public can be reduced to a minimum. Estimating the risks posed by toxic chemicals in the environment involves the compilation and evaluation of complex sets of data. Government regulators, therefore, turn to specialists to perform or assist with risk assessments. These specialists include scientists with degrees in toxicology (the study of the toxic effects of chemicals) and epidemiology (the study of disease or illness in populations) as well as physicians, biologists, chemists, and engineers.

The EPA is the leading environmental risk assessment agency at the federal level. The World Health Organization with support from the International Program for Chemical Safety prepares Guidelines for Drinking Water Quality, and also guidance for water reuse. In California, the Office of Environmental Health Hazard Assessment (OEHHA) in the California Environmental Protection Agency (Cal/EPA) has the primary responsibility for developing procedures and practices for performing health risk assessments. OEHHA’s health risk assessments are used by the Department of Health Services to develop California’s drinking water standards. The State of California is generally more aggressive in identifying and responding to perceived health threats than other states. California will frequently address problems before they are addressed by the EPA. These agencies’ decisions take into account the seriousness of potential health effects along with the economic and technical feasibility of measures that can reduce the health risks.

Risk Assessment Process
The risk assessment process typically consists of four basic steps: hazard identification, exposure assessment, dose-response assessment, and risk characterization.

---

[1] The risk assessment and risk management discussion was drawn and adapted from *A Guide to Risk Assessment*, California Office of Environmental Health Hazard Assessment

Step 1 Hazard Identification – In the first step, scientists determine the types of health problems a chemical could cause by reviewing studies of its effects in humans and laboratory animals, as well as what is known about similar chemicals (structure/activity relationships).

Depending on the chemical, these health effects may include short-term ailments, such as headaches, nausea, and eye, nose, and throat irritation, or chronic diseases, such as cancer. Effects on sensitive populations, such as pregnant women and their developing fetuses, the elderly, or those with health problems (including those with weakened immune systems), must also be considered. Responses to toxic chemicals will vary depending on the amount and length of exposure. For example, short-term exposure to low concentrations of chemicals may produce no noticeable effect, but continued exposure to the same levels of chemicals over a long period of time may eventually cause harm.

An important step in hazard identification is the selection of key research studies that can provide accurate, timely information on the hazards posed to humans by a particular chemical. The selection of a study is based upon factors such as whether the study has been peer reviewed by qualified scientists, whether the study's findings have been verified by other studies, and the species tested (human studies provide the best evidence). Some studies may involve humans that have been exposed to the chemical, but most have to rely largely, if not entirely, upon studies with laboratory animals.

Human data can be useful but are often limited for evaluating human health risks associated with chemical exposures. Human epidemiologic studies typically retrospectively examine the effects of chemical exposure on people, such as environmental exposures to large population groups, or employees exposed to varying concentrations of chemicals in the workplace. Drinking water epidemiology studies for chemical risk evaluation are especially difficult to rely on because the exposures involved are usually so minute (parts per billon or parts per trillion), and not continuous.

Epidemiology studies include descriptive and analytical types. Descriptive studies are used to summarize disease information and assess geographical or patterns of disease occurrence over time. These must be interpreted cautiously because they do not attempt to assess all of the possible contributing or confounding factors. Analytical studies are much more detailed and quantitative and can include cohort or follow-up, and case-control studies that match cases of disease with people in similar circumstances who do not have the disease. However, even these studies usually contain uncertainties, especially when relatively slight associations are observed, which is frequently the case.

Occupational studies sometimes offer a greater potential to identify associations between exposures and disease because the exposures in the workplace are often much larger than in the general environment, and more information may be available about worker populations. However, occupational studies can also have weaknesses including:

- They generally measure the effects of chemicals on healthy workers and do not consider children, the elderly, those with pre-existing medical conditions, or other sensitive groups.
- Exposure of workers to other chemicals at the same time as well as other lifestyle considerations may also influence and complicate the results.

When ethically possible, controlled laboratory studies using human volunteers are better able to gauge some health effects, because chemical exposures and effects can then be measured with precision. Prescription drugs must receive some level of testing in humans before they are approved for use, however, most other chemicals cannot receive that type of testing. Case reports of an industrial or accidental exposure in which individuals were unintentionally exposed to a chemical may sometimes provide useful information. Human studies would be ideal for risk assessment, so risk assessors make every effort to use them when they are available, which, however, is not very frequent. Usually they provide some information to supplement animal studies.

Because the effects of the vast majority of chemicals have not and cannot be studied in humans, scientists often rely on animal studies at very high doses to evaluate a chemical's health effects. Animal studies have the advantage of being performed under controlled laboratory conditions with genetically similar test animals that reduce part of the uncertainty that arises from human epidemiological studies. Animal tests are conducted at high doses to increase the potential that an effect will be detected. Those high doses must then be extrapolated to the much lower doses that humans are exposed to attempt to predict if a human will be affected and to what extent. Scientists must determine whether a chemical's health effects in humans are likely to be similar to those in the animals tested. This is complicated, because, in fact, even a mouse study does not always predict what will happen in a rat and *vice versa*. Although effects seen in animals can also occur in humans, there may be subtle or even significant differences in the ways humans and experimental animals react to a chemical. Comparison of human and animal metabolism may be useful in selecting the animal species that should be studied, but it is often not possible to determine which species is most like humans in its response to a chemical exposure. However, if similar effects were found in more than one species of animal, the results would strengthen the likelihood that humans may also be at risk. Risk assessors frequently use the most sensitive animal species to project to human effects so as to be cautious and be less likely to underestimate the possible human effects.

Step 2 Exposure Assessment – In exposure assessment, scientists attempt to determine how long people were exposed to a chemical; how much of the chemical they were exposed to every day, whether the exposure was continuous or intermittent, and how people were exposed—through breathing, skin contact, eating, drinking water and other liquids. All of this information is combined with factors such as breathing rates, water consumption, and daily activity patterns to estimate how much of the chemical was taken into the bodies of those exposed. To estimate exposure levels, scientists rely on air, water, and soil monitoring; human blood and urine samples; or computer modeling.

Although monitoring of a pollutant provides excellent data, it cannot cover all situations, and is costly. For those reasons, scientists often use computer modeling, which applies mathematical equations to describe how a chemical is released and to estimate the speed and direction of its movement through the surrounding environment. Drinking water exposures are some of the most predictable and quantifiable types and have less uncertainty than most other environmental exposures.

To accurately assess the range human exposures, scientists make assumptions in order to estimate human exposure to a chemical. To avoid underestimating actual human exposure to a chemical, scientists often look at the range of possible exposures. For example, people who jog in the afternoon, when urban air pollution levels are highest, would have much higher exposures to air pollutants than people who come home after work and relax indoors. Basing an exposure estimate on a value near the higher end of a range of exposure levels (closer to the levels experienced by the jogger than by the person remaining indoors) provides a realistic worst-case estimate of exposure. These kinds of conservative assumptions, which presume that people are exposed to the highest amounts of a chemical that can be considered credible, are referred to as “health-protective” assumptions.

Step 3 Dose-Response Assessment – In dose-response assessment, scientists evaluate the information obtained during the hazard identification step to estimate the amount of a chemical that is likely to result in a particular health effect in humans.

An established principle in toxicology is that “the dose makes the poison.” For example, table salt is essential to life in small quantities, can cause illness in large doses, and complicate certain chronic diseases at moderate quantities in sensitive individuals (e.g. people with high blood pressure). Scientists perform a dose-response assessment to estimate how different levels of exposure to a chemical can impact the likelihood and severity of health effects. The dose-response relationship that is assumed to occur at exposures too low to study in humans or animals is thought to be different for many chemicals that cause cancer than it is for those that cause other kinds of health problems.

> **Cancer Effects –** For chemicals that cause cancer by genotoxic mechanisms (i.e., interaction with DNA), the general conservative assumption in risk assessment has been that any exposures may have some risk unless there is clear evidence otherwise. In other words, even a very low exposure to a cancer-causing chemical may have some finite (albeit very small) risk of cancer if the chemical happens to alter cellular functions in a way that could cause cancer to develop. It becomes a matter of trying to predict a probability. Scientists use mathematical models based on studies of animals exposed to high levels of a chemical to attempt to project the risk of cancer developing in a diverse population of humans exposed much lower levels (perhaps a million times less). The uncertainty in these estimates is very large and a function of the assumptions that must be made in the modeling due to the lack of a complete understanding of the mechanism of the toxic effect. These assessments give upperbound risk values, and the lowerbound risks could be zero. They are designed to be conservative and more likely to overestimate rather than underestimate the human risks. These risks are usually so low that they would not be detectable by epidemiology studies. Continuing research is being conducted toward trying to improve the understanding of mechanisms of chemical toxicity and the validity of risk extrapolation models.

> **Non-cancerous Effects –** Non-cancerous health effects (such as asthma, nervous system disorders, birth defects, and developmental problems in children) typically become more severe and frequent as exposure to a chemical increases. One goal of dose-response assessment is to estimate levels of exposure that pose only a low or negligible risk for noncancer health effects. Scientists analyze studies of the health effects of a chemical to develop this estimate. They take into account such factors as the quality of the scientific studies, whether humans or laboratory animals were studied, and the degree to which

some people may be more sensitive to the chemical than others. The dose level that causes no adverse effect in the most sensitive animal species is usually divided by a large uncertainty (safety) factor to arrive at a 'safe' value for human exposure i.e. unlikely to result in any adverse effect under normal conditions.

Step 4 Risk Characterization – The last step in risk assessment brings together the information developed in the previous three steps to estimate the risk of health effects in an exposed population. In the risk characterization step, scientists analyze the information developed during the exposure and dose-response assessments to describe the resulting health risks that are expected to occur. This information is presented in different ways for cancer, noncancer, and microbial risk health effects, as explained below.

Cancer Risk – This is often expressed as the maximum number of new cases of cancer projected to occur in a population of one million people due to exposure to the substance over a 70-year lifetime. For example, a cancer risk of one in one million means that in a population of one million people, not more than one additional person would be expected to develop cancer during their lifetime as the result of the exposure to the substance causing that risk. These are not actuarial risks i.e. counting actual cancer cases; they are hypothetical projections. Cancer risks presented in risk assessments are often inappropriately compared to the actual incidence of cancer in the general U.S. population (about 300,000 cases for every one million people), or to the risk posed by all harmful chemicals in a particular medium, such as the air. The cancer risk from breathing current levels of pollutants in California's ambient air over a 70-year lifetime has been estimated/projected to be 760 in one million.

Non-cancerous Risk – This is usually determined by comparing the actual level of exposure to a chemical to the level of exposure that is not expected to cause any adverse effects, even in the most susceptible people. Levels of exposure at which no adverse health effects are expected are called "health reference levels," and they generally are based on the results of animal studies. Health reference levels are set much lower than the levels of exposure that were found to have no adverse effects in the animals tested. This approach helps to ensure that real health risks are not underestimated. Adjustments are made for possible differences in a chemical's effects on laboratory animals and humans; the possibility that some humans, such as children and the elderly, may be particularly sensitive to a chemical; and possible deficiencies in data from the animal studies.

Depending on the amount of uncertainty in the data, scientists may set a health reference level as little as 10 times lower if good human data are available, but usually from 100 to 1,000 times lower than the levels of exposure observed to have no adverse effects in animal studies. Occasionally, a factor as large as 10,000 might be used if the data base is extremely weak. Exposures above the health reference level are not necessarily harmful, but the risk of toxic effects increases as the dose increases. If an assessment determines that human exposure to a chemical exceeds the health reference level, further investigation is warranted.

Microbial Risk – A quantitative assessment that attempts to follow the same basic steps as chemical risk assessment – 1) hazard assessment, 2) exposure assessment, 3) dose-response analysis, and 4) risk characterization. Alternative (but similar) protocols have been published (ILSI, 1996, 2000) that are specifically designed to apply to waterborne pathogens. However, microorganisms function in ways that are very different from chemicals, e.g. they are alive and they reproduce. Some of the differences between microorganism risk and chemical risk assessment include:

- As few as one microorganism of certain types has the potential to cause infection. For chemical agents, it is likely that far more molecules are necessary to have a health effect.
- There may be a wide range of susceptibilities across a population (which could also be true for chemicals).
- Once infected, an individual may infect others and produce illness through person-to-person contact unrelated to water.
- Prior exposure to a particular microorganism (via water or other routes) may induce partial or complete immunity in an individual.

Microbial risk assessment, like risk assessment in general, has many inputs that are uncertain. These include 1) uncertainty about the best dose-response model for the pathogen or indicator organism of interest, 2) lack of data about pathogen behavior at low doses and susceptible populations, 3) assumptions about water consumption and other water-related exposures, and 4) uncertainty about occurrence and concentration of pathogens or their relationships to indicators in water.

Risk Management: How Health Risk Assessment Is Used

Risk managers rely on risk assessments when making regulatory decisions, such as setting drinking water standards. Risk managers are responsible for protecting human health, but they must also consider public acceptance when arriving at their decisions, as well as technological, economic, social, and political factors. For example, they may need to consider how much it would cost to remove a contaminant from drinking water supplies or how seriously the loss of jobs would affect a community if a factory were to close due to the challenge of meeting regulatory requirements that are set at the most stringent level. Health risk assessments can help risk managers weigh the significance of a risk, and the benefits and costs of various alternatives for reducing exposure to chemicals.

One of the most difficult questions of risk management is: How much risk is acceptable? While it would be ideal to completely eliminate all exposure to hazardous chemicals, it is usually not possible or feasible to remove all traces of a chemical once it has been released into the environment. The goal of most regulators is to reduce the health risks associated with exposure to hazardous pollutants to a negligibly low level. The EPA uses a metric in setting drinking water standards for carcinogens that nominal lifetime risks in the range of from 1 per 10,000 to 1 per 1,000,000 are safe and protective of public health. The World Health Organization sets drinking water guidelines for genotoxic carcinogens at the nominal 1 per 100,000 risk level and advises nations that they may choose other values for standards considering technological and economic factors.

Risk managers generally presume that a one-in-one million risk of cancer from life-long exposure to a hazardous chemical is an "acceptable risk" level because the risk is extremely low compared to the overall cancer rate. If a drinking water standard for a cancer-causing chemical were set at the level posing a "one-in-one million" risk, it would mean that not more than one additional cancer case (beyond what would normally occur in the population) would potentially occur in a population of one million people drinking water meeting that standard over a 70-year lifetime. It is important to realize that these risk levels are still very low compared to the average cancer risk in a human lifetime (approximately 1 in 4)

Actual regulatory standards for chemicals or hazardous waste cleanups may be set at less stringent risk levels, such as one in 100,000 (not more than one additional cancer case per 100,000 people) or one in 10,000 (not more than one additional cancer case per 10,000 people). These less stringent, but still minute, hypothetical risk levels are often due to economic or technological considerations. Regulatory agencies generally view these higher risk levels to be acceptable if it is not feasible or financially reasonable to reduce the risks further.

Setting Standards

The principles of risk assessment and risk management are used by both federal and state drinking water regulators. Federal drinking water standards to control the level of contaminants in the nation's drinking water are set by the EPA as required by the Safe Drinking Water Act (passed in 1974 and amended in 1986 and 1996). Water recycling projects that involve human consumption of the water must meet drinking water standards as well as other requirements. These standards are part of the Safe Drinking Water Act's "multiple-barrier" approach to drinking water protection. The multiple-barrier approach includes assessing and protecting drinking water sources; applying appropriate (and often redundant) treatment technologies, making sure water is treated by qualified operators; and protecting the distribution system. These barriers ensure that tap water in the United States is safe to drink and will be discussed in more detail in later sections.

In California, the EPA has delegated drinking water standard implementation and enforcement to the state. Other states are also free to set their own standards but their standards must be at least as stringent as the federal standard. California drinking water standards are set by the California Department of Health Services (DHS) using risk assessment information developed by the California Office of Environmental Health Hazard Assessment (OEHHA, described in more detail below). To this end, California generally sets more stringent drinking water standards than those established by the EPA.

Process for Setting Federal Standards – IPR projects must produce water that meets or surpasses drinking water standards**.** The EPA is required to follow several steps to determine whether setting a standard for a particular contaminant is appropriate, and if so, what that standard should be. Peer-reviewed science (studies reviewed and accepted by the scientific community as valid) and other data support an intensive evaluation. This evaluation looks at occurrence of the contaminant in drinking water; how much of the contaminant humans are exposed to and risks of adverse health effects for both healthy and sensitive people (like infants and the elderly), the contribution to the total exposure (food, air, dermal), by our ability to measure the contaminant, the ability of water treatment methods to control the contaminant, and the impacts of regulation on water systems and the economy, and always protection of public health.

After reviewing health effects studies, the EPA sets a Maximum Contaminant Level Goal (MCLG). This is the maximum level of a contaminant in drinking water at which ‘no known or anticipated adverse effect on the health of persons would occur, and which allows an adequate margin of safety’. MCLGs are non-enforceable public health goals (these are similar to California’s “public health goals” discussed later). Since MCLGs consider only public health and not the limits of detection and treatment technology, sometimes they are set at a level that water systems cannot meet. For carcinogens and a few other substances, the MCLGs are set at zero, as an ideal goal.

Once the MCLG is determined, the EPA sets an enforceable standard. In most cases, the standard is a Maximum Contaminant Level (MCL), the maximum permissible level of a contaminant in water that is delivered to any user of a public water system. The MCL is set as close to the MCLG as feasible. Feasible is defined as the level that may be achieved with the use of the best available technology, treatment techniques, and other means which the EPA finds are available, taking cost into consideration. If monitoring for the contaminant is not technically and economically feasible, a *Treatment Technique* is set instead. This is an enforceable method that public water systems must follow to ensure control of a contaminant.

As part of the determination of an MCL or Treatment Technique, the EPA completes an economic analysis to determine whether the benefits of potential standards justify the costs. If not, the EPA may adjust the MCL for a particular class or group of systems to a level that "maximizes health risk reduction benefits at a cost that is justified by the benefits." EPA is careful to keep the risk assessment process of setting a MCLG which involves careful consideration of the best science available separate from the risk management process of setting an MCL which involves balancing feasibility and economics.

Process for Setting State Drinking Water Standards – OEHHA is required to establish a Public Health Goal for every contaminant in drinking water for which there is an existing or state proposed MCL (State of California, Safe Drinking Water Act, 1996). Public Health Goals are concentrations of drinking water contaminants that pose no significant health risk if consumed for a lifetime. They are set by OEHHA using the process described above.

Health and Safety Code §116365(a) requires DHS to establish a drinking water contaminant's maximum contaminant level (MCL) at a level as close as is technically and economically

feasible to its Public Health Goal. Similar to the federal process, DHS conducts an in-depth risk management analysis that evaluates the technical and economic feasibility of regulating a chemical contaminant. The State regulatory process is summarized in **Figure 1** below.

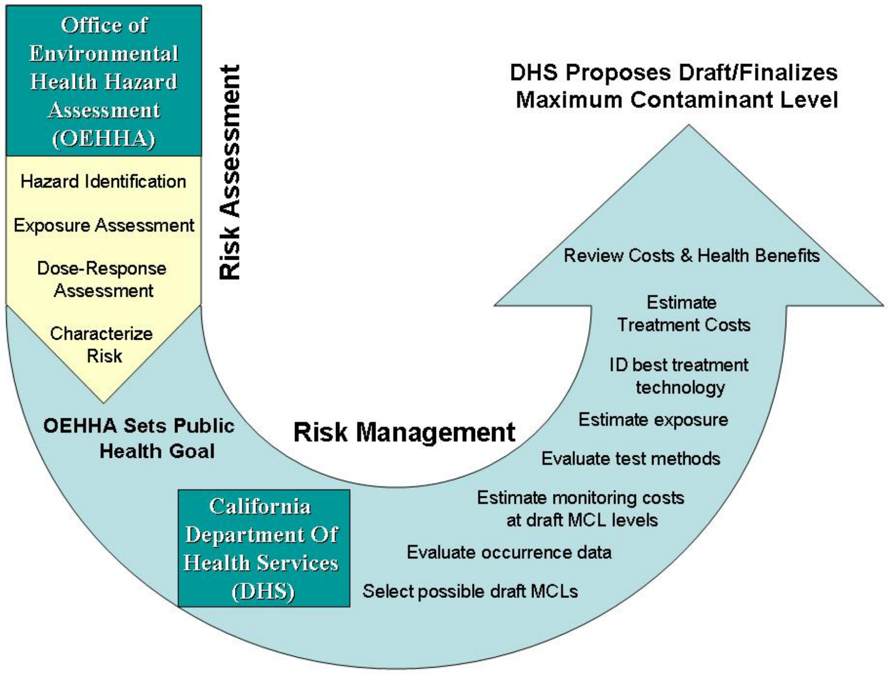

Figure 1 – California Process for Setting Drinking Water Standards

DHS:

- Receives the Public Health Goal from OEHHA.
- Selects possible draft MCL concentration or concentrations for evaluation.
- Evaluates the occurrence data.
- Evaluates available analytical methods and estimates monitoring costs at one or more draft MCL concentration(s).
- Estimates population exposures at those concentrations.
- Identifies best available treatment technologies.
- Estimates treatment costs to meet the draft MCL levels.
- Reviews the costs and associated health benefits (health risk reductions) that result from treatment.
- Proposes the draft MCL concentration or selects from the possible draft MCL concentrations considered previously.

Proposed regulations are released for a 45-day public comment period. DHS considers the comments, modifies the proposed regulations as appropriate and submits the regulation package (including responses to public comments), to the Office of Administrative Law. The Office of Administrative Law has 30 working days to review the regulation and approve or reject it. Once approved, it is filed with the Secretary of State and becomes effective 30 calendar days later.

Section 2 Recycled Water Regulations and Uses

California has developed enforceable regulations in addition to issuing guidance and recommendations. These regulations and guidance documents are part of the permit issuance process the California regulatory agencies require cities and water districts to follow prior to gaining approval for a recycling project to operate. The regulation of recycled water is found in several State documents. These are briefly described below.

Porter-Cologne Act

While the history of California water use and protection regulations extends back to the early years of the 20th Century, the heart of today's current regulations is the landmark 1969 Porter-Cologne Water Quality Act. Sections of the Act were used as the basis for the 1972 Federal Water Pollution Control Act, commonly known as the CWA.

Under "Porter-Cologne", the State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards (RWQCBs) are given the authority to preserve and enhance beneficial uses of the State's waters. Beneficial uses include all the uses we make of water supplies including fishing, swimming, boating, irrigation, drinking water, etc. The Act is contained in the California Water Code, Division 7 – Water Quality, and has been modified and amended through the years to address new issues and concerns affecting water use, clean water, water conservation, reuse, and water quality. RWQCBs issue the recycled water permits under State law but rely on the advice and consent of DHS regarding public health.

Health and Safety Code

In California, Part 12 of the Health and Safety Code contains the California Safe Drinking Water Act, which addresses health aspects of drinking water. The Porter-Cologne Act refers to the Health and Safety Code and defers to its interpretation of what is harmful or hazardous to human health (hence the involvement of DHS). The water produced by indirect potable reuse projects must also comply with the California Safe Drinking Water Act requirements.

California Code of Regulations

The provisions of both the Porter-Cologne Act and the Health and Safety Code are included as enforceable regulations in the California Code of Regulations (CCR) under *Title 22 – Social Security*. Relevant topics under this heading include water recycling criteria and water permits.

State Guidance and Policy Statements

While the CCR contains established and enforceable regulations, the DHS has issued a number of guidance documents addressing water recycling. Several are listed below:

- *California Health Laws Related to Recycled Water* (State of California, June 2001)
- *Guidelines for the Preparation of an Engineering Report for the Production, Distribution, and Use of Recycled Water* (State of California, March 2001)
- *Treatment Technology Report for Recycled Water* (State of California, September 2004)

State Regulation of Water Recycling

While regulations mandate that water for consumption be of the highest quality and safe to drink, non-potable or non-consumptive uses also require high quality water that must be treated to standards appropriate for its intended use.

Regulation of Recycled Water for Non-Potable Uses – Section 13521 of the Porter-Cologne Act grants DHS the authority to set criteria for recycled water use where such use would require specific protection of public health. As a result, DHS developed comprehensive uniform regulations that establish acceptable uses of recycled water, water quality, and treatment process requirements to ensure that recycled water use does not pose health risks, use area requirements, engineering report requirements, reporting and record keeping requirements, and design requirements to ensure operational reliability of treatment. These requirements are regulated under Title 22 of the California Administrative Code (Title 22, California Code of Regulations, §60301 *et seq.*) and enforced by the RWQCBs and each issues permits for individual projects to conform to the regulations and recommendations adopted by DHS.

California has a number of definitions for differing grades of recycled water based on level of treatment and effluent water quality criteria. The basic water quality criteria for recycled water in most water recycling permits are the MCL of chemicals and microbes allowed in drinking water. These standards generally apply to both non-potable and indirect potable uses of recycled water.

Proposed Draft Groundwater Recharge Regulations for Indirect Potable Reuse – The indirect use of recycled water to augment potable supplies is permissible under California law and is currently allowed through groundwater recharge using direct injection or surface spreading and, potentially, through addition to surface water reservoirs (State of California, 2001, 2004). The DHS evaluates every proposed project on a case-by-case basis to assure that the proposed treatment method, distribution and monitoring produces recycled water that is protective of public health.

The DHS has issued draft groundwater recharge reuse regulations (December 2004). The draft regulations are applicable to all groundwater recharge reuse projects which the State defines as "one that uses recycled water and has been designed, constructed, or operated for the purpose of recharging by infiltration or injection of recycled water, a groundwater basin designated in the Water Quality Control Plan for use as a source of domestic water supply."

The draft regulations require the control of contaminants at the source, multi-barrier treatment methods to control pathogens, inorganic and organic contaminants, treatment standards, recharge methods, extraction well location, and monitoring requirements. DHS is currently accepting comments on the draft regulations. While this is only a draft rule, DHS is incorporating the rule in their issuance of mandatory permits that recycled water producers must obtain from the State prior to operation. In addition to groundwater recharge projects, key parts of these draft rules would be applied to reservoir augmentation projects as well (DHS, personal communication, January 2005).

Although regulations related to groundwater recharge projects are still in the proposal stage, guidelines and criteria in place reflect a conservative approach by the DHS toward short-term and long-term health concerns.

Non-Potable Uses for Recycled Water

The California State Water Resources Control Board estimates that nearly 525,000 acre-feet of water were recycled in California in 2001 (State of California, 2002). This includes both non-potable uses (such as irrigation) and indirect potable use, such as groundwater recharge. The City produces recycled water that is primarily used for irrigation and industrial processes. The percentage breakdown for each category of use within the state of California during 2001 is illustrated in **Figure 2**.

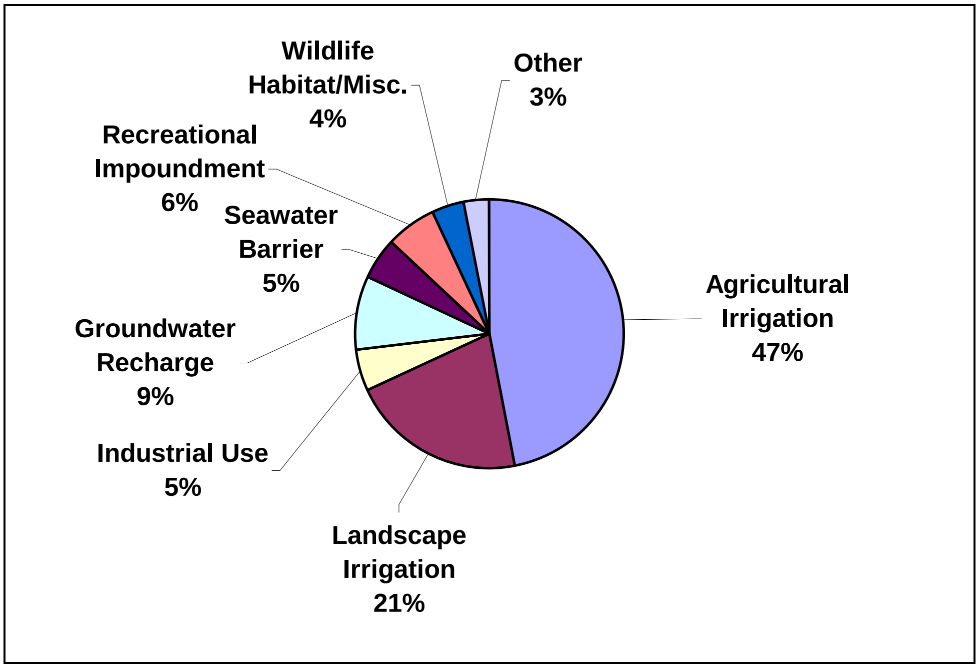

Figure 2 – Year 2001 California Recycled Water Use by Category
Source: Adapted from SWRCB data

Irrigation – As illustrated in **Figure 2**, the primary non-potable use of recycled water in California is irrigation. The primary constituents of concern when using recycled water for agricultural irrigation are salinity, sodium, inorganic elements, chlorine residual, and nutrients. Many of these can be harmful to plants or have long-term adverse effects on the soil. A number of recent references provide detailed information regarding recommended contaminant limits for recycled water for irrigation (EPA, 2004).

While irrigation water is not directly consumed, there may be indirect human contact and thus it is subject to regulations regarding pathogen loads and public health. California classifies recycled water based on level of treatment based primarily on the level of pathogen removal

(*e.g.*, “disinfected secondary-2.2 recycled water”, “disinfected tertiary recycled water,”) and then stipulates appropriate irrigation uses. For example, only disinfected tertiary recycled water (the highest level of treatment for irrigation uses) is allowed for irrigating root crops (food) or schoolyards. Food crops, where the edible portion is above ground and does not contact water, may use a lesser grade (disinfected secondary-2.2 recycled water).

The California State Water Resources Control Board *2001 Municipal Wastewater Recycling Survey* (State of California, 2002) lists 173 water reclamation facilities in California providing recycled water for agricultural irrigation and 98 facilities providing recycled water for landscape irrigation. In San Diego County, 16 facilities provide recycled water for some type of irrigation use, including the City of San Diego's North City Water Reclamation Plant. The cities of Carlsbad, Escondido, Fallbrook, Oceanside, Ramona, Olivenhain, among others, distribute recycled water for irrigation.

Cooling Water – For many industries, cooling water for commercial air conditioning systems comprises the largest use of recycled water. The water quality issues associated with cooling water use include corrosion, biological growth, and scaling; many of the same issues that are present with potable water. The same treatment methods used to manage these issues in potable water systems are often used in these recycled water systems (for example, corrosion inhibitors, biocides, etc.).

Recycled water produced by the West Basin Municipal Water District in Los Angeles County is distributed locally to over 100 customers, representing a wide range of beneficial irrigation and industrial uses. Two large refineries, Chevron and Mobil, use West Basin's recycled water in their cooling towers.

Irvine Ranch Water District converted a new office building in 2002 to recycled water use in two air conditioning cooling towers.

The Delta Diablo Sanitation District Recycled Water Facility in Antioch provides up to 8,600 acre feet per year of tertiary treated recycled water to two power plants for cooling tower makeup. The City of Benicia and the Valero Refinery are pursuing a recycled water project that would divert a significant fraction of the City's reclamation treatment plant effluent to the refinery. The largest potential application of recycled water identified at the refinery is the cooling towers, but other potential refinery applications include use as boiler feed water.

East Bay Municipal Utility District's North Richmond Water Reclamation Plant produces recycled water for three cooling towers located at ChevronTexaco's Richmond refinery. The City of Glendale supplies its own steam power plant with recycled water for cooling.

Water for Boilers – Another industrial use for recycled water is the replacement of evaporated water in commercial boilers. This is water used to replace the water lost to steam generation or evaporation. Often additional treatment of the recycled water is required to further reduce hardness and other inorganic contaminants that form scale in these systems (like that formed in hot water heaters over time). Generally, higher boiler operating pressures require higher quality water. Some municipalities even offer a range of recycled water qualities for industrial uses, charging a premium for very high quality (RO treated) boiler-ready water.

West Basin Municipal Water District's Boiler Feed Recycled Water Supply Program produces 4.3 MGD of two grades of high purity recycled water for Chevron Refinery's high pressure and low-pressure boilers in the City of El Segundo.

Fire Protection – The use of recycled water in fire protection is particularly problematic because of the large fluctuation in volume of water necessary for fire fighting and the enormous infrastructure required to support it. Recycled water for firefighting would have to be stored in large reservoirs and the distribution system would have to be able to maintain the pressures required by the fire fighter agencies. Water quality issues include corrosion products and biological growth as well as pathogenic considerations (fire fighting may produce breathable mists). In California, only disinfected tertiary recycled water is allowed for structural fire fighting, while lesser quality water may be used for non-structural fire fighting, such as forest fires.

The City of Livermore pumps recycled water to its Doolan Tank Reservoir where it is stored for irrigation, fire protection, and fire suppression uses. Water recycling agencies that have significant storage capacity can use their recycled water for fire protection and fire suppression.

Interior Sanitary Uses – Recycled water may be employed in commercial building sanitary uses such as flushing toilets and urinals and priming drain traps. While water quality is less important for this use, the water must still be disinfected tertiary treated recycled water to assure there is no risk of human exposure to pathogens in the water.

The first dual-plumbed new office building was built in San Rafael in the mid-1990s. Recycled water is supplied to this building by the Marin Municipal Water District. Irvine Ranch Water District provides recycled water for interior sanitary use in at least 11 high-rise buildings in Irvine, California. These office buildings, in addition to Irvine Ranch Water District's headquarters building and operation center buildings, are using recycled water for toilet and urinal flushing. The Inland Empire Utilities Agency's Administration Headquarters in Chino uses recycled water for their urinals and toilets.

Other Industrial Processes – Recycled water can be used by other industries including pulp and paper, chemical processing, petroleum refining, and textiles. The quality of water required for each of these businesses is use dependent. Some are capable of using water of fairly low quality, while others demand water that is highly treated. Parameters of concern include inorganic contaminants, hardness, alkalinity, total dissolved/suspended solids, and color.

Several carpet mills have converted their carpet dyeing process from domestic to recycled water. One conversion in Irvine alone saves 500,000 to one million gallons of potable water per day. Tuftex Industries' carpet dyeing operation in Santa Fe Springs is the largest recycled water user in the Central Basin Municipal Water District area, using 108 million gallons annually.

Environmental/Recreational Use – Environmental and recreational applications include wetland restoration and enhancements as well as incidental contact (fishing, boating) and direct contact (swimming, wading) uses. Both contaminant levels (especially nutrients) and pathogens are considerations. California allows recycled water use but restricts its application depending upon the likelihood and degree of body contact. Unrestricted recreational uses require

disinfected tertiary recycled water and extra monitoring for pathogens.

The City of Arcata's Marsh and Wildlife Sanctuary uses recycled water for wetlands, ponds, and related wildlife habitat. The recycled water flows through five marshes in the 170-acre sanctuary, where natural organisms filter the water before it is released into Arcata Bay.

The Padre Dam Municipal Water District provides recycled water to the 190 acre Santee Lakes Recreation Preserve that includes lakes, bird habitat, and recreational opportunities for camping, fishing, hiking and picnicking.

The San Jacinto Multipurpose Constructed Wetlands occupy 26 acres through which secondary-treated recycled water flows through an arrangement of marsh and open water segments, removing nitrogen before it is blended with additional recycled water and made available for irrigation at nearby farms, a duck club and the San Jacinto Wildlife Area.

Behind Prado Dam in Riverside County, 465 acres of constructed wetlands receive nearly 50 percent of the flow of the Santa Ana River, which itself consists primarily of tertiary treated recycled water from upstream wastewater treatment plants. Natural treatment occurring in the wetlands allows this water to be used for groundwater recharge downstream of the dam.

Since 1988, Union Sanitary District has been providing secondary effluent to assist in a marsh restoration project on the Hayward Shoreline along San Francisco Bay. Treated wastewater effluent is the only freshwater source to the marsh. The marsh was created when 172 acres of deteriorating salt flats were restored into a five basin system. Studies have documented the cleansing effect of the wetland on certain metals. The East Bay Regional Park District has counted over 200 different species of birds utilizing the marsh.

Other Uses – Given the increasing scarcity of potable water, recycled water has also been used in decorative fountains and water features, commercial laundries, dust suppression, backfill consolidation, and artificial snowmaking. Each of these applications has its own individual requirements from both a water quality and pathogenic consideration.

The Arizona Snowbowl Ski Resort was given the go-ahead for creating artificial snow using recycled water. The U.S. Forest Service has approved the use of recycled water to make snow to keep the Arizona Snowbowl Ski Resort open, mostly based on economic reasons. The Arizona Department of Environmental Quality (as well as the California Department of Health Services) allows tertiary-treated recycled water to be used for snowmaking.

In 1993, a Marin Municipal Water District customer was the first car wash in the state to convert to recycled water.

Indirect Potable Reuse for Recycled Water

IPR is recycled water that is purposely discharged into either groundwater or surface water that ultimately supplies a public drinking water system (NAS, 2004).

Discharge of wastewater to surface lakes and rivers is common in the United States and many of these waters serve as sources of drinking water supply. Whenever a wastewater treatment plant discharges to surface water or groundwater that serves as a drinking water source for downstream cities, indirect potable reuse occurs. This kind of reuse of treated wastewater has occurred for many decades throughout the United States. Every wastewater plant discharging into the Mississippi River contributes to the water supply for downstream cities. Similarly, wastewater treatment facilities operated by cities in the Colorado River basin or in the Sacramento/San Joaquin Delta discharge back to the rivers, and river water is subsequently delivered to Southern California, treated and distributed to water districts through the region.

There are three basic types of IPR projects: groundwater spreading, groundwater injection and reservoir augmentation which are described below. The only form of potable reuse currently regulated in California is groundwater recharge with the permit approval process under the auspices of the local RWQCB. However, DHS provides important recommendations to the RWQCB regarding the acceptability of a project. DHS will not issue a recommendation for project approval unless the proponent provides extensive evidence that the project will not be detrimental to public health. The DHS recommendations are based on treatment provided, effluent quality and quantity, spreading area operations, soil characteristics, hydrogeology, residence time, and distance to withdrawal.

Groundwater Recharge – Spreading – Surface spreading is a direct recharge method where recycled water is released into open basins and the water seeps down into the groundwater basin. It is used generally when enough land area is available, certain soil conditions are present, and if the groundwater basin is "unconfined", that is water moves through the basin. Again, depending on soil conditions, water quality may improve considerably as the water moves down through the soil and across the basin.

Since 1962, the County Sanitation Districts of Los Angeles County, the Los Angeles County Department of Public Works, and the Water Replenishment District of Southern California have teamed in a cooperative project to replenish a local groundwater aquifer with recycled water. One of the largest programs of its kind, the project has spread approximately one million acre-feet of recycled water, reducing the overdraft condition of the basin by roughly two-thirds and also reducing the area's dependence on imported water supplies.

Victor Valley Wastewater Reclamation Authority spreads 3 MGD into nine percolation ponds that recharge the Mohave River groundwater basin.

A major groundwater spreading system called the Groundwater Replenishment System is being built by the Orange County Sanitation District (OCSD) and the Orange County Water District (OCWD). Treated wastewater currently discharged into the ocean will undergo microfiltration, reverse osmosis and ultraviolet light treatment. The recycled water will be pumped to storage lakes near the Santa Ana River for percolation into the groundwater basin and ultimate consumption by Orange County residents.

Groundwater Recharge – Injection – Another method of adding to groundwater resources is through injection. Recycled water injection simply pumps the recycled water down to the groundwater, bypassing the soil percolation step. Because direct injection introduces recycled water directly into the groundwater it does not provide the treatment benefits that percolation provides. Accordingly, the injected water must be of higher quality than that used for surface spreading. Some states require treatment to drinking water standards prior to injection.

The Los Angeles County Department of Public Works operates a series of injection wells along the coast, referred to as the “West Coast Basin Seawater Intrusion Barrier”. These wells inject water along the barrier to ensure that the water level near the ocean stays high enough to keep the seawater from seeping into the local aquifers. A combination of 50 percent imported potable water and 50 percent of West Basin Municipal Water District’s (WBMWD’s) advanced treated recycled water is injected into the seawater barrier. The DHS recently granted conditional approval to increase the blend to 75 percent recycled water based upon the technical work of WBMWD, a review by a scientific expert panel and installation of ultraviolet light (UV) treatment on the water (Rich Nagel, personal communication, 2004).

Since 1976, OCWD has been operating Water Factory 21, an internationally renowned groundwater recharge and seawater barrier project. This effort was initiated to protect the groundwater basin from saltwater intrusion – which previously had encroached as far as five miles inland – and to replenish the local aquifers, which supply 75 percent of the water needs for nearly 2 million residents.

The project includes a 15 mgd advanced reclamation treatment plant with 23 multi-point injection wells that deliver water into four separate aquifers. The injection water is a blended combination of RO and UV-treated water, carbon adsorption-treated water, and deep well water. This is being replaced by the Ground Water Replenishment System described above.

Reservoir Augmentation – Reservoir augmentation adds highly treated recycled water directly to a water reservoir to increase the overall water supply. Water used in reservoir augmentation projects would undergo advanced treatment (typically membranes) and disinfection. In addition to the advanced treatment methods used, reservoir augmentation projects also allow the treated water to reside under natural environmental conditions for a period of time. This provides an additional public health barrier, as natural reduction of trace contaminants due to microbial degradation, oxidation and dilution occurs. The reservoir water would ultimately be pumped out and treated by a potable water treatment plant and used for drinking purposes.

Allowable recycled water uses and treatment level requirements are depicted in **Table 1** (State of California, June 2003). **Table 1** reflects the concept that the higher the likelihood of human contact with the recycled water, the higher the degree of required water treatment.

Table 1
Treatment Levels for Allowable Recycled Water Uses

Types of Recycled Water Use	Recycled Water Treatment Level		
	Disinfected Tertiary	Disinfected Secondary	Undisinfected Secondary
Urban Uses and Landscape Irrigation			
Fire Protection	✓		
Toilet and Urinal Flushing	✓		
Irrigation of Parks, Schoolyards, Residential Landscaping	✓		
Irrigation of Cemeteries, Highway Landscaping		✓	
Irrigation of Nurseries		✓	
Landscape Impoundment	✓	✓ *	
Agricultural Irrigation			
Pasture for Milk Producing Animals		✓	
Fodder and Fiber Crops			✓
Orchards (no contact between fruit and recycled water)			✓
Vineyards (no contact between fruit and recycled water)			✓
Non-Food Bearing Trees			✓
Food Crops Eaten After Processing		✓	
Food Crops Eaten Raw	✓		
Commercial/Industrial			
Cooling & Air Conditioning – w/ cooling towers	✓	✓ *	
Structural Fire Fighting	✓		
Commercial Car Washes	✓		
Commercial Laundries	✓		
Artificial Snow Making	✓		
Soil Compaction, Concrete Mixing		✓	
Environmental and Other Uses			
Recreational Ponds with Body Contact (Swimming)	✓		
Wildlife Habitat/Wetland		✓	
Aquaculture	✓	✓ *	
Groundwater Recharge			
Seawater Intrusion Barrier	✓ *		
Replenishment of Potable Aquifers	✓ *		

* Restrictions may apply

Source: WaterRecycling 2030, California's Recycled Water Task Force, June 2003.

Section 3 Recycled Water Treatment Technology

Numerous contaminants are regulated in recycled water, but not all contaminants. This is because either monitoring methods do not exist, are too complicated for routine monitoring, are very costly, or there is no reason to believe the contaminants are present to begin with.

Public health professionals manage this uncertainty by using what is referred to as a multiple-barrier treatment approach. This approach is used for drinking water treatment as well as recycled water treatment (Davies et al, 2003; Luna et al, 2004). The basis of this approach is to ensure that the water treatment methods used have reasonable checks and balances to minimize the risk of failure and, ultimately, prevent exposure of consumers to water that presents a health risk.

It is important to understand the nature of water treatment methods before we discuss the multi-barrier approach in more detail. The following text presents an overview of water treatment.

Typical Recycled Water Treatment Methods

The following paragraphs provide an overview of the various treatment methods commonly used to produce recycled water of various qualities and end uses. There are several treatment methods that can be linked together to provide water treatment for recycled water uses. These methods are placed in sequence in a treatment plant depending on the required water quality needed. As a result of different levels of treatment, recycled water is suitable for different uses. The level of treatment is guided by the need to be protective of public health and the quality of water needed for the end use. These levels of treatment are briefly described below. The reader is referred to Wastewater Engineering: Treatment and Reuse (Tchobanoglous et al, 2002), Water Treatment Principles and Design (Montgomery, 1985) or Integrated Design and Operation of Water Treatment Facilities (Kawamura, 2000), for a detailed description of water and wastewater treatment methods,

Pretreatment – Pretreatment methods include the use of source control to minimize the introduction of contaminants into the wastewater that must then be treated to remove. The City's Metropolitan Wastewater Department regulates the quality of the wastewater that enters the wastewater system through an enforceable Industrial Wastewater Control Program (City of San Diego, 2005; EPA, 1992). The program is a joint effort between the City, other agencies served by the system, and local industry to control contaminants before they enter the wastewater system. The Program issues discharge permits, performs inspections, conducts wastewater monitoring, and enforces discharge standards at businesses and industries throughout the entire service area.

More than 1,900 industries and businesses in the service area have been identified as potential dischargers of prohibited wastes or toxic pollutants. The job of protecting the wastewater quality (for reuse or ocean discharge) begins by eliminating or pretreating contaminants at their source, before they enter the wastewater stream. The EPA has identified a list of priority pollutants that are either prohibited or strictly limited in discharges to the wastewater system. Some of the common toxic pollutants include arsenic, benzenes, chloroform, cyanide, phenols, pesticides, and heavy metals such as cadmium, chromium, copper, lead, mercury, nickel, silver and zinc.

Some of the types of local industry that are regulated to prevent contaminants from entering the wastewater system include aerospace manufacturing, metal forming, casting and finishing, pharmaceutical manufacturing, hospitals and medical centers, film processors, laundries, dry cleaners, and a variety of laboratories.

Through this program new contaminants used and discharged into the wastewater system by industry and business can be identified and managed to control their impacts on recycled water.

The Groundwater Replenishment System of the OCWD receives treated wastewater from the OCSD, which is further treated by OCWD to IPR requirements. This project will have an expanded Source Control Program to address new pollutants of concern in the wastewater stream. It is likely that DHS would require similar elements in other IPR projects. OCSD is developing an updated list of pollutants of concern to include drinking water standards and establishing a task force committee consisting of members from OCWD, OCSD, DHS, and the regulated communities. The expanded program includes:

- Expanded Wastewater Discharge Regulations to develop new regulatory provisions and local limits, where applicable, for the new regulated pollutants.
- Expansion of the permit and enforcement.
- Revising the industrial wastewater permits (point source) to include standards and requirements to control the new pollutants of concerns (i.e. NDMA, 1,4-dioxane, tritium, and 1,2,3 tri-choloropropane).
- Developing and implementing a new permitting program to control the non-point (commercial and residential) wastewater sources
- Developing and implementing a new compliance screening, follow-up and enforcement actions proceedings.
- Developing and implementing a screening mechanism to determine the potential and upcoming pollutant of concern
- Developing a new inventory program to document the chemicals used within manufacturing processes of the industrial users (permittees).
- Expansion of the sampling and monitoring program to include conducting investigative sampling and monitoring to identify the potential source discharge of the new pollutants of concern

The West Basin Municipal Water District has the following language in the DHS "Findings of Fact" as part of their conditional permit for increasing the injection percentage of recycled water into the groundwater basin to 75 percent (State, of California Public Summary, December 10, 2002):

The West Basin shall develop a Source Control Implementation Plan for proactive source control. This plan should include, but is not limited to the following elements: 1) monitoring of raw influent water from LA Bureau of Sanitation Hyperion Plant in addition to West Basin influent; 2) proactive plan for maintaining an inventory of compounds discharged into the City's *wastewater collection system so that new compounds of concern can be evaluated rapidly; 3)*

analysis of percent reduction through each West Basin plant process for all drinking water MCL's; 4) spike or seed studies for possibly constituents of concern determined by the DHS; 5) investigation program focused on the identified target compounds and their potential ability to persist through the treatment systems; 6) cooperative Memorandum of Agreement with the City of Los Angeles to address the source(s) of persistent constituents of concern, including evaluation of all chemicals and parameters listed in Attachment 1, and develop an comprehensive outreach program; and 7) time schedule for implementation of the preceding elements. The required Source Control Implementation Plan supplementing the source control program shall be provided to the Department by June 30, 2005 for review and approval, before expanded barrier operations may commence. A Memorandum of Agreement between West Basin and the City of L.A specifying responsibility of the Source Control Implementation Plan shall be signed and agreed upon by both parties following approval of the SCIP by DHS. All above elements must be implemented prior to increasing the monthly running average RWC to 100 percent. No expanded plant operations may begin without Department approval of the Source Control Implementation Plan and signature of the Memorandum of Agreement between West Basin and the City of Los Angeles.

Primary Treatment – Primary treatment removes materials that are suspended in the water. In most large treatment plants, this is done by first passing the water through screens and skimmers and then through large tanks (sedimentation tanks) where heavier materials settle out of the water. This is the method by which suspended solids are removed at the City's two water reclamation plants. After this treatment, the water is called primary effluent. Such an effluent is suitable for ocean disposal in special circumstances. Some removal of pathogens occurs in primary treatment.

Secondary Treatment – Additional biological treatment of the primary effluent is what allows water to be recycled for some types of irrigation and industrial uses. Secondary treatment removes biodegradable organic matter and pathogenic microorganisms. Naturally occurring bacteria and other microorganisms help break down the waste materials in the water. For this reason it is sometimes referred to as *biological treatment*. Secondary effluent has much lower levels of both biodegradable organic matter and pathogenic microorganisms than primary effluent, and it meets EPA standards for discharge to most rivers, estuaries and the ocean. DHS also allows its use for watering of a limited number of crops (e.g., watering of food crops where the water does not contact the edible portion, or animal food and fiber crops).

***Tertiary Treatment* –** The City's water reclamation plants use tertiary treatment which consists of filtration through sand and/or other filter material, followed by disinfection, usually with chlorine, after secondary treatment. The filtration step removes particles from the water that might protect harmful microorganisms from the disinfectant. It also removes many of the microorganisms themselves. Following filtration, disinfection is used to further reduce pathogens. Tertiary treatment is required where human contact is anticipated (such as on parks and golf courses).

Advanced Treatment Methods

More advanced water treatment methods may be used in water recycling when very specific contaminants must be removed. Advanced treatment may be necessary where certain contaminants affect the intended end use (for example, salt removal may be needed where the water is going to be used in boilers that concentrate salt), or the recycled water will enter a drinking water supply, such as a groundwater basin or surface water reservoir.

The treatment methods used to produce recycled water for special applications may include membrane filtration (either microfiltration (MF) or ultrafiltration (UF)), reverse osmosis (RO), ion exchange (IX) treatment, advanced oxidation, granular activated carbon (GAC), soil aquifer treatment, wetlands treatment, and disinfection.

The water quality goals that can be achieved using these technologies include:

- salinity reduction or salt removal,
- pathogen destruction and removal,
- chemical destruction and removal, and
- ammonia and nitrate reduction to remove nutrients that may promote algae growth in reservoir

Adams et al (2002) found that certain processes associated with advanced treatment (powdered activated carbon and RO) followed by oxidation with chlorine or ozone were effective in removing seven common antibiotics. Ternes et al (1999a, 1999b, 2002) also found that ozonation and granular activated carbon (GAC) treatment were effective in removing certain pharmaceutical compounds. Huber (2003) reported that advanced oxidation processes including ozonation are effective in reducing pharmaceuticals in drinking water. Similarly, the City is seeing very promising results in treatment tests on RO and UV + peroxide which will be discussed later.

Membrane Filtration (microfiltration or ultrafiltration) – In IPR projects, membrane filtration is most commonly used as a pre-treatment step for RO. It is also used to replace sand and other filter media filtration in the tertiary treatment method described above.

Filtration membranes have actual holes or "pores". The pores in the membrane are very small such that larger particles or contaminants are filtered out. Engineers choose the pore size of the membrane based on the desired level of treatment or the size of the contaminant that must be removed. The categories of membranes typically used for RO pretreatment are microfiltration and the smaller pore-size ultrafiltration. Membrane filtration does not remove dissolved constituents like salts.

Membrane filters have recently supplanted more traditional forms of filtration (like sand filters) because they can be installed in a smaller area, are more easily automated, and may be more reliable.

Reverse Osmosis (RO) – RO may be used in water recycling treatment when the intended use requires very low levels of salts and other dissolved compounds. It is a very good barrier against inorganics, organics and microorganisms (Montgomery, 1985; Kawamura, 2000; Tchobanoglous et al, 2002; Agenson et al, 2003). For instance, use of tertiary treated recycled water for industrial boilers would not be practical because the levels of salts in the recycled water would cause severe damage to the boilers. RO, a water treatment method by which salts can be removed to very low levels, is commonly used to make recycled water acceptable for these types of salt-sensitive uses. RO is a common method used for desalination of seawater or other salt-laden waters.

Removal is accomplished by the diffusion of water through a thin membrane. RO membranes, have smaller spaces than microfiltration and ultrafiltration membranes through which water can travel. RO uses pressure to push water through the membrane, leaving contaminants behind. Huang and Sedlak (2001) found that RO removes more than 95 percent of estrogenicity (a hormone mimicking effect) from wastewater effluent, and RO was considered effective for removal of all types of tested endocrine disrupting compounds (EDCs), pharmaceuticals and personal care products (PPCPs) (Snyder et al, 2003, 2004).

Because of its effectiveness at removing contaminants, RO has emerged as a common treatment method for IPR projects. The draft proposed regulations for direct injection into groundwater require RO treatment and UV + peroxide addition. These processes would be required for reservoir augmentation (DHS, personal communication, 2005).

Ion Exchange (IX) **–** IX is commonly used for calcium and magnesium (softening) and sometimes nitrate removal in drinking water treatment, and for producing ultra-high purity water for industrial uses such as semiconductor manufacturing. IX is commonly used in home water softeners (to reduce the hardness of water) and in the production of bottled drinking water. It uses special resin beads that remove a particular ion in the water, “exchanging” it with another specific ion from the surface of the beads. In the example of home ion exchange water softeners, the resin removes calcium and magnesium (naturally occurring minerals that make water form scale on plumbing fixtures) and exchanges those minerals with sodium on the beads. Once the beads are full of calcium and magnesium, a sodium chloride (salt or brine) solution is rinsed through the ion exchange resin. The sodium replaces the calcium and magnesium making a fresh resin to be used again. The brine solution must then be disposed.

Advanced Oxidation **–** Another relatively recent treatment advancement is advanced oxidation. Virtually all man-made chemicals can be removed by oxidation (bleaching is a form of oxidation), but sometimes oxidation alone is too slow to be practical. The basic idea of advanced oxidation is to use a combination of treatment chemicals in water to create hydroxyl radicals, which is essentially the water molecule, H_2O, without one of the hydrogen atoms. These hydroxyl radicals are quick-reacting oxidizers that can destroy organic chemicals depending on how the process is designed. Also, advanced oxidation methods can be designed to kill disease-causing microorganisms.

There are two methods of advanced oxidation that are most common. The first produces hydroxyl radicals by reacting hydrogen peroxide (H_2O_2) with ozone. The MWD is installing this treatment method at the Robert Skinner Water Filtration Plant, which serves treated drinking water to San Diego County. It is very effective at destroying algae-produced organic compounds that give the water an earthy-musty taste and odor and helps kill disease-causing microorganisms that can occur in lakes and rivers. Ternes et al (2002) examined the elimination of selected pharmaceuticals (bezafibrate, clofibric acid, carbamazepine, diclofenac) during drinking water treatment processes at lab and pilot scale and in real waterworks. In lab-scale experiments, 0.5 mg/L ozone was shown to reduce the concentrations of diclofenac and carbamazepine by more than 90 percent, while bezafibrate was eliminated by 50 percent with a 1.5 mg/L ozone dose.

UV Lamps by
WEDECO Ag Water Technology

The second method exposes the hydrogen peroxide to UV, which breaks the hydrogen peroxide into hydroxyl radicals, which then reacts with many organic molecules. This method is used commonly to destroy organic contaminants at hazardous waste sites. It is very effective against many trace organics (it is also used as a powerful disinfectant). OCWD is currently using advanced oxidation with UV and hydrogen peroxide in their recycled water to control N-nitrosodimethlyamine (NDMA) with great success (Soroushian et al, 2001). Subsequent work has demonstrated the effectiveness of UV + peroxide on 1-4 dioxane as well. West Basin Municipal Water District has also observed significant destruction of NDMA (Nagel et al, 2001). Recent pilot testing at the NCWRP have confirmed the effectiveness of UV and hydrogen peroxide on local recycled water.

Granular Activated Carbon (GAC) – GAC is effective at removing many organic contaminants in drinking water. The extent of removal depends on the contaminant. EPA evaluated the various components of the drinking water treatment process and identified granular activated carbon as the method to be used for the removal of endocrine disrupting compounds from drinking water (EPA, 2001). GAC is considered Best Available Technology for several organic endocrine-disrupting compounds (EPA, 2001), and removal efficiency was considered “good” to “excellent” for a variety of EDCs and personal care products (Snyder et al, 2003).

GAC filters in home water treatment units are quite common, however, most of those systems primarily remove the chlorine taste rather than significant amounts of organic chemicals, especially if they are not replaced frequently. GAC is not commonly used in utility drinking water treatment, as it can be a relatively expensive solution to removing organic contaminants. Part of the cost of using GAC is related to the need to periodically remove the carbon from the treatment plant and reactivate it in high temperature ovens to destroy the organics attached to the carbon.

GAC is also a porous media that can provide filtration or allow biofilm development. Biofilms can help biodegrade organic contaminants. GAC and more frequently, powdered activated carbon, are sometimes used in drinking water treatment to remove taste and odor compounds produced by algae in lakes and rivers.

Soil Aquifer Treatment – Water recycling projects, which have indirect potable reuse as their goal, use advanced water treatment. A common and effective form of advanced water treatment practice is soil aquifer treatment (AwwaRF, 2001; Asano et al, 2004, Drewes et al, 2003).

In soil aquifer treatment, the recycled water is first treated using tertiary and sometimes advanced methods as described above and then released into basins (such as dry river beds) where it slowly seeps into the groundwater. The water is ultimately pumped up and used (including for drinking purposes). Studies conducted over the past forty years have shown that a broad variety of organic and inorganic constituents are removed from the water as it seeps and moves through the soil. This method of treatment is used in Los Angeles and Orange Counties, California and elsewhere. It can be very effective at removing both organics and microorganisms (Bouwer et al, 1981; Anders, 2004; Snyder et al, 2004; Gerba et al, 1991).

Preliminary assessments suggest that advanced wastewater treatment plants and soil aquifer treatment systems effectively reduce the concentrations of Pharmaceutically Active Compounds (PhACs), but not always to concentrations below detection limits (Sedlak et al, 2005).

***Wetlands Treatment* –** Many contaminants that are released into natural water environments can be removed or degraded by natural processes (Gearheart et al, 1988). Degradation by sunlight (Boreen et al, 2003; Horne 2000), uptake by plants (Horne 1995, 2000, 2003) and biodegradation can occur for some contaminants. Gersberg et al (1987) examined the survival of several indicators of viral pollution applied in primary municipal wastewater to artificial wetland ecosystems and found substantial removal possible. Taking advantage of these processes by constructing treatment wetlands is an option to help remove nutrients, metals, pesticides, and pathogens from urban runoff or wastewater.

Constructed wetlands can treat large volumes of water and can remove pollutants down to low levels but their effectiveness depends on how they are designed, operated, and maintained. In addition to reducing pollutants to low levels, constructed wetlands can enhance wildlife habitat, aesthetics, recreation, and property value. Natural wetlands, on the other hand, are generally not efficient at removing pollutants because the residence time (the time the water remains in the wetland) is often too short for effective treatment.

Treatment wetlands are not perfect however. Some contaminants appear to resist biodegradation especially when they are present at very low concentrations. Engineered treatment wetlands do not appear to have a large effect on concentrations of pharmaceuticals (Sedlak et al, 2005). Wetlands can also increase the concentration of some water contaminants. For example, recycled water treated by RO and discharged into wetlands would have such low levels of organic carbon to start with that the water would actually pick up organic carbon from decaying vegetation as well as salts (due to water evaporation in the wetlands).

A summary of contaminant removal capability for surface and sub-surface wetlands is shown in **Table 2** below (Horne, 2003).

Table 2
Comparison of the Strengths and Weaknesses of Free-Surface and Sub-Surface Wetlands (Horne, 2003)

Parameter	Free-surface wetland	Sub-surface wetland
Hydrology	Fast flow 10^{-2} cm/s	Slow flow 10^{-4} cm/s
Clogging	No	Yes
Sediment Removal	Good	Moderate
BOD removal	Moderate	Moderate-poor
P removal	Poor	Poor
N removal	Excellent	Moderate?
NH_4 to NO_3	Poor	Poor
Insect vectors (e.g. mosquitoes)	Need control	None present
Heavy metals	Moderate	Moderate
Pesticides	Good?	unknown
Vegetation types	Bulrush, cattail, common reed, duckweed, water grasses	Cattail, reeds, grasses, wide variety of plants
Vegetation diversity	Low	High
Recommended use	Large volumes, water features	Small systems, warm summers

Disinfection – Disinfection is used in water treatment to protect the public health by killing waterborne disease-causing microorganisms. The most commonly used disinfectant in the United States is chlorine. The broad use of chlorine with filtration to treat drinking water in the United States was largely responsible for the elimination of such waterborne disease epidemics as cholera and typhoid. Specific disinfection standards exist in drinking water treatment plants today to ensure that all water that is produced has achieved required levels of disinfection. There are also minimum chlorine residual requirements to ensure the water remains safe to drink while it travels through the distribution system to the consumer's tap.

Removal of Contaminants by Treatment

The treatment methods discussed in the previous section have varying abilities to remove contaminants in water. These contaminants can be broken into broad classes, which will be discussed briefly in the following text.

The broad classes of contaminants water treatment methods remove or reduce include:

- Organic chemicals (including trace contaminants)
- Inorganic chemicals
- Microorganisms
- Physical measurements
- Radiologicals

Recycled water treatment methods are specifically designed to reduce the amount of these contaminants to levels that reliably meet existing drinking water standards. The treatment methods that are used remove or reduce the target contaminants for which they are designed but they also provide a barrier for other similar contaminants.

Organic Chemicals – Most of the organic materials in wastewater originate from plants, animals, along with some man-made organic compounds in the waste stream. Many organics are proteins, carbohydrates, or other forms that are biodegradable, which means they can be consumed and broken down by microorganisms.

Some organic chemicals pose a risk of adverse health effects or environmental damage, even at relatively low concentrations. Accordingly, water recycling projects are designed, operated and regulated to reduce the amount of organics to levels that health regulators deem safe for human consumption.

Advances in laboratory analysis methods allow us to detect more chemicals and at smaller and smaller concentrations in our environment. In some cases, our ability to detect contaminants has outstripped our understanding of their human health significance.

An example of this is the current scientific debate over the significance of the occurrence of classes of organics referred to as PPCPs and EDCs in the environment (Daughton, 2004). These include common substances that many people consume daily such as caffeine, aspirin, birth control pills, antibiotics, and other drugs.

These substances may be found in our rivers, streams, lakes, drinking water and wastewater – usually at very low levels. In 1999 and 2000, the U.S. Geological Survey (USGS) tested 139 streams in 30 states for 95 wastewater-related pharmaceuticals, hormones and other wastewater contaminants (Kolpin et al, 2002). The sampling locations were biased toward stream receiving discharges from urban areas or stockyards. Samples were analyzed using new methods capable of detecting concentrations in the nanogram per liter (part per trillion) range. There are no drinking-water standards or health advisories for 81 of the compounds. The USGS study detected one or more of the compounds in 80 percent of the samples; half of the streams contained seven or more compounds, and one sample contained 38 compounds. Eighty-two of the 95 compounds were detected at least once nationwide. The most frequently detected compounds at trace levels included steroids (including cholesterol), nonprescription drugs (such as caffeine, nicotine metabolites, and pain relievers), and DEET, the active ingredient in many insect repellents. Detergents, steroids, and plasticizers generally were detected at the highest concentrations, however, most were less than 1 microgram per liter (part per billion). Antibiotics were detected in more than half of the samples.

The relationship of human diseases of the endocrine system and exposure to environmental contaminants is poorly understood and scientifically controversial (EPA, 2005). The primary concern over these substances in wastewater has focused on effects to aquatic life and mostly where wastewater that has not received advanced treatment is released into lakes or rivers, in other words, not IPR projects where advanced water treatment is present (Harries et al, 1996, 1997; Desbrow et al, 1998; Witters et al, 2001).

But scientists also wonder what effect, if any, these low levels of substances might have on humans. These substances occur at levels far lower than what some might take for therapeutic benefit. For example and to provide a sense of scale, a person with a headache might take a 200-milligram ibuprofen tablet. The untreated wastewater stream might have levels of ibuprofen at 1,000 times lower, and in a river that receives wastewater discharges, ibuprofen levels might be a million times lower. A person would have to drink over 30 Olympic-sized swimming pools filled with river water to ingest the same amount of ibuprofen found in a 200-milligram tablet. In fact, this level is so small that ibuprofen typically cannot be detected by the most advanced analytical methods in RO treated recycled water.

The World Health Organization (WHO, 2002) examined the state of the science regarding endocrine disruption and concluded:

- There is sufficient evidence available to conclude that adverse, endocrine-mediated effects have occurred in some wildlife populations.
- There is weak evidence to suggest that human health has been adversely affected by exposure to endocrine active chemicals,
- Many examples of adverse human health effects have been observed at high exposure levels. Further study is required to determine effects of low dose exposure and exposure during critical developmental periods (in utero, childhood, adolescence).

The EPA has attempted to develop requirements and methods for the screening and testing of thousands of pesticides, commercial chemicals, and environmental contaminants for their potential to disrupt the endocrine system through the Endocrine Disruptor Screening Program (EDSP). EPA has some data on endocrine-disrupting pesticides, however, few data are available for most of the estimated 87,000 chemicals produced today to allow for an evaluation of endocrine associated risks. The science related to measuring and demonstrating endocrine disruption is relatively new and validated testing methods are still being researched. The reader is referred to the EPA website for more information on the EDSP (http://www.epa.gov/scipoly/oscpendo/edspoverview/index.htm).

We cannot say that trace levels of PPCPs and EDCs cause human health problems. However, we cannot dismiss the concern because some contaminants might be able to produce health effects at very low levels. So, how do we manage this potential risk in drinking water and recycled water? DHS manages this uncertainty by establishing guidelines and requirements during the permitting process that consider and control trace organics in water (State of California, 2004). They require IPR projects to use advanced water treatment methods (like RO and ozone or UV oxidation) as these methods have been shown to be effective in removing these substances from both wastewater and drinking water. Monitoring requirements also exist for certain of these substances in recycled water used for IPR. It is interesting to note that none of these requirements currently apply to conventional drinking water source waters from rivers that receive upstream waste discharges. A combination of advanced water treatment processes being tested by the City is currently reducing these contaminant levels to below our ability to detect them.

Inorganic Chemicals – Inorganic chemicals in untreated wastewater include minerals, metals, and salts from both residential and nonresidential sources. Most inorganic substances are relatively stable, and not amenable to breaking down in wastewater, however many have very high removal rates in membrane treatment methods like reverse osmosis and are therefore of little concern in indirect potable reuse projects. Drinking water regulations for inorganic chemicals must be met for IPR projects.

Microorganisms **–** Prevention of microbial water borne disease is by far the greatest concern of all water supplies. Pathogens that are capable of causing disease like certain bacteria, viruses and protozoa are present in wastewater and often in high numbers (Rose, et al, 1991, 1996, 2001). For this reason, the primary purpose of water treatment is to remove or inactivate pathogens. Recycled water treatment is capable of large reductions in pathogen concentrations. Properly operated treatment methods are capable of removing pathogens to levels below our detection capability. However, recycled water used for non-potable purposes cannot be deemed "pathogen-free". Studies have demonstrated that *cryptosporidium parvum* (a pathogen that causes gastroenteritis) that are capable of causing infection can pass through primary, secondary and tertiary water treatment processes and adequate disinfection and monitoring is needed to insure public health is protected (Gennaccaro et al, 2003; Clancy et al, WERF, 2005).

Pathogens are controlled by instituting preventive technologies so that they will not appear in the finished drinking water. Because it is often difficult and expensive to directly measure microorganisms (including pathogens) routinely in water, substitute measurements are used to demonstrate the effectiveness of the treatment system.. *Indicator bacteria,* such as the total coliform group and more directly fecal coliforms or E. coli, and certain viruses are used to assess the potential presence of bacteria and virus in drinking water, recycled water, and wastewater. Protozoan pathogens require different measurements. Recycled water must meet coliform and other standards to be deemed safe for different uses. The National Research Council (NRC, 2004) published an extensive review of indicators for waterborne pathogens as well as specific recommendations to improve the use of indicators as indirect measures of waterborne disease risk to consumers of water. According to the NRC "a single, unique indicator or even a small set of microbial water quality indicators cannot meet this diversity of needs and applications, what is required is development and use of a "tool box" in which the indicator(s) and method(s) are matched to the requirements of a particular microbial water quality application." In practice wastewater treatment systems and recycling projects use multiple treatment barriers coupled with monitoring systems (including indicator bacteria and viruses) to provide assurance that the product water is safe for its intended and permitted use.

Physical Characteristics **–** Physical characteristics include temperature, color, clarity (which may be caused by turbidity and particulate matter), and odor. Conventional drinking water and wastewater treatment improves physical characteristics of water significantly (though characteristics like temperature may not be changed significantly). Advanced tertiary and membrane treatment processes such as RO can dramatically improve most physical characteristics. This is important to assure public acceptance of the water for its intended use.

Radiologicals **–** Radioactive substances emit energetic waves and/or particles that can cause both carcinogenic and non-carcinogenic health effects. Radioactive substances in water systems can affect individuals through several pathways: 1) direct contact, 2) ingestion, 3) inhalation, or 4) external exposure to the contaminated water. While most radiation occurs naturally, and is regulated, intentional and non-intentional releases of radioactive substances from industrial sources (such as hospitals and pharmaceutical companies) into wastewater systems can occur. IPR projects must measure and meet drinking water standards for radioactive substances.

Use of Multiple Barrier Treatment for Indirect Potable Reuse

Drinking water treatment as regulated by the DHS uses a “multiple- barrier approach” (Velz, 1970, AWWA, 1987). Each of the treatment barriers is designed by engineers to be as independent as possible such that, if one temporarily fails, the others ensure the safety of the water. Also, because each treatment barrier is not equally effective for every contaminant, barriers are selected, designed and built to produce the desired end water quality in the aggregate. In general, the lower the chances of human contact with the water, the less elaborate the water treatment. Since IPR involves human consumption of the water, California law requires very high levels of treatment and monitoring.

The multi-barrier treatment approach also provides significant protection against unknown or unmeasured contaminants. Technologies remove a range of substances, not just those that are identified. For example, a group of contaminants called nitrosamines received significant attention as potent carcinogens produced by the conversion of nitrite (from cured meats and other sources) in the stomach (NAS, 1992), and also found in some foods.. There are several nitrosamines that are chemically similar, differing only by the length and composition of the organic side-chain attached to the nitrosamine group. One of them, NDMA, has a California standard (notification level) associated with it. N-nitroso*diethyl*amine, or NDEA, is believed to potentially co-occur with NDMA but there are no occurrence data available Further, NDEA may present a similar health risk (IRIS, 2004). The water treatment technology (UV + hydrogen peroxide) that is effective for NDMA destruction in wastewater (Soroushian et al, 2001) is also likely to be effective for NDEA because it is structurally similar to NDMA. Thus, while there is no standard or routine monitoring for NDEA, the treatment method used to control NDMA also controls NDEA (and many other unknowns).

Another example is harmful bacteria and viruses. Physical removal processes (like filtration or RO) are broadly effective against these organisms, not just the ones we can detect. Similarly, disinfection (by chlorine, ozone, UV, etc.) works against all these organisms. Disinfection effectiveness can vary by the type of organism but the “treatment barrier” provides broader protection against health risks beyond the ones we know about.

No single treatment method is an absolute barrier to pathogens or chemical contaminants. A series of treatment methods that includes RO treatment is the most aggressive and thorough approach. Combinations of the treatment methods detailed above can be configured to meet all current and draft water quality regulations in existence both in California and elsewhere.

To comply with the DHS requirements for IPR, and to protect public health and safety, a City reservoir augmentation project would begin with treated high quality recycled water from the NCWRP or the SBWRP and would be configured to provide additional advanced treatment as indicated in **Figure 3-1** below**.**

As shown in the figure, the required IPR treatment train could follow two paths: reservoir augmentation or groundwater recharge. Either train would use RO followed by advanced oxidation. The advanced oxidation process would provide high levels of additional disinfection and destruction of organic chemicals. Ion exchange (IX) is included only as an optional treatment based on the results of recent full scale plant studies at OCWD and West Basin Municipal Water District that show modern membranes are so effective at nitrate rejection that IX is not required. GAC is an optional process that could provide yet another organics removal barrier. It is not typically included in IPR projects but could be if the community deems additional barriers are desirable and affordable. Wetlands treatment could be added but, given the high quality of the water entering the wetland, it is likely that the water quality would be degraded in a wetland due to plant decay products, wildlife fecal contamination and salt increase due to evaporation of water through plants.

The treatment process train as depicted in **Figure 3** is capable of producing an exceptionally high quality of water in comparison to virtually any existing drinking water treatment plant in the United States.

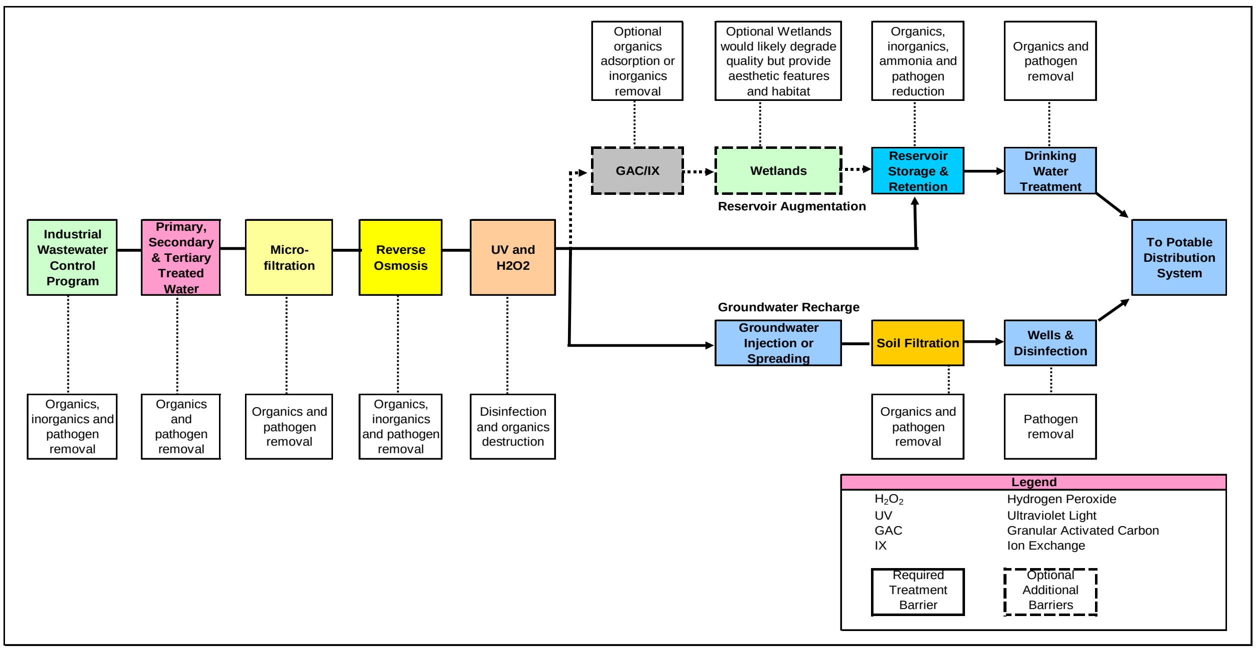

Figure 3 – Multi-barrier Treatment Methods for Indirect Potable Reuse

The water treatment methods are selected to produce a water quality that more than meets the regulatory requirements for the expected end use of the water (in the example above, IPR).

The use of multiple treatment barriers is the basis of all recycled water regulation. A major advantage of the use of multiple barrier water treatment methods is that the methods can also be effective at removing unknown contaminants that are similar in chemical structure or behavior to the ones we actually know about.

The general potential of different treatment methods to remove classes of contaminants in water is shown in **Table 3**. The effectiveness of the method depends on the nature of the contaminant, the design of the method as well as how it is operated.

Table 3
Treatment Method Contaminant Control Potential
(box indicates method can reduce indicated contaminant)

Treatment Method	Contaminant Class						
		Pathogens					
	Particles	Bacteria	Viruses	Parasites	Inorganics	Organics	Radionuclides
Pretreatment	✓				✓	✓	✓
Primary Treatment	✓					✓	
Secondary Treatment	✓					✓	
Tertiary Treatment	✓	✓	✓	✓	✓	✓	✓
Microfiltration	✓	✓		✓			
Ultrafiltration	✓	✓	✓	✓		✓	
Reverse Osmosis	✓	✓	✓	✓	✓	✓	✓
Ion Exchange					✓		✓
Ozone		✓	✓	✓		✓	
UV + hydrogen peroxide		✓	✓	✓		✓	
Granular Activated Carbon						✓	
Soil Aquifer Treatment	✓	✓	✓	✓		✓	
Wetlands	✓				✓	✓	
Chlorine Disinfection		✓	✓				

Advanced Treatment Research in Support of the Water Reuse Study 2005

As a part of the Water Reuse Study 2005, new pilot testing projects are being performed to examine several important treatment method advancements made in the past ten years (Montgomery Watson Harza, October, November, and December, 2004). These projects address some of the public health concerns expressed by stakeholder groups and during public input sessions. These projects will assess the quality of San Diego's tertiary treated water and the ability of advanced treatment technologies to improve the quality of our local water and to eliminate possible EDCs and PPCPs.

The City has a long history of research and testing of technologies for the treatment of water and wastewater. Several of these projects have been funded by EPA grants, dating back to the early 1970's and the passage of the Clean Water Act. These projects are collectively referred to as the Total Resource and Recovery projects (refer to the "Health Effects Study" prepared by the Western Consortium for Public Health, 1992, for a review of these early studies). Specifically, the City Water Department has tested and performed certification studies on RO membranes for more than 15 years and is presently continuing this work using low pressure RO membranes and advanced oxidation to determine the destruction of representative chemicals that may be of human health concern or believed to be difficult to remove by conventional treatment. For more information on EDCs and PPCPs please refer to "Occurrence Survey of Pharmaceutically Active Compounds" (Sedlak et al, 2005).

The City and the Water Authority pursued a Water Repurification Project (Project) to increase local water supply reliability. The proposed project would have used advanced water treatment on recycled water from the NCWRP, stored the treated water in the San Vicente Reservoir, treated that water again at a drinking water treatment and finally, distributed the water in the potable system. After reviewing the project plan, DHS gave conditional approval in 1994, to move forward with the Project. To address DHS conditions of approval, pilot testing of the proposed advanced water treatment processes was conducted in 1995 (Trussell et al, 2000).

Relatively recent improvements in treatment equipment include the use of state-of-the-art spiral wound hollow fiber RO membranes in place of cellulose acetate membranes, and the use of ultraviolet light instead of ozone in the advanced oxidation process. Preliminary testing shows that the current processes have much greater removal efficiencies and will reliably produce much higher quality water using fewer treatment steps.

The pilot treatment evaluation is designed to accomplish specific goals including:

- Review the current state of knowledge of issues related to: the integrity of RO membranes, effectiveness of RO membranes, RO operating parameters and optimization of UV + peroxide (advanced oxidation) for destruction of EDCs.
- Evaluate the performance of advanced water treatment methods consisting of ultrafiltration followed by RO followed by a combination of UV + peroxide on current treated wastewater from the NCWRP.
- Assess the effectiveness of new RO membrane technologies for water recycling;
- Perform field testing of direct and indirect integrity measuring methods for RO membranes.
- Determine the impact of hydrogen peroxide + UV on representative EDCs and PPCPs.

Advanced Water Treatment Performance Evaluation – The current pilot testing is being conducted in three phases. Phase I testing was designed to study monitoring methods and the integrity of RO membranes during operation, using equipment from four different manufacturers. Reliable water treatment requires membranes that do not have leaks or tears and have high "integrity" to prevent the passage of contaminants "around" membranes into the treated water. Phase II testing was designed to evaluate the best performing membranes from Phase I at a higher rate of water recovery (in other words, increasing the stress on the membranes by forcing more water through them). Phase III examined the ability of monitoring methods to detect very small membrane integrity problems.

The main purpose of this work is to gain a better understanding of the ability of advanced water treatment methods to remove contaminants present in NCWRP water that may represent a water quality concern if they are not removed. To this end, a comprehensive monitoring program is being used that also looks at contaminants that are not usually monitored or regulated.

The membrane treatment methods were operated based upon membrane studies previously conducted by the project team along with recent testing at OCWD, West Basin Municipal Water District both in California, and the City of Scottsdale, Arizona. In addition, the project team worked closely with membrane suppliers to fine tune operating conditions. The UV operating conditions were determined with a goal of at least a 90 percent removal of the test contaminant, NDMA, that was added after RO and before UV treatment.

A wide variety of inorganic and organic compounds are being measured using the best analytical equipment and methods available today. The data represented in this report are from the initial two rounds of comprehensive sampling, with additional rounds of sampling scheduled to take place over summer 2005. In general, inorganic substance monitoring includes metals, minerals, hardness, silica and physical parameters such as color, odor and turbidity. The specific organic contaminants of concern include a wide range of herbicides, pesticides, semi-volatile and volatile chemicals (compounds were selected from California's Drinking Water standards and draft ground water recharge reuse regulations). Also, a target list containing twenty-nine EDCs and PPCPs were measured entering and leaving each of the advanced water treatment processes. The selected list is believed to be a good indicator for such compounds since a broad range of chemical structures are represented. The list contains contaminants that are commonly found in secondary treated wastewater such as caffeine and ibuprofen along with others found in the environment or that have been shown to pass through reverse osmosis membranes. Though many of these are not currently regulated, many appear in the Draft California groundwater recharge reuse regulations (State of California, December, 2004).

Results – The tertiary treated water from the NCWRP was fed to the advanced treatment pilot facility. Testing to date suggest that the feed water is relatively constant and does not have much seasonal variation, based on an analysis of historical plant data. The product water from NCWRP is considered to be of excellent quality relative to similar treatment facilities across the country as initial testing has found few contaminants in comparatively low concentrations. The advanced water treatment pilot processes removed inorganic and organic contaminants to levels near or below detection limits of the most sophisticated test methods currently available. All measured contaminants in the RO/UV + peroxide treated water were either not detectable or well below federal and California drinking water standards.

In these tests, RO has been shown to provide an effective barrier against contaminant passage. The addition of UV + peroxide to breakdown chemical contaminants was also shown to be an effective barrier. Of the large number of regulated organic contaminants monitored in the water treated with RO and UV + peroxide, only low-level concentrations were detected for trihalomethanes (chloroform and similar compounds). Trihalomethanes are formed to some degree in all waters that are disinfected with chlorine. The trihalomethane levels detected were well below regulatory limits and were about 10 times lower than occur in most chlorinated drinking water systems in the United States.

The monitoring results included twenty-nine specific EDCs and PPCPs and showed that most compounds were effectively removed to below the level of detection (e.g., one part per trillion). Eight compounds that were not reduced to below the limit of detection by RO alone, and the one compound that remained detectable after advanced oxidation are reported in Table 4. This compound was triclosan and is probably due to a soap residue in the sample bottles. Triclosan is a common ingredient in antibacterial soap, used by most laboratories to wash sample bottles and other glassware. At the concentrations being tested, it is very difficult to rinse sample bottles completely free of triclosan, so only new sample bottles will be used in future rounds of testing. One of the main conclusions that can be drawn from this data is the benefit of a multi-barrier treatment train. Although RO effectively reduced the concentration of all monitored compounds by well over 99 percent, the remaining trace detectable concentrations were further reduced to below the level of detection of one part per trillion, by the advanced oxidation process.

Table 4
Preliminary Results from Pilot Scale Testing for Removal of Endocrine Disrupting Compounds and Pharmaceutically Active

	3/25/2005			4/13/2005				
Compound	RO Feed	RO Permeate	% Removal	RO Feed	RO Permeate	% Removal	UV/H2O2 Product	% Removal
Trimethoprim	427	2.2	99.5	335	2.6	99.2	<1.0	>99.7
Acetaminophen	<1.0	<1.0	NA	<1.0	1.2	NA	<1.0	NA
Sulfamethoxazole	834	3.7	99.6	787	3.6	99.5	<1.0	>99.9
Meprobamate	279	1.5	99.5	256	1.5	99.4	<1.0	>99.6
Carbamazepine	254	1.6	99.4	309	2,4	99.2	<1.0	>99.7
DEET	164	<1.0	>99.4	375	2.6	99.3	<1.0	>99.7
Iopromide	717	<1.0	>99.9	681	1.4	99.8	<1.0	>99.9
Triclosan	127	453	-256.7	334	172	48.5	194	41.9

* One part per trillion is equivalent to one drop of dye in 500,000 barrels of water.

** Compounds all results are in parts per trillion (ppt), the lowest detectable level was 1.0 ppt*

NA – Below detection limit, not possible to calculate percent removal or slight increase noted within analytical variability of the method.

The pilot test results to date show that advanced water treatment methods are capable of removing or reducing contaminants in NCWRP water to easily meet drinking water standards and, where standards do not exist, produce high quality water. Additional testing is ongoing and all results will be made available when routine quality control measures are complete, and the grant funding agencies have reviewed the complete set of data.

Operation Reliability and Monitoring

The NRC report (1998) reached several key conclusions regarding the safe, reliable operation of a potable reuse water system:

- Potable water reuse systems should employ independent multiple barriers to contaminants, and each barrier should be examined separately for its efficacy for removal of each contaminant.
- The multiple barriers for microbiological contaminants should be more robust than those for many other forms of contamination, due to the acute danger such contaminants pose at high doses even for short time periods.
- Systems should monitor process performance to keep critical processes under tight control.

- Utilities using surface waters or aquifers as environmental buffers should take care to prevent "short-circuiting," by which influent treated wastewater either fails to mix with the ambient water fully or moves through the system to the drinking water intake faster than expected.
- Risk management strategies should be used to reduce the risk from the wide variety of synthetic organic chemicals that may be present in municipal wastewater and consequently in reclaimed water **(**stringent industrial pretreatment and pollutant source control programs)
- Potable reuse operations should have alternative means for disposing of the reclaimed water in the event that it does not meet required .standards.
- Every water agency using reclaimed waters as drinking water should implement well-coordinated public health surveillance systems to document and possibly provide early warning of any adverse health events associated with exposure to reclaimed water.
- Operators of water reclamation facilities should receive adequate training.

Section 4 Summary of Key Health Effects Studies

Non Potable Reuse

Although there have been no confirmed outbreaks of infectious disease from the use of properly treated and managed recycled water in the U.S., the potential for infection is still a concern (Crook, 1998). Tanaka (Tanaka, 1998) used a microbial risk model and concluded that when filtered secondary effluent (tertiary treatment) was chlorinated at about 10 mg/L there was virtually no difference in the probability of enteric virus infection between recycled or domestic water used for golf course irrigation, crop irrigation, or groundwater recharge. Similar observations were made for the use of chlorinated secondary effluent and the recycled water from contact filtration with chlorine doses of below 5 mg/L.

In another quantitative microbial risk assessment (Rose and Gerba, 1991), concluded that “well operated plants with secondary treatment, filtration, and disinfection will produce a quality of recycled water which can be used for unrestricted irrigation, while maintaining an adequate margin of safety by limiting the population exposed to these waters containing low levels of pathogens.”

The State of Florida used quantitative microbial risk assessment to develop guidelines for *Giardia*, *Cryptosporidium*, and enteric viruses in recycled water used for residential irrigation and public access areas (York et. al, 2003). An annual acceptable risk of infection of 1×10^{-4} was used in the analysis. In 1999, Florida began to require periodic monitoring for *Giardia* and *Cryptosporidium* in recycled water systems.

A five-year study in Monterey County, California determined that process controls required by *CCR* Title 22 (coagulation, flocculation, filtration, and disinfection) were sufficient to exclude the possibility of residual pathogen content in recycled water used for irrigation of food crops (Sheikh, 1990).

The findings of the study are summarized included:

- No enteric viruses were detected in the recycled water or recovered from crop samples during the entire 5-year study.
- Aerosols generated from sprinkler irrigation did not contain bacteria of wastewater origin.
- Medical monitoring of project staff did not reveal any adverse health impacts.

In a 1997 follow-up to this study, a monitoring program called the Tertiary Water Food Safety Study was conducted to test the continued validity of the earlier field pilot project (Sheikh, 1997, Sheikh, 1998). This study did not detect any *Salmonella*, *Cyclospora*, *E. Coli* 0157:H7, *Cryptosporidium*, or *Legionella* in any of the samples of disinfected tertiary recycled water. Based on the data collected, *Giardia* in the influent were reduced by 5 to 6 logs through the treatment plant. The authors concluded that the *Giardia* cysts remaining in the tertiary recycled water were non-viable.

The County Sanitation Districts of Los Angeles County demonstrated that *Giardia* cysts found in disinfected tertiary recycled water were probably not capable of causing infection (Garcia, 2002).

Potable Reuse

Human health and environmental risks typically associated with contaminated drinking water and other surface and subsurface water supplies are well documented regarding *untreated or partially treated wastewater* (Blumenthal et al, 2001; Higashitani et al, 2003; Isaac-Renton et al, 1996; Kindzierski et al, 1994). Studies of advanced treated wastewater effluent in rats and human populations (Condie et al, 1994a, 1994b; Frerichs, 1984) had shown no health effects. The Condie et al (1994a) study specifically examined RO treated wastewater. Other studies suggest that adverse environmental impacts associated with the aquatic disposal of untreated industrial effluents can be mitigated by treatment with RO (Dube et al, 2000, 2001; Hewitt et al, 2002).

Relatively low concentrations of some trace organic contaminants in incompletely treated waste stream discharges have been linked to adverse environmental impacts such as the feminization of aquatic wildlife, wildlife birth defects and other impacts (Dube et al, 2000, 2001; Giesy et al, 2000; Harries et al, 1996, 1997; Hayes et al, 2002; Jones et al, 2004). However, scientists have been unable to conclude these trace levels represent a human health concern, especially in advanced treated wastewater where trace contaminants are at low nanogram per liter concentrations or not detectable at all.

Virtually all scientific studies have limitations that are often imposed by the costs of conducting such studies. Also, there are a variety of potential health effects that any study can assess. Accordingly, the studies that are available to learn from are rarely directly comparable. However, as a body of information, they are important to consider when making decisions about IPR in a community.

Potable Reuse Health Issues Identified in the National Academy of Sciences Report – In 1998 the NAS issued a comprehensive report – *Issues in Potable Reuse: The Viability of Augmenting Drinking Water Supplies with Reclaimed Water (NAS, 1998).* Authored by NAS' Committee to Evaluate the Viability of Augmenting Potable Water Supplies with Reclaimed

Water, the report built on the NRC 1982 report, *Water Quality Criteria for Water Reuse* but emphasized the public health aspects of potable reuse of recycled water.

The report referenced several large-scale health effects studies of recycled water covering both microbiological and chemical contaminants (Windhoek, South Africa; Los Angeles County, CA; Washington, D.C.; Denver, CO; San Diego, CA; and Tampa, FL), noting that these studies identified no obvious adverse health effects associated with indirect potable reuse in the specific projects examined. These studies varied widely in approach and should be considered individually (and are discussed further below). There are also design drawbacks in each of these studies, which limit their individual and overall usefulness to assess risk. The studies varied considerably from combinations of simple screening and chemical identification studies to toxicology testing. Only the Denver and Tampa studies addressed a broad range of toxicological concerns.

The report made several observations including:

- Several IPR projects in the United States generally produce reclaimed water that meets or exceeds the quality of the raw waters those systems would use otherwise, as measured by current standards.
- Current potable reuse projects and studies have demonstrated the capability to produce reclaimed water of excellent measurable quality and to ensure system reliability.
- In communities using reclaimed water where analytical testing, toxicological testing, and epidemiological studies have been conducted, significant health risks have not been identified.
- . . . the best available current information suggests that the risks from IPR projects are comparable to or less than the risks associated with many conventional supplies.
- The requirements for IPR systems thus should exceed the requirements that apply to conventional drinking water treatment facilities.

The general conclusion of the NAS report was that "planned, indirect potable reuse is a viable application of reclaimed water—but only when there is a careful, thorough, project-specific assessment that includes contaminant monitoring, health and safety testing, and system reliability evaluation**."** Also, the report recommends "that water agencies considering potable reuse fully evaluate the potential public health impacts from the microbial pathogens and chemical contaminants found or likely to be found in treated wastewater through special microbiological, chemical, toxicological, and epidemiological studies, monitoring programs, risk assessments, and system reliability assessments."

Studies Evaluated in the 1998 NAS Report

Montebello Forebay, Los Angeles County toxicological studies (Nellor et al, 1984) **–** In 1978, a five-year study of the potential health effects resulting from spreading recycled water in the Montebello Forebay was started. Study topics included 1) determining microbial and chemical constituents in the tertiary-treated recycled water and the replenished groundwater, 2) conducting toxicological testing of various recharge waters and imported drinking water, and 3) conducting epidemiological studies of populations ingesting groundwater influenced by the spreading project.

Two short-term genetic toxicity tests (Ames *Salmonella* test and mammalian cell transformation assay) were performed using waters concentrated by factors of 10,000 to 20,000. Substances concentrated in the water were found to be capable of producing changes in the DNA of bacteria. This change is called mutagenic activity. Mutagenic activity was highest in storm water runoff followed by dry weather runoff, recycled water, groundwater, and imported drinking water. No relation was observed between percent reclaimed water in wells and observed mutagenicity of residues isolated from wells.

Montebello Forebay epidemiological studies – The first epidemiological study was initiated in 1979 and examined health outcomes from 1969 – 1980 (Frerichs, 1984). The second studied health outcomes from 1987 – 1991 (Sloss et al, 1996), while the third examined birth outcomes from 1982 – 1993 (Sloss et al, 1999). The first two studies used an ecologic design where the incidence of a health outcome in one geographical area was compared to that of another area. In this case, areas known to use groundwater replenished with recycled water were evaluated against control areas where water supplies had not been impacted by the replenishment project, but possessed demographic features similar to the recycled water areas.

Populations in the first two studies exceeded one million people, divided roughly in half between exposure to recycled water and control groups. Census tracts were divided into exposed areas and control areas. Water quality and hydrogeologic data were used to model the estimated percentage of recycled water in potable water supply wells serving the population potentially impacted with recycled water in their water supply. The percentage of recycled water that populations were exposed to over the thirty-year study period ranged from 0 to 31 percent for the water systems in the Montebello Forebay area. Each census tract was then assigned into one of four (or five in the second study) exposure categories: high and low recycled water areas, and two control areas.

The studies concluded that there was no evidence of consistently higher rates of adverse health outcomes (general or specific mortality or morbidity) in the population who lived in the areas receiving higher percentages of recycled water. Short-term and long-term health outcomes included occurrence of infectious diseases, adverse birth outcomes, and cancer incidence. No consistent dose-response relationship was observed between exposure to recycled water and illness rates. In 1987, a Science Advisory Panel on Groundwater Recharge with Reclaimed Water issued a review of the Montebello Forebay health effects studies endorsing the continuation of the Montebello Forebay replenishment project.

The third epidemiological study (that of birth outcomes only) was not complete at the time the NRC report had been published. It was an extension of the original OLAC study of birth outcomes occurring in the Montebello Forebay populations between 1969 and 1980, focusing on the years 1982 though 1993. A cohort study using a Zip-code-level of surrogate exposure was designed to examine the association between residence in areas being served different percentages of recycled water in their potable water and several adverse birth outcomes.

Outcomes were classified into 24 categories: infant mortality, four related to prenatal development, and 19 for various types of birth defects.

The study's authors concluded that the rate of adverse birth outcomes was similar in the Montebello Forebay regions receiving recycled water when compared to the control group not receiving any recycled water. Further, within the exposed populations, the rate of these outcomes was similar in groups receiving "high" and "low" percentages of recycled water. Several limitations inherent in the study design were noted:

- There was no data on individual exposure to recycled water.
- Potential confounding factors such as cigarette smoking, alcohol consumption, and occupational exposures were assumed to be equal in the exposed and control cohorts.
- High population mobility could hamper detecting an effect.

Potomac Estuary Experimental Wastewater Treatment Plant (James M. Montgomery, Inc., 1983) **–** Beginning in 1980, the Army Corps of Engineers managed a two-year testing program of a demonstration drinking water treatment plant in Washington, D.C. The influent to the plant, a 50:50 blend of secondary-treated wastewater effluent and Potomac estuary water, simulated the water quality conditions that could occur in Potomac estuary drinking water treatment plant intakes in the event of a severe drought. The blended water received additional treatment with GAC, and post-disinfection chlorination. Two short-term genetic toxicity tests were conducted on organic extracts concentrated from the Potomac Estuary Experimental Wastewater Treatment Plant influent water, the product water, and finished water from three local conventional drinking water treatment plants. Organic concentrates were used in Ames *Salmonella* and mammalian cell transformation tests. Results showed low levels of mutagenic activity in the Ames test, with GAC treated water exhibiting less activity than the local drinking water. The cell transformation test showed a small number of positive samples with no difference between GAC treated water and finished drinking water.

Denver Potable Water Reuse Project (Lauer et al, 1990) – The health effects testing program for the Denver Potable Reuse Demonstration Project, the results of which were published in 1993, was designed to evaluate the relative health effects of highly treated recycled water in comparison with Denver's drinking water. A two-year animal study revealed no toxicologic, carcinogenic, reproductive, or developmental effects that could be attributed to the recycled water or Denver drinking water. The studies found that the quality of recycled water from the Denver Potable Reuse Demonstration Plant equaled or exceeded that of the existing drinking water supply and that it exceeded all federal and state standards for definable constituents (Lauer and Rogers, 1993; Condie, 1994a, 1994b).

Tampa Water Resource Recovery Project (CH_2M Hill, 1993) – In the 1980s, the City of Tampa, Florida evaluated advanced tertiary-treated, denitrified recycled water as an alternative for augmenting its surface water supply. Toxicological testing of finished water produced from four different unit process methods was completed in 1992. A short-term toxicity test was used to screen for mutagenicity.

The concentrate from the treatment train with GAC had the lowest mutagenic activity. Further toxicological examination included more mutagenicity testing, carcinogenicity assays, fetotoxicity, and subchronic toxicity. Ames *Salmonella*, micronucleus, and sister chromatid exchange tests of up to 1000x organic concentrates at three dose levels were conducted. No mutagenic activity was observed in any of the samples. *In vivo* testing included mouse skin initiation, strain A mouse lung adenoma, 90-day subchronic assay on mice and rats, developmental toxicity study on mice and rats, and reproductive study on mice. All tests were negative, except for some fetal toxicity exhibited in rats, but not mice, for the advanced water treatment sample.

Total Resource Recovery Project (Western Consortium for Public Health, 1996) – Between 1988 and 1990, the City compared genetic effects in recycled water concentrates and their potable water supply. 150-600x organic concentrates were used in Ames *Salmonella* test, micronucleus, 6-thioguanine resistance, and mammalian cell transformation testing. The Ames test showed some mutagenic activity, but recycled water was less active than drinking water from the Miramar Plant. The micronucleus test showed positive results only at the high (600x) doses for both treatments. *In vivo* fish biomonitoring (28-day bioaccumulation and swimming tests) showed no positive results. Baseline reproductive health and vital statistics were collected.

Windhoek, South Africa ((Isaacson and Sayed, 1988) – Introducing direct recycled water use in Windhoek prompted an epidemiological study to assess health effects of drinking recycled water directly. An analysis of more than 15,000 episodes of diarrheal diseases, jaundice and death between August 1976 and March 1983 found no relationship to drinking water source. Because of Windhoek's unique environment and demographics, these results cannot be extrapolated to other populations in industrial countries

Santa Ana River Water Quality and Health Study (2004)

The Santa Ana River Water Quality and Health Study (NWRI, 2004) was started by the OCWD in 1994 to address questions about the use of Santa Ana River (SAR) water (which is a wastewater effluent dominated river for recharging the Orange County groundwater basin). The study was designed to provide scientific information to help address concerns frequently expressed by DHS regarding the use of reclaimed water to recharge groundwater subsequently withdrawn for potable use. Researchers from several universities, research institutions and government agencies participated in the study. OCWD commissioned a Scientific Advisory Panel to assess the SAR Water Quality and Health Study. The study examined microbial risk, organic carbon, toxicology, and health effects. The Scientific Advisory Panel ultimately concluded that no chemicals of wastewater origin were identified at concentrations that are of public health concern in the SAR, in water in the infiltration basins, or in nearby groundwaters.

The discovery of new contaminants (NDMA and 1,4-dioxane, both carcinogens) in untreated wastewater, recycled water and groundwater recharged with recycled water is driving the addition of UV + hydrogen peroxide treatment in many recycling projects (including in Orange County and at West Basin). UV + hydrogen peroxide has been shown to be very effective at destroying these compounds.

Pomona, OLAC and Monterey Health Effects Studies

The Pomona Virus Study in the 1970's, the Orange County and Los Angeles County (OLAC) Health Effects Study and the Monterey Wastewater Reclamation Study for Agriculture in the

1980's served to provide a technical basis for development of regulations and guidelines for irrigation, recreational impoundments, and groundwater recharge.
The Pomona Virus Study was conducted by the County Sanitation Districts of Los Angeles County in the mid-1970's to determine what type of water treatment was necessary to control waterborne pathogens in recycled water used in recreational lakes and to evaluate more cost-effective options to meet the requirements in the California Wastewater Reclamation Criteria at that time.

The Monterey Wastewater Reclamation Study for Agriculture began in 1980 and was designed to evaluate the safety and feasibility of irrigating food crops (many eaten raw) with tertiary-treated municipal wastewater. The study results showed that use of this recycled water for food crop irrigation is safe and acceptable.

The Pomona Virus Study and the Monterey Study (Sheikh, 1990, 1998, 1999) provided evidence that effective virus removal can be accomplished using several different tertiary treatment methods and disinfection with chlorine. The latter study also showed that food crops that are eaten uncooked could be irrigated with appropriately treated recycled water without adverse environmental or health effects.

The County Sanitation Districts of Los Angeles County conducted another investigation in the 1980's evaluating potential health effects associated with groundwater recharge of recycled water in the Montebello Forebay. The study included water quality characterization, epidemiological investigations, and toxicity testing. The study's findings that no measurable adverse impacts on the area's groundwater or the health of the population ingesting the water from wells downstream of the recharge basins was further evaluated by an independent panel of experts selected by the State of California, who concluded that the risks associated with the Districts' groundwater replenishment project were minimal and probably no different from those of commonly used surface waters (Asano and Levine, 1996). The study provided a technical basis for establishing statewide criteria for groundwater recharge.

San Diego Health Effects Study

Laying the groundwork for the eventual proposal to augment the San Vicente Reservoir with advanced treated recycled water (Water Repurification Project), the City conducted a health effects study (Cooper et al, 1992) for what was then termed the San Diego Total Resource Recovery Project. The primary objective of the study was to determine if "an advanced water recycling treatment system could reliably reduce contaminants of public health concern to levels such that the health risks posed by any proposed IPR of the treated water are no greater than those associated with the present water supply". The Health Advisory Committee formed by the City to address potential public health issues associated with the Total Resource Recovery Project ultimately concluded that "the health risks associated with the use of the Aqua II Advanced Water Treatment Facility water as a raw water supply is less than or equal to that of the existing City raw water..."

There was also a reproductive survey, vital statistics collection and neural tube defects baseline study associated with the San Diego Total Resource Recovery Program published in 1990 (Molgaard et al, 1990). The baseline study could serve as a basis for future comparative work.

In May 1993, the State of California created the Potable Reuse Committee to examine the feasibility and safety of potable reuse of advance treated recycled water. This committee eventually generated a report proposing a framework for regulating IPR for surface water augmentation in 1996 (State of California, 1996). The committee recommended six criteria to be met before this type of project would be approved:

- Application of Best Available Technology.
- Maintenance of appropriate retention times based on reservoir dynamics.
- Maintenance of operational reliability to meet primary drinking water standards.
- Compliance with State of California criteria for groundwater recharge for direct injection with recycled water.
- Maintenance of reservoir quality.
- Provision for an effective source control program.

For the City's proposed Water Repurification Project, DHS used the then-current Draft Ground Water Recharge regulations as a starting point for regulatory review. Because the reservoir augmentation project would not include the soil filtration barrier of a ground water recharge project, DHS looked to the City to propose and demonstrate how reservoir processes and operations could provide substitute barriers of equal effectiveness. This led to the development of the retention time, dilution, and short-circuiting prevention conditions.

In May 1994 an independent panel of experts on drinking water and public health that was convened to review the Water Repurification Project proposal gave it their endorsement. DHS gave its approval, conditioning the approval on additional virus testing in August 1994. A special panel of prominent citizens convened that fall to review the proposal and concluded: "There is sufficient information available to determine the suitability of water repurification as a supplement to the San Diego region's water supply. Additional planning, economic analysis and environmental studies should proceed."

Technical studies continued including a siting analysis, pilot scale study of advanced treatment methods, and a reservoir hydrodynamic study. In the late summer and fall of 1995, pilot work was done to confirm virus removal as requested by DHS. These studies culminated in the preparation of the City's Water Repurification Report in 1996.

Additional health effects studies using a larger advanced pilot treatment facility were conducted which corroborated the findings of the 1992 health effects study.

A "Blue Ribbon Panel" of drinking water and public health experts was convened in 1998 by the NWRI. The panel included individuals who had served on the earlier independent advisory panel as well as some additional individuals prominently recognized in the drinking water and environmental/health community. In their September 1998 report, the panel found the project to be a, "…safe and appropriate supplemental drinking water supply for the City of San Diego." However, City Council adopted a resolution to terminate the project on May 18, 1999.

Lessons Learned From Assessment of Indirect Potable Reuse Projects

While case studies are necessarily site specific, they collectively provide a high level of comfort that IPR projects can be designed and implemented in a fashion that meets conservative State regulatory requirements and guidelines and can therefore be deemed safe by health authorities. Even with State health regulator support, community acceptance and support is most critical. The following text discusses IPR projects across the U.S. that provide useful insight into the practice.

Recycling in the City of San Diego

The City's Total Resource Recovery Project sought to show the feasibility of using natural systems combined with advanced treatment of recycled water to provide a water supply equivalent to or better than imported water supplied to the region. The goals of the program were to:

- Demonstrate treatment methods that would provide effective advanced treatment of recycled water.
- Examine the health effects of using highly treated recycled water.
- Examine the reliability of the water treatment process train.
- Construct and successfully operate a full-scale plant to provide a quality of water sufficient to be a raw water supply.

In 1974, RO pilot testing began (Aqua I) for demonstration and to provide irrigation water for the stadium's sod farm.

A technical advisory committee was appointed in 1981 to guide the work plan for a demonstration plant, called Aqua II. Phase 1 included pilot testing to examine total resource recovery through an aquatic treatment pond system and an advanced treatment plant. In 1985, a health effects study was added to the program.

The advanced treatment train included a package water treatment plant followed by RO membranes, carbon adsorption treatment, UV treatment and an aeration tower. The investigators concluded that the combination of treatment methods could reliably produce water that could be safely used as a raw water supply. Final water quality met or surpassed all national drinking water standards.

In 1994, the City committed to implementing a water reclamation program with capacity to treat 45 MGD by 2010. The original Water Repurification Project concept involved both non-potable and indirect potable reuse. The proposed water treatment methods included: 1) MF or UF; 2) RO; 3) IX; 4) ozone/peroxide contactor; 5) chlorination; and 6) dechlorination prior to discharge into the San Vicente Reservoir. In addition to removing chemical contaminants, these methods provided additional barriers and protection from pathogens.

Including a reservoir as one of the reuse project's multiple barriers would take advantage of natural treatment, dilution, and water retention time. Modeling of water behavior in the reservoir indicated that recycled water could short-circuit through the reservoir but that there was still a substantial residence time with the current reservoir capacity to take advantage of natural treatment and dilution.

The health risk of drinking water treated from the San Vicente Reservoir after augmentation with recycled water was concluded to be no greater than drinking water treated from non-augmented sources (Western Consortium for Public Health, 1996, Olivieri et al, 1996).

Recent discussions with California DHS regarding indirect potable reuse **–** Preliminary discussions with DHS representatives in January 2005 indicated that any new proposal for a reservoir augmentation project would need to consider the changes made to the Draft Ground Water Recharge regulations (State of California, December 2004) since approval of the City's 1998 Water Repurification Project. As described above, the new draft regulations have more strict requirements on total organic carbon, nitrogen, and source control. In addition, the RWQCB may add more requirements for inflows to the reservoir, particularly with regard to nitrogen. DHS would likely require two treatment barriers for each type of contaminant. As long as the project meets all DHS treatment and reservoir management requirements, introduction of highly treated recycled water into a drinking water treatment plant source reservoir could be permitted.

Section 5 Other Community Experiences

Montebello Forebay Groundwater Recharge Project, Los Angeles County

The oldest and most successful planned IPR project continues to expand because of its history of leadership in recycled water research and the project's advanced water quality monitoring program. This recycled water spreading project, begun in 1961, has contributed over the years numerous landmark recycled water treatment and health effects studies that have advanced other such projects, and increased our knowledge in the area of operations, maintenance, and water quality monitoring.

In the County of Los Angeles, the Montebello Forebay Groundwater Recharge Project is part of the San Gabriel River Conservation System. Today runoff, impounded water from canyon dams, recycled water from three County Sanitation Districts of Los Angeles County (CSDLC) treatment plants, and imported surface water can be directed to spreading grounds at points along the length of the river for the purpose of groundwater recharge in the San Gabriel Valley and the coastal plain.

The planned use of recycled water for groundwater recharge in the Montebello Forebay began in 1962. Today, three treatment plants designed, built, and operated by the CSDLC provide recycled water for spreading in the Rio Hondo and San Gabriel recharge basins. CSDLC's goal is to recycle as much water as possible.

Recycled water quality must comply with all drinking water standards established by DHS as determined by a running annual average.

Three major health effects studies and many water quality and operational research studies have been conducted on this reuse project over the years. The focal point of these studies was the Montebello Forebay. The first epidemiological study was initiated in 1979 and examined health outcomes from 1969 – 1980 (Frerichs, 1984). The study found no evidence of adverse health effects.

In 1987, a Science Advisory Panel on Groundwater Recharge with Reclaimed Water, created by the same state water agencies that created the 1975 expert panel, reviewed the OLAC Health Effects Study and endorsed the continuation of the Montebello Forebay recycled water spreading project. A second study of cancer incidence, mortality and incidence of infectious disease health outcomes from 1987 – 1991 (Sloss et al, 1996) and a third study examining birth outcomes from 1982 – 1993 (Sloss et al, 1999) were completed. The studies have shown no evidence of adverse effects.

Occoquan Reservoir Replenishment, Virginia

The Occoquan Reservoir is the principal water supply source for over one million people in Fairfax County, Northern Virginia. The 1,475-km2 (570 sq-mile) Occoquan Watershed was largely rural until the 1960's. Rapid growth led to water quality problems in the reservoir. The Upper Occoquan Sewage Authority (UOSA) water reclamation plant has added recycled water to the Occoquan Reservoir since 1978. The Occoquan Reservoir is a water source for the Fairfax County Water Authority's drinking water treatment plant. Recycled water from the UOSA water reclamation facility is discharged into Bull Run, a tributary of the Occoquan Reservoir, and then travels approximately six miles downstream to the reservoir. In periods of drought the plant supplies up to 90 percent of the reservoir's inflow. The water quality of the recycled water discharge is typically better than the water quality in the receiving stream and in the reservoir. After entering the reservoir, the water is then carried an additional 20 miles to the Fairfax County Water Authority's drinking water treatment plant inlet. The reclamation plant's discharge into the reservoir was at first a source of considerable controversy. Studies on the quality of the water are regularly conducted. These have established that the water from the plant is comparable to and may be better than the reservoir's other water sources.

One study investigated UOSA's treatment methods as barriers to pathogenic as well as alternative and traditional-indicator microorganisms. Samples were collected once a month for one year from eight sites within UOSA's advanced water reclamation plant. The eight sites were monitored for indicator bacteria total and bacteria, viruses and protozoa. Overall, the plant was able to achieve 99.999 percent to 99.99999 percent reduction of bacteria, 99.999 percent reduction of enteroviruses, and over 99.99 percent reduction of protozoa. No enteroviruses or fecal coliforms were detected in the final effluent. All measurements indicated that the recycled water was of a better quality than the water in the reservoir.

The Virginia State Water Control Board imposes strict conditions requiring that recycled water be monitored by an independent water monitoring agency. In addition, they require that any plant expansion be carried out in stages of no greater than 4 MGD. However, in more than 25 years of operation, there have been no water quality issues of health concern. Due to its 25 year track record of having consistently achieved good quality discharges, UOSA was given approval by the Virginia State Water Control Board to increase the plant capacity from 27 to 46 MGD instead of in 4 MGD increments.

Occoquan is often cited by water industry professionals as the longest running potable reuse project in the U.S. Occoquan is viewed as successful for two reasons:

- There was a serious water-quality problem to be solved and the project solved this problem creating very visible improvement.
- Water-quality credibility was achieved by forming a separate water quality authority, which continues to monitor and report on water quality.

West Basin Municipal Water District, El Segundo, California

The West Basin Municipal Water District is a wholesaler of treated, imported water to cities and other water systems in southwest Los Angeles County. The need to import drinking water became a critical issue in the 1950's when excessive groundwater pumping caused intrusion of ocean water into the potable water aquifers of the West Coast groundwater basin. A complex network of injection wells, called the West Coast Basin Seawater Intrusion Barrier, was constructed beginning in the 1960's by Los Angeles County to prevent any additional intrusion. Up until the mid-1990's, imported water was used as the sole source of injection water. In a major drinking water conservation effort, West Basin Municipal Water District built a water recycling facility to provide tertiary-treated recycled water for irrigation and industrial applications in their service area and advanced water treatment methods to replace a portion of the imported water injected for seawater intrusion control.

The approval process for using 100 percent recycled water underwent substantial expert and public review. A Blue Ribbon panel evaluated the treatment methods and water quality objectives and made a number of recommendations, many of which were incorporated into the DHS draft groundwater recharge criteria. Numerous studies were conducted that examined the occurrence, removal, and groundwater transport of total organic carbon, regulated priority pollutants, pathogens, disinfection byproducts, and trace contaminants, tentatively identified compounds, and pharmaceuticals.

The engineering report noted that, with the exception of ammonia concentrations, the recycled water exhibited superior water quality to the surface water supplies which they would replace (treated surface water from MWD), and represented an overall improvement in the protection of public health in this IPR project.

West Basin recently received regulatory approval from the DHS to increase the percent of advanced treated recycled water that can be injected into the groundwater to 75 percent (a staged approach to ultimately move to 100 percent recycled water, Rich Nagel, personal communication, 2004).

Las Vegas, Nevada

Since the 1950s, recycled water from Las Vegas has been discharged into the Las Vegas Wash, located between the Las Vegas metropolitan area and Lake Mead. Return flow credits permit a Colorado River water user to use and reuse the same water until it finally evaporates or sinks into the ground. Since Lake Mead is the primary source of drinking water for the Las Vegas region, as well as the destination for the region's recycled water, the principle of return flow credits allows Las Vegas to withdraw more than the 300,000 acre-feet from Lake Mead. For example, in

2001, approximately 420,000 acre-feet was withdrawn from the lake, with 120,000 acre-feet of return flow credits from the return of recycled water.

An additional concern has been raised by environmental groups in the area. Originally, the relatively small quantity of water discharged into the Las Vegas Wash created a wetlands and encouraged the establishment of a varied wildlife population. Wetlands vegetation helps clean the water that comes from the valley by filtering the water and further reducing pollutants as the water travels toward Lake Mead. The waterway also became a major rest area for migrating birds traveling through the western U.S. The increased quantity of water discharge has changed the habitat in recent years, and the wetlands areas are being destroyed by erosion. This has had a negative impact on the pollutant reduction that occurs in the wash; it is eliminating the wildlife habitat as well as producing additional sediment deposits in Lake Mead. The fact that the wetlands were artificially created by humans does not reduce the concern for their ongoing destruction. Erosion control features are now being constructed in the wash to slow water flow and control erosion.

Public health is always a concern when a potable water source includes recycled water. In the case of the Las Vegas Wash discharge, there is a large capacity for natural treatment and dilution in the cycle of water discharge through Las Vegas Wash to Lake Mead. At capacity, the lake holds approximately 28 million acre-feet of water, and even during severe droughts such as 2004, the reservoir holds approximately 14 million acre-feet of water. The 120,000 acre-feet of discharge (at 2001 flows) from the Las Vegas area is treated and disinfected to secondary treatment standards, then passes through the wetlands and stream beds of the Las Vegas Wash prior to reaching the lake, which holds more than 100 times the annual discharge.

Gwinnett County, Georgia

In 1995, Gwinnett County approved a new 20 MGD reclamation treatment plant called the North City Advanced Water Reclamation Facility (NCAWRF). This project is an example of IPR because numerous drinking water treatment intakes for the metropolitan Atlanta area are located downstream of the proposed discharge point. The proposed treatment included advanced secondary treatment for nutrient removal, membrane filtration, multi-media and activated carbon filters, and ozone disinfection.

The major public issue surrounding the proposed discharge of recycled water into Lake Lanier, a major source of drinking water for the metropolitan Atlanta area, was the potential aesthetic impacts such a discharge may have on the commercial and recreational activities around the lake. The idea of introducing recycled water into the lake close to the intake of a major drinking water treatment plant created relatively little public response compared to the environmental and economic concerns.

In 1999, the regulators delayed issuing a discharge permit for expansion of the NCAWRF until they could establish water quality standards for the lake. One year later, in early 2000, the standards were released; in November of the same year the State issued a National Pollutant Discharge Elimination System (NPDES) permit to Gwinnett County. Eventually, environmentalists and lakeside residents sued the county and state regulators, arguing that the discharge permit issued by the State for the expansion and discharge into the lake established treatment standards that were not as stringent as the plant's proposed capability based on the water quality produced in the already operating 20 MGD facility.

The plaintiffs' fear is that the water will eventually degrade the lake putting recreational users and habitat at risk. The concept of IPR does not seem to be the major issue, primarily because there are already other wastewater dischargers around the lake. The quality of these return flows is considered by many people (but not all) to be "cleaner" than the current lake quality with respect to drinking water quality, but not necessarily for maintaining the ecological health of the lake. The recycled water discharged into Lake Lanier would contain nutrients like phosphorus that may encourage the growth of algae and other aquatic plants.

An administrative law judge ruled against the environmental groups in September 2002, but a Hall County Superior Court judge reversed that ruling in March 2003. The Georgia State Supreme Court later struck down the permit that had been issued by the State ruling that Gwinnett County's discharge permit would not protect water quality in Lake Lanier. The Court stated that "the clear and unambiguous language of Georgia's anti-degradation rules require the permittee to use the 'highest and best (level of treatment) practicable under existing technology'". In the meantime, Gwinnett County has asked the regulators for a temporary permit to discharge 9 MGD into the Chattahoochee River above the 20 MGD already permitted for Gwinnett's existing reclamation plant.

Dublin San Ramon Services District, California

Dublin San Ramon Services District (DSRSD) proposed an IPR project using groundwater injection as the best and most cost-effective means to resolve their wastewater disposal problem created by rapid growth in their service area (Requa, D., personal communication, November 2004). The recycled water was to be injected into wells in Livermore but the majority of the water withdrawn would be delivered to Pleasanton and Dublin. The Environmental Impact Report process included an extensive public involvement program and an analysis of alternatives including local stream discharge and a seasonal storage reservoir. The DSRSD Board of Directors subsequently approved the project and moved ahead with design and construction.

The Pleasanton community believed that they were bearing the brunt of other communities' growth problems. In the face of strong public opposition, and when the need for additional wastewater treatment capacity was eliminated with approval for expansion of the ocean outfall, DSRSD withdrew the IPR component of their project and advanced the non-potable aspects of the project.

DSRSD entered into an agreement with the City of Pleasanton in which Pleasanton agreed not to challenge the project if DHS and the RWQCB approved the project. Upon completion of construction, DSRSD was approved to place the project into operation by these agencies. Ultimately, two of the agencies that were to receive the water withdrew their support of the project due in large part to their perception that public support of the project had been lost.

DSRSD dropped the project since it was no longer required to provide wastewater service, even though surveys indicated that a majority of the residents supported or accepted the project. Although the injection project that would have provided recycled water for IPR did not proceed, DSRSD has gone forward with non-potable reuse of this water supply.

The experience suggests that IPR projects are permittable in California. Community support is essential. Also, it could be inferred that a water supply agency is better suited to sponsor a water reuse project because water resource benefits are primary and wastewater disposal aspects are secondary. Public outreach and involvement should be thorough and continue throughout the development and construction of a project.

Orange County Groundwater Replenishment System

OCWD built Water Factory 21 in the 1970's to produce recycled water for injection into the groundwater to create a seawater intrusion barrier. The OCWD is proceeding with design and construction of a significant expansion/upgrade with advanced treatment technology. The number of seawater intrusion injection wells will be increased, a pipeline to deliver recycled water to the Anaheim Forebay (upper part of groundwater basin where current SAR spreading operations occur). According to Ruetten (2003):

The program has experienced success to date as OCWD has identified a clear set of problems that are perceived to be significant enough to warrant expansion of GWR and indirect-potable reuse These include protection of the aquifer against seawater intrusion, decreasing dependence on imported water supplies, improving drought resistance and reducing wastewater discharges to ocean beaches. In addition, they are using state-of-the-art treatment processes including reverse osmosis, have an established track record (with Water Factory 21) of being proactive with respect to emerging water-quality issues, have established themselves as a credible source of water quality information and their communication program is diligent and consistent.

These factors have fostered feelings of trust and credibility and are the basis for the success of the project so far. The only apparent water-quality issue that is still open is the desire by some key audiences to get the Department of Health Services (DHS) officially involved in the pre-treatment standards that govern the wastewater treatment plant.

Section 6 Conclusions

Based upon an assessment of the issues, studies and experiences, indirect potable and non-potable reuse projects can be implemented and can meet water quality and public safety goals.

The available human health studies are sufficient to convince the DHS that highly treated recycled water can be safely consumed by humans through IPR projects. Accordingly, DHS has permitted several such projects in the state, making California a leader in this area.

Permitted IPR projects protect the public health through:

- Use of advanced water treatment methods that reliably remove contaminants of concern.
- Careful operation and maintenance of those methods.
- Use of multiple monitoring systems to ensure consistently high quality water is produced.

Numerous science-based, health effects studies and regulations support IPR. While additional studies can and will be conducted in the future, these studies provide evidence of the safety of recycled water. While IPR is supported by and allowed under California regulations, successful implementation of projects has only occurred where there is community and political support.

Section 7 References

Adams C.; M. Asce; Y. Wang; K. Loftin; and M. Meyer. *Removal of Antibiotics from Surface and Distilled Water in Conventional Water Treatment Processes*, J. Environ. Eng., p. 253-260, March 2002.

Agenson K.O.; J. Oh; T. Urase. *Retention of a Wide Variety of Organic Pollutants by Different Nanofiltration/Reverse Osmosis Membranes: Controlling Parameters of Process*. Journal of Membrane Science 225: p. 91–103, 2003.

American Water Works Association. Organisms in Water Committee. *Committee report: microbiological considerations for drinking water regulation revisions*. Journal of the American Water Works Association 79(5): 81-88. 1987.

American Water Works Association Research Foundation, *Investigation of Soil-Aquifer Treatment for Sustainable Water Reuse*, (AwwaRF Report #487), Phase I, 2001.

Anders R.; W.A. Yanko; R.A. Schroeder; and J.L. Jackson, *Virus Fate and Transport During Recharge Using Recycled Water at a Research Field Site in the Montebello Forebay, Los Angeles, County, California, 1997-2000.* U.S. Geological Survey, Scientific Investigations Report 2004-5161. Sacramento, California, 2004.

Asano, T. and Cotruvo, J. *Groundwater Recharge with Reclaimed Municipal Water: Health and Regulatory Considerations*, Water Research 38: p.1941 – 1951, 2004.

Blumenthal, U.J.; E. Cifuentes; S. Bennett; M. Quigley; and G. Ruiz-Palacios. *The Risk of Enteric Infections Associated with Wastewater Reuse: The Effect of Season and Degree of Storage of Wastewater.* Transactions of the Royal Society of Tropical, Medicine and Hygiene 95: p. 131, 2001.

Bolton, J.R.; Ho Te-Fu, L.; and E. Lipczynska-Kochany. *Quantum Yields for the Photodegradation of Pollutants in Dilute Aqueous Solution: Phenol, 4-Chloropheno and N-Nitrosodimethylamine*. J. Advanced Oxidation Tech 1: No. 2, p. 170-178, 1996.

Boreen, A.L.; W.A. Arnold; and K. McNeill. *Photodegradation of Pharmaceuticals in the Aquatic Environment: A Review*. Aquatic Sciences 65: p. 320, 2003.

Bouwer, E.J.; P.L. McCarty; and J.C. Lance. *Trace Organic Behavior In Soil Columns During Rapid Infiltration Of Secondary Wastewater*. Water Research 15: p. 151-159, 1981.
CH2M Hill, *Tampa Water Resource Recovery Project: Pilot Studies*, Tampa, Florida, 1993.

Condie, et. al. *Denver Potable Reuse Demonstration Project: Comprehensive Chronic Mouse Study*, Journal of Toxicology and Environmental Health, 1994.

Condie, L.W.; W.C. Lauer; G.W. Wolfe; E.T. Czeh; and J.M. Burns. *Denver Potable Water Reuse Demonstration Project: Comprehensive Chronic Rat Study.* Fd. Chem. Toxic. 32(11): p. 1021-1030, 1994.

Cooper, R.C.; A.W. Olivieri; D. E. Eisenberg; R. E. Danielson; L.A. Pettegrew; W.A. Fairchild; and L.A. Sanchez. "San Diego Aqua II Pilot Plant Health Effects Study." Prepared by the Western Consortium for Public Health, 1992.

Cooper R.; A. Olivieri; D. Eisenberg; J. Soller; and T. Hall. *The City of San Diego Water Repurification Project Public Health Assessment.* Prepared by the Western Consortium for Public Health in association with EOA, Inc. 1992.

Crook, J. *From the Lab to the Lawn*. American City and Country. February 1998.

Daughton, C. *Pharmaceuticals and Personal Care Products in the Environment: Overarching Issues and Overview*. 2004. <www.epa.gov/nerlesd1/chemistry/pharma/book-summary.htm>.

Davies, J.-M.; A. Mazumder. *Health and Environmental Policy Issues in Canada: the Role of Watershed Management in Sustaining Clean Drinking Water Quality at Surface Sources*. Journal of Environmental Management 68, p. 273, 2003.

Desbrow, C.; E.J. Routledge; G.C. Brighty; J.P. Sumpter; and M. Waldock. *Identification of Estrogenic Chemicals in STW Effluent.* Chemical Fractionation and in Vitro Biological Screening. Environmental Science and Technology 32(11): p. 1549-1558, 1998.

Dobbs, R.A.; J.M. Cohen. *Carbon Adsorption Isotherms for Toxic Organics*, USEPA, EPA-600/8-80-023, 1980.

Drewes, J.E.; M. Reinhard; and P. Fox, *Comparing Microfiltration-Reverse Osmosis and Soil-Aquifer Treatment for Indirect Potable Reuse of Water.* Water Research 37: p. 3612–3621, 2003.

Dube, M.G.; D.L. MacLatchy. *Endocrine Responses of Fundulus Heteroclitus to Effluent from a Bleached-Kraft Pulp Mill Before and After Installation of Reverse Osmosis Treatment of a Waste Stream.* Environmental Toxicology and Chemistry 19(11): p. 2788, 2000.

Dube, M.G. and D.L. MacLatchy, *Identification and Treatment of A Waste Stream at a Bleached-Kraft Pulp Mill That Depresses a Sex Steroid in The Mummichog (fundulus heteroclitus).* Environmental Toxicology and Chemistry 20(5): p. 985, 2001.

Frerichs, R. *Epidemiologic Monitoring of Possible Health Outcomes of Wastewater Reuse.* The Science of the Total Environment 32, p. 353 – 363, 1984.

Garcia, A.; et. al. *Giardia Cysts in Treated Wastewater Effluents: Are They Infective?* Water Environment Research. November/December, 2002.

Gearheart, R.A.; F. Klop; and G. Allen. "Constructed Free Surface Wetlands to Treat and Receive Wastewater: Pilot Project to Full Scale." Pp.121-137. In: *Constructed wetlands for wastewater treatment: municipal, industrial, and agricultural*. D.A. Hammer, (ed.) Lewis, 1988.

Gennaccaro, A.; McLaughlin M.; Quintero-Betancourt, W.; Huffman, D.; and J.B. Rose. *Infectious Cryptosporidium parvum Oocysts in Final Reclaimed Effluent*. Appl. Env. Microbiol. 69:8, p. 4983-4984. 2003.

Gerba, C.P.; D.K. Powelson; M.T. Yahya; L.G. Wilson; and G.L. Amy. *Fate of Viruses in Treated Sewage Effluent During Soil Aquifer Treatment Designed for Wastewater Reclamation and Reuse*. Water Science and Technology 24(9): p. 95-102, 1991.

Gersberg, R.M.; R. Lyon; R. Brenner; B.V. Elklin. *Fate of Viruses in Artificial Wetlands*. Applied and Environmental Microbiology, p. 731-736, April 1987.

Giesy, J.P.; S.L. Pierens; E.M. Snyder; S. Miles-Richardson; V.J. Kramer; S.A. Snyder; K.M. Nichols; and D.A. Villeneuve. *Effects of 4-Nonylphenol on Fecundity and Biomarkers of Estrogenicity in Fathead Minnows (Pimephales Promelas).* Environmental Toxicology and Chemistry 19(5): p. 1368-1377, 2000.

Harries, J.E.; D.A. Sheahan; S. Jobling; P. Matthiessen; P. Meall; E.J. Routledge; R. Rycroft; J.P. Sumpter; and T. Tylor. *A Survey of Estrogenic Activity in United Kingdom Inland Waters.* Environmental Toxicology and Chemistry 15(11): p. 1993-2002, 1996.

Harries, et. al.; *Estrogenic Activity in five United Kingdom Rivers Detected by Measurement of Vitellogenesis in Caged Male Trout*. Environmental Toxicology and Chemistry 16. p. 534 – 542, 1997.

Hayes, T.B.; A. Collins; M. Lee; M. Mendoza; N. Noriega; A.A. Stuart; and A. Vonk. *Hermaphroditic, Demasculinized Frogs After Exposure to the Herbicide Atrazine at Low Ecologically Relevant Doses.* Proceedings of the National Academy of Sciences of the United States of America. 99(8): p. 5476-5480, 2002.

Hewitt, L.M.; S.A.M. Smyth; M.G. Dube; C.I. Gilman; and D.L. MacLatchy. *Isolation of Compounds from Bleached Kraft Mill Recovery Condensates Associated with Reduced Levels of Testosterone in Mummichog (fundulus heteroclitus).* Environmental Toxicology and Chemistry 21(7): p. 1359, 2002.

Higashitani, T.; H. Tamamoto; A. Takahashi; and H. Tanaka. *Study of Estrogenic Effects on Carp (Cyprinus Carpio) Exposed to Sewage Treatment Plant Effluents.* Water Science and Technology 47(9): p. 93-100, 2003.

Horne, A.J. *Phytoremediation by Constructed Wetlands*. In Phytoremediation of contaminated soil and groundwater. CRC Press. Boca Raton, Florida. p. 13-60, 2000.

Horne, A.J. *Wetland and Rivers: Ecology and Management.* Civil and Environmental Engineering 118, 2003.

Huang, C.-H.; D.L. Sedlak. *Analysis of Estrogenic Hormones in Municipal Wastewater Effluent and Surface Water Using Enzyme-Linked Immunosorbent Assay and Gas Chromatography/Tandem Mass Spectrometry*. Environmental Toxicology and Chemistry 20(1): p. 133-139, 2001.

Huber, M.M.; S. Canonica, G.-Y. Park; and U.V. Gunten. *Oxidation of Pharmaceuticals during*

Ozonation and Advanced Oxidation Processes. Environmental Science and Technology 37(5): p. 1016, 2003.

International Life Sciences Institute. *Framework for Microbial Risk Assessment*, Washington, D.C., ILSI Press, 1996, 2000.

IRIS. Integrated Risk Information System. USEPA, 2004.

Isaac-Renton, J.; W. Moorehead; and A. Ross. *Longitudinal Studies of Giardia Contamination in Two Community Drinking Water Supplies: Cyst Levels, Parasite Viability, and Health Impact.* Applied and Environmental Microbiology 62(1): p. 47, 1996.

Isaacson, M.; Sayed, A. *Health Aspects of the Use of Recycled Water in Windhoek, SWA/Namibia: Diarrhoeal Diseases and the Consumption of Reclaimed Water 1974 – 1983*. South African Medical Journal 73: p. 596 – 599, 1988.

James M. Montgomery; Consulting Engineers, Inc. *Operation, Maintenance and Performance Evaluation of the Potomac Estuary Wastewater Treatment Plant*. Alexandria, VA, 1983.

James M. Montgomery, Consulting Engineers Inc. *Water Treatment Principles and Design*. New York: John Wiley. 1985.

Kawamura, S. Integrated Design and Operation of Water Treatment Facilities, 2nd Edition. John Wiley and Sons, 2000.

Kindzierski, W.B. and S. Gabos. *Health Effects Associated with Wastewater Treatment, Disposal, and Reuse.* Water Environment Research 66(4): p. 651, 1994.

Kolpin, D.W.; E.T. Furlong; M.T. Meyer; E.M. Thurman; S.D. Zaugg; L.B. Barber; and H.T. Buxton. *Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. Streams, 1999-2000: A national reconnaissance*. Environmental Science and Technology 36(6): p. 1202-1211, 2002.

Lauer, W. C.; F. J. Johns; G. W. Wolfe; B. A. Meyers; L. W. Condie; and J. F. Borzelleca. *Comprehensive health effects testing program for Denver's potable water reuse demonstration project.* J. Toxicol. & Environ. Health 30: p.305–321., 1990.

Lauer, W., Rogers. S., Denver’s *Direct Potable Reuse Demonstration Project – Final Report*. Denver Water Department, Denver, Colorado, 1993.

Luna, J. P. and J. E. Drewes. *Re-Assessing the Multi-Barrier Concept for Unregulated Organics in Indirect Potable Reuse.* 2004 WateReuse Annual Symposium, Las Vegas, NV, 2004.

McCuin, R. and J. L. Clancy. *Cryptosporidium in Wastewater: Occurrence, Removal and Inactivation*. Water Environment Research Foundation. 2005.

Molgaard, C.A; A.L. Golbeck; and J.P. Elder. *Final Report: The Epidemiology Component of the San Diego Total Resource Recovery Program, Division of Epidemiology and Biostatistics*. Graduate School of Public Health, San Diego State University. April 28, 1990.

Montgomery Watson. *Membrane Prequalification Pilot Study*. Prepared for City of San Diego, October 1997.

Montgomery Watson. *Water Repurification Project Membrane Prequalification Pilot Project, Draft Final Report*. Prepared for City of San Diego, October 1997.

Montgomery Watson. *Water Purification Project Report.* Prepared for the City of San Diego, March 1996.

Montgomery Watson Harza. *Aqua 2030 Research Center Experimental Plan for Impact of UV on Emerging Contaminants of Concern.* Prepared for the City of San Diego, December 2004.

Montgomery Watson Harza. *Aqua 2030 Research Center Experimental Plan for Long Term Testing of New Generation of Reverse Osmosis Membranes and Determination of Removal Efficiency for Emerging Recycled Water Contaminants.* Prepared for the City of San Diego, November 2004.

Montgomery Watson Harza. *Aqua 2030 Research Center Experimental Plan for Reverse Osmosis Integrity*. Prepared for the City of San Diego, October 2004.

Nagel, R. General Manager. West Basin Municipal Water District. Personal Communication, 2005.

Nagel, R.A.; McGovern, L.; Shields, P.; Oelker, G.; and J. R. Bolton. *Using Ultraviolet (UV) Light to Remove N-Nitrosodimethylamine from Recycled Water*. WateReuse Symposium. San Diego, CA. 2001.

National Academy of Sciences (NAS). *Issues in Potable Reuse, The Viability of Augmenting Drinking Water Supplies with Reclaimed Water*. Washington, D.C., National Academy Press, 1998.

NAS, Woteki. C.E. Thomas and P.R. Thomas, ed. *Eat for Life: The Food and Nutrition Board's Guide to Reducing Your Risk of Chronic Disease.* Committee on Diet and Health Food and Nutrition Board, Institute of Medicine, National Academy of Sciences, National Academy Press, Washington, D.C. 1992.

National Water Research Institute. Report of the Scientific Advisory Panel. Orange County Water District's Santa Ana River Water Quality and Health Study, August 2004.

Nellor, M.; Baird R.; Smyth, J. *Health Effects Final Report*. County Sanitation Districts of Los Angeles County, 1984.

National Research Council (NRC). *Groundwater Recharge Using Waters of Impaired Quality*. Washington, D.C., National Academy Press, 1994.

NRC. *Indicators for Waterborne Pathogens*. Washington, D.C., National Academy Press, 2004.

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

NRC. *Quality Criteria for Water Reuse*. Washington, D.C. National Academy Press, 1982.

Olivieri, A.W.; Eisenberg, D.M.; Cooper, R.C.; Tchobanoglous, G.; and P. Gagliardo. *Recycled water -- a source of potable water: City of San Diego health effects study*. Water Science and Technology 33 (10-11): p. 285–296, IWA Publishing, 1996.

Requa, D. Personal Communication. Dublin San Ramon Services District. November 2004.

Rose, J.; D.E. Huffman; K. Riley; S.R. Farrah; J.O. Lukasik; and C.L. Hamann. *Reduction of Enteric Microorganisms at the Upper Occoquan Sewage Authority Water Reclamation Plant.* Water Environment Research. 73(6): p. 711, 2001.

Rose, J.; Gerba, C. *Assessing Potential Health Risks form Viruses and Parasites in Reclaimed Water in Arizona and Florida*. USA, Water Science and Technology 23: p. 2091 – 2098, 1991.

Rose, J.; L.J. Dickson; S.R. Farrah; and R.P. Carnahan. *Removal of Pathogenic and Indicator Microorganisms by a Full-Scale Water Reclamation Facility*. Water Research. 30(11): p. 2785-2797, 1996.

Ruetten, et al. The Rules of Indirect Potable Reuse: Managing Public Perceptions of Indirect Potable Reuse Project. Water Reuse Foundation (WRF) project WRF 001-4. WateReuse Symposium, San Antonio, TX, 2003.

Sedlak, et. al. *Understanding Microcontaminants in Recycled Water*, Environmental Science and Technology 34: p. 12. December 2000.

Sedlak, D.L.; Gray, J.L.; and K.E. Pinkston. *Effluent-Derived Microcontaminants in Recycled Water*. Environmental Science and Technology (submitted, 2000).

Sedlak, D.L.; Pinkston, K.; and Ching-Hua Huang. *Occurrence Survey of Pharmaceutically Active Compounds*. AwwaRF report, 2005.

Sheikh, B.; Cooper, R.; and Israel, K. *Hygienic Evaluation of Reclaimed Water Used to Irrigate Food Crops: A Case Study*. Water Science and Technology 40: p. 261–268, 1999.

Sheikh, B.; Cooper, R.; *Recycled Water Food Safety*. Report to Monterey County Water Resources Agency and Monterey Regional Water Pollution Control Agency, 1998.

Sheikh, B., et. al., Monterey *Wastewater Reclamation Study for Agriculture*, J. Water Pollution Control Federation. 62: p. 216-226, 1990.

Sloss, et. al. *Groundwater Recharge with Reclaimed Water: Birth Outcomes in Los Angeles County, 1982 – 1993*. Santa Monica, California, RAND Corporation, 1999.

Sloss, et. al. *Groundwater Recharge with Reclaimed Water: an Epidemiological Assessment in Los Angeles County, 1987 – 1991*. Santa Monica, California, RAND Corporation, 1996.

Snyder, S.A.; D.L. Villeneuve; E.M. Snyder; and J.P. Giesy. *Identification and Quantification of Estrogen Receptor Agonists in Wastewater Effluents.* Environmental Science and Technology 35(18): p. 3620-3625, 2001.

Snyder, S. *Endocrine Disruptors as Water Contaminants: Toxicological Implications for Humans and Wildlife*. Southwest Hydrology, Vol. 2, November/December, 2003.

Snyder, S.A.; J. Leising; P. Westerhoff; Y. Yoon; H. Mash; and B. Vanderford. *Biological and Physical Attenuation of Endocrine Disruptors and Pharmaceuticals: Implications for Water Reuse.* Ground Water Monitoring & Remediation. 24(2), 2004.

Snyder, S.A.; P. Westerhoff. *Removal of EDCs and Pharmaceuticals by Pharmaceuticals by Conventional and Advanced Conventional and Advanced Water Treatment. in Water Reuse Foundation's Annual Water Reuse Research Conference: Shaping the Future of Water Reuse Through Research*. Las Vegas, NV, 2004.

Snyder, S. A.; P. Westerhoff; Y. Yoon; and D. L. Sedlak. *Pharmaceuticals, Personal Care Products, and Endocrine Disruptors in Water: Implications for the Water Industry*. Environ. Eng. Sci. 20(5), 2003.

Soroushian, F.; Y. Shen; M. Patel; and M. Wehner. *Evaluation and Pilot-Testing of Advanced Treatment Processes for NDMA Removal and Reformation Prevention*. AWWA 2001 Conference Proceedings. 2001.

State of California. *A Proposed Framework for Regulating the Indirect Potable Reuse of Advanced Treated Reclaimed Water by Surface Water Augmentation in California.* California Potable Reuse Committee. January 1996.

State of California. *California Department of Health Services California Drinking Water: NDMA-Related Activities*. April 2003 <www.dhs.ca.gov/ps/ddwem/chemicals/NDMA>.

State of California. *California Health Laws Related to Recycled Water – "The Purple Book."* June 2001.

State of California. California's Recycled Water Task Force. *Water Recycling 2030*, June 2003.

State of California, Health and Safety Code Section 11635, Calderon-Sher California Safe Drinking Water Act of 1996. 1996.

State of California, State Water Resources Control Board, 2001 Municipal Wastewater Recycling Survey, 2002.

State of California Department of Health Services. *Groundwater Recharge Reuse Regulations (DRAFT)*. (22 *CCR*, Division 4 – Environmental Health, Chapter 3 – Recycling Criteria) http://www.dhs.ca.gov/ps/ddwem/publications/waterrecycling/rechargeregulationsdraft-12-01-04.pdf). December 1, 2004.

State of California Department of Health Services. *Guidelines for the Preparation of an Engineering Report for the Production, Distribution, and Use of Recycled Water,* March 2001.

State of California Department of Health Services. Public Hear Findings of Fact regarding the proposed West Basin Water Recycling Plant (WBWRP). West Coast Basin Barrier Project Expansion Phase III, December 10, 2002.

State of California Department of Health Services. *Treatment Technology Report for Recycled Water*, September 2004.

State of California Office of Environmental Health Hazard Assessment. *A Guide to Risk Assessment*.

Tanaka, et. al. *Estimating the Safety of Wastewater Reclamation and Reuse Using Enteric Virus Monitoring Data*. Water Environmental Research. 70: p. 39-51, 1998.

Tchobanoglous, G.; et. al.. *Wastewater Engineering: Treatment and Reuse.* 4th Ed. McGraw-Hill 2002.

Ternes T.; M Meisenheimer; D. McDowell; F. Acher; H.J. Brauch; B. Haist-Gulde; G. Preuss; U. Wilme and N. Zulei-Seibert. *Removal of Pharmaceuticals during Drinking Water Treatment*. Environ. Sci. Technol. 36: p. 3855-3863, 2002.

Ternes, T.A.; P. Kreckel; and J. Mueller. *Behavior and Occurrence of Estrogens in Municipal Sewage Treatment Plants-ii. Aerobic Batch Experiments with Activated Sludge.* The Science of the Total Environment. 225: p. 91-99, 1999.

Ternes, T.A.; M. Stumpf; J. Mueller; K. Haberer; R.-D. Wilken; and M. Servos. *Behavior and Occurrence of Estrogens in Municipal Sewage Treatment Plants-I. Investigations in Germany, Canada and Brazil*. The Science of the Total Environment 225: p. 81-90, 1999.

Trussell, R.; Adham, S.; Gagliardo, P.; and Tennison, P. *Potable Reuse – An Overview of the San Diego Project,* 2002. Proceedings of the International Conference on Wastewater Management & Technologies for Highly Urbanized Coastal Cities, Hong Kong Polytechnical University, Hung, Hom, Kowloon, Hong Kong. 10-12 June 2002.

US EPA. *Guidelines for Water Reuse* (EPA/625/R-04/108). September 2004.

US EPA. *Model Pretreatment Ordinance.* Office of Wastewater Enforcement and Compliance, June 1992.

US EPA. Office of Research and Development. *Removal of Endocrine Disruptor Chemicals Using Drinking Water Treatment Processes*. EPA/625/R-00/015, 2001.
Velz, C. Applied Stream Sanitation. New York: John Wiley, 1970.

Western Consortium for Public Health. *City of San Diego Total Resource Recovery Project Health Effects Study*. September 1992.

Western Consortium for Public Health. *City of San Diego Total Resource Recovery Project Health Effects Study*. 1997.

Witters, H.E.; C. Vangenechten; and P. Berkmans. *Detection of Estrogenic Activity in Flemish Surface Waters using an In Vitro Recombinant Assay with Yeast Cells.* Water Science and Technology 43(2): p. 117-123, 2001.

World Health Organization. *Global Assessment of the State-of-the-Science of Endocrine Disruptors.* 2002.

York, D.; et. al. *Monitoring for Protozoan Pathogens in Reclaimed Water: Florida's Requirements and Experience*. <www.dep.state.fl.us/water/reuse/techdocs, 2003>.