Development of Indirect Potable Reuse in Impacted Areas of the United States

By Harm Jansen

Acknowledgements

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Disclaimer

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1.0 Executive summary

1.1 Key Words

California, Indirect Potable Reuse, Institutional Barriers, Membranes, Water Policy, Water Reclamation

1.2 Problem statement

What is the future for water reclamation related to Indirect Potable Reuse [IPR] in impacted areas in the United States and which technologies will prevail?

1.3 Abstract

Water resources are in short supply in many areas of the United States. Water supply is impacted by the increasing risk of periodic droughts and on-going development. In response to both concerns, additional water supplies are being developed. Water reclamation is viewed as a new source of water and is being rapidly developed in many areas, particularly in Southern California, Arizona, and Florida. Despite the need for additional water and the promise of water reclamation, there are technical and institutional barriers that challenge its implementation and development.

In order to quantify the amount of reclamation and the problems associated with its development, a survey of both successful and failed projects in California, Arizona and Florida was performed. These three states were selected because of the need for reclamation due to arid conditions and rapid development, as well as previously attempted successful and unsuccessful projects. Affiliation with Indirect Potable Reuse [IPR] was the main criterion for selecting projects. IPR is a method of reusing treated waters and wastewaters for potable use through at least one environmental barrier that serves to isolate, as well as protect consumers. Examples of barriers include a groundwater basin or reservoir providing more than one-year retention time. Projects involving IPR are much harder to implement because of the public's concern and there are many noteworthy examples.

A survey was conducted by collecting historical data on each plant as well as visiting the plant. Current records were obtained including assessments of their evolving water treatment technologies. Twenty-six

projects were reviewed and nineteen of the projects were visited. The relevant laws and regulations that governed the project were also reviewed. The various projects were categorized by size, technology, goals, successes and failures. The results are presented in tabular form and patterns of successes and failures are identified. Relative costs are presented.

Technological barriers were not a limiting factor. Institutional barriers and challenges, such as public perception, local politics, risk communication, and impacts of confusing or partially developed regulations were most often limiting. The most successful projects involved the public and other stakeholders before the conception of the project. Lower water reuse objectives [Non-Potable Reuse [NPR]] were more easily implemented than higher use projects [IPR]. There were no examples of successfully implemented Direct Potable Reuse [DPR] found in the United States. In some cases, projects that began with IPR goals were converted to or augmented with lower use goals by displacing potable water with reclaimed water.

A review of the technologies of successful projects reveals a declining use of traditional water treatment technologies, such as granular media filtration, carbon adsorption, lime clarification, ammonia stripping and chlorination with membrane-based technologies, such as [submerged] Micro Filtration [MF], Nano Filtration [NF], Reverse Osmosis [RO], disinfection with Ultra Violet [UV] light, and advanced oxidation with hydrogen peroxide.

1.4 Approach

This thesis begins with an introduction to IPR in Chapter 2.0, which gives an impression of the history, types and the presence of IPR, particularly in California. After the introduction, three categories are considered to determine the institutional hurdles IPR faces. The first is water rights, which are covered in Chapter 3.0. The second category covers legislative and executive hurdles of which the areas of international and national will be covered in Chapter 4.2 and 4.3. California and other state legislative and executive hurdles follow in Chapter 4.4. A final challenge and third category of institutional hurdles is the acceptance of the general public and detailed attention is paid to this subject in the Chapter 5.0.

After this broad institutional approach, the remainder of this thesis presents a more detailed approach to quantify the development of IPR in the US by covering newly emerging constituents, up to date technology, and relevant facilities. Constituents of concern are discussed in Chapter 6.0. Current available technologies for IPR are covered in Chapter 7.0 for an up-to-date status, while the relevant facilities are examined in Chapter 8.0. Chapter 9.0 covers a variety of facilities that have not been visited, but have been reviewed to complete the survey. Analyses of all findings are presented in Chapter 10.0 with its conclusion in Chapter 11. Relevant addendums can be found in chapter 13.0.

2.0 Indirect Potable Reuse: an overview

2.1 Introduction

The hydrological cycle, the continuous transfer of water from ocean to air and land then back to the ocean, designates nature as the ultimate water recycler. The simple underlying principle is that all water is recycled and that true fresh water does not exist. For many years, people have augmented the hydrological cycle with treated wastewater. This treated wastewater augments water streams and is treated further by nature. When people need potable water, it is withdrawn from those same streams and treated for potable purposes. There are numerous examples of Wastewater Treatment Plants [WWTP] discharging into waters that are used as drinking water sources. More than 25 major Water Treatment Plants [WTP] in the US use water from rivers that receive wastewater discharges that amount up to 50 percent of the stream flow during low flow conditions[1]. These are examples of unplanned Indirect Potable Reuse [IPR] [Figure 1].

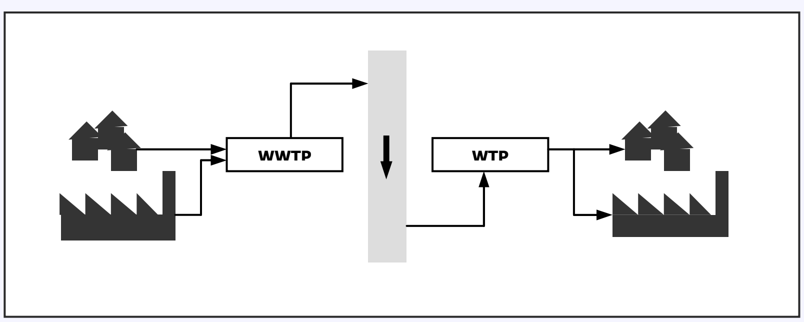

Figure 1: Unplanned IPR

On the other hand, planned IPR is the purposeful augmentation of a water supply source with tertiary or advanced treated wastewater [Figure 2] from a Water Reclamation Plant [WRP]. While drinking water obtained from the best available source should be the guiding principle for water supply development, in some cases the only feasible source of complementary water is reclaimed water. A growing number of communities have implemented or are planning IPR projects. After it has been purposely augmented and before it can be retrieved for drinking water treatment, the water has undergone a certain residence time. During this time many viruses and bacteria decay.

[1] Issues in Potable Reuse: The Viability of Augmenting Drinking Water Supplies with Reclaimed Water, 1998, page 2.

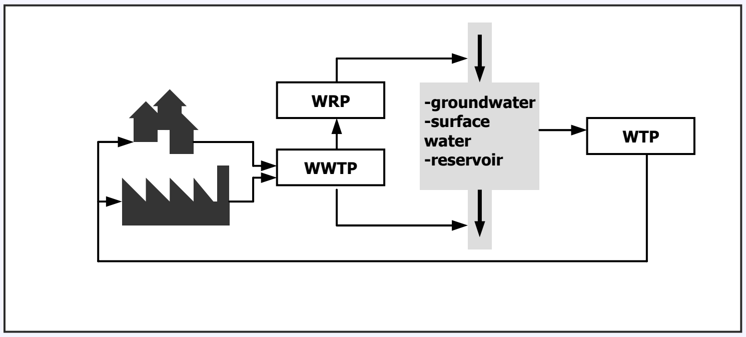

Figure 2: Planned IPR

Planned IPR is widely implemented in today's hydrological world. Current potable reuse projects and studies have demonstrated the capability to consistently produce recycled water of a high quantifiable quality. In addition, there have been no clear adverse health effects in areas where recycled water has been used for potable purposes. Public health concern focuses on water quality, treatment reliability, and the difficulty of identifying and estimating human exposures to pathogenic microorganisms and potentially toxic chemicals that may be present in the inherently suspicious water source. While most health related data generated to date prove such water is safe, definitive data is absent.

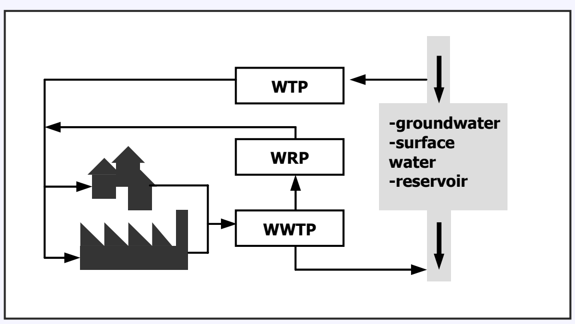

Figure 3: direct potable reuse

Direct Potable Reuse [DPR] is the direct reintroduction of highly treated effluent into the potable water distribution system [Figure 3]. Currently, this is only practiced in Windhoek, Namibia [9.2.2] and is at this time not a feasible option in the United States in the near future. The Denver Potable Water Reuse Project [9.1.3] has conducted extensive research on DPR. Health studies in both Windhoek and Denver have shown no adverse health effects.

Presently, the supply of fresh water cannot keep up with the increased usage by people for recreation, industry and agriculture. The problem is intensified by a decrease in supply, a steady increasing risk for drought, more stringent environmental legislation, and rapidly expanding developments. Population increase is the main cause to the shortage of drinking water and is predicted to be limited in the near future by the lack of potable water supply. Reclaiming water is only answer to this problem. A focus towards water reclamation [and IPR] therefore characterizes today's wastewater treatment [Table 1].

Table 1: Overview of change in focus of the treatment of wastewater [after Ødegaard, 2000]

	Focus	Period
1850-1950	Hygiene	Sanitary engineering
1950-2000	Environment	Environmental engineering
2000-present	Reuse	Water environment management

2.2 Types of IPR

IPR is achieved by augmenting three types of drinking water sources with highly treated wastewater: surface waters, reservoirs, or groundwater. Surface water augmentation is the most common form of unplanned IPR, while augmenting reservoirs and groundwater are the most common form of planned IPR. A combination is possible when the augmented surface water also recharges to groundwater that serves as a drinking water supply. The discharged effluent in the drinking water source is to lose its identity through a degree of mixing and retention time. Mixing ratios and retention times found in literature vary significantly and range from 5 to 50% and 3 months to 2 years.

IPR through groundwater augmentation can be achieved in three ways: surface spreading, direct injection or vadose zone injection [Figure 3]. Direct injection is practiced when water is placed directly into a confined aquifer. Surface spreading, as opposed to direct injection, requires the existence of an unsaturated aquifer. Surface spreading is an indirect method of recharge whereby the water moves from the land surface to the groundwater by infiltration and percolation through the soil matrix. The third possible form of groundwater recharge is the vadose zone injection. Vadose zone injection for IPR purposes is not favorable because the wells cannot be backwashed and a severely clogged well can be permanently destroyed. However, a lifecycle of 5 years for a vadose injection well can still make this an economical choice. More detailed information about the characteristics of ground water recharge is found in Table 2.

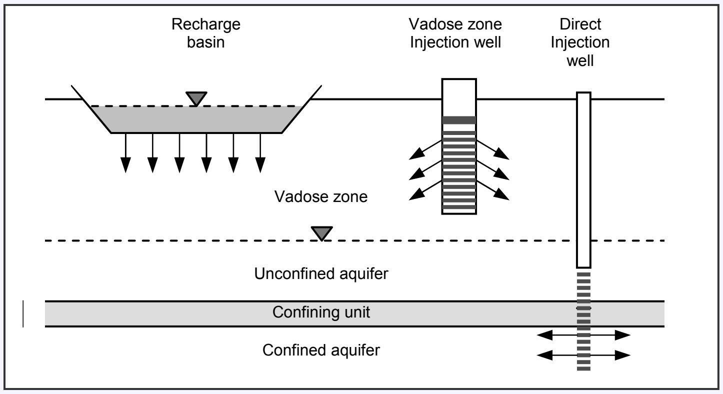

Figure 3: Types of groundwater recharge.

Table 2: Characteristics of the types of groundwater recharge for IPR

	recharge basins	vadose zone injection wells	direct injection wells
aquifer type	Unconfined	unconfined	unconfined or confined
pretreatment requirements	tertiary treatment	tertiary treatment	advanced treatment
estimated capital cost [$]	land and distribution system	25,000-75,000 per well	500,000-1,500,000 per well
capacity [m3/hectare-day]	100-20,000	1000-3000	2000-6000
maintenance requirements	drying and scraping	drying and disinfection	disinfection-flow reversal
estimated life cycle [years]	>100	5-20	35-50
soil aquifer treatment	vadose and saturated zone	vadose and saturated zone	saturated zone

2.3 IPR in California

Maintaining a reliable water supply is one of the most important issues facing a record fast growing California. In average water years, California receives about 240 km^3 of water from precipitation and imports from Colorado, Oregon and Mexico[2] of which 40 to 50% is dedicated supply[3]. Southern California relies on diverting water from the California Aqueduct [State Water Project], the Los Angeles aqueduct, and the

[2] Coachella and All American Canals, 2004
[3] including reuse

Colorado River Aqueduct in addition to its limited local natural supply. Diverting water lacks reliability due to droughts and is becoming less acceptable because of growing awareness of the environmental impacts of these practices.

Population growth in Southern California is expected to rise from 18.2 million in 2000 to 26.9 million in 2030[4]. The supply from the Colorado River Aqueduct has been reduced because Arizona and Nevada have recently demanded their portion[5]. The Los Angeles Aqueduct had to return a fraction of its flow to account for Mono Lake's revival. The supply from the California Aqueduct has been reduced to account for reallocation of the State Water Project to the Northern California Delta. These reductions have significantly decreased Southern California's overall water supply. The California Department of Water Recourse [DWR] has predicted chronic water shortages by the year 2020 and driven by an increasing population, the need for water is expected to grow. DWR predicts that "by the year 2020, Californians will be short 8.6 km^3 of water per year during a period of drought and 3.6 km^3 in an average year." Southern California is, therefore, forced to be trendsetter in the reuse of water.

The Colorado River is currently in its 6th consecutive year of drought [1999-2005], which translates to 11 km^3 water. Historical stream flow records make this the worst drought in the last 80 years[6], which is amplified by the current population growth. According to tree-ring data, the worst drought on record dates back to the late 1500's and lasted 20 years, placing the current drought as the 7th worst ever in a 500 year proxy. The current drought in the Snow Water Content in the Upper Colorado River Basin is already at 75 to 115% of its yearly average, but may not result run-off for reservoirs to hold if followed by dry warm periods.

Recognizing the water's importance to the state's economy and quality of life, California is focusing on developing a mix of complementary water resources. The majority of municipal wastewater produced statewide is still being disposed into the Pacific Ocean. This untapped resource represents one of the largest potential complementary water resources for new water in California. California's recycled water use in 2004 was 0.6 km^3, half of the State's goal of 1.2 km^3 per year by 2010. Today, many communities are planning new or expanded water reclamation programs.

2.4 Exhausted alternatives to IPR

The highest quality water should be reserved for drinking water purposes. It is therefore unlikely that IPR will gain popularity unless water of lesser-suspected sources have been fully investigated and ruled out as viable options. Other options such as displacing potable water through dual distribution systems, conservation through aggressive volume based rates and education should be considered as well. Displacing water from agricultural uses, which accounts for 85% of the water use in California, takes planning and a long time to achieve because agricultural land needs to be purchased and taken out of service, which many corporations and farmers loath to do. It is, therefore, not considered to be an alternative in this thesis.

[4] California Demographic Futures, 2005 summary report
[5] Also see: 3.2.1
[6] Cisco, Green and PHDI

Implementing dual distribution systems in existing infrastructure has proven to be economically unfeasible. Non-potable urban demands are as widely dispersed physically as potable demands are and, therefore, require a near duplicate of the current existing distribution system. Treating water to the required standards for non-potable uses further elevates the cost for the dual distribution option. Urban demand for non-potable use also fluctuates daily and seasonally. In order to permit usage of these costly and large storage systems, water needs to be drinking water quality. It is, therefore, more cost effective to treat reclaimed water to drinking water standards and use the existing distribution system to supply the demand of urban non-potable use and thus, to practice IPR.

Non potable use through a separate distribution system is generally economically feasible for large users, such as golf courses, industry, and parks that are located in a certain vicinity of the water reclamation facility, which justifies the relatively inexpensive, separate distribution system. Most of the facilities inventoried in this project have a clientele consisting of such large users. Advanced planning of dual distribution systems in future urban development is economically feasible and is implemented in the Chino Valley area in California [see 8.2.4].

Conservation should be an important part of our daily lives and it is difficult to argue against. Californians and Americans in general, are large volume consumers. The urban areas of Southern California have the highest average usage, with 430 liter per capita per day [lpcpd], whereas the entire United States average is 280 lpcpd and an average usage for Western Europe is 120 lpcpd. Water and its availability impact economic development and both the US's decentralized governing system and highly competitive society makes quantitative water use difficult to regulate. Markets for water are not well developed in California and the remainder of the United States. Although, an increase in price reflecting true cost would motivate users to conserve if such water pricing policy were allowed to operate. Wastewater and drinking water treatment facilities are reaching out to the public through the Internet, tours, and brochures, yet the knowledge of conservation is still lacking among the public. An aggressive leak detection and repair program should be in its place since 14%[7] of all water is wasted through leaks. Similarly, over-watering of residential lawns, gardens using sprinklers and evaporation losses can be avoided by converting to drip irrigation systems.

2.5 Desalination: a viable alternative to IPR

Desalination has been extensively researched over the past few years and is more often considered a viable option for urban areas within the vicinity of the Ocean [53% of the US population lives within 150 km of the coast]. Desalination has become more affordable with the prices of imported water rising and the operating costs of desalination declining with higher flux membranes. Operating and managing costs are competitive when compared to IPR where secondary wastewater effluent must be treated to drinking water standards and serve a certain retention time after augmentation before being retrieved and treated by a drinking water facility. This will be even more of a viable option when the desalination plant is coupled with an existing coastal power plant, which can provide cheap electricity and the infrastructure for intake and discharge of ocean water.

[7] American Water Works Association 1999

Problems that have been encountered at both pilot plant and full size operating plant scale are the high residual concentration of Boron after treatment. High chloride and total dissolved solids concentrations form an issue at intake. Other problems are algae and other aquatic microorganisms [8.5.1]. All of these factors abuse the treatment units to a much greater extent than advanced wastewater treatment. Desalination will not be further discussed, as it is considered a different topic in the framework of this thesis.

3.0 Water rights

3.1 Introduction

Water rights have played a major role throughout the entire history of the United States, especially in the arid regions of the Southwestern part. They are considered a separate entity from water quality laws and regulations, which cover quality parameters of water. Water rights consider water solely as a commodity.

A first form of water rights originated in North America with the native inhabitants who lived in California along the lower Colorado River and in Owens Valley. Living in symbiosis with nature, they would take dams down after they had served their purpose, essentially giving nature the ultimate right over water. This changed during the Spanish and Mexican eras. Their desire to unite nature and humans resulted in force-laboring natives in constructing a life sustaining hydraulic system for community purposes. This is when the Pueblo Water Rights[8] were introduced--a paramount law associated with these early missions and still present in several states today.

After the United States conquest, the attitude towards water became one of acquisition such from others and to subsequently prosper at their expense. The doctrine of seniority, "First in time, first in right," which originated during the gold rush and was applied to gold found on federal land, was also applied to water. The traditional Hispanic community rights changed to individual rights with limited federal governmental influence. These evolving complexities of the federal system have been present in every water project since, setting the State of California apart from the remainder of the United States.

3.2 Water rights and its basics

Water rights are property rights. The holders of these rights do not own the water itself; they possess the right to use it. They can be split up in riparian and appropriator rights. A water right of a riparian [primarily found in the Eastern States] is superior to the water rights of an appropriator [the "First in time, first in right" principle] except in cases where the water has been appropriated before the riparian acquired the exclusive rights to the property and after the passage of the Mining Act of 1866, which recognized appropriation. A sensible use by a riparian will often take precedence over an appropriative right as long as the riparian parcel has been acquired prior to the date of appropriation. Water availability and needs differ significantly throughout the State of California, which result in a unique compilation of both appropriative

[8] Spanish medieval form of water right for municipal purposes

and riparian rights.[9]. As far as groundwater is concerned, California classifies three legal categories: underflow of a surface stream, underground streams, and percolating waters. Surface water rights are applied to the first two categories, whereas distinctive groundwater laws apply to percolating waters, which include water in underground basins and water escaped from streams. Water right cases have historically played an important role in California and examples are given in 3.2.1.

When examining wastewater rights, one comes to the conclusion that the producer does not necessarily have the right to the use of its own effluent, although some states provide the owner of the wastewater treatment plant with the ultimate right to anyone who supplied the influent. During IPR, the effluent is either directly or indirectly discharged to surface and/or groundwater from which point on it requires the consideration of water rights. Wastewater that was discharged to surface water prior to 1980 in California did not need approval to be diverted, although case law would generally permit a wastewater producer to reduce its flow before it would leave its premises. Today's legislation requires the SWRCB to give approval for the reuse of wastewater by a wastewater producer to protect the appropriative rights of downstream users. Several examples of reclaimed water cases are mentioned in 3.2.2.

3.2.1 Water rights cases

- The California Bay-Delta Act of 2003 reduced supply from the California aqueduct to Southern California by 15% to protect the San Francisco Bay-Delta ecosystem.

- The Los Angeles Department of Water and Power was required to stop diverting one-fifth of the water it historically exported from the Mono Basin water in order to restore Mono Lake. Mono Lake's water quality and natural resources were declining progressively from a lack of stream flow.

Figure 4: Mono Lake

[9] State water resources control board: the water right process

- The ever-increasing water needs of the City of Los Angeles have caused severe aquifer depletion in Owens Valley [a 63 mile trough west of the Sierra Nevada Mountains], which have contributed to an increasing arid environment. This resulted in alkaline dust storms, which threatened the health of its native inhabitants. In 1997, after a 27 year dragging battle, the California Third District Court of appeals ordered Los Angeles to restore the pumping-decimated lower Owens River to what it had been before Los Angeles began diverting water in 1913.

- In the Colorado River Compact[10], water has been divided between the upper basin [Colorado, New Mexico, Utah, and Wyoming] and the lower basin [California, Nevada, and Arizona]. The water from the Colorado River has been appropriated in the Arizona vs. California case. The United States Supreme court ruled a monumental decision in favor of Arizona in 1963 in the amount of 3.5 km^3.

- In an international treaty, the Mexican Water Treaty [1943], The United States has agreed to annually deliver 1.8 km^3 of the Colorado River to Mexico.

3.2.2 Reclaimed water rights cases

- In 1968, the City of Roswell, New Mexico, acquired the Walker Air Force Base along with the right to use 0.11 m^3/s of groundwater designated to the property and the air force base's wastewater treatment plant, which effluent was used for nearby irrigation. The city later abandoned the treatment plant and diverted its influent to the city's wastewater treatment plant. Due to its loss in return flow, the city then proposed to increase the number of wells in order to maintain their 0.11 m^3/s. The state engineer granted the proposal under the condition that the present use of reclaimed water continue. It was ruled in the Supreme Court that the state engineer might only infringe such contingencies if the allocation of reclaimed water would impair the rights of others.

- Several cities in the Arizona Public Service vs. Long were contracted to sell a total of 5.3 m^3/s of cooling water for the Palos Verdes Nuclear power Plant. Downstream appropriators brought a suit to the city arguing that the contract was in conflict with the Arizona Groundwater Code. The city countered by stating that the reclaimed water was not subject to regulation because it had lost its original character and because it was property of the treatment provider. In 1998, the supreme state court of Arizona validated the contract ruling that the reclaimed water was neither surface nor groundwater and amended its related laws to exclude them from regulating reclaimed water.

- Deer Creek Decision in 1994, by the California Regional Board held, downstream user rights secondary to the discharger's reclaimed water effluent. Irrigation and domestic use relied on the continuous flow created

[10] Compact: a contractual agreement between two or more states

by the Deer Creek Wastewater Treatment plant, which had contracted a development to buy 110 m^3/s. However, fish and wild life had gained legal status as users.

3.2.3 Water rights and Indian tribes

Indian tribes are an exclusive entity within the United States and also within the world of water management. They have unique water rights, which are often misunderstood, but at the same time are able to significantly influence future water rights. Indian tribes are responsible for developing sound, scientifically defensible standards, as well as criteria, advisories, and guidelines under the federal laws [Clean Water Act [4.3.1.1] and the Safe Drinking Water Act [4.3.1.4]]. The court decision of 1908 in Winters v. United States, states that there is an existence of water rights for Indians, but its meaning, which has been clouded by many debates over half a century, eventually resulted in a crisis of national importance. The Winters decision, the so called “Reserved” rights, constitutes rights significantly different from all other water rights. Unlike riparian rights, diverting a stream onto non-riparian land can revoke the reserved rights. Unlike the doctrine of proprietary rights, the existence of reserved rights depend on whether the Indians are using the water and remains unimpaired should the Indians cease their uses. Until recently, there had been no decisive, evident, or clarifying view concerning the quantum, legitimate uses and priority of the Indian water rights.

4.0 Legislative and executive hurdles

4.1 Introduction

Within this thesis, the legislative and executive barriers are considered the second category of hurdles for IPR. These barriers are encountered during the production, distribution, use, and discharge of reclaimed water. The complete hierarchy of laws and regulations and their execution in relation to wastewater and its reuse components will be further explored in this chapter. Understanding the complex and often inefficient methodology in regulating is necessary to show the current status of IPR in the United States and its possible path in the future. Figure 5 shows the relationship between the legislative and executive branch on a state, national and international level. They will be covered in more detail in the following sections of this chapter.

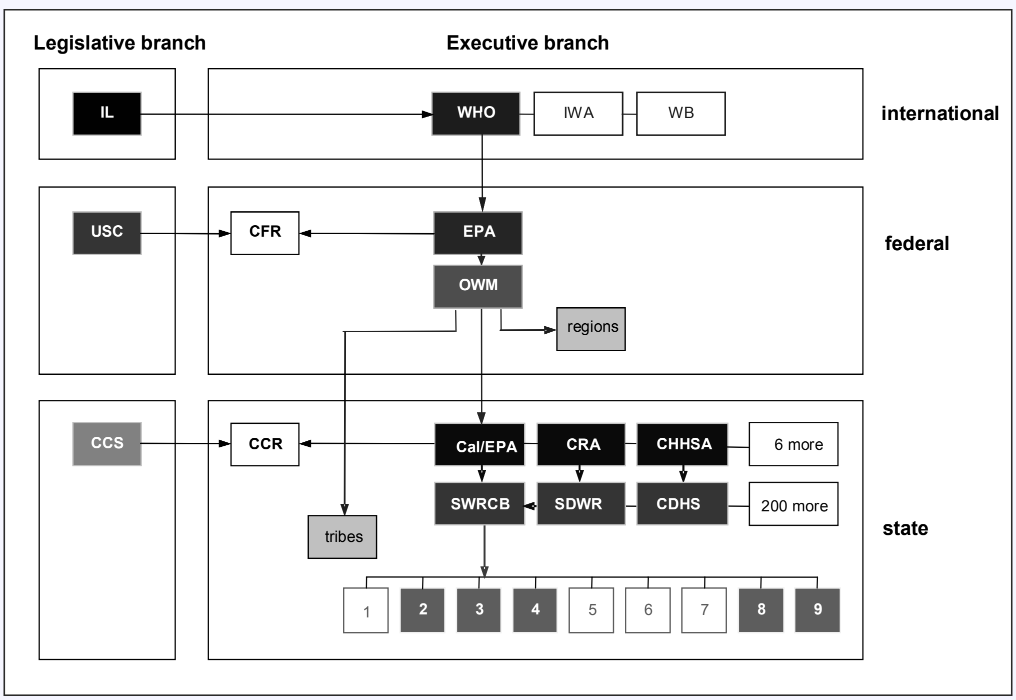

Figure 5: Inter-relations between branches on international, federal, and [California] state level.

Table 3: Abbreviations for Figure 5

IL	International Law
WHO	World Health Organization
IWA	International Water Association
WB	World Bank
USC	United States Codes
CFR	Codes of Federal Regulations
EPA	Environmental Protection Agency
OWM	Office of Wastewater Management
CCS	California Codes and Statutes
CCR	California Codes of Regulations
Cal/EPA	California Environmental Protection Agency
CRA	California Recourses Agency
CHHSA	California Human Health Services Agency
SWRCB	State Water Regional Control Board
SDWR	State Department of Water Resources
CDHS	California Department of Health Services
1-9 [RWQCBs]	Regional Water Quality Control Board

4.2 Institutions involved on an international level

Wastewater regulations on an international level are mainly implemented in development areas where the health burden is high, where interventions could make a major difference and where the present state of knowledge is poor. Every country has to comply with standards set by these international organizations. Standards in the United States are much stricter and in some cases even too strict, according to the World Health Organization [WHO], resulting in setting an unrealistic example for countries struggling to meet WHO standards. A brief summation of international organizations [Figure 6] involved in either establishing regulations or supporting IPR project are described in the following paragraphs:

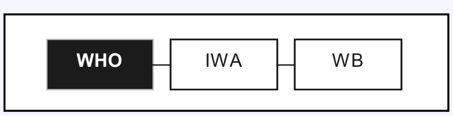

Figure 6: International organizations involved in wastewater

- World Health Organization

The World Health Organization [WHO] is a specialized agency within the United Nations. The WHO works on various aspects of water, sanitation, and hygiene. IPR in the form of artificial recharge is recognized by the WHO as an attractive option. According to the WHO, recharge should neither degrade the quality of the groundwater, nor impose any additional treatment after pumping. The WHO's aquifer recharge regulations do not rely on the natural cleansing capability of the aquifer to remove contaminants to meet the water quality required within the aquifer. However, the capacity of the aquifer to remove contaminants is considered an additional barrier in protecting the abstracted water quality. As stated by the WHO, the recharge water reaching the saturated zone of the aquifer should have previously acquired the quality acceptable for drinking water.

According to the WHO, if the recharge is direct, then the injected water should be potable and should, as a minimum requirement, either meet the standards enforced in the country or contained in the WHO Guidelines for Drinking-water Quality[11]. In addition, the WHO advises that the injected water should be treated to prevent clogging around the injection wells, long-term health risks linked to mineral and trace organic compounds, and the degradation of the aquifer.

- International Water Association

The International Water Association [IWA] is a founding member of the World Water Council and is involved in the Global Water Partnership, as well as the Collaborative Council on Water Supply and Sanitation. The IWA was founded in 1999 with the merger of the International Association of Water Quality [IAWQ] and the International Water Supply Association [ISWA]. The IWA supports water professionals' discoveries of sustainable solutions to challenging global water needs. The IWA connects water professionals around the globe, integrating the leading edge of expert thoughts and ideas on research and practice and regulators and the regulated, across national boundaries and across the drinking water, wastewater, and storm water disciplines.

- World Bank group

The World Bank [WB] group collaborates with The World Bank and The World Health Organization in dealing with water sanitation on projects of common interest. The WB's division of water supply and sanitation focuses mainly on development areas. The World Bank has invested in projects that contain a water reuse component and supports socially and environmentally acceptable and economically efficient water reuse related projects.

4.3 Federal executive and legislative hurdles

The government of the United States consists of a legislative, an executive, and a judicial branch. Promulgating and execution of laws and regulations result from an interaction among these three branches. Each of the fifty states has a level of local autonomy, but the regulation of wastewater is exclusively a state prerogative. The rationale behind the passive federal approach is that the states themselves are in a better position to assess their water reclamation needs and interests. The federal cabinet departments may be

[11] WHO, 1996

involved in regulating reclaimed water, yet often only in the form of guidelines. The federal legislative branch is involved in drinking water and wastewater related legislative cases, which involve more than one state. The possible effect of judicial branch on water and reclaimed water has been indirectly discussed in chapter 3.0. Relations between reclaimed water and the legislative and executive branch will be laid out in further details in the next two sections.

The cabinet's federal executive departments and administrative agencies regarding wastewater [Figure 7] write regulations to implement the authority of laws which are published in the Codes of Federal Regulations [CFR]. The Environmental Protection Agency [EPA] is the latest addition to the Federal executive branch, which regulates water related issues, as well as for land and air.

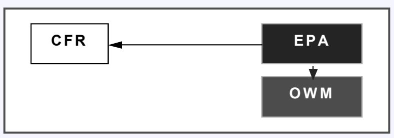

Figure 7: Federal executive departments concerning wastewater

- Environmental Protection Agency

The EPA was established in 1970 in response to a growing demand by the public for a cleaner environment. The EPA's mission is to protect human health and the natural environment. Prior to the establishment of the EPA, the federal government was not structured to make a coordinated attack on the contaminants that threatened human health and the environment.

The EPA works to develop and enforce regulations that implement environmental laws enacted by Congress. The EPA is responsible for researching and setting national standards for water management and delegates the responsibility for issuing permits for wastewater discharges [and thus, indirectly for IPR] and for monitoring and enforcing compliance to states and tribes. Where national standards are not met, the EPA can issue sanctions and take other measurements to assist states in attaining the preferred levels of water quality. The Office of Wastewater Management [OWM] is a branch of the EPA that handles recycled water. The OWM oversees a range of programs contributing to the quality of the waters and watersheds. OWM is in compliance for 30 years with requirements set by the Federal Clean Water Act [4.3.1.1].

4.3.1 Reclaimed water and the federal legislative branch

The federal legislative branch consists of the Congress [House of Representatives and Senate], which enacts all federal laws. The United States Code [USC] is the official compilation of Federal laws and the Code of Federal Regulations [CFR] is the official compilation of regulations, which expand on the laws written by the Congress. The final rules and regulations are published in the Federal Register after review by the U.S President's Office of Management and Budget. The Code of Federal Regulations [CFR] is divided into 50 titles, which represent broad areas subject to Federal regulation. The EPA covers Title 40. Figure 8 shows the relations between the legislative and executive branch and its laws and regulations that concern wastewater and drinking water.

Laws amended at a federal level that mainly control IPR are the Safe Drinking Water Act [SDWA] and the Federal Water Pollution Control Act, which is often referred to as the Clean Water Act [CWA]. The CWA addresses the contamination of the nation's surface waters and regulates discharges through permits issued pursuant to the National Pollution Discharge Elimination System [NPDES] and by limiting the total mass of a specific discharged contaminant through the total maximum daily loads [TMDL] limits. The National Primary Drinking Water Regulations [NPDWR] of the SDWA often functions as a starting point to define potable water quality objectives, although it was not intended to define these when the source is municipal wastewater. Programs under both acts have historically followed independent paths while using different indicators for contamination and different approaches. Concerns about the potential increases in microbial contamination and the potential for the emergence of new pollutants, such as trace organics, has necessitated the consideration for a future strategy in which both acts are united. Another, yet subordinate federal regulation involved in the use of water and wastewater, is the National Toxics Rule [NTR]. The NTR establishes numeric priority toxic water quality regulations in order to bring states in compliance with the CWA. A final federal regulation, which is important to mention is The National Environmental Policy Act [NEPA], which requires federal agencies to consider the environmental impacts of any newly proposed IPR project. The above-mentioned laws and others are further discussed in this chapter.

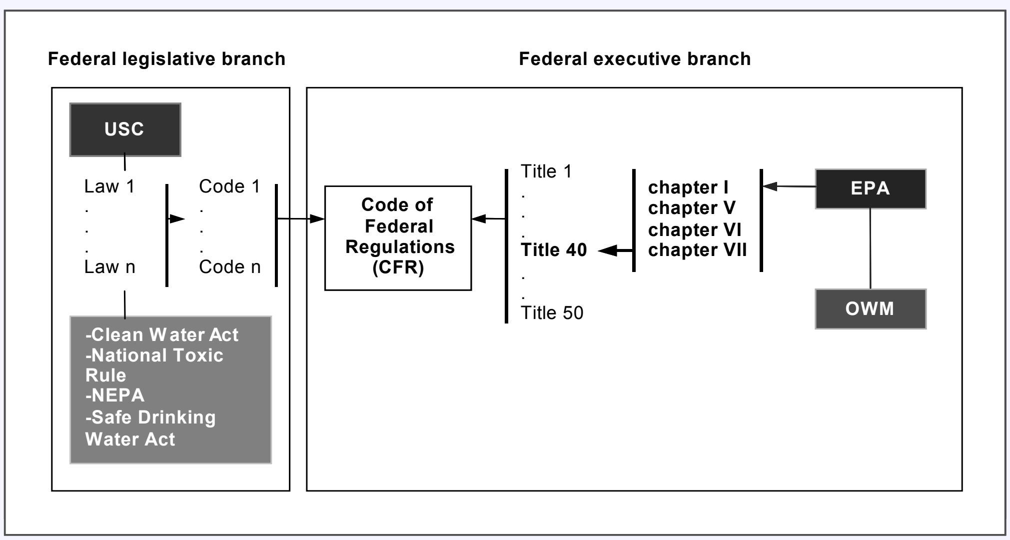

Figure 8: Relationships between Federal law, regulations and departments.

4.3.1.1 Water quality and IPR: the Clean Water Act[12]

The Clean Water Act [CWA], also known as the Federal Water Pollution Control Act, is a Federal legislation enabling the protection of surface waters used as a drinking water resource. In addition, it indirectly controls the augmentation involved with IPR by controlling any discharge therein. The CWA ensures that the quality of the receiving waters is protected. The law employs regulatory and non-regulatory standards. The act does not deal directly with ground water.

For many years following the passage of CWA in 1972, executive departments, such as the EPA focused mainly on the chemical aspects of the CWA. During the last few decades, more attention has been given to physical and biological integrity. In addition, focus has broadened over time from traditional point source facilities [municipal sewage plants, industrial facilities] to runoff from streets, construction sites, and other non-point wet weather sources. The CWA program has also included a shift towards an integrated approach versus a channeled one. The Clean Water Act approaches the water quality based aspect through three primary thrusts:

- Pollutant tolerance: the Total Maximum Daily Loads[13]

  CWA requires a Total Maximum Daily Load [TMDL] for surface water, which is impaired for its water quality. A point source, such as a wastewater facility, which discharges into a river or water stream, is given a Water Load Allocation. Different regulations apply to discharges to groundwater. A TMDL is a conservative and quantitative analysis of the total amount of pollutants a water stream can handle. The discharge of wastewater into a drinking water source for the purpose of IPR is thus regulated by the CWA through TMDLs. The number of TMDLs approved or established nationally has steadily increased from 500 in 1999 to nearly 3000 in 2002. In 2003, the EPA temporarily halted the rule's implementation. States, industry, and local governments questioned the complexity, cost, and legal authority of many of the new July 2000 provisions. Environmentalists addressed the lack of attention to water quality impairment by non-point sources such as wet weather discharges. The rule was challenged in court on a dozen occasions.

- Quality deprivation: the Anti-degradation Policy[14]

  This policy prohibits new contamination into already impaired streams and protects clean water from becoming degraded. Most states do not succeed in applying the anti-degradation policy to either clean or dirty waters. Anti-degradation provides a three-way approach to water quality protection:

  - Protects existing uses: does not permit activity that would eliminate or interfere with an existing use establishing the absolute floor water quality.
  - Maintain "high quality waters": Avoid, or at least hold to an absolute minimum, any lowering of quality of waters that meet currently or exceed standards.

[12] 33 USC 1251 to 1387
[13] 42 USC 300f-300j-26
[14] 40 CFR 131.12

- Protect "outstanding" waters. Give the most ecologically significant and sensitive, the cleanest, and most recreationally popular waters the strict protection they need and deserve.

  Each state must acquire an anti-degradation policy that is in accordance with or more stringent than the federal policy. States must also develop a system for implementing this policy consistent with all three tiers of its anti-degradation policy. Anti-degradation applies parameter by parameter. The Anti degradation rule can be applied locally on a section of a water body. Exceptions are made when the discharge proves to be of beneficial use for the local community when surface or ground water is augmented for IPR purposes.

- Discharge permits: the National Pollution Discharge Elimination System

  The CWA requires that all point source wastewater dischargers obtain National Pollution Discharge Elimination System [NPDES] permits, which are issued either by the EPA or by federal authorized states; NPDES permits are meant to sharply reduce contaminated discharges into water streams. The enforcement in California is carried out by the state through regional boards, which are mandated to adopt standards at least as stringent as the federal ones. Permit holders are allowed to discharge pollution into public waters in exchange for reporting the results of required monitoring and meeting the terms of the NPDES permits. The terms are required by law to prevent dischargers from causing or contributing to the infringement of water quality standards, though states and the EPA are often unsuccessful in meeting legal requirements. The terms of permits can also be enforced through citizens' lawsuits.

4.3.1.2 Water contamination criteria: the National Toxic Rule

The National Toxic Rule [NTR] was promulgated by the EPA in 1993 to bring 14 states, including California, Arizona, and Florida in compliance with the CWA requirements regarding the implementation of numeric criteria as part of a state's water quality standards[15]. The NTR sets water quality standards for toxic pollutants known to be protective of human and aquatic life that, in turn, could result in water quality protection related effluent limitations. This rule also comes into effect when surface water is augmented for the purpose of IPR.

- The California Toxic Rule halted

  Numeric priority toxic pollutant criteria were stymied in California due to a lawsuit brought upon the state by several dischargers that successfully challenged how the rule was implemented. From 1994 through 1998, California was without water quality standards for most priority toxic pollutants in the State's inland surface waters, enclosed bays, and estuaries as is required by the CWA[16]. The CTR was finally promulgated by the EPA on May 18, 2000 [40 CFR 131].

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[15] section 303[c][2][B]
[16] Section 303[c][2][B]

- The Arizona Toxic Rule overruled

In 1976, the EPA found that Arizona's revisions to its water quality standards did not meet the requirements of the Clean Water Act [CWA] and promulgated federal numeric nutrient criteria for total nitrates and total phosphates for several river segments in Arizona. The Arizona Department of Environmental Quality adopted these numeric criteria and the EPA approved these adoptions and withdrew its federal standards.

4.3.1.3 Implementation of IPR projects: the National Environmental Policy Act

The National Environmental Policy Act [NEPA] requires federal agencies to integrate environmental values into decision-making processes by considering the environmental impacts of proposed actions and reasonable alternatives to those actions. To meet this requirement, federal agencies prepare a detailed statement known as an Environmental Impact Statement [EIS]. When implementing new IPR projects, an EIS is drawn up. EPA reviews and comments on these EISs and assures that its own actions comply with NEPA.

4.3.1.4 Drinking water quality and IPR: the Safe Drinking Water Act[17]

The SDWA was originally passed in 1974, amended in 1986, and again in 1996[18], in order to establish health-based standards to protect drinking water quality by regulating 22 contaminants previously controlled by the Public Health Services. Twelve years following its inception, the SDWA had added only one new contaminant, which resulted in the 1986 amendment to expand the number of regulated contaminants to 83 and a mandatory addition of 25 contaminants per every 5 years. The 1996 amendment established a more realistic goal to add 3 contaminants every 5 years [see Figure 9]. Currently, 87 contaminants are regulated, while an additional 60 contaminants are pending, which at the time of this publication are not subject to any proposed or promulgated national primary drinking water regulations, even though they are known to or anticipated to occur in public water systems and may require future regulations under SDWA.

The SDWA drinking water standards are used to regulate IPR because any regulations for IPR standards are currently absent. The SDWA regulates two categories of drinking water standards. The primary standards are legally enforceable standards that limit the levels of specific contaminants known or anticipated to occur in water, which have an adverse effect on public health. They take form in Maximum Contaminant Levels [MCL] and the treatment techniques described below. The secondary standards are non-enforceable and concern both cosmetic and aesthetic effects. States have the option to adopt them as enforceable standards.

In the primary standards, the SWDA requires two objectives for each contaminant: 1] the Maximum Contaminant Level Goal, levels of which no adverse health effects are known, while allowing an adequate safety margin and 2] its enforceable derivation, the MCL. The MCL is set as close to the MCLG as feasibly possible, which the SDWA defines as the level that may be achieved with the best treatment techniques and

[17] 42 USC 300f-300j-26
[18] 42 USC 300g-8

technology available. When it is not economically and/or technically feasible to measure a contaminant level, a Treatment Technique [TT] is set rather than utilizing a MCL.

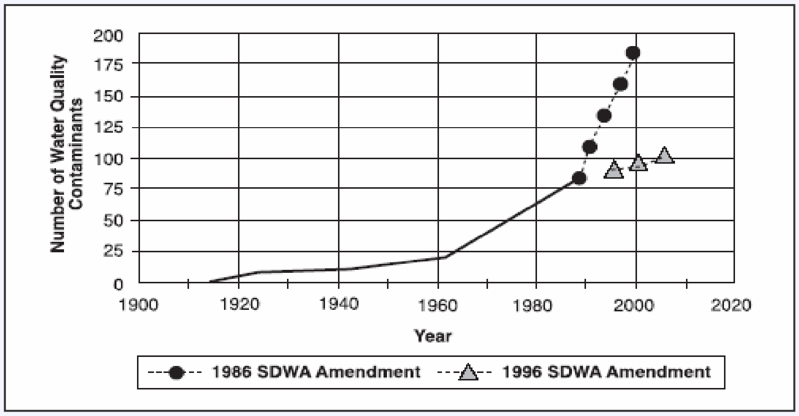

Figure 9: Contaminants Regulated by the SDWA[19]

A proposed change to the SDWA concerns the request of information collection of the monitoring and enforcement of the Underground Injection Control [UIC] portion of the SDWA, which will indirectly regulate IPR. The EPA continues to work toward the strengthening of the control of microbial organisms, including Cryptosporidium, as well as for disinfectants and disinfectant by-products, a new standard for radon, revising the current radio nuclides regulation, and to set a new standard for uranium, protecting groundwater from microbial contamination and revising standards for arsenic.

Additional concerns have been raised regarding the fate and transport of trace organic compounds. These include endocrine disruptors, pharmaceuticals, hormones, antibiotics, anti-inflammatories, and personal care products [antibacterial soaps, sunscreen, bath gels, etc.] that are present in municipal wastewaters. None of these individual compounds are regulated or monitored by Maximum Contaminant Levels [MCLs] in the SDWA. These newly emerging contaminants will be discussed in Chapter 6.5.

4.3.1.5 Federal laws and regulations under the SDWA

The following are specific drinking water laws including their most recent revisions. These laws apply to drinking water only, but are listed briefly to complete the cycle of IPR. The latest revisions illustrate the tendency towards a more stringent regulation of microbial contamination and disinfection byproducts and the systematic collection of information for future regulating.

[19] Adapted from EPA, Guidelines for Water Reuse, September 2004

- Enhanced Surface Water Treatment Rule

  The original Surface Water Treatment Rule [SWTR], which became effective in December 31, 1991, was designed to protect against Giardia. During the process of developing the ESWTR, the United States had its first major outbreak in Milwaukee, WI. Rather than delay the rulemaking for Giardia, the EPA promulgated the ESTWR, reserving the right for later regulation of Cryptosporidium.

  The EPA's latest addition, the Long Term 1 ESWTR [LT1ESWTR], was implemented in May 2004 as extension to the ESWRT. Its purpose mainly serves to improve the control of microbial pathogens, specifically the protozoan Cryptosporidium in drinking water. The rule requires monitoring of systems that serve communities greater than 100,000. A LT2ESWTR has been proposed by the EPA to supplement existing regulations targeting Cryptosporidium treatment requirements in higher risk systems.

- Disinfection/Disinfection Byproducts Rule

  The Disinfection/Disinfection Byproducts Rule [D/DPR] regulates toxic compounds that are formed during the disinfection process in a two-stage process: Stage 1 establishes maximum residual disinfectant level goals [MRDLGs] and maximum residual disinfectant levels [MRDLs] for chlorine, chloramine and chlorine dioxide. It also establishes maximum contaminant level goals [MCLGs] and maximum contaminant levels [MCLs] for total trihalomethanes, halo-acetic acids, chlorite and bromate and Stage 2, DBPR, focuses on public health protection by limiting exposure to DBPs, specifically Total Trihalomethanes [TTHM] and five halo-acetic acids [HAA5], which can develop in water through disinfectants used to control microbial pathogens by a primary or residual disinfectant other than UV. To assess risks associated with the control of pathogens and to limit contact to DBPs, the Stage 2 DBPR and LT2ESWTR are being developed concurrently.

- Information Collection Rule

  In order to support future regulation of microbial contaminants, disinfectants, and disinfection byproducts, the EPA has brought the Information Collection Rule [ICR] into effect. The rule was intended to provide EPA with information on DBPs, pathogens, and engineering data to control these pollutants and contaminants.

4.4 State executive and legislative hurdles

The structure of the predominant autonomous United States' state governments is similar to the federal government. California executive departments and administrative agencies write regulations to implement the authority of state laws. A number of these departments [Figure 10] are directly involved with water reclamation in order to protect and control water quality, water availability and public health. California is the trendsetter in the United States in developing water reuse regulations. Several of its laws implementing these regulations capitalize on the preceding federal laws. The purpose of this chapter is to provide an overview of California's executive and legislative structure in relation to water reclamation and IPR.

4.4.1 IPR and the California state executive branch

The state of California has nine cabinet level agencies of which the California Environmental Protection Agency [Cal/EPA], California Recourses Agencies [CRA], and the California Health and Human Services Agency [CHHSA] regulate water reclamation and indirectly IPR in regards to water quality, water availability, and public health. The California Department of Health Services [CDHS] and The California Department of Water Recourses [DWR] are subordinate departments of the CHHSA and the CRA that execute water related regulatory issues. The DHS is responsible for the adoption of regulations for the use of recycled water in IPR. The California Regional Water Quality Control Boards [RWQCB], which are subordinate departments of the CEPA, issue requirements for individual projects in conformance with the regulations adopted by DHS whereas the DWR has a more advisory role. These state executive departments and their relationships are schematically presented in Figure 10 and a short description follows next.

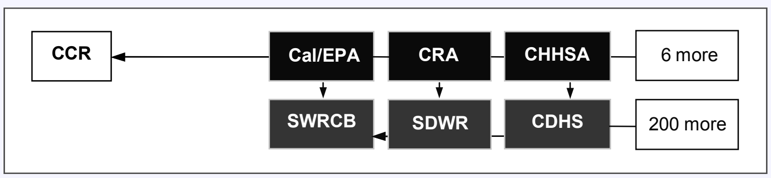

Figure 10: California state executive agencies [top] and departments [bottom] dealing with wastewater

In 1991, California's environmental authority, the California Environmental Protection Agency [Cal/EPA, previously referred to in this thesis as the CEPA] merged into a single cabinet agency, bringing six boards and departments under the Cal/EPA umbrella organization. Among those were the Water Board, which consists of the State Water Resources Control Board [SWRCB], and the nine Regional Water Quality Control Boards [RWQCBs]. These state executive departments and their relationships are schematically presented in Figure 10 and a short description follows in the next three sections.

4.4.1.1 Water quality: State Water Resources Control Board

The State Water Resources Control Board [SWRCB] and the nine Regional Water Quality Control Boards, also referred to as the Regional Boards [delineated consistently with the major watersheds and groundwater resources], make up the Water Board. The California Regional Boards issue requirements for water reclamation projects in conformance with the regulations adopted by the California Department of Health Services [CDHS]. With passage of the Porter-Cologne Water Quality Control Act in 1969, together the Boards became the "principal state agencies with primary responsibility for the coordination and control of water quality."

Within the State Board, the Division of Water Quality is responsible for providing the statewide perspective on a wide range of water quality planning and regulatory functions, including the regulation of activities affecting wetlands under Federal and state Clean Water Act programs. The Division of Water Rights is also involved in regulating IPR discharges to wetlands.

4.4.1.2 Water availability: Department of Water Resources[20]

The Department of Water Resources [DWR] is one of the 8 subordinate departments of the California Resources Agency [CRA] and manages the water resources of California in cooperation with the State Water Resources Control Board and the Department of Health Services. The DWR controls the State Water Project, which supplies water through the California aqueduct to Southern California. The DWR also educates the public on the importance of water and its proper use and distributes water related information to the public. The DWR established the Recycled Water Task Force in 2002, the goal of which is to increase the use of recycled water from a current 0.86 km^3 per year to 1.2 km^3 by 2010 in several forms of which IPR is one.

4.4.1.3 Public health: California Department of Health Services

The California Department of Health Services [CDHS] is one of the 12 subordinate departments of the California Health and Human Services Agency [CHHSA]. CDHS establishes water quality standards and treatment reliability criteria for water reclamation under Title 22, Chapter 4, of the California Code of Regulations, in cooperation with the Regional Boards and the Department of Water resources. Requirements for use of recycled water not addressed by the uniform statewide criteria are established by the DHS on a case-by-case basis. The CDHS also reviews newly emerging technologies. No regulations for IPR are currently in place.

4.4.2 Reclaimed water and the California legislative branch

Laws enacted by the California legislative branch concerning water reclamation are the most stringent in the United States and often more specific than federal laws. Water reclamation projects have operated successfully since 1920. The California legislature started regulating water reuse in 1969 and has alone enacted over 100 statutes relating to reclaimed water. However, there currently are no laws or regulations for IPR. Laws and regulations that predominantly control IPR indirect are Title 22, the California safe drinking water act [CSDWA] and the California Water Code [CWC]. The water quality provisions set forth in the California Water Code have been written to supplement provisions of several codes. Among them are the Porter-Cologne Act, the Water Reclamation Act 1991, and the California Environmental Quality Act [CEQA]. These laws and regulations and their relations are shown schematically in Figure 11 and further discussed in this section.

[20] CCR 23, division 3, CWC chapter 2, article 1

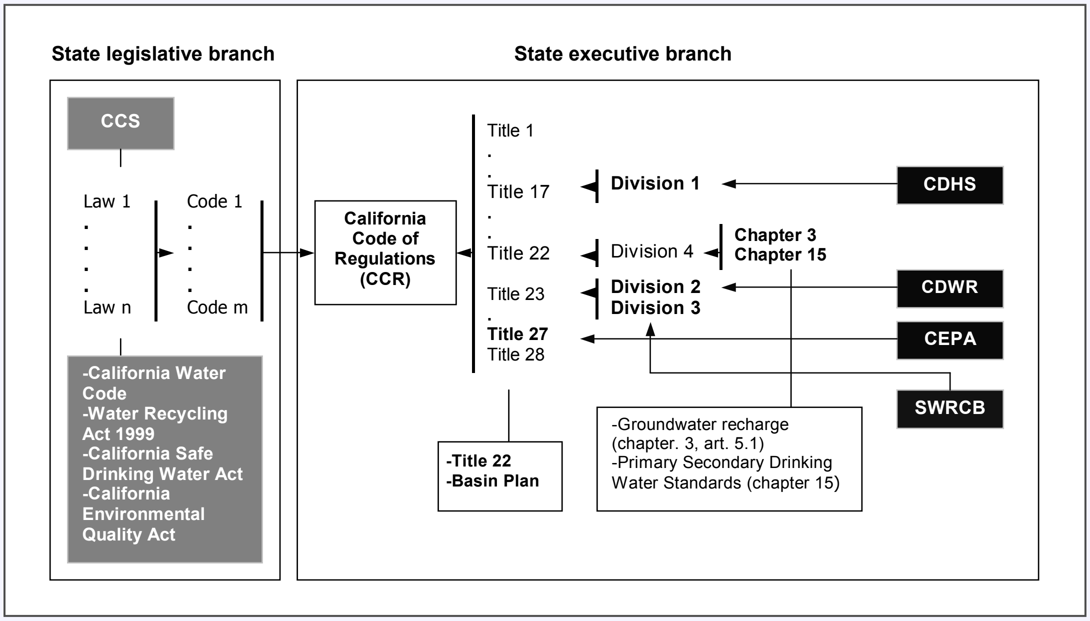

Figure 11: California's legislative and executive branch

4.4.2.1 All about water: the California Water Code

The California Water Code emphasizes a distinct strategy favoring the beneficial reuse of water to the maximum practical extent. It is the principal state regulation governing the use of water resources within the State of California. This law controls water rights, development and use of state water resources, water quality protection and management, management of water-oriented agencies, and more. The water code is mandated to be updated every 5 years and will be again in 2006. The following act is part of this code.

- Porter Cologne Water Quality Control Act

The Porter-Cologne Water Quality Control Act [Porter-Cologne Act], which was the precursor to the federal Clean Water Act of 1972, is an important part of the California Water Code. With the adoption of the Porter-Cologne Act in 1969, the State Legislature declared its intent to regulate water quality in California and to encourage the development of water reclamation. This act created the nine Regional Water Quality Control Boards and the State Water Resources Control Board. Under the Porter-Cologne Act, the discharge of waste is a privilege subject to specific permit conditions, not a right. The Porter-Cologne Act considers recycled water, which defines such as water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that otherwise would not occur. It also declared recycled or recycled water to be a valuable resource. Aspects of the Porter-Cologne Act are similar, yet go further than federal water quality regulations.

The economic rule under Part B of the Porter Cologne Act states that compliance with any rule or law causing a facility to incur an unreasonably high cost could be overruled. The Los Angeles Bureau of Sanitation is currently involved in a lawsuit with the Regional Board claiming that the California Toxic Rule leaves the Tillman Plant [see: 8.3.1] with no other option than to install expensive membrane technology to deliver their Title 22 water. The lawsuit was initiated in 1998 and is currently headed towards the State Supreme Court.

4.4.2.2 Authorized water reuse: Water reclamation act 1991

Chapter 187 of the Water Reclamation Act of 1991 mandated reclaimed water to be used for irrigation and other non-potable applications whenever it is economically feasible. Legislation was signed in 2001. The Department of Water Recourses [DWR] has created a task force to investigate additional opportunities to use recycled water such as IPR.

The Water Reclamation Act of 2005, introduced during the current legislative session, would authorize the implementation of recommendations made by the Recycled Water Task Force that are intended to streamline regulations related to reclaimed water. These recommendations include adherence by local jurisdictions to uniform statewide water reclamation criteria as established by the Department of Health Services and to increase the use of recycled water by using dual plumbing of buildings and new developments. This proposed Act is intended to help the state meet its goal of reclamation 1.2 km^3 water per year by 2010.

4.4.2.3 Regulations for reclaimed water quality, discharge, distribution, and production: Title 22

Title 22 is the Social Security section in the California Code of Regulations. Division 4 of this title covers environmental health, which contains water related issues. They are divided into several chapters. For example, Chapter 3 covers all recycled water quality standards [see Figure 11: California's legislative and executive branch]. Several aspects of water reclamation are divided under this chapter and the relevant ones are listed in detail below and Chapter 15 regulates the primary and secondary drinking water standards. Title 22 is commonly referred to as the law that allows for many uses of recycled water.

- Groundwater Recharge

The California Department of Health Services' recommendations to the Regional Water Quality Control Boards for proposed expansion of and existing groundwater recharge projects, solely with reclaimed water through surface spreading, will be made on an individual case basis. These recommendations will depend on the provided treatment, effluent quality and quantity, recharge method, spreading area operations, soil characteristics, hydrogeology, residence time, and distance to withdrawal. Reclaimed water used for IPR, through either direct and indirect groundwater recharge or surface water augmentation, must meet primary drinking water standards specified in Title 22. This accounts for inorganic and organic contaminants, trihalomethanes and other disinfection by-products [DBP], radioactive man-made constituents, and bacteriological quality.

- Design and reliability

  Under Title 22, a water reclamation facility must allow for efficiency and convenience in operation and maintenance, as well as provide the highest possible degree of treatment under varying circumstances. All reclamation facilities are required to have adequate warning and backup systems to guarantee uninterrupted and reliable operations. The design of most of the facility's components require redundancy, such as duplicate treatment units, power back up supply, and long term storage and disposal systems.

- Treatment requirements

  Title 22 sets bacteriological water quality standards on the basis of the expected degree of public contact with recycled water. For water reuse applications with a high potential for the public to come in contact with the recycled water, Title 22 requires disinfected tertiary treatment. For applications with a lower potential for public contact, Title 22 requires three levels of secondary treatment, which differ in the amount of disinfection required.

4.4.2.4 <u>More laws and regulations implicated with IPR</u>

- Implementation of IPR projects: the California Environmental Quality Act

  The CEQA is the basis for environmental law and policy to protect environmental quality in the State of California. The CEQA is a statute that requires state and local agencies to identify the significant environmental impacts of their actions and to avoid or mitigate those impacts if feasible. These include the discharge of highly treated wastewater for the purpose of IPR. In addition, they are required to respond to comments from the public and other agencies concerning the project in question.

- Water quality: California Safe Drinking Water Act

  The California Safe Drinking Water Act [CA SDWA] was passed to build on and strengthen the federal Safe Drinking Water Act [SDWA]. The CA SDWA authorizes the state's Department of Health Services [DHS] to protect the public from contaminants in drinking water by establishing maximum contaminants levels [MCLs] that are at least as stringent as those developed by the United States EPA and as required by the federal SDWA. Primary and secondary [except color] drinking water standards are used in Title 22 and for ground water injection for the purpose of IPR.

- Regulating local quality and discharge: the Basin Plan

  The Regional Board uses the Basin Plan as a regulatory tool. The Regional Board cites the Basin Plan's water quality standards and prohibitions to control a particular discharge. IPR will be controlled when a discharge augments potable water supplies. Its goal is to provide a program of actions designed to preserve and enhance water quality and to protect beneficial uses. The Basin Plan is also used by other agencies in their permitting and resource management activities.

4.4.3 Laws and regulations in California: a schematic overview

Figure 12 shows the inter-relations for the state of California between laws discussed in this and the previous chapter, and IPR. The left column shows the laws [CWA: 4.3.1.1, CWC: 4.4.2.1, CTR: 4.3.1.2, CEQA: 4.4.2.4] that control regulations and subordinate laws [Title 22: 4.4.2.3, TMDL-Antideg.-Basin Plan: 4.3.1.1], which determine the eventual discharge permits [NDPES: 4.3.1.1]. In turn, the NDPES controls the discharge from a Wastewater Treatment Plant [WWTP], an Advanced WWTP, and the discharge from groundwater, as well as a reservoir or surface water stream into other waters. The next column on the left shows how water rights [3.0] control the effluent of a WWTP, of AWT, the influent for a WTP, and the intake of other water. In addition, this same column shows that Title 22 controls treatment unit processes for AWT. The right part of Figure 12 shows the laws and regulations that control the WTP and drinking water [WRA '99: 4.4.2.2, Title 22, CASDWA: 4.4.2.4 and its implemented federal regulations: D/DBPR, RPHL, ESWTR: 4.3.1.5]. The dotted line represents the route of Direct Potable Reuse [DPR] that would hypothetically bypass all drinking water qualities regulations.

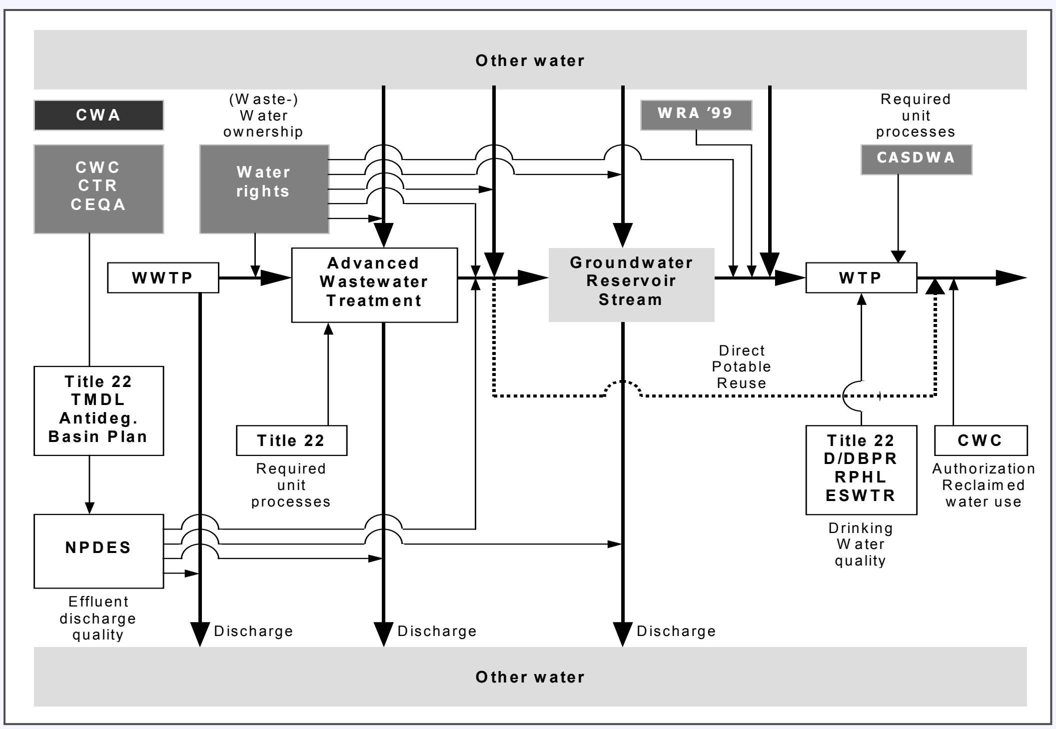

Figure 12: Laws and regulations and its inter-relations with IPR in California

Table 4: Abbreviations for figure 12

CWA	Clean Water Act
CWC	California Water Code
CTR	California Toxic Rule
CEQA	California Environmental Quality Act
WWTP	Wastewater Treatment Plant
TMDL	Total Maximum Daily Load
Antideg.	Anti-degradation Policy
NPDES	National Pollution Discharge Elimination System
CASDWA	California Safe Drinking Water Act
WTP	Water Treatment Plant
D/DBR	Disinfection/Disinfection By-Product Rule
ESWTR	Enhanced Surface Water Treatment Rule

4.5 Executive and legislative barriers for Florida and Arizona

Other impacted areas in the United States in which IPR is frequently practiced are the states of Arizona and Florida. In this chapter, they are addressed in short detail in regards to their executive, legislative, and institutional barriers and challenges. Several IPR facilities in these states are part of the conducted survey. Next to California, these two states have extensive reuse practice in the United States. Table 5 gives an overview of regulations that are currently in place for IPR for states that either have regulations or practice planned IPR.

Table 5: IPR in the United States[21]

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Not regulated	Case by case	Advanced treatment, high-level disinfection	Not regulated	Not regulated	Not regulated	Oxidized, coagulated filtered, RO, disinfected
BOD [mg/L]			20				5
TSS [mg/L]			5				5
Turbidity [NTU]			Not specified				0.1 [average] 0.5 [max]
Coliform [n/100ml]			Total all samples less than detection				Total 1 [average] 5 [max]
Total nitrogen [mg/L]			10				10
TOC [mg/L]			3 [average] 5 [max]				1
Primary and secondary standards			Compliance with most primary and secondary				Compliance with most primary and secondary

4.5.1 The Florida and Arizona executive departments involved in water reclamation

Compared to California, Florida and Arizona have a significantly less complex, as well as a less extensive executive and legislative branch. California serves in these areas as an example for both states and others, which are taking a back seat in the development of their new laws for water reclamation and IPR. Whereas Arizona has no regulations for IPR and California considers requirements on a case-by-case basis, Florida has clear requirements. Florida's requirements apply solely to the augmentation of surface water sources designated for the domestic drinking water supply and covers treatment and both primary and secondary drinking water standards. Arizona and Florida's main departments involved with water reclamation are discussed in the following bullet points:

[21] adapted from EPA, Guidelines for Water Reuse, September 2004

- Water quality: Arizona Department of Environmental Quality

  In 1986, the Arizona Legislature established the Arizona Department of Environmental Quality [ADEQ] in response to growing concerns about groundwater quality. ADEQ regulates the discharge and treatment of wastewater through the Arizona Pollutant Discharge Elimination System permits [AZPDES], Aquifer Protection Permits [APP], TMDLs, and Wastewater Reuse Permits [WRP]. These permits establish specific discharge limits, monitoring and reporting requirements, and may also require these facilities to undertake special measures to protect the environment from pollutants. The primary focus of these permits is municipal/domestic and non-domestic [industrial] direct dischargers.

- Water availability: Arizona Department of Water Resources

  The Arizona Department of Water Resources [ADWR] works to secure long-term water supplies for Arizona's communities. The Department administers state water laws, explores methods of augmenting water supplies to meet future demands, and develops policies that promote conservation and equitable distribution of water. In addition, the Department oversees the use of surface and groundwater resources under state jurisdiction and negotiates with external political entities to protect Arizona's Colorado River water supply.

- Public health: Arizona Department of Health Services

  The Arizona Department of Health Services [ADHS] assists in protecting health by providing a full range of Public Health Laboratory services. The Laboratory monitors both groundwater and surface water for the presence of chemical and microbiological pollutants. The ADHS will draw up water quality regulations through its findings in cooperation with the Arizona Department of Water Resources and the Arizona Department of Environmental Quality.

- Water quality: Florida Department of Environmental Protection

  In 1993, the Florida Legislature merged the Department of Environmental Regulation with the Department of Natural Resources to form the Florida Department of Environmental Protection [FDEP], which is one of fifteen state government agencies in its executive branch. The FDEP is the lead agency in state government for environmental management. The department administers regulatory programs and issues permits for air, water and waste management.

- Water availability: Florida Water Management Districts

  The FDEP delegates its distribution of water use permits to its 5 water management districts [WMD]. The Florida WMDs are regional agencies charged with managing and protecting water resources. They are delegated by the FDEP to distribute water reuse permits.

- Public health: Florida Department of Health

  The Federal Safe Drinking Water Act [SDWA] is administered by the EPA, which has delegated this responsibility to the FDEP, who in turn, has an agreement with the Florida Department of Health [FDOH] to implement this act. Under this agreement, the public drinking water systems program is responsible for the implementation of the SDWA program.

4.5.2 Florida and Arizona legislative branch: key water reclamation laws and regulations

- Water recharge: Arizona Groundwater Code

  Recharge programs included in the Arizona Groundwater Code allow the injection of surface water or treated wastewater into an aquifer for storage. Surplus renewable water supplies can be stored for future uses through these recharge programs. Under the Groundwater Code, Arizona has created 5 Active Management Areas [AMA] to manage ground water covering only 20% of the arid state's surface. The groundwater code requires management plans to be in place until 2025.

- Water reuse law: Florida Apricot Act of 1994

  Two provisions of this act are significant to Florida's reuse program. The first allows for permitting of backup discharges for reuse systems when the utility provides advanced wastewater treatment and the second allows high-quality reclaimed water to be injected into potable ground waters.

- IPR Regulation: Florida's Domestic Wastewater to Wetlands Rule

  The most common form of IPR in Florida is when wetlands, serving as or contributing to drinking water resources, are supplemented with advanced treated wastewater [see 8.4.4]. The Wastewater to Wetlands Rule controls the quality and quantity of wastewater subject to being discharged to the wetlands, and the quality of water discharged from the wetlands to contiguous surface waters. The regulation promotes the use of constructed and hydrologically altered wetlands by requiring less monitoring and allowing higher hydraulic and nutrient loading rates for those systems. These regulatory incentives attempt to create and restore wetlands. Many wetland systems are classified as reuse of reclaimed water per Regulation 62-610.810[g], F.A.C.. IPR through wetlands requires more stringent treatment [see: Table 5: IPR in the United States] than other types of reuse.

5.0 Public's relation

5.1 Introduction

The third category of institutional barriers covered in this thesis is public acceptance. Technology is far advanced but obsolete if water reclamation is not accepted by general public. Several recent IPR projects have found their destiny in public opposition whether or not scientifically justified.

Although IPR has been in the planning stages since 1950, it was only twenty years ago that researchers started looking into the public's perceptions and acceptance of this practice. Most of the recent studies conducted in the United States were primarily aimed at using applied incentives to increase the public's acceptance. This early approach viewed the public acceptance as an obstacle while implementing IPR projects. The next approach attempted to persuade the public to accept these projects. It is now generally accepted that social marketing or persuasion is ineffective. Public acceptance and perception are currently considered the main ingredients in the succeeding of an IPR project.

Understanding why the public is reluctant to IPR requires the explanation of certain human cognitive fundamentals through the law of contagion. This is covered next, followed by what today's literature considers to be the influencing factors in the public's acceptation and perception of IPR. Implementing reuse projects in today's society is also covered in this section while the final topic covers the current general concerns in California regarding IPR.

5.2 Why humans react the way they react: law of contagion

Why the public objects to IPR projects requires a greater understanding of human cognition associated with the Law of Contagion. The Law of Contagion [also referred to as the Law of Contact] is the second sub-law of the Law of Association [first is the Law of Similarity[22]]. This law states that objects, which have once been in contact with another object, continue to have influence on each other at a distance even though complete physical separation has been established. Water that has been in contact with contaminants will remain contaminated even after treatment has fully decontaminated the water. Thus, people will respond with disgust to both the contaminant and the associated water.

[22] The first sub-law of association, the Law of Similarity, suggests that appearance equals reality. Something is perceived to be what it looks like. A container known to filled with potable water yet marked wastewater will not be consumed. If IPR will be considered wastewater, it will not be consumed

Psychological contamination is easy to achieve, whereas psychological decontamination is difficult to achieve. This explains why in depth conversations on the safety of IPR projects are not completely successful in diverting people's perceptions away from IPR water as being contaminated. The perceived presence of contagion is often permanent. There are some people who believe nothing will work to purify contaminated water. There are two primary ways to persuade them otherwise: first, extreme methods of purification [redundancy in treatment, 24 log removal, proven successful technology] are often effective for those using a physical-contact model of contagion. Second, for those using a non-physical model, opposite-contact [manufacturer of baby foods endorsing an IPR project] could redeem the contaminated.

Another way to further understand the law of contagion is to consider an object's essence. People associate purity with an object's history, not just its current physical condition. As a result, perceptions of recycled water include where it has been and what it once was. The public's perception of the essence of IPR water can change if the public's understanding of the validity of IPR changes.

There also appears to be a predisposition toward purity in the form of naturalness. People prefer natural [or pure] to artificial or processed products, even when the two products are physically identical [natural foods vs. genetically altered foods]. The general population prefers natural processes to human processes and consider process more important than content. This predisposition partially explains why unplanned IPR is generally more accepted than planned IPR. Unplanned IPR is a more natural course of events as opposed to when it is planned.

People deal with these cognitive patterns by a process called framing. Framing ignores part of reality. People choose to ignore where objects have been in order to benefit from its advantages, i.e., cheap products made by underpaid underage workers in third world countries. A greater perceived benefit for IPR projects will increase the acceptability thereof. It is of great importance that the public is educated on the urge to conserve and reuse water to avoid future shortages.

5.3 Acceptance and perception issues in IPR

Resistance to IPR often starts on a small level and intensifies when local politicians get involved. Resistance has been shown to launch itself at any time during the course of the project. It has also shown that the lack of communication between proponents and opponents results in the delay and possible termination of the entire project. Insight from a social psychological point of view may result in reviving the project. The following is a summary of the main factors found in literature[23] that influence the public's acceptability of a reuse project.

- The Disgust or "Yuck" Factor

Objects such as excrement, urine, saliva, dirt and mud generally provoke a reaction of disgust, which will make the use of recycled water to be associated with the Law of Contagion. In CISRO 2003, the psychological rejection of potable reuse is said to be the main contributor for the part of the public that

[23] Wagner 1994, Bruvold 1998, CSIRO 2003

rejects potable reuse completely. It is for this reason that reuse projects avoid using the term "recycled" and choose for names such as NEWater [Singapore] and Re-purified Water [San Diego] in order to steer away from terms that relate to treated wastewater. Recycled water treated to the highest standards may still be perceived to be "disgusting" for its contact with the items mentioned below:

- Risk perception

Risk perception is often related to the safety of using recycled water considering that its source contained potential lethal pathogens and the not fully known effects of disinfection by-products and trace organics. Risk perception is said to be different between the lay public and experts[24]. The public tends to incorporate factors such as uncertainty, potential, and chance into their own formulated risk equation. Experts may consider a one in a million risk[25] of getting sick from drinking recycled water acceptable, whereas the public may perceive this as totally unacceptable because that one person could be them or, in what is considered an even worse case scenario, their own child. Especially in cases where the risks of a reuse project were poorly defined [The East Valley Water Reclamation Project: 8.3.1, The San Diego Re-purification Project 8.3.2], the level of outrage is likely to be significant. Risk communication is, therefore, considered crucial.

Affective decision-making begins with an assessment of the benefits: do I like what is being proposed? If yes, risk is perceived to be low. If no, risk is perceived to be high. The greater the perceived benefit is, the lower the perceived risk is. So, while experts consider risk and benefits to be positively related, the public often perceives them to be reciprocally related.

- Specific use

The closer the public is involved with the recycled water project, the more likely it will be rejected. Figure 13 shows the opposition as discussed in Bruvold [1998]. Bruvold proposes two major influencing categories on the public's perceptions of water reuse projects:

1. Degree of human contract
2. The Five Factors [health, environment, treatment, distribution, and conservation]

The first of the five factors was said to have the greatest influence on the public's perception for IPR projects, whereas the second factor had the next greatest impact when NPR was involved.

- Sources

Directly associated with the "Yuck-factor" in recycled water projects is the source of the water to be recycled, as well as the perceived quality of the recycled water and the perceived control over its quality.

[24] CISCO 2003
[25] Which is the same risk of drinking ½ liter of wine or smoking 1.4 cigarettes per year

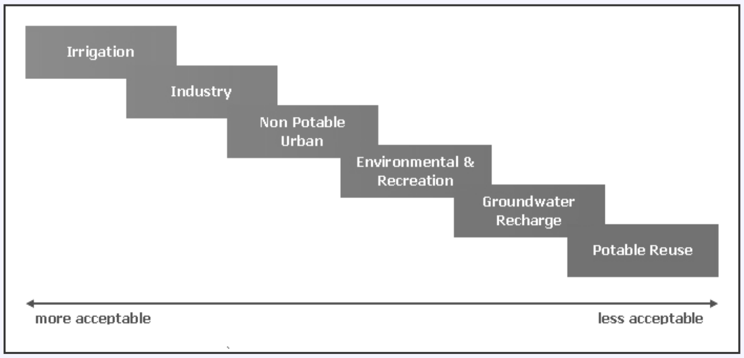

Figure 13: Reclaimed water use and its acceptability

- Choice, trust, and knowledge

In areas where water shortage is an issue, the public was more likely to choose recycled water as a viable source although the need for recycled water does not necessarily guarantee public's acceptance. Many studies in the US have shown that the lack of trust in the United States Department of Energy plays a major role in the public's acceptance. Mistrust in technology also impacts the acceptability negatively.

- Justified use

There is also perceived notice among the general public that reuse projects should be geared towards large water users before domestic uses are targeted. The volume consumed for domestic use is said to be minimal. In addition, it is expected by the public that the price for recycled water should be less than regular drinking water as it is considered to be of lower quality.

- Socio-demographic factors

Bruvold [1998] categorized his study findings on the relationship between socio-demographic variables and attitudes towards IPR and concluded that there is a positive correlation between educational, occupational level and income level. Knowledge about recycled water and the male gender were believed to have a positive link as well, while age and the length of residency were considered negatively linked. Bruvold also studied the correlation between belief variables and recycled water and concluded that the section of the public with a positive perception believed that the existing water supply was already contaminated, a water shortage was present, technology would be successful, health risks would be insubstantial, economic benefits would be persuasive and that the general public favors recycled water. The section of the public with negative perception believed the exact opposites. It is suggested in literature that demographic factors were of significant influence in accepting recycled water; however, the findings are inconsistent. Currently, there is no significant global relationship between age, gender, and income other than the fact that older women tend to be less supportive [Hartley, 2003]. Table 6 shows responses to several types of reuse.

- Water supply availability and population growth concerns

  Population growth is said to be induced by an increasing supply of water. The stakeholder that opposes the new development and its assumed associated population growth uses the scarcity of water availability as leverage, which eventually results in the opposition of any water project that is perceived to provide additional population growth. However, most reclaimed water projects are meant to preserve water reliability and to decrease the dependence on imported water for the existing population.

- Environmental justice and equity issues

  Environmental justice is defined by the EPA as the "fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies." Environmental justice and equity issues are a result of either procedural or geographic inequity. Procedural inequities occur when meaningful involvement of community or stakeholder groups is absent. Geographic inequity occurs when the project places a greater portion of the risk on a particular community. These issues primarily surface for projects that are located in the economically less affluent areas. Environmental justice and equity issues emerge in recycled water project implementation when a disadvantaged community perceives that it is required to share the bulk of the burden.

- Economic concerns

  Stakeholders may perceive a water reclamation project as unnecessary and may assess the economics of potential alternatives differently by placing varied values and priorities to certain aspects of the project. When implementing a water reclamation project, it is important to stress the avoided costs, such as the ones affiliated with newly imported potable supplies or expansions of existing treatment infrastructure in order to paint a complete picture of the economics of the project.

Table 6: The percentage of respondents opposed to specific uses of recycled water*

	ARCWS 2002 N=665	Sydney Water 1999 n=900	Lohman & Miliken 1985 n=403	Miliken & Lohman 1983 n=399	Olsen et al. 1979 n=244	Kasperon et al. 1974 n=400	Stone & Kahle 1974 n=1000	Bruvold 1972 n=972
Drinking	74	69	67	63	54	44	46	56
Cooking	--	62	55	55	52	42	34	55
Bathing	52	43	38	40	37	--	22	37
Washing	30	22	30	24	19	15	--	23
Toilet	4	4	4	3	7	--	5	23
Irrigation crops	--	--	9	7	15	16	--	14
Irrigation home	4	3	3	1	6	--	6	3
Irrigation golf course	2	--	--	--	3	2	5	2

[*] after Bruvold 1998]

5.4 Implementing IPR projects succesfully

Implementing an IPR project is a complex task as the phases of a typical IPR project found in today's literature show below. The two main requirements for successful implementation of an IPR project throughout these phases have proven to be the involvement of the numerous stakeholders during all phases of the project and the subsequent risk communication to these stakeholders. Details on the project phases and these two requirements are listed below.

- Phases of a typical IPR project
  - Developing presentations and information-gathering sessions
  - Distributing information about the project
  - Providing educational information explaining the need for the project
  - Providing information about the history and safety of recycled water use
  - Implementing a 24-hour project information telephone hotline and an effective web site
  - Informing and educating media representatives regarding details of the recycled water project
  - Implementing, sponsoring, or supporting either new or existing educational programs about recycled water
  - Giving individual attention in the form of customized responses
  - Multi-tiered communication assuring that stakeholders will communicate with each other on relevant issues

- Engage stakeholders before conception and during all phases

  It is a human trait to intrinsically favor restoring the bad, such as improving the quality of contaminated water, rather than improving the current supply[26]. Therefore, it is necessary to communicate to the stakeholders that the restoration of lost quality is more favorable than the improvement of the current quality rather than an attempt to satisfy the human need for restoration. The "Toilet-to-tap" scenario has become stigmatized and requires a form of de-conditioning. Ways to reduce adverse reactions is to build familiarity with the project and to desensitize it. This requires education through engaging the stakeholder during all phases of the project. The policy processes that are involved are characterized by relying large amounts of technical information. The basic message underlying this information is that water reuse technology applies redundancy in removing contaminants in wastewater through the use of multiple barriers. Its effluent is therefore useable for several uses of which IPR is one of them. This could be demonstrated through intensive water quality analyses.

- Risk communication with stakeholders

  Relaying risk assessments is the most challenging part of communication with the stakeholders. The core concern of stakeholders opposing the project will take position based on affective reasoning rather than a logical and analytical one. They will fixate on the unknown regarding constituents and subsequently advance their position. This precautionary principle is the basis of today's risk assessment decision-making process used by regulators. Using the risk assessment principle responsibly encourages risks to be assessed and analyzed, the impacts and effects of the alternatives to be weighed, and the most effective project alternative to be selected.

  Another mechanism that can be used to proactively address concerns regarding risks is the use of a "blue ribbon" panel or commission. A "blue ribbon" panel or commission is a panel comprised of technical experts and/or community members whose mission is to investigate either an issue or a project. For IPR, members can be drawn from academia, public and private sector wastewater or recycled water professionals, and interest groups. These "blue ribbon" panels or commissions have been successfully used by the OCWD to investigate new technology in the development of Water Factory 21.

5.5 Public's concerns in California

Today's implementation of IPR projects in California raises specific concerns among the public for the general acceptance and perception issues listed in 5.3. The rapid population growth is sometimes linked to the increase in water supply through reclaimed water projects. Environmental justice and equity issues, as well as economic issues are among the concerns raised. Several examples are listed under the following bullet points.

[26] CH2Mhill, 2004

- Water supply availability and population growth concerns in California

Due to Southern California's arid climate and its subsequent distant location form potable water recourses, water supply availability is an important issue for any new urban development project. Several laws have been amended requiring developers to supply detailed information about sufficient water supply to answer the demands of large development projects. The Dublin San Ramon Services District Clean Water Revival Project is an example of a project that was both subject to the concern of induced population growth and to the health effects of IPR. The MF/RO treated reclaimed water was meant to alleviate an effluent discharge problem by recharging a local groundwater basin. The project was eventually approved by having the advanced treated reclaimed effluent serve as urban irrigation water.

- Environmental justice and equity issues in California

One of the strong opponents of the San Diego Re-purification Project [see 8.3.2], Herman Collins[27], stated that he was opposed to the perceived injustice because lesser affluent people were the main recipients of the recycled water. This untrue injustice eventually resulted in this project being put on indefinite hold. Equity issues are potential for political opportunism, which was not only the case in the San Diego Water Re-Purification Project, but also in the East Valley Wastewater Reclamation Project. The project was used as leverage in mayoral campaigns and the former city attorney James Hahn suspended the project exclaiming that the DWP had been unsuccessful in sufficiently informing the public about its conception and possible health risks.

- Economic concerns in California

The City of Redwood City is an example of stakeholders developing alternative solutions to water resource issues different from those recommended by the agency project sponsor [i.e. the City of Redwood City]. Stakeholders in Redwood were opposed to using recycled water for irrigation in 2000 because it was using more than its contractual allotment from the Hetch-Hetchy system. The stakeholders perceived the water reclamation project as unnecessary by placing different values to certain aspects of the project and assessed the project to be uneconomical.

[27] Herman Collins later admitted that he has been misinformed by local politicians and regretted having supported the opposition against the San Diego Re-Purification Project

6.0 Constituents of concern

6.1 Introduction

This chapter focuses on heavy metals and the variety of trace organic compounds found in traditional secondary treated effluent. First, a brief coverage of detection methods is discussed [6.2] followed by [6.3], a discussion regarding newly emerging constituents. Finally, the conclusion of this chapter is accompanied with an overview of heavy metals and trace organic compounds that are considered the two main categories of concern [6.4 and 6.5].

6.2 Current detection methods

Identification of constituents found in wastewater is a never ending quest with the ever-improving analytical detection methods. The limiting factor in finding these constituents is the detection method used, which will be covered for each contaminant in 6.5. Even though there has been a dramatic increase in the ability to detect contaminants in the recent years, there are still concerns that the current toxicological methods are not sensitive enough to characterize today's level of water pollution.

Toxicity is the main parameter on which a target constituent is judged. All constituents are quantitatively detected. In order to manage the millions of constituents detected, only those that are potentially toxic will be identified and further explored to assess potential health effects. Spectral identification techniques, such as gas [low molecular weight] and liquid [high molecular weight] chromatography are coupled with low and high-resolution electron-impact mass spectrometry [GC-LC/EI-MS], are utilized to identify target constituents. Tandem mass spectrometry [LC-MS-MS] has experienced an impressive progress in recent years that has made the analysis possible of many environmental pollutants in a faster and more sensitive way.

6.3 Constituents of concern and the need to remove

Of growing concern are the newly emerging constituents in wastewater. Although not routinely detected for by advanced wastewater treatment facilities, newly emerging pollutants have raised concern for their unknown health effects, fate, and transport. They include: heavy metals, endocrine disrupters, pharmaceuticals, hormones, antibiotics, anti-inflammatories, and personal care products.

This newest water pollution starts with the intake and use of everyday products ranging from antibiotics to hormones, personal care products, and detergents. It is estimated that United States consumers spent 22 billion dollars on over the counter medication in 2003[28] alone of which its majority ends up in the municipal wastewater treatment plant. In addition to the constituents found in wastewater, there are pollutants that have been found in groundwater, such as perchlorate and Methyl Tert Butyl Ether [MTBE]. The Human Calci Virus has also raised concerns when serious outbreaks have occurred on cruise ships in recent years.

Among the conventional contaminants, nitrates are of particular concern in advanced wastewater treatment. Standard secondary treatment does not remove nutrients in the United Stated, while this is customary in Europe. Nitrate removal is, therefore, an important part of advanced treatment and has been the focus for regulation in recent years. Nitrates have human and environmental effects and have been found to be responsible for the Blue Baby Syndrome and to cause harmful algal blooms.

Antibiotics are expected to be the next future constituent of concern. Antibiotics induce or maintain genes conferring antibiotic resistance in microbial populations. Antibiotic resistance in human bacterial pathogens is a growing human health concern and the contribution of agriculture via antibiotic use for growth promotion [in contrast to therapeutic use] remains a topic of intense controversy.

6.4 Inorganic compounds of concern: heavy metals

Heavy metals are metals with densities higher than 5 g/cm3, such as lead, copper, iron, and zinc are naturally found in trace amounts in the earth's crust. However, heavy metals are used extensively in manufacturing and industry [see pesticides] and prolonged exposure can cause deadly health effects. Examples associated with dangerous heavy metals include the manufacturing of: DDT, dioxins, and polychlorinated biphenyls [PCBs].

Heavy metals in wastewater come from industries and municipal sewage and are one of the main causes of water and soil pollution. Accumulation of these metals in wastewater depends on many local factors, such as type of industries in the region, people's way of life, and awareness of its impact on the environment by careless disposal of wastes. Therefore, the presence of heavy metals in wastewater is not only of great environmental concern, but also strongly reduces microbial activity and as a result, adversely affects biological wastewater treatment processes.

Moreover, the toxicity of heavy metals in wastewater was shown to be dependant on factors such as metal species and concentration, pH, wastewater pollution load, and solubility of the metal ions. Biosorption of heavy metals by microbial cells has been recognized as a potential alternative to existing technologies for the recovery of heavy metals from industrial waste streams. Most studies of biosorption for metal removal have involved the use of either laboratory-grown microorganisms or biomass, generated by the pharmacology and food processing industries or wastewater treatment units.

[28] NCPA: Study #270, shopping for drugs: 2004

6.5 Emerging trace organic compounds

Wastewater and its constituents have been established to be one of the major sources of surface water and groundwater pollution in the United States. The specific trace organics discussed in this section are usually discharged into sewers that transport these chemicals to wastewater treatment facilities. During conventional wastewater treatment, some of these organic compounds are aerobically degraded, which can result in compounds that are even more toxic than the parent compounds. The overall objective of this section is to investigate the occurrence, distribution, and fate of these compounds in municipal wastewater treatment facilities and effluent discharges, as well as the impact of these compounds on the water quality and ecological environment. The following most frequent emerging trace organic compounds are further explored:

- N-Nitrosodimethylamine

In 1998, N-nitrosodimethylamine [NDMA] was found in a drinking water well in Northern California through direct contamination. NDMA was also found to be a byproduct of drinking water treatment from residual effects of chlorination. As a result of these early findings, DHS established a notification level in 1998 for NDMA because it is an extremely potent carcinogens part of the N-nitrosamines. Due to the relatively high concentrations of NDMA formed during wastewater chlorination, the planned and unplanned reuse of wastewater has become an important area of concern. Only a few laboratories are capable of detecting NDMA at very low concentrations on the order of just a few nanograms per liter [ng/L], or parts per trillion. Ultraviolet [UV] treatment can effectively remove NDMA, but there is considerable interest in the development world for less expensive alternative treatment technologies. These alternative technologies include approaches for removing organic nitrogen-containing NDMA precursors prior to chlorination and the use of sunlight photolysis and in site bioremediation in order to remove NDMA and its precursors. More about NDMA and its occurrences at the inventoried facilities can be found in chapter 8.0

- Endocrine Disrupting Compounds

For over 70 years, scientists have reported that certain synthetic and natural compounds could mimic natural hormones in the endocrine systems of animals. These substances are now collectively known as Endocrine Disrupting Compounds [EDCs] and have been linked to a variety of adverse effects in both humans and wildlife. Reports of EDCs in water have raised substantial concern among the public and regulatory agencies; however, very little is known about the fate of these compounds during drinking and wastewater treatment process. Numerous studies have shown that conventional drinking and wastewater treatment plants cannot completely remove many EDCs. Oxidation with chlorine and ozone can result in transformation of some compounds with reactive functional groups under the conditions employed in water and wastewater treatment plants. Advanced treatment technologies, such as activated carbon and reverse osmosis, appear viable for the removal of many trace organics including EDCs.

- 1,4-Dioxane

1,4-Dioxane is classified as a probable human carcinogen. It is used as a stabilizer for chlorinated solvents and it is formed as a by-product during the manufacturing of polyester and several polyethoxylated compounds. Inappropriate disposal and accidental solvent spills have resulted in the contamination of groundwater with 1,4-dioxane. Volatilization and sorption are not significant reduction mechanisms due to 1,4-dioxane's complete miscibility with water. At present, advanced oxidation processes [AOPs] are the only proven technology for 1,4-dioxane treatment. 1,4-Dioxane was believed to be very resistant to both a-biotic and biologically mediated degradation. However, recent studies have shown that 1,4-dioxane can be biodegraded and that cost-effective biological treatment processes can be developed.

- Alkylphenol Polyethoxylates

Alkylphenol Polyethoxylates [APEO] are widely used as components for detergents, paints, herbicides and insecticides. They are usually discharged into sewers, which transports these chemicals to wastewater treatment facilities. APEO are nonionic surfactants whose degradation metabolites are of estrogenic properties. They are relatively stable and have been found in both sediment and surface water. The environmental significance of APEO metabolites and the threat they pose to wildlife is still a matter of debate. Even though advanced analytical procedures are available, researchers have been unable to obtain a complete mass balance during biodegradation studies. The ultimate fate of APEO and their metabolites is not fully understood. Biodegradation is believed to be the dominant degrading process, but photo degradation may also play an important part.

- Fluorinated Alkyl Substances

Fluorinated Alkyl Substances [FAS], which include perfluorooctanesulfonate [PFOS] and perfluorooctanoic acid [PFOA], consist of a diverse class of chemicals that are utilized in a wide range of products. As a result of their chemical stability and widespread use, FAS have been detected in marine mammals and aquatic organisms throughout the world, including relatively pristine environments, such as the Artic. PFOS and related perfluorinated compounds have been associated with a variety of toxic effects including mortality, carcinogenity, and adverse development. Their widespread dispersal throughout the world and their potential toxicity has caused increasing concern among scientists and regulators. FAS were identified and quantified in groundwater, surface waters, and wastewaters, yet little is known about their transport or behavior in the environment. Numerous laboratory and field experiments are still needed to elucidate these processes. In addition, techniques for treating wastewaters containing FAS must be found to prevent their release into the environment.

- Perchlorate

Perchlorate [ClO42] emergence in water has been primarily associated with the manufacturing and use of rocket propellant. Perchlorate can spread over large distances when disposed into groundwater since it is highly water soluble and absorbs poorly to soil. The successful perchlorate bioreactor tests indicate that biological treatment is a suitable method for soil remediation and water treatment of perchlorate-contaminated water. Perchlorate is on the EPA's Contaminant Candidate List [CCL], which means that it is a potential candidate for regulation. In addition, the ongoing Unregulated Contaminant Monitoring Rule [UCMR] requires perchlorate monitoring for large systems.

Studies have indicated that perchlorate inhibits the transport in the body of iodine, which in fetuses and children is necessary for brain development. It has been linked to thyroid damage, learning disabilities, decreased IQ and attention deficit disorder in children. It leaches into the ground and has been found in drinking water supplies in 35 states and has also been found in vegetables. A study by Texas Tech University researchers found that breast milk samples were on average five times higher than those detected in dairy milk purchased from grocery stores.

The chemical was found in virtually every sample taken in a new study of nursing mothers' milk in Lubbock, Texas, but researchers say it is too early to know whether these perchlorate levels are dangerous. It has also been found in the Colorado River, the major source of drinking water and irrigation in Southern California and Arizona. According to public health advocates, perchlorate has leaked into the drinking water supplies of more than 16 million Californians through unsafe disposal and storage methods practiced by the aerospace, defense, fireworks, and road flare industries.

Two techniques proven to remove perchlorate from drinking water are anaerobic biological reactors and ion exchange. Some bacteria can use perchlorate as an electron acceptor while oxidizing a large range of substrates. Perchlorate-respiring bacteria [PRB] are widely distributed in the environment and are enriched at perchlorate-contaminated sites. For those utilities with perchlorate contamination, perchlorate is a particularly difficult contaminant to treat, requiring the use of technologies such as ion exchange or reverse osmosis. For all of the above reasons, perchlorate is becoming an increasingly important issue to drinking water utilities.

- Methyl Tert Butyl Ether [MTBE]

The production and use of fuel oxygenates has increased dramatically since the early 1990s due to federal and state regulations aimed to improve air quality. Currently, Methyl Tert-Butyl Ether [MTBE] is the most widely used oxygenate in gasoline followed by ethanol. Widespread use of oxygenates in gasoline has been accompanied by widespread release of these materials into the environment. Accidental gasoline releases from underground storage tanks and pipelines are the most significant point sources of oxygenates in groundwater. Because of their polar characteristics, oxygenates migrate through aquifers with minimal retardation, raising great concerns nationwide of their potential for reaching drinking water sources.

An evaluation of MTBE's occurrence in drinking water sources over time in three states showed that the frequency of MTBE detection since 1999 appears to be stabilizing in groundwater and slightly decreasing over time in surface water. Recent studies have demonstrated the effectiveness of conventional treatment technologies and the promise of emerging technologies for MTBE removal from contaminated media. However, the removal from water of Tert-Butyl Alcohol [TBA], an impurity in MTBE-blended fuels and an MTBE breakdown product, can be problematic using some conventional technologies such as air stripping and granular activated carbon. These limitations may generate additional problems for water purveyors, regulators, and site managers.

- Human Calici Viruses[29]

There has been a notable surge of interest with regard to the viruses known as Human Calici Viruses [HuCVs] and their impact on water-borne disease. Recent epidemiologic studies in Europe, combined with an active waterborne disease surveillance system in the United States, have identified the Norovirus, a member of the HuCVs, as a prominent agent of waterborne disease. Current estimates suggest that upwards of 95–96% of nonbacterial gastroenteritis outbreaks of unidentified etiology may be due to HuCV. Moreover, there have been a number of documented waterborne outbreaks of Norovirus both in developed and developing countries worldwide.

It is with the recent advanced molecular techniques that we have begun to develop a strategy for the detection of this organism in water. However, because of the lack of a culture method for the HuCV it is difficult to perform research on their removal or inactivation during both water and wastewater treatment processes. Alternative approaches, included: using recombinant Norwalk virus particles, indirect measures of inactivation based on molecular methods, or the cultivable Feline Calici Virus as a surrogate. Results from these studies raise concerns about the mobility of HuCV in groundwater and their resistance to chlorine and mono-chloramine and suggest that ultraviolet radiation may be an effective inactivation method.

[29] Environmental Engineering Science, Volume 20, Number 5, 2003

7.0 Advanced Treatment

7.1 Introduction

Environmental requirements in California often require that wastewaters be treated beyond secondary drinking water standards for reclaimed water projects, and up to and beyond primary drinking water standards for projects involving IPR. Advanced wastewater is designed to remove suspended solids and nutrients commonly found in secondary effluent and prepare effluents for more reliable disinfection. In some cases, the advanced wastewater treatment may replace or be combined with the conventional secondary treatment. Factors necessary to consider when choosing the appropriate configuration of an advanced wastewater facility are the nature of the constituents required to be removed, the use of the final effluent [NPR, IPR], and the handling of the concentrate. This chapter starts with a general overview of the constituents targeted in advanced treatment [7.2]. Next it will present an overview of advanced wastewater treatment facility configurations encountered during the fieldwork [7.3], followed by a detailed section covering each treatment process [7.4] with a separate section will cover the up to date membrane technologies [7.5]. The final section briefly covers the disposal of the concentrate [7.6].

7.2 Categories of constituents removal

Advanced wastewater treatment targets the removal of constituents in four categories. For these four categories, the relevant impacts for each type of constituent are presented in Table 7 through Table 10.

- Residual organic and inorganic colloidal and suspended solids
- Dissolved organic constituents
- Dissolved inorganic constituents
- Biological constituents

Table 7: Residual organic and inorganic colloidal and suspended solids

	Residual organic and inorganic colloidal and suspended solids
Suspended solids	• may cause sludge deposits or interfere with receiving waters • can impact disinfection by shielding organisms
Colloidal solids	• may effect effluent turbidity
Organic matter	• may shield bacteria during disinfection • may deplete oxygen resources

Table 8: Dissolved organic constituents

	Dissolved organic constituents
Total organic carbon	• may deplete oxygen resource
Refractory organics	• toxic to humans • carcinogens
Volatile organic compounds	• toxic to humans • carcinogens • form photochemical oxidants
Pharmaceuticals	• impact aqua species [e.g. endocrine disruption: sex reversal]
Surfactants	• cause foaming and may interfere with coagulation

Table 9: Dissolved inorganic constituents

	Dissolved inorganic constituents
Ammonia	• increases chlorine demand for disinfection • can be converted to nitrates and can deplete oxygen resource • with phosphorus, may lead to undesirable aquatic growth • unionized form is toxic to fish
Nitrate	• stimulates algal and aquatic growth
Phosphorus	• stimulates algal and aquatic growth • interferes with coagulation • interferes with lime clarification
Calcium and magnesium	• increases hardness and total dissolved solids
Total dissolved solids	• interfere with agricultural and industrial processes

Table 10: Biological constituents

	Biological constituents
Bacteria	• may cause diseases
Protozoan cysts and oocysts	• may cause diseases
Viruses	• may cause diseases

7.3 Encountered configurations in the survey

Several advanced wastewater treatment configurations were encountered during the conducted fieldwork. Figure 14 presents a schematic overview encompassing those configurations. All of the surveyed facilities produced effluent greater than secondary quality required for reclaimed water projects. In order to comply with newly enforced regulations for nitrates, several facilities complemented their existing configuration with a Nitrification/De-Nitrification process. Micro Filtration [and recently Submerged Micro Filtration], in arrangement with reverse osmosis replaced the traditional configuration consisting of granular media filtration, carbon adsorption, lime clarification and chlorination. Some of the surveyed facilities also carried out the preliminary and primary treatment. More details about the surveyed facilities can be found in chapter 8.0 and 9.0.

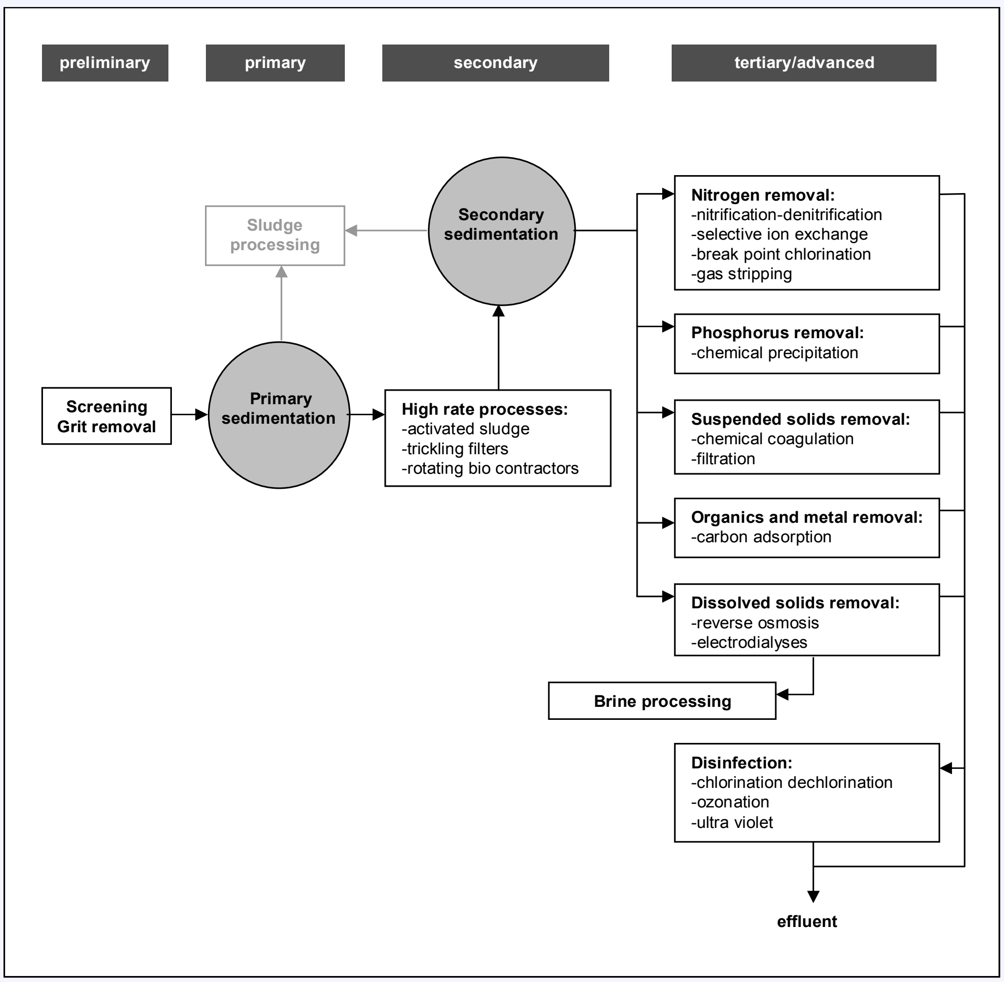

Figure 14: Possible advanced wastewater treatment configurations as encountered during survey

7.4 Types of advanced treatment

Encountered advanced treatment types are listed in Table 11 along with its main targeted category of constituents discussed in section 7.2. The table below does not take into effect the secondary categories of constituents partly removed by advanced treatment processes. Each of these listed treatment process is covered in detail in the following sections, except from membrane filtration [MF and RO] which will be covered more elaborately in section 7.5.

Table 11: Advanced treatment types and the targeted category of constituents*

Advanced treatment type:	**Residual organic and inorganic colloidal and suspended solids**	**Dissolved organic constituents**	**Dissolved inorganic constituents**	**Biological constituents**
Filtration	X			
Membrane filtration [MF]**	X			
Coagulation/flocculation	X			
Activated carbon		X		
Chemical precipitation			X	
Nitrogen removal		X	X	
Reverse osmosis [RO]**		X	X	X
Chlorination				X
Ozonation				X
UV disinfection				X
Advanced oxidation				X

[*] represents only the category that a certain type of advanced treatment predominantly targets, it may target more

[**] discussed in 7.5

- Filtration [depth, pressure and surface]

Filtration is the heart of the advanced wastewater treatment facility. It is the physical and chemical process of separating suspended and colloidal constituents from water by passage through a bed of granular material. Filtration goes beyond the process of mechanical straining principles commonly thought of in technical disciplines outside the water treatment world. Most common non-straining mechanisms are interception, sedimentation and diffusion. Filters can be classified by the direction of flow through the bed, the type of used filter media, flow rate, and whether driven by gravity or mechanical applied pressure. The filters encountered during the survey were depth filtration, which often consisted out of single or multi media; pressure filters; and surface filtration, which was encountered only once. Depth filtration is used for supplemental removal of suspended constituents to allow effective disinfection and, more recently, as a pretreatment for membrane filtration. Depth filtration can be replaced by surface filtration, which is the removal of suspended constituents through mechanically sieving of the water by a thin filter material much like a strainer. Membrane filtration will be covered in detail in chapter 7.5.

- Coagulation and flocculation

Secondary effluent contains a variety of colloidal and suspended particles that cause color and turbidity. The physiological processes that are involved in tertiary treatment through coagulation and flocculation are the uniformly rapid mixing of coagulation chemicals [most often Alum] in the water followed by slow mixing, which will cause aggregation of particles that forms a settable of filterable mass. Constituents that are targeted range in size from 0.1 μm to 1.0 μm. Distinct mechanisms of the chemically induced coagulation include the double layer compression surrounding the suspended particles and subsequently refraining them from coagulating and settling, charge neutralization and, adsorption to induce the settling agglomeration of the particles. All inventoried facilities with tertiary treatment used coagulation and flocculation.

- Activated carbon [powdered, granular]

Traditional treatment may remove nearly all Biochemical Oxygen Demand [BOD] related organics, but is effective as the refractory organics measured by the Chemical Oxygen Demand [COD]. Pore structure and large surface area [1000 m^2/g] are the most important characteristics of activated carbon, which are responsible for the adsorption of constituents. Influencing factors during this process are the characteristics and concentration of the adsorbed constituent, pH and suspended solid contents of the wastewater, and the mode of operation. Granular or Powdered Activated Carbon [GAC, PAC] was used in the surveyed facilities as efficient processes capable of removing organics and even some inorganics, which include some potentially toxic heavy metals from wastewater.

- Chemical precipitation

Chemical precipitation in advanced wastewater treatment has been encountered in the form of lime clarification and has been traditionally used to target phosphorus removal and is used more recently as part of the pretreatment for RO systems. Lime is the term used for a variety of alkaline chemicals mainly containing calcium and oxygen. Two of the most frequently used forms are Quicklime [CaO] and Hydrated Lime [CA[OH]2]. The clarification process is completed by final sedimentation through gravity sometimes chemically enhanced by polymers, silica or other aids. Inherent to lime clarification is final process stage of recarbonation. Recarbonation is the addition of carbon dioxide to water in order to lower alkalinity, which, incidentally, is high due to the secondary effect of the upstream lime treatment. The previously formed hydroxides are converted to carbonates and bicarbonates and thus, lowering the alkalinity or pH. This avoids the problems of deposition of calcium scale in pipelines and on filter and carbon beds because the lowering of pH establishes calcium-carbonate equilibrium in the effluent. Lowering pH through recarbonation is also crucial for the downstream processes, such as filtration and activated carbon as it promotes the adsorption of organics. Lime clarification has recently been replaced by MF for cost and area reducing purposes. MF also eliminates recarbonation and is becoming a standard process stage in advanced wastewater treatment.

- Nitrogen removal

The removal or control of nitrogenous matter in wastewater is associated with various environmental problems. Nitrogen compounds may cause undesired algal growth. Ammonia [NH3] can cause toxicity to aquatic life, corrosiveness, has detrimental effects on disinfection and nitrogen oxide [NO3], and is a health hazard. Covered in more detail are the following four processes of nitrogen removal.

1 Nitrification/De-Nitrification

Nitrification/De-Nitrification [NDN] is the process of converting nitrogen into a form, which can ultimately be removed. The influent ammonia nitrogen is first oxidized to nitrate nitrogen. This is carried out by two groups of autotrophic bacteria: Nitrosomonas and Nitrobacter, which are present in trickling filters and activated bio filters. At this point, the nitrogen has merely changed forms and has not yet been removed from the wastewater. In the second step, denitrification, nitrate nitrogen is converted into nitrogen gas in an anoxic environment by a broad range of bacteria, such as Pseudomonas, Micrococcus, Achromobacter, and Bacillus. The nitrogen gas naturally discharges into the atmosphere. Methanol is being used to speed up this otherwise slow process.

2 Ion exchange

Ion exchange selective for ammonium or nitrate, is the process stage during which clinoptilolite is used as a regenerant. This is a zeolite occurring naturally in bentonite deposits in the Western United States and consists of complex aluminoscilates with sodium as the mobile ion. The most widespread use of this technology in advanced wastewater treatment is for the purpose of water softening during which calcium and magnesium ions are being removed. It can be operated in a batch or in continuous mode.

3 Breakpoint chlorination

Breakpoint chlorination is the addition of chlorine to water until the chlorine demand has been satisfied. At this point, further additions of chlorine will result in free residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint. This breakpoint process is capable of a near complete removal of ammonia. More details as far as chlorine, its disinfection, and related effects are discussed in 4.6.

4 Ammonia stripping

Ammonia stripping is the easiest form of nitrogen removal to operate and control, but it is limited by its inability to operate in freezing temperatures and it is subject to calcium carbonate scaling. Removing the nitrogen in the form of ammonia is an economical solution and recovered ammonia can be used for fertilizer. Elevating the pH to 12 is required, which is established when put in series with lime clarification shifting the equilibrium between ammonium and ammonia to the gaseous part of the equation. Ammonia stripping also causes other gasses subsequently removed from the treated water, such as carbon dioxide, oxygen, hydrogen sulfide, and a variety of volatile organic compounds.

- Chlorine disinfection and why not to do it

Chlorination has been the major disinfectant process for waste and drinking water for many years. Chlorine destroys the targeted organisms by oxidation of the cellular material. It may be applied as chlorine gas, hypo-chloride or other chlorine compounds in either solid or liquid form. Dosages range from 5 to 15 mg/L and contact times from 30 minutes to 2 hours.

Drawbacks of chlorine disinfection include the formation of Disinfection By-Products [DBPs], such as Trihalomethanes [THMs] and Haloaceticacids [HAAs] through the reaction of chlorine with residual natural organic matter. Investigation of the possible association between the exposure to these products and cancer [and more recently adverse re-productiveness] has raised concern about potential health effects. In addition, there is a large resistance to transporting hazardous chemicals, such as chlorine gas. Its sensitivity to terrorist acts in situ is another reason for objection. This altogether has led to exploration and use of alternative methods of disinfection.

Relatively few health-related studies have been carried out by studying the effects of DBPs on reproductive health outcomes. However, several studies point towards a connection between trihalomethanes [THMs] and low birth weight, although the evidence is not definitive. Doses used in these studies have been high and the assessment of exposure was often limited. So far, the main limitation of most studies has been the relatively crude methodology, in particular for assessment of exposure.

There is no perfect disinfectant, but several characteristics can be considered in choosing the best suitable disinfectant. Factors that play a role in choosing the disinfectant for a treatment facility are the ability to oxidize pathogens, the level of hazardous in using the disinfectant, the level of disinfection byproducts, and the operation and maintenance costs.

- Ozone disinfection

Ozone is another strong oxidizing agent. The unstable gas is generated by an electrical discharge through either dry air or pure oxygen. Because of its high oxidation potential, ozone oxidizes cell components of the bacterial cell wall and subsequently all of its essential components. Ozone has no residual due to its rapid decomposition, which in turn leaves no way of measuring it efficacy.

Ozone is more effective than chlorine, utilizes a shorter contact time, and can be generated in situ being a mere must due to its instability. Ozone is also not affected by the ammonium ion and pH, which is the case with the use of chlorine. Also, additional aeration might not be necessary due to the near oxygen saturation as ozone decomposes to oxygen. On the other hand, ozonation is a more complex technology, requires corrosion resistant materials, and is expensive both as a capital investment and energy wise.

The main preference of using Ozone over Chlorine is the absence of chlorinated DBPs, such as THMs and HAAs. DBPs may be produced when high concentrations of bromide were present prior to treatment. Other DBPs [aldehyds and acids] can be formed in the absence of bromide. Ozone has been used in combination with chlorine and chloramine. Many disinfection byproducts formed by ozone and combinations of ozone with chlorine have been identified to be the same type of halogenated DBPs as formed by chlorine only, but they were fewer in number and lower in concentration.

- Ultra Violet disinfection

An Ultraviolet [UV] disinfection system transfers electromagnetic energy from a mercury arc lamp to an organism's genetic material. When the UV radiation penetrates the cell wall of an organism, it destroys the cell's ability to reproduce. UV radiation is generated by an electrical discharge through mercury vapor and penetrates the genetic material of microorganisms and retards their ability to reproduce.

The source of UV radiation is either the low-pressure, medium or high-pressure lamp with low or high intensities ranging from 100 to 120 mWs/cm2. Medium and high-pressure lamps with high intensities are 15 to 20 times more effective and are generally used for large facilities. The medium and high-pressure lamp disinfects faster and has a greater penetration capability because of the higher intensity. These lamps operate at higher temperatures and consume significantly higher amounts of energy. Today, there is a tendency towards use of high pressure lamps.

The physical process is the main advantage of UV disinfection over a chemical process. This eliminates the need to produce, handle, transport, or store hazardous or corrosive chemicals. UV disinfection requires significantly less floor space and there is no residual effect that can be harmful to humans or aquatic life. Organisms can sometimes repair and reverse the destructive effects of UV through either photo reactivation or dark repair, while residual suspended solids in the wastewater can leave UV disinfection ineffective. UV is less cost effective than chlorination, but significantly cheaper than ozonation. UV is added to most IPR projects in the United States as a final step, to mainly target NDMA.

- Advanced Oxidation Processes

Advanced Oxidation Processes [AOPs] are used in advanced wastewater technology to oxidize complex organic compounds in that are residually present after the final step of the physical separation process, generally being RO. These chemicals include low molecular weight constituents, such as agricultural pesticides and herbicides, fuels, solvents, and pharmaceuticals.

The purpose of all Advanced Oxidation Processes [AOPs], is to produce hydroxyl radicals [•OH], a highly reactive oxidizing agent that reacts with the dissolved constituents and initiates a series of oxidation processes until the targeted constituent is completely mineralized. Its main purpose is to target low molecular weight contaminants.

When AOPs are used, it may not be necessary to completely oxidize the targeted constituent[30]. Partial oxidation is often sufficient to reduce their toxicity. Because most of the oxidation by-products are unknown in their toxicity, it is common to completely oxidize the targeted constituents. The AOP can be characterized by the extent of degradation of the final oxidation process as follows[31]:

- Primary oxidation: a structural change in the parent constituent.
- Acceptable degradation [defusing]: a structural change in the parent constituent to the extent that toxicity is reduced.

[30] Metcalf and Eddy, fourth edition, pg 1196
[31] Rice, 1996

- Ultimate degradation [mineralization]: conversion of the organic carbon to inorganic CO2.
- Unacceptable degradation [fusing]: a structural change in the parent constituent resulting in increased toxicity.

There are currently a variety of advanced oxidation approaches available. Each has a scope of wastewater treatment applications that it is suited for best. Most common combination used in advanced wastewater treatment are H2O2/UV and H2O2/O3. Advantages and disadvantages of these two approaches are listed in Table 12

Table 12[32]: Advantages and disadvantages of the most commonly used advanced oxidation processes

	Advantages	Disadvantages
H2O2/UV	-H2O2 is quite stable and can be stored on-site for long periods of times	-H2O2 has poor UV absorption characteristics and if the water matrix absorbs a lot of UV light energy, then most of the light input to the reactor will be waster. -Special reactors designed for UV illumination are required. -Residual H2O2 must be addressed
H2O2/O3	-Waters with poor UV light transmissions may be treated -Special reactors designed for UV illuminations are not required	-Volatile organics will be stripped from the ozone contactor -Production of O3 can be an expensive and inefficient process -Gaseous ozone present in the off-gas of the ozone contactor must be removed -Maintaining and determining the proper O3/H2O2 dosages may be difficult -Low pH is detrimental to the process

7.5 Membrane filtration

The heart of today's advanced treatment facility is membrane filtration. Membrane technology has existed since the 1960's and has developed from an open technology to a closed technology. The Membrane market today is highly competitive making disclosure of the latest developments a disadvantage. What did become apparent during the visits paid to three membrane factories in Southern California were trends towards the developments of lower fouling mechanisms and lower feed pressures. In addition, the market for Reverse Osmosis [7.5.5] membranes stabilized, while the market for Submerged Micro Filtration [7.5.2] experiences a steep development curve.

There basically are four types of membrane filtration treatment techniques available: Micro, Ultra, Nano Filtration, and Reverse Osmosis. While granular [or depth] filtration consists out of only two streams [feed and filtrate], membrane filtration [also at times referred to as cross flow filtration] distinguishes itself through the presence of a third stream named the concentrate. Granular filtration is the process during which particulate and colloidal matter is separated from water, whereas membrane filtration is extended to include dissolved constituents. The membrane is the separation barrier through which certain dissolved

[32] After Water Treatment: Principles and Design, second edition 2005, pg 584

constituents [see Figure 15] are allowed to pass while others are physically retained. The driving force to achieve this separation is a hydrostatic pressure or vacuum differential generated by pumps.

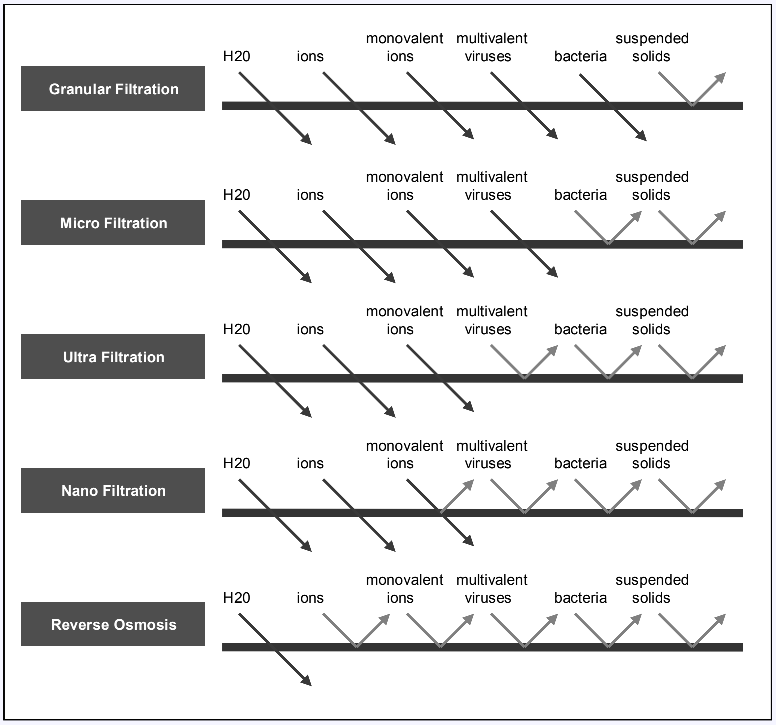

Figure 15: Schematic overview of filtration characteristics

Membranes consist of a thin skin with a thickness between 0.20 and 0.25 µm supported by a structure of higher porosity with a thickness of 100 µm to provide stability. The principle materials used in fabricating membranes are cellulose acetate, polypropylene and thin-film composite, which recently has become the most popular material for RO membranes. Thin film composites with improved characteristics are those of higher water permeability, lower feed pressures [and subsequently lower power costs], and higher salt rejection. The use of hollow fiber membranes [often for micro filtration] as a pretreatment for reverse osmosis enables the application of thin film composite membranes for wastewater reclamation. The benefits are the operation of RO at lower feed water pressures and it permeates with lower salinity levels than was possible when using cellulose acetate membranes.

Membranes used in the water reuse industry are present on today's commercial market in the form of either tubular, hollow fiber or spiral wound. Tubular wound is rarely used due to its low packing density. Spiral wound uses two types of flat sheet membranes, asymmetric and composite, and is the most common used configuration in water reclamation. Hollow fiber is used mainly for MF. Hollow fiber has the highest packed density, allows fewer membrane alternatives and requires high quality feed water. Spiral wound is most the popular configuration for UF, NF, and RO. In addition, hollow fiber is equally popular for UF applications.

Membrane fouling is the process during membrane filtration in which feed water constituents deposit on the membrane surface and in the membrane matrix. The retention of these constituents [called foulants] cause an increase of resistance over the membrane and a decrease of flux. Four forms of fouling mechanisms can be distinguished and are schematically drawn in Figure 16[33]:

- Gel/cake formation: depositions on membrane surface [a][34]
- Pore plugging: blocking of the membrane pores [b]
- Pore narrowing: adsorption inside the membrane pores [c]
- Concentration polarization: high concentration of foulants near the membrane [d]

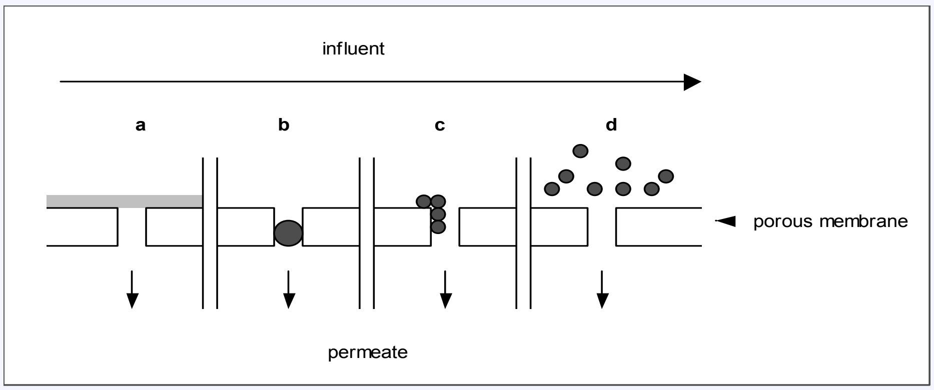

Figure 16: Types of membrane fouling

[33] adapted from Metcalf and Eddy, 4th edition, pg 1118, and Filtration characteristics in dead end ultra filtration, Roorda, pg 19
[34] this layer is also subjected to compression which could be considered as an additional fifth fouling mechanism

Table 13: Overview of filtration characteristics

	granular	MF	UF	NF	RO
popular material	anthracite sand	polysulfone	polysulfone	polyamide	polyamide
pore size	>0.2	0.04-10	0.003-0.2	0.001-0.003	<0.0005
Molecular weight cut off	suspended particals 2-3 micron	500,000-100,000	3,000-100,000	200-10,000	<200
constituents barrier	suspended particles greater than 0.1 mm	suspended particles greater than 0.1 mm	most organics over 1000 MW	-95% divalent ions, -40% monovalent ion -organics greater than 150-300 MW	-99% of most ions
feed pressure range [kPa]	7-14	35-350	175-1,000	1,000-3,100	1,400-10,000 reclamation: 3,100 desalination: 10,000
popular configuration	dual media	hollow fiber [submerged]	hollow fiber spiral wound	spiral wound	spiral wound
reclamation applications	membrane pretreatment -removal suspended particals	-RO pretreatment -granular replacement -removal of small suspended solids	removal of pathogens, bacteria, viruses, and colloids.	-hardness removal -organic and microbiological removal	-mono-valent ions -inorganic removal

7.5.1 Micro filtration

Micro Filtration [MF] is a low-pressure membrane process that removes virtually all particles greater than approximately 0.2 mm. Its performance is far superior to conventional granular media filtration. The footprint is small and MF is, as mentioned earlier, often used in reuse projects as pretreatment for RO in order to prevent premature fouling. It serves as pretreatment of surface water, municipal and industrial wastewater. MF functions in potable water production as a barrier for bacteria or as form of clarification.

7.5.2 Submerged Micro Filtration

Submerged Micro Filtration [SMF] has been commercially developed to eliminate the footprint completely. Bundles of hollow fibers are inserted directly into a coagulation basin of a drinking water treatment plant and/or directly into the aeration basin of an activated sludge wastewater treatment plant, in order to put a particle separation within other treatment functions. Permeate [product] water is generated by application of a partial vacuum [<70 kPa], i.e., a negative pressure.

While submerged MF is very promising, relatively little fundamental information is available to describe the process by which particles form a cake on the outside of the hollow fibers. Cake formation leads to fouling of the membrane surface. Therefore, a greater partial vacuum must be applied to produce the same permeate flux [water flow rate per unit area of membrane]. This increases the cost of operation. Aeration is usually applied to generate water movement along the length of the fiber in order to limit development of the cake layer in order to retard the rate of increase in partial vacuum that is needed to maintain a constant permeate flux.

Engineering practice could benefit by quantification of effect of aeration on fouling reduction based on the type of particles to be removed, the concentration of these particles, and the length and diameter of the fibers [i.e., their fundamental filtration characteristics]. Results of a well-controlled pilot test by Water Factory 21 to study submerged MF is discussed in 8.2.1.1.

7.5.3 Ultra filtration

Ultra Filtration [UF] is used when the influent is of better quality as opposed to situations where MF is required for pretreatment. The assumption that UF is an excellent pretreatment for Nano Filtration is supported by data from UF/RO treatment configurations. UF also targets viruses, such as Cryptosporidium and Giardia, but it essentially performs colloidal removal. UF is known to have a 4 log removal of bacteria and viruses and is therefore, used more in drinking water treatment applications. UF is a low-pressure [175-1,000 kPa] process. When used in wastewater applications, UF treats biologically treated municipal secondary effluent for either discharge to surface water, for reuse, or for feed to RO.

7.5.4 Nano Filtration

Nano Filtration [NF] is used in potable drinking water applications and is meant to remove both colloidal and many soluble organics. It will partially reduce hardness, Total Dissolved Salts [TDS], and organics. It also reduces THM precursors while limiting the formation of THMs during chlorination. Nano filtration is a low to moderately high pressure [typically 1,000 – 3,100 kPa] process in which mono-valent ions will pass freely through the membrane, while highly charged multivalent salts and low molecular weight organics will be rejected to a certain degree. NF applications are typically found in wastewater treatment facilities for water softening and in drinking water treatment facilities.

7.5.5 Reverse Osmosis

Osmosis is the spontaneous process of water flow across a semi-permeable membrane barrier from the solution of low concentration to the solution of higher concentration. Reverse Osmosis [RO] is the reverse process driven by pressure. RO is used in wastewater applications as the final physical treatment step for both NPR and for IPR. RO membrane elements are housed serially in pressure vessels in numbers ranging from 5 to 7. Today’s pressure vessels configuration in water reclamation are in three arrays each decreasing their vessel numbers by 50 percent . For example, the feed water will first pass through 20 vessels, then through 10 and eventually a third time through 5 vessels. Feed pressure ranges from 1,400 to 3,100 kPa for water reclamation and 10,000 kPa for desalination.

The application of RO membrane technology for treatment of municipal wastewater's secondary or tertiary effluent has increased since the early 1990s. High fouling rates have been reduced with a new generation of low fouling composite membranes, which is to be attributed to the hydrophilic membrane surface. Proprietary details regarding the low fouling physical system were not available. Details regarding pretreatment improvements, chemical additions to feed water, and the increase size of the RO elements and configuration were available and will be discussed in the following section. These developments in recent years have enhanced the performance of RO systems.

7.5.5.1 Reverse Osmosis pretreatment

The traditional multi-step RO pretreatment approach [flocculation, settling, clarification, media filtration, and disinfection] has resulted in high membrane fouling rates regardless the membrane type [cellulose acetate or composite polyamide]. Recently, the new pretreatment technology used in RO processing of municipal secondary or tertiary effluent is UF, MF, or submerged MF.

Another form of pretreatment is the installation of carbon filters. The advantages are their ability to remove organics from the feed water that could foul the RO and their higher reliability in treating feed waters as opposed to a chemical pretreatment system. The disadvantage is that carbon filters are notorious for breeding bacteria, which can result in a biological fouling of the RO membranes.

7.5.5.2 Chemical enhancement of Reverse Osmosis systems[35]

- Acids

Acids, typically hydrochloric [HCl] or sulfuric [H2SO4], are added to lower the feed water pH. The feed water pH is often adjusted to prevent precipitation. Sulfuric acid is used more often than HCl acid. The sulfate ion has a lower operating cost, a reduced fuming to the atmosphere, less corroding of the surrounding metal components, and a better membrane rejection than the chloride ion.

- Caustic

Caustics can be injected to increase the RO feed pH for a few process applications. Typically, the only caustic injected is sodium hydroxide [NaOH] because of its cost, availability, and its solubility in water. The quality of the NaOH can be technical grade [and free of any additives] most of the time. Brackish waters can contain potential foulants that become more of an issue at higher pH [e.g. hardness, alkalinity, iron,

[35] From: Chemical pretreatment for NF and RO, March 2002, Hydranautics

manganese, etc.]. Pretreatment frequently uses a weak acid cation exchange system and a degasifier to remove these potential foulants.

- Dechlorination chemicals

  Free available chlorine in RO feed waters needs to be reduced for compliance with composite polyamide membrane warranties issued by the manufacturers. The two most common pretreatment methods for reducing chlorine levels are either by absorption onto activated granular carbon filter media or through the use of a chemical reducing agent, such as sodium bi-sulfite. Dechlorination after chloramination may be required prior to feeding the influent to the RO membranes. Chloramines are produced by mixing chlorine and ammonia. Residual free chlorine, which can deteriorate membranes significantly quicker than chloramines, can be present if insufficient ammonia is used. Chloramine tolerance can vary by either the catalytic effects of high temperature, low pH, or the presence of transition metals.

- Anti-scalants and dispersants

  There is a variety of proprietary anti-scalants and dispersants available on today's market to improve the operation of RO systems. Anti-scalants are chemicals designed to inhibit the formation and precipitation of crystallized mineral salts that form scale. Most anti-scalants are proprietary organic man-made polymers. Dispersants are organic man-made polymers designed to inhibit the agglomeration and deposition of foulants onto the membrane surface. Dispersants are sometimes referred to as anti-foulants. Foulants tend to be a softer, non-crystalline deposit. Dispersant chemicals frequently have anti-scalant properties. The efficacy of differing dispersants can vary for different foulants, so one needs to know what foulant they are treating for. Foulants treated by dispersants are:

  - Mineral scales
  - Metal oxides and hydroxides [iron, manganese, aluminum]
  - Polymerized silica
  - Colloidal material
  - Biological matter

7.5.5.3 Size and configuration: developments in membrane characteristics

RO membrane elements are being developed in larger sizes to increase permeate flow and to increase flux through lowering the feed pressure [without compromising the quality performance]. This results in minimizing the floor space used by the membrane arrays. Pressure vessels that contain the RO membrane elements are made more pressure resistant enabling them to encase more elements. Koch Membrane Systems currently tests their latest oversized membrane, the MegaMagnum® RO Element at the Scottsdale Water Campus [also see 8.4.1]. The MegaMagnum delivers nearly 5 times the permeate flow when compared to the regular, already oversized Magnum and up to 8 times the permeate flow of other available membrane elements. More characteristics of these membranes are listed in Table 14.

Figure 17: MegaMagnum® RO Element [picture by Harm Jansen]

Table 14: Membrane characteristics

	Koch 8832 HR-575 Magnum	Koch TFC 18061 HR MegaMagnum	Hydranautics ESPA2	Hydranautics LFC1	GE Osmonics
permeate flow [m^3/d]	56.8	277	34.1	41.6	41.6
salt rejection [min]	99.5	99.5	99.5	99.5	99.5
membrane chemistry	proprietary TFC polyamide	proprietary TFC-HR polyamide	proprietary composite polyamide	proprietary composite polyamide	proprietary composite polyamide
membrane area [$m^{2]}$	53.4	260	37.0	37.0	37.0
max pressure [kPa]	4,140	2,070	4,140	4,140	4,140
max chlorine [ppm]	<0.1	<0.1	<0.1	<0.1	<0.1
max temperature [c]	45	45	45	45	45
feedwater pH range	4-11	4-11	3-10	3-10	3-10
max feedwater turbidity [ntu]	1	1	1	1	1
max pressure drop [kPa]	69/104	69/104	69	69	69
length [mm]	1,524	1,549	1,016	1,016	1,016
total diameter [mm]	203	457	202	202	202
weight [kg]	29	113	16.4	16.4	16.4

7.6 Concentrate Disposal

Concentrate disposal is an important issue since the ultimate goal of advanced treatment is to achieve a net gain. Disposal of the RO concentrate streams is often a challenge because the waste stream volume is about 15% of the feed stream volume. High salinity and anaerobic state makes the concentrate toxic to plants and animals, which limits the option for concentrate reuse. RO cleaning solutions are acidic or basic solutions that contain detergents or surfactants, which further contaminates the concentrate. The concentrate may be classified as hazardous material when RO is used to remove a specific contaminant, such as arsenic and radium. Concentrate disposal is classified as an industrial waste and regulated by federal, state, and by local laws. The most common forms of concentrate disposals in the United States are:[36]

- Discharge to brackish surface water [oceans, brackish rivers, and estuaries]
- Discharge to a municipal sewer
- Deep well injection

Most plants [50%] discharge to the ocean. Inland facilities [30%] will discharge to the municipal sewer or a separately constructed pipeline to the ocean. Only 10% of facilities will use deep well injection, which is most common in Florida. Other technical feasible options are evaporation ponds and infiltration basis, but are used by only a small number of plants in the US. They require large surface areas and involve high operating and maintenance costs and are, therefore, used when no other alternatives are available and where the value of product water is high.

[36] After Water Treatment: Principles and Design, second edition 2005, pg 1495

8.0 The surveyed projects

8.1 Introduction

Fieldwork for this thesis has been conducted in California, Arizona, and Florida. A standard template was used to characterize these facilities by size, technology, type of IPR practiced, goals and the outcomes thereof. More specific details, such as used membrane types, relative costs and specific applicable laws and regulations were also inventoried. When available, studies conducted by the facility on emerging pollutants and membranes were also studied. Several people were interviewed per facility ranging from plant operator to designing engineers. Each facility is briefly described in the following chapters and summarized in tables at the end of each section. The influent and effluent quality parameters of each plant, as far as they were available, are put in tables found in chapter 13.0.

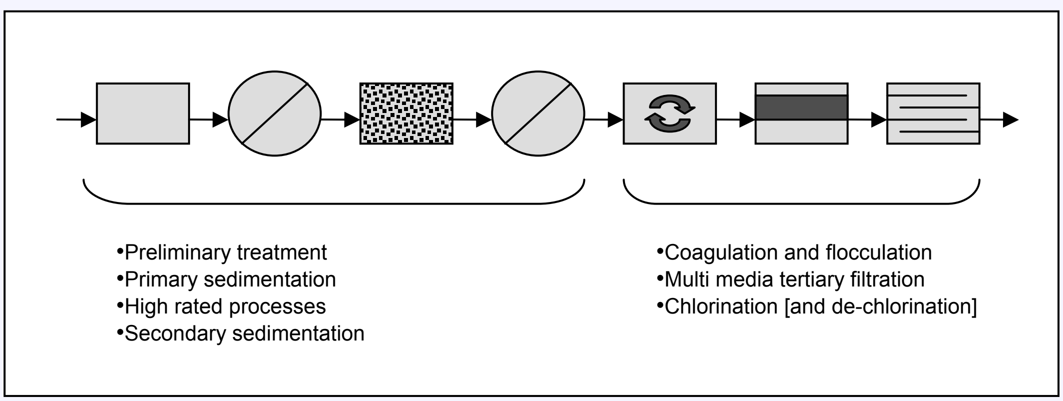

Figure 18: Traditional secondary [left] and tertiary [right] treatment

The inventoried facilities were encountered in several configurations. The majority of the facilities consisted of traditional treatment for their preliminary, primary, secondary and tertiary stage [Figure 18] and is referred to as "traditional secondary" and "traditional tertiary" treatment in the remainder of this chapter. Advanced wastewater treatment facilities using secondary or tertiary effluent as their influent had RO centrally configured in their tertiary and/or advanced treatment. Two standard RO configurations were most often encountered, referred to in this thesis as "traditional RO pretreatment" [Figure 19] and "contemporary advanced treatment" [Figure 20]. A few alternatives to and combinations of these two treatment formations were encountered as well and will be illustrated separately for each relevant facility.

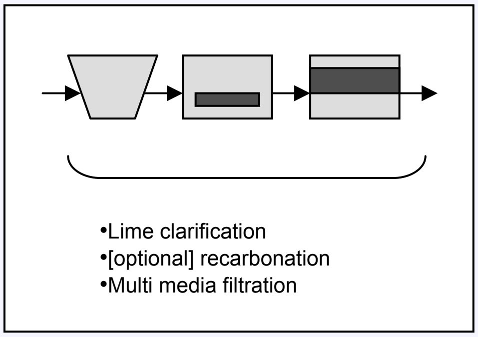

Figure 19: Traditional RO pretreatment

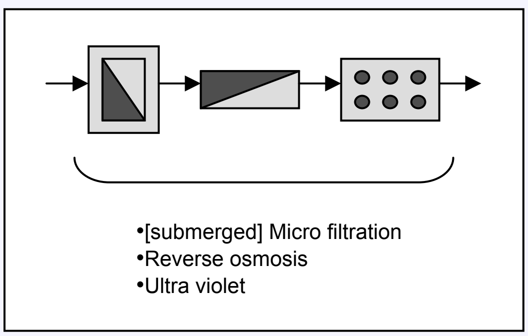

Figure 20: Contemporary advanced treatment

8.2 IPR projects in Southern California

8.2.1 Orange County, California: Water Factory 21

One of the most highly recognized and most regarded water purification facilities in the world of wastewater industry is Water Factory 21, a project built and operated by the Orange County Water District [OCWD]. It was the first project in California to treat wastewater water to drinking water standards. [Previous to this project, the secondary treated wastewater was discharged into the ocean]. The now advanced treated effluent is used as a hydraulic barrier against the intrusion of seawater into the local groundwater supply through injection into the local aquifer. This leads to IPR as the aquifer also serves as a drinking source. Since 1976, Water Factory 21 has been protecting the integrity of the large groundwater basin that serves north and central Orange County, while also helping to increase the reliability of the area's water supply. In

1977, a 0.2 m^3/s RO system was installed for the removal of salts and organics. Ammonia stripping was discontinued in 1999 and WF 21 was permitted to inject 100% reclaimed water.

The facility takes conventional secondary treated effluent [high rated processes: 20% trickling filters, 80% activated sludge] from their neighboring Orange County Sanitation District and provides additional treatment using traditional RO pretreatment [lime clarification, re-carbonation, mixed media filtration] after which two-thirds of the flow would pass through granular activated carbon and one third of the flow would pass though RO and chlorination. The combined effluent meets or surpasses all drinking water standards even before it is blended with water from other supplies and injected into the groundwater basin. After blending it totals to 1.0 m^3/s which, is used for the 23 multi-point-injection into four separate aquifers, which supplies 75% of the water needs for nearly 2 million people.

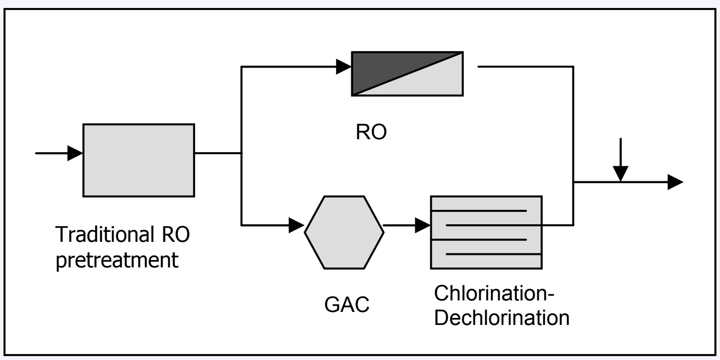

Figure 21: Process flow diagram of Water Factory 21

Table 15: MF and RO data WF 21

	MF	RO
type	Memcor CMF-S	Koch Fluid Systems 8832-HR polyamide
recovery	85%	85%
flux	41L/m^2hr	18/m^2hr
configuration	24x[6]	6 units [24-12-6] [6 elements per vessel]

8.2.1.1 Membrane pretreatment study at Water Factory 21

Water Factory 21 [WF 21] conducted an intensive research project in 2001 for their RO membrane pretreatment and pilot tested submerged MF, MF, and tubular UF. The objective was to determine the feasibility of each system for pretreatment, to establish design criteria and to demonstrate successful operation of the system at the established design criteria. Minimum design objectives demanded from the manufacturers were as follows:

- Test membranes must have been successfully tested at the Orange County Water District [OCWD][37]
- A minimum of 250 m^3/d capacity
- Ability to produce acceptable quality for the RO feed
- Minimum of a 3 week run between cleaning
- Ability to run 150% of the design flux for 48 hours [clean flux start]

The three tested systems were:

1. Vivendi/US Filter/Memcor Continuous Micro filtration-Submerged [CMF-S] System: 32 modules
2. Pall Corporation Microza Micro filtration Systems [Pall]: 50 modules
3. Zenon Environmental Systems Zeeweed Water Treatment System [Zenon] [UF]: 6 module cassette

The water for demonstration was activated sludge secondary effluent provided by the Orange County Sanitation District [OCSD], which was known to be of better quality than what the full scale facility would receive, making it imperative that the pretreatment systems would achieve the appropriate cleaning intervals. Feed water temperature varied between 22º C and 28.5º C. Table 16 through Table 18 show the water quality of the feed and the filtrate streams for each of the demonstration units during the testing.

Table 16: CMF-S filtrate

	Q1-feed			CMF-S filtrate		
Parameter	Turbidity	TSS	SDI	Turbidity	TSS	SDI
Unites	NTU	mg/L		NTU	mg/L	
Average	3.59	5.41	N/A	0.18	<1	1.52
Maximum	10.9	12.0	N/A	0.68	<1	3.56
Minimum	1.66	2.20	N/A	0.03	<1	0.13

Table 17: Pall filtrate

	Pall chlorinated 2^n effluent			Pall filtrate		
Parameter	Turbidity	TSS	SDI	Turbidity	TSS	SDI
Unites	NTU	mg/L		NTU	mg/L	
Average	3.52	5.41	N/A	0.15	<1	0.67
Maximum	12.2	12.0	N/A	0.93	<1	0.68
Minimum	1.31	2.20	N/A	0.06	<1	0.66

[37] The predecessor of WF 21

Table 18: Zenon filtrate

	Zenon chlorinated 2° effluent			Zenon filtrate		
Parameter	Turbidity	TSS	SDI	Turbidity	TSS	SDI
Unites	NTU	mg/L		NTU	mg/L	
Average	4.04	5.31	N/A	0.18	<1	1.97
Maximum	7.94	13.0	N/A	0.53	<1	5.50
Minimum	2.55	2.40	N/A	0.05	<1	0.23

In order to achieve at least 21-days between cleaning and being able to maintain operation during peak flow events [1.5 times the normal instantaneous flow], the tested samples produced the following results in Table 19. All three tested systems passed the test and the CMF-S System was elected on economical grounds.

Table 19: Test results WF 21 MF pilot testing

	CMF-S		Pall		Zenon	
	Normal flow	Peak flow	Normal flow	Peak flow	mid recovery	Peak flow
Duration [days]	28, 28	3, 3.5	19, 21	2, 7	25	2, 2.1
Recovery [%]	88	88	90	90	90	84
Instant filtrate flux [gfd]	20.4	30.6	21.4	36.1	18	27
Instant filtrate flow [gfd/module]	4.5	6.75	9	13.5	8.2	12.5
Backwash cycle [min]	22	22	22.4	20	9.5	9.5
Backwash duration [sec]	30	30	110	220	30	30
Backwash flow [gpm/module]	10.5	10.5	7	7	12.3	18.5

8.2.1.2 Groundwater Replenishment System

After 29 years of operation, Water Factory 21 has proven that advanced treated wastewater can successfully be treated to drinking water quality and can be used for injection into groundwater basins. Currently, under construction, the GWR System remodels the Water Factory 21 and increases the water-reclamation production with significant numbers [see Table 27] by treating wastewater to drinking water standards. The GWR System, scheduled to produce water in 2007, belongs to an overall plan to aid in preventing the predicted water shortages in Orange County. The Orange County Water District [OCWD] and the Orange County Sanitation District [OCSD] are developing the GWR jointly. After five years of planning and analysis, the GWR was determined to be the most economical and most feasible new water supply for the region.

With OCSD, secondary treated effluent as its influent, the GWR System would supply the additional contemporary advanced treatment [SMF-RO-UV/H202]. UV/H2O2 was chosen to comply with future NMDA regulations. The advanced treated water will then be conveyed to either:

- Existing spreading basins for percolation into and replenishing the groundwater supply
- Injection wells for a seawater intrusion control barrier

The Groundwater Replenishment System would be implemented in three phases, providing roughly 2.63 m^3/s of new water by the year 2003, 3.72 m^3/s by 2010, and up to 4.38 m^3/s by 2020.

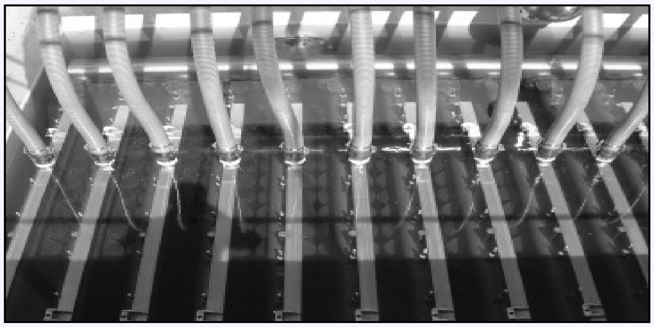

Figure 22: Inactive submerged MF modules at GWR System [picture by Harm Jansen]

For OCWD/OCSD, the PI&E effort has been and continues to be extensive. Outreach started with the public, politicians, and community leaders. Focus groups are used extensively to test program messages, which include: education approaches, phone conversations, survey questions, etc. Outreach channels include the GWR System's website, press releases, mail campaigns, tours and briefings, cable television ads, telephone surveys, focus groups, and legislative lobbying. Significant effort has been placed on identifying demographic sources of potential opposition.

Table 20: 2003 average NMDA concentrations at Water Factory 21

	Influent	Before UV	After UV	After mixing
NDMA [ppt]	33.2	252.3	7.8	4.8

Table 21: MF and RO data GWR System

	MF	RO
type	U.S Filter S10T sub-modules [15,000 hollow fibers] polypropylene	Hydranautics ESPA 2 composite polyamide
Recovery [%]	89	85
Flux [L/m^2hr]	34.4	--
configuration	Cell no. 1: 4 cloversx8x19 racks = 608 modules Cell no. 2: 4 cloversx9x19 racks = 684 modules	4 units [24-12-6] [6 elements per vessel]

8.2.2 Los Angeles County, California: West Basin Water Reclamation Project

The government owned West Basin Municipal Water District's wastewater reclamation facility in El Segundo, California has been privately operative since 1995. Reclaimed wastewater provides a variety of benefits for the West Basin service area, including irrigation, industrial use and injection for a seawater barrier. West Basin uses a combination of imported water and purified wastewater for the one-half mile long seawater barrier that encompasses over 100 injection wells to help protect the District's productive groundwater basin from seawater intrusion. The secondary effect of this practice is IPR as the by West Basin augmented groundwater basin also serves as a drinking water source.

Currently, 0.32 m^3/s of water that has been treated by micro filtration and RO processes provides high quality water, which is mixed with 0.45 m^3/s of imported water, which is supposed to improve the overall quality of the water mix in the groundwater basin that supplies the region's drinking water requirements. By 2006, the plant will expand to 0.55 m^3/s and eventually take full account for the 0.77 m^3/s needed for injection. The West Basin will implement UV disinfection in combination with H2O2 advanced oxidation in order to comply with the non-enforceable guidelines on NDMA. The West Basin claims that NDMA enters and leaves the plant in the same concentrations, but is elevated during treatment by the addition of chlorine and subsequently lowered by RO. UV treatment is 10 times more costly than disinfection alone.

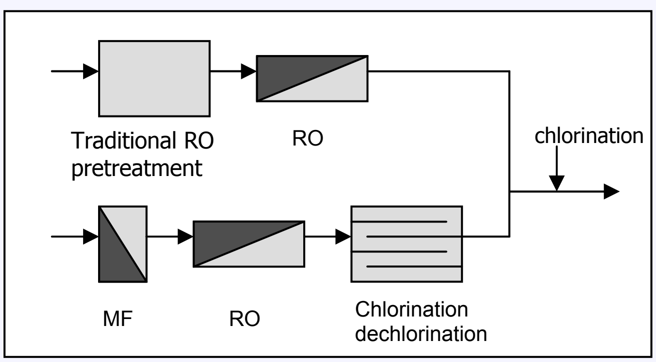

Figure 23: Process flow diagram of West Basin Water Reclamation Project

Table 22: Reverse Osmosis Membrane data West Basin

	RO
type	Unit 1 and 2: Hydranautics ESPA 2 Unit 3:Fluid Systems [Koch] 8822HR
recovery	85%
flux	16 L/m^{2}hr
configuration	Unit 1 and 2: [72:36:18] [6 elements per vessel] Unit 3: [60:36:120] [7 elements per vessel]

8.2.3 Los Angeles County, California: Montebello Forebay Groundwater Recharge Project

The Water Replenishment District [WRD] of Southern California operates the Montebello Forebay Groundwater Recharge Project, one of the oldest natural groundwater recharge sewer water projects in the nation. WRD has managed the project, which has been located in southeastern Los Angeles County since 1962. The San Jose Creek, Pomona, and the Whittier Narrows water reclamation plants provide traditional tertiary effluent, which underwent a change in 2003 [with addition of NDN] to comply with newly implemented nutrient regulations. Whittier Narrows was completed in 1962 as a result of a 1948 wastewater reuse study and is the first plant contributing to the Montebello Forebay basin.

The Montebello Project practices IPR by filtering an average of 1.97 m^3/s of advanced treated wastewater through 252 hectares of the Rio Hondo and the San Gabriel Spreading Grounds into the Los Angeles Central groundwater basin which serves as a drinking water source for 3.7 million people. This recycled water, which meets state and federal primary drinking water standards, makes up about 35 percent of the total recharge to the groundwater basin. Imported water purchased from the Metropolitan Water District of Southern California and storm water runoff make up the remainder of the water used to replenish the basin.

The Rand Corporation has conducted three epidemiological studies on the Montebello project. In two of the studies, health outcomes were examined for about 0.9 million people who receive water naturally filtered by the ground in their drinking water supply and compared to a group of about 0.7 million whose water supplies did not include the ground-filtered water. The conclusion reached by the Rand researchers was that there was no association between project water and any ill health effects, such as cancer, mortality, infectious disease, or adverse birth outcomes.

8.2.3.1 NDMA studies in Montebello Forebay

Typically, NDMA levels at the Montebello Forebay plants are well under 1000 ng/L but since July 2003, the levels have been greater than 1000 ng/L. The high NDMA levels coincide with the conversion to the Nitrification/De-Nitrification [NDN] treatment process, which was necessary in order to comply with the ammonia Basin Plan objectives. In addition, as a result of continuing work on enhancements for the NDN process, polymer usage has temporarily increased NDMA forming potential within the chlorine disinfection process. Measurements are taken to optimize the current polymer dosing system in an effort to lower NDMA effluent concentrations. Although the final effluent levels at the plants are higher than usual, attenuation of

NDMA within the Montebello Forebay is expected to occur as a result of photolysis and soil aquifer treatment.

Table 23: NDMA levels for Montabello Forebay WWTPs

	San Jose East		San Jose West		Whittier Narrows		Pomona	
	mg/L	ng/L	mg/L	ng/L	mg/L	ng/L	mg/L	ng/L
10-2003		2550		1290		260		410
11-2003		2400		1700	<5	190		150
12-2003		>1000		83		180		250
01-2004		1300		700		70		610
02-2004	<5	2200	<5	590	<5	170	<5	550
03-2004		>1000		>1000		110		420
04-2004		3300		1600		850	<5	520
05-2004		3000		1200	<5	170		460
06-2004		>1000		3700		100		610
07-2007		>1000		2300		230		610
08-2004	<5	>1000	<5	200	<5	240	<5	760
09-20004		4300		1000		340	<5	580

NDMA has been detected in five of the six monitoring wells in 2003 and 2004, with six detections above the Action Level [AL] of 10 ng/L at two monitoring wells. The data suggest that the October 2003 spike was temporary and that water quality levels are continuing to decrease. An investigation is underway to determine the cause of the high NDMA levels at these two wells. Beginning January 15, 2004 and continuing until the conclusion of the investigation, reclaimed water will not be diverted from the San Jose Creek Outfall for spreading to the San Gabriel Spreading Grounds.

Table 24: NDMA levels for Montabello Forebay production and monitoring wells

	10-2003	12-2003	02-2004	04-2004	06-2004	08-2004
Production well nr.						
2947LM	**--**	ND	--	--	3.2	--
Monitoring well nr.						
1582W	ND	ND	ND	ND	2.5	ND
1590AL	ND	ND	ND	ND	ND	ND
1612T	**170**	**25**	**12.7**	ND	ND	ND
1613V	ND	ND	ND	ND	2.3	ND
1620RR	**460**	**41**	**60**	ND	ND	ND

Figure 24: Montebello Forebay spreading basins [Rio Hondo]

8.2.4 San Bernardino County, California: Chino Valley Basin

In an effort to augment local stream and groundwater supplies, the Inland Empire Utilities Agency [IEUA] was formed in 1950 for the purpose of importing supplemental water from the Colorado River and other outside water supplies. Since its formation, the IEUA has expanded its services to include regional sewage treatment and the production of recycled water. Recycled water is treated through sand media filtration and is also exposed to chemical and UV disinfection.

The Chino Basin covers an area of about 600 km^2 of the upper Santa Ana River watershed and is one of the largest groundwater basins in Southern California. The basin contains about 6 km^3 of water, with an additional unused storage capacity estimated to be about 1.2 km^3. The average safe-yield of the basin has been set at 0.17 km^3 per year in the Chino Basin. This basin also functions as a drinking water source and recharging this basin with reclaimed water results in IPR. Other reclamation strategies by the IEUA offset an additional 1.3 and 1.8 m^3/s of potable water.

In an effort to meet growing demand, the IEUA has adopted water rates that provide an incentive for use of recycled water. IEUA produces recycled water that is used for groundwater recharge, industrial process water, and irrigation. Presently, about 15 percent of the 2.63 m^3/s of water currently generated by the agency's four wastewater treatment plants is reused locally each day.

8.2.4.1 <u>NDMA studies in Chino Valley basin</u>

The IEUA has a program of continuously evaluating changes to its wastewater treatment process in order to improve process operational efficiency and performance. Through this program, the IEUA has discovered that operating its activated sludge plants at very high mixed liquor suspended solids [MLSSs] concentrations and long solids retention times [SRTs] result in the removal of trace organics. The removals of trace organics have been investigated at the IEUA's RWRP-1, RWRP-2, and the Carbon Canyon facility and have included NDMA, diazinon, chlorpyrifos, and 17 beta-estradiol. The raw wastewater characterizations for NDMA in 2002 are presented in Table 25.

Table 25: NDMA levels for Chino Valley basin WWTPs, 2002

	RWRP-1			RWRP-1			Carbon Canyon		
10/01-02/02	min	max	avg	min	max	avg	min	max	avg
NDMA [ngL]	17	**180**	60	--	--	--	--	--	--

Table 26 presents the observed treated effluent concentrations for NDMA in 2003. The NDMA effluent concentration data collected by the IEUA is not considered sufficient to determine process removal rates.

Table 26: NDMA levels for Chino Valley basin WWTPs, 2003

	RWRP-1			RWRP-1			Carbon Canyon		
06/02/05-03	min	max	avg	min	max	avg	min	max	avg
NDMA [ngL]	2	79	12	4	5	4.5	2	10	6

8.2.5 Victorville, California: Victor Valley Water Reclamation Authority

The Victor Valley region is experiencing a surge in residential and business growth. Wastewater facilities had to expand to meet the demand of the growing population. Current projections show a shortfall of water and a need to expand wastewater facilities over the next 20 years. The Victor Valley Wastewater Reclamation Authority [VVWRA] augments local aquifers serving as drinking water resources and marginally supplies recycled water that is sold for irrigation, which off-sets imported potable water use.

The effluent is discharged in the Mojave River and to local recharge basins. The VVWRA practices IPR because both the Mojave River and the basins recharge to local aquifers that serve as drinking water sources. The Mojave River is low sub-surface flow river and recharges completely to the local aquifers 5 to 6 miles downstream from the point of discharge.

The VVWRA has undergone one major change. In 1998, the implementation of nitrogen removal through activated sludge in order to comply with current regulations. The plant has undergone several expansions since its initial construction in 1981 from 0.2 m^3/s to 0.50 m^3/s in 2002. An expansion to 0.64 m^3/s is under construction, while an expansion to 0.79 m^3/s is planned to start construction in January 2006.

Table 27: Overview of current indirect potable projects in Southern California

Plant name location	Year	Size	O&M	Technology	Type of IPR	Objective	Outcome
Water Factory 21 Fountain Valley, CA [Orange County]	1976	1.14 m^3/s IPR	0.41 usd/1000l	Lime clarification Re-carbonation Mixed media filtration GAC + Chlorination or: pH sulfuric acid + RO	Augmenting ground [drinking] water supply by direct ground water injection [to prevent sea water intrusion]	-Prevent sea water intrusion by deep well injection of advanced treated wastewater [while augmenting drinking water supplies]	-Water Factory 21 has demonstrated that highly treated reclaimed water can be used successfully for direct injection projects.
GWR System Fountain Valley, CA [Orange County]	2003-2020	2.63 m^3/s IPR	0.25 usd/1000l [phase I]	Submerged MF RO UV/H2O2	Augmenting ground [drinking] water supply by direct ground water injection [to prevent sea water intrusion]	-Phase II and III are scheduled to produce 3.73 m^3/s in 2010 and 4.38 m^3/s in 2020	TBD
West Basin El Segundo, CA [Los Angeles County]	1995	0.13 m^3/s other 0.33 m^3/s IPR		Lime clarification Re-carbonation MF RO Chlorination	Augmenting ground [drinking] water supply by direct ground water injection [to prevent sea water intrusion]	-Reduce the region's dependence on imported water induced by droughts -Increase portion of reuse for injection to 100% [765 m^3/s]	-1.53 m^3/s for 5 different reuse purposes of which 330 m^3/s for GW injection. -TBD
Montebello Forebay Natural GW Recharge Project Pomona, CA [Los Angeles County] [3 plants]	1962	1.98 m^3/s IPR	0.14 [East] 0.11 [West] 0.18 [Pomona] 0.32 [Whittier] usd/1000l	Primary sedimentation Nitrification-denitrification Secondary sedimentation Chlorination Alum Coag/flocculation Dual media filtration Dechlorination	Augmenting ground [drinking] water supply through a surface water recharge basin	-Replenish the Central Basin by developing a local water supply through reclaimed water	-No degradation of groundwater quality over 42 years while 30% of the recharge has been reclaimed water
Chino Valley Basin. Chino Hills, CA [San Bernardino County, CA] [5 plants]	1950	0.66 m^3/s IPR 2.63 m^3/s total		Primary sedimentation Nitrification-denitrification Secondary sedimentation Single media filtration Chlorination-dechlorination	Augmenting ground [drinking] water supply through a surface water recharge basin	-Meet growing demand and reduce dependency on imported water -Offset and additional 1,300-1.8 m^3/s in 10 years	-25% of the effluent of the 5 plants is reused locally -TBD

	Victor Valley Water Reclamation Authority. Victorville, CA	1981	0.50 m^3/s IPR	0.28 usd/1000l	Primary sedimentation Nitrification-denitrification Secondary sedimentation Alum Coag/flocculation Tertiary moving bed filters Dechlorination	Augmenting ground [drinking] water supply through a surface water recharge basin	-Meet growing demand and reduce dependency on imported water -Sell recycled water for cooling towers	-Expansions are in place and under construction -projects are being developed.

8.3 Failed IPR projects in Southern California

The following two projects have exemplified how IPR projects, when compared to other water supply and wastewater management options, can offer the greatest benefits for the least cost. At the same time, these same projects have confirmed how public involvement and education are indispensable components and instrumental in successful project development. For example, the East Valley Water Reclamation Project never completed its construction because of public outrage instigated by political figures and the San Diego Re-purification project had proceeded up to 30% of its design, but has been put off indefinitely because of policy and public perception issues raised by politicians.

8.3.1 Los Angeles County, California: East Valley Water Reclamation Project

In June 1990, the Los Angeles City Council adopted a goal of reusing about 40% of the City's wastewater by 2010. In response to this goal, the City's Department of Water and Power [DWP] began the development of the East Valley Water Reclamation Project [EVWRP]. The EVWRP was to have transported 1.4 m^3/s of de-chlorinated conventionally tertiary treated effluent from the Tillman Water Reclamation Plant and convey such through a 20-mile pipeline for groundwater recharge at the Hansen Spreading Grounds in the San Fernando Valley. Future planned industrial and irrigation uses were included. The volume was to be tripled when the project showed favorable monitoring results through its thorough well testing. This project was also part of a long-term effort to replace water supply which was lost as part of the Mono Lake case [also see 3.2.1].

EVWRP took an intensive approach in educating and informing the public. However, making the project details available to its potential users after conception was the indirect initiator to the public's outrage. Significant public opposition arose when local media, which initially supported the project, began using the phrase "Toilet to tap". The project was then used as leverage in mayoral campaigns and the then city attorney, James Hahn, suspended the project claiming that the DWP had been unsuccessful in sufficiently informing the public about its impending project and the possible health risks associated with it. Once Hahn was elected Mayor in 2001, he shut down the EVWRP, and despite a 40 year history of successfully replenishing groundwater with recycled water in the Los Angeles County Montebello Forebay area, the 55 million dollar project was also shut down completely after having produced a mere 80 m^3.

The project was wrongfully associated with environmental injustice claiming that the burden of reuse of water fell on the economically depressed San Fernando Valley. The city of Los Angeles currently considers adding groundwater recharge of recycled water as part of the recommended draft alternatives under the Integrated Resources Plan [IRP]. The city is required by the Clean Water Act to perform wastewater facility planning once every 10 years, which emphasizes water reclamation. A draft for review will be available in the summer of 2005. Adding groundwater recharge to their options will create the possibility for the EVWRP to be reinstated.

8.3.2 San Diego, California: San Diego Water Re-purification Project

One place where water reclamation could help clear the pressures of growth is the arid San Diego, which imports 90 percent of its water. The City of San Diego had proposed, in conjunction with the San Diego County Water Authority [SDCWA] and the US Bureau of Reclamation, one of the largest potable uses of recycled water in the nation--the San Diego Water Re-purification Project.

This project would achieve IPR of recycled water from the San Diego's North City Water Reclamation Plant [NCWRP] [also see 8.6]. The Advanced Water Treatment Plant [AWTP] would treat conventional treated tertiary effluent from the NCWRP using a treatment process train including MF, RO, Ion exchange, and ozonation. The advanced treated effluent from NCWRP would augment imported supplies in the city's San Vicente reservoir for a retention time of one year. The augmented water from San Vicente Reservoir would then be conveyed to the Alvarado Filtration Plant prior to being discharged to the San Diego's potable water distribution system. It was proposed to reach its customers by the end of 2005.

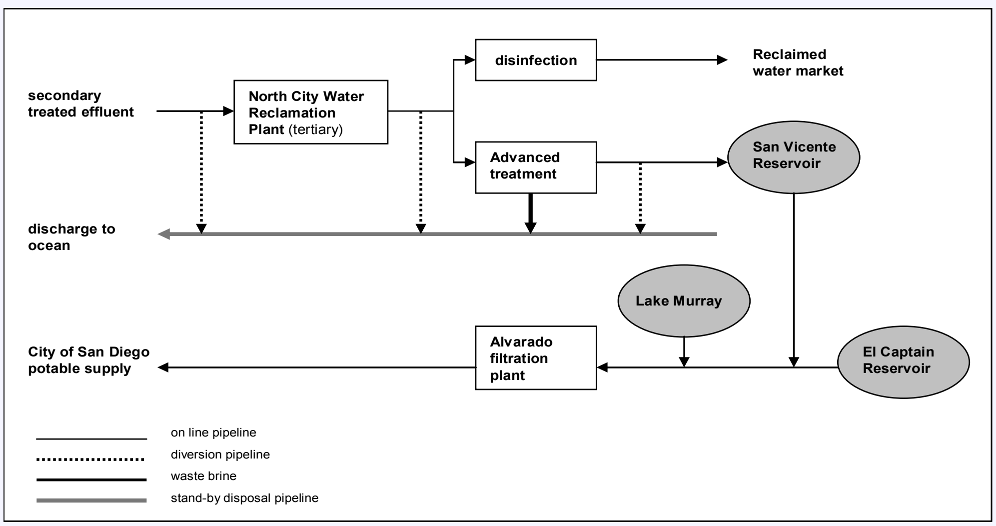

Figure 25: Schematic overview of the SDWRP

The project was introduced to the community as a means of protecting the city from potential future droughts. The San Diego City Council and the San Diego County Water Authority understood the significance of public acceptance and, therefore, created an inclusive research project to better understand the public's compliance with recycled water use and to recognize potential issues that needed to be addressed[38]. The City of San Diego presented their water re-purification project proposal to an independent advisory panel and a public review committee to further assure public acceptance. In both cases, it was concluded that recycled water was a viable option and would supply a much-needed alternative water source to the region. Additional public outreach included brochures, video presentations, feature stories in the news and other media outlets, and a telephone inquiry line.

[38] Katz & Tennyson, 1997

The project received strong support from the public but became entangled in a political campaign. This campaign claimed that the city intended to treat wastewater from the more affluent communities to distribute as drinking water among those less fortunate. Health dangers from the project were specifically highlighted. The State Department of Health Services subsequently called a hearing for the project to which hundreds of worried residents turned up. The public had been exposed to negatively advertised posters stating the motto "Toilet to Tap" and the project was eventually put on indefinite hold by the city of San Diego.

8.3.2.1 San Diego, California: Advanced Water Treatment Pilot Plant[39]

The City of San Diego is currently pilot-testing two different UF membranes, four different RO membranes and a UV light on tertiary effluent from the NCWRP. This testing will help clarify water quality, membrane integrity and UV dosing issues. The basic treatment train being evaluated consists of tertiary effluent treated by either UF or MF and followed by RO and H2O2/UV. The peroxide and UV light are combined to perform advanced oxidation, which is very similar to what Orange County is practicing. The UV light being tested is a low-pressure, high output lamp.

The pilot work is being performed by MWH Americas, Inc. as three separate research projects for the City of San Diego. Two of the projects are partially funded by the California Department of Water Resources and the San Diego County Water Authority. These three projects are:

- Reverse Osmosis Membrane Integrity
- Long Term Testing of New Generation RO Membranes and Determination of Removal Efficiency for Recycled Water Contaminates[40]"
- Impact of UV on Emerging Contaminates

These projects, which include literature review, bench scale testing, columinated beam testing, analysis, and final reports are scheduled for completion in October 2005. Interim data from these projects were provided as information for the Water Reuse Study Independent Advisory Council in May 2005. Encouraging results are an incentive for the San Diego Water Re-Purification Project to be reinstated.

[39] By Bill Pierce, City of San Diego Water Research Manager,04-05-2005
[40] NDMA, EDC and pharmaceuticals

Table 28: Overview of proposed IPR projects in Southern California

Plant name location	Year	Size	O&M	Technology	Type of indirect potable	Objective	Outcome
East Valley Water Recycling Project Los Angeles, CA	1995	2.0 m^3/s IPR	0.08 usd/1000l	Primary sedimentation Nitrification-denitrification Secondary sedimentation Alum Coag/flocculation Rapid sand filters Dechlorination	Augmenting ground [drinking] water supply through a surface water recharge basin	1.4 m^3/s for ground water recharge by 1999 [including irrigation and industrial use]	Put on indefinite hold due to public opposition
San Diego Water Re-purification Project San Diego, CA	1985	0.94 m^3/s IPR 1.0 m^3/s total	0.47 usd/1000l	Lime clarification Re-carbonation MF RO Chlorination	Drinking water reservoir augmentation	Operate a full-scale plant supply by 2005 and provide a quality of water sufficient to raw water	Water quality surpassed quality of imported water, yet project was put on indefinite hold in 2003 due to political controversies.
Advanced Water Treatment Pilot Plant San Diego, CA	2005	--	--	UF or MF RO UV/H2O2	N/a	Clarify water quality, membrane integrity, and UV dosing issues	TBD

8.4 IPR projects in Arizona and Florida

Other areas in the US in which IPR projects are in production and commonly more accepted are either impacted by arid conditions, a rapid growing population, or depleting aquifers due to an increased potable water demand. This is mainly the case in Florida and Arizona.

Florida's flat topography gives little opportunity to hold water as a supply source. While some of the rainfall percolates into the groundwater and enhances the groundwater level, the majority of the rainfall after evaporation results in run off and eventually flows to the ocean. This water supply problem is further compounded by the additional influx of new residents, which has increased 24 percent in the past 10 years[41]. In addition, the new population settles in the coastal regions were groundwater supply is scarce due to salt-water intrusion.

Arizona, at the other hand, is arid and has very little natural water resources and demand for water continues to rise. Between 1990 and 2000, it has experienced a 40 percent population growth rate, which is three times the national average. Both states have extensively increased water reclamation. Next are the most prominent projects, which have been surveyed.

8.4.1 Scottsdale, Arizona: City of Scottsdale Water Campus

Scottsdale, located in the desert of Arizona, has no natural surface water resources and relies on their ground water supply as a drinking water resource. Historically, the city has treated and disposed their wastewater. However, it was confronted with several water management problems due to a rapidly increasing population. It was being charged for its wastewater disposal and because its sewerage system needed upgrading. When the city also experienced a decrease in their ground water supply and fell subject to the passing of the Groundwater Management Act [GMA 1980], which mandated water lost by the city to be replaced, it was forced to explore alternative venues. GMA gave credits when groundwater was recharged and Scottsdale subsequently developed the Scottsdale Water Campus to treat wastewater to acceptable standards required for groundwater recharge.

Since 1998, the Water Campus has produced 0.53 m^3/s of highly treated wastewater through traditional tertiary treatment [see Figure 18] with recently installed disk filters for anthracite filters and chloramines disinfection, which effluent is primarily used for golf course irrigation. When irrigation is reduced in the winter, 0.45 m^3/s undergoes contemporary advanced treatment [see Figure 20] at the Scottsdale Water Campus where MF and RO treat the water to meet or surpass drinking water standards. Pretreatment to the MF consists of 400-micron screens and ammonia is added to tertiary effluent to ensure that the membranes are not exposed to free chlorine. This final effluent is subsurface recharged through 27 vadose zone wells to an aquifer, which serves as a drinking water source. Subsequently, this brings IPR into effect. Imported water [CAP water[42]] is being used for recharge during the summer months and treated by MF only. The Water Campus is currently being expanded to 0.88 m^3/s in order to maintain a balanced water supply for

[41] William H. Frey and Dowell Myers' analysis of Census 2000; and the Social Science Data Analysis Network [SSDAN]
[42] Arizona Department of Water Recourses: Central Arizona Project [CAP]: The reclamation project and works authorized to bring about 1.5 million acre-feet of Colorado River water per year to Pima, Pinal and Maricopa counties

which it is considering using the in situ tested Koch Membrane Systems MegaMagnum® RO Elements [see 7.5.5.3] to save floor space.

Table 29: MF and RO configuration Scottsdale Water Campus.

	MF	RO
Type	U.S Filter 90M10C	Koch Fluid Systems 8832-HR polyamide
recovery	--	85%
flux	41L/m^{2}hr	18L/m^{2}hr
configuration	24x[6]	14x[24-10-5]

NDMA and perchlorate are contaminants that are a concern in Scottsdale and to prepare for this, the Water Campus is involved in several research projects covering the spectrum of emerging contaminants under scrutiny today. A future proposed solution is the addition of UV disinfection to the advanced treatment. Salinity will become another future regionally binding issue as the increasing population stresses traditional supplies to meet demands results in brackish groundwater and reclaimed effluent. Brine disposal issues are already present at the Water Campus and the Central Arizona Salinity Study [CASS] has entered a phase in which it attempts to develop solutions.

8.4.1.1 NMDA at Scottsdale Water Campus

NDMA sampling at the Scottsdale Water Campus started in 2001 and had no showing initially. NMDA showed concentrations of 6 and 30 ppt at wells near the recharge site. NMDA has not shown up since 2004 in the remaining 2 wells. No reason for the coming and going of NDMA has been found yet.

8.4.2 Tucson, Arizona: Roger Road Wastewater Plant & Tucson Water's Filtration Plant

The recycled water treatment process begins at Pima County's Roger Road Wastewater Treatment Plant [WWTP]. Part of its effluent is conveyed to the Tucson Water's Filtration plant for advanced treatment. This water passes through pressure dual media [sand and coal] filters, sand filtration and is disinfected with chlorine. It is then stored in a reservoir for Soil Aquifer Treatment [SAT] and is recovered through wells. It is mixed with the Roger Road WWTP's effluent to guarantee that the recycled water meets standards set by the Arizona Department of Environmental Quality before it is delivered for irrigation to its customers. The Roger Road WWTP uses traditional secondary treatment with bio trickling towers as their high rated process to comply with the newly enforced 2004 nutrient restrictions. Its final reclaimed effluent undergoes additional de-chlorination for discharge to the Santa Cruz River to preserve aquatic species. This river recharges an aquifer that is used as a drinking water resource, resulting in unplanned IPR.

In 1991, the city of Tucson established the right to own 90% of the Roger Road WWTP's effluent. At that time, this effluent was already known to be an important commodity. The city's department, Tucson Water, is considering IPR in the next 20 years by treating this effluent with a new full-scale contemporary advanced treatment facility [MF/RO/UV] and groundwater recharge. This is proposed in order to meet their predicted water needs in 2040 as is stated in their Water Plan 2000-2050. Tucson Water has expanded their intensive public outreach program and will involve the general public from initiation in the development of IPR options. Emphasis lays on educating the public to increase the awareness of future water shortages. No pilot testing as of today has been conducted. Future location of the new facility will most likely be near the Roger Road WTF premises.

Figure 26: Trickling Bio towers at Roger Road WWTP [picture by Harm Jansen]

8.4.3 Mesa, Arizona: Northwest Water Reclamation Plant [NWWRP]

The Northwest Water Reclamation Plant uses traditional secondary and tertiary treatment [no disinfection is required] to achieve their final effluent. This effluent is discharged to percolation ponds totaling 102 acres and recharging the local aquifer. When the discharge exceeds the holding capacity of these ponds, the effluent is discharged to the Salt River and UV disinfection will be used in order to comply with their NDPES permit.

Mesa's NWWRP currently produces approximately 0.40 m^3/s of reclaimed water. Mesa's NWWRP direct uses for recycled water are supposedly limited to non-potable water purposes, such as irrigation and industrial uses because the Mesa's public's acceptance of IPR is known to be extremely low. Although not explicitly acknowledged by the NWWRP, IPR does take place through the means of recovering groundwater from its by NWWRP augmented aquifer for drinking water purposes. NWWRP is rewarded with Long Term Storage Credits [GMA] for this aquifer recharge. These credits are recovered when water is extracted from the same aquifer after a retention time extending one year. Mesa has approximately 0.03 km^3 of Long Term Storage Credits for its injected recycled water.

Mesa recently signed an agreement with the Gila River Indian Community through which Mesa will ultimately deliver 0.035 km^3 per year of recycled water to the Gila River Indian Community and in exchange will receive 0.028 km^3 per year of CAP water. This agreement allows Mesa to exchange what was essentially a non-potable water supply for a potable supply.

8.4.4 West Palm Beach, FL: Wetlands Demonstration Project

The demonstration advanced wastewater treatment facility called the Wetlands Demonstration Project was constructed and managed at the East Central Regional Wastewater Treatment Plant [ECRWWTP] to demonstrate that wetlands in Southeast Florida can provide additional treatment of a high quality, advanced wastewater treatment effluent and to determine the optimal design for full-scale implementation of a wetlands based water reclamation program for planned IPR. The treatment processes of the AWT Demonstration Plant are designed to remove suspended solids and total phosphorus [TP] using coagulation in a solids contact clarifier, filtration and biological de-nitrification using attached growth in a de-nitrification filter [DNF] and disinfection by free chlorine contact. It was proposed that a combined membrane process train involving MF followed by RO could serve as alternative technology.

It was recommended to ECRWWTP to utilize traditional AWT instead of MF/RO [even though MF/RO did achieve lower concentrations for most parameters]. This was recommended mainly because of the substantially higher capital and O&M costs [224%] involved with MF/RO. These additional costs were not deemed necessary because both processes are expected to meet anticipated regulatory standards especially since Soil Aquifer Treatment [SAT] was involved in the process as well. UV was favored over chlorination/de-chlorination as a disinfection process. Non-quantitative factors, such as liability and safety concerns involved with chlorine outweighed the slight economical disadvantage of UV.

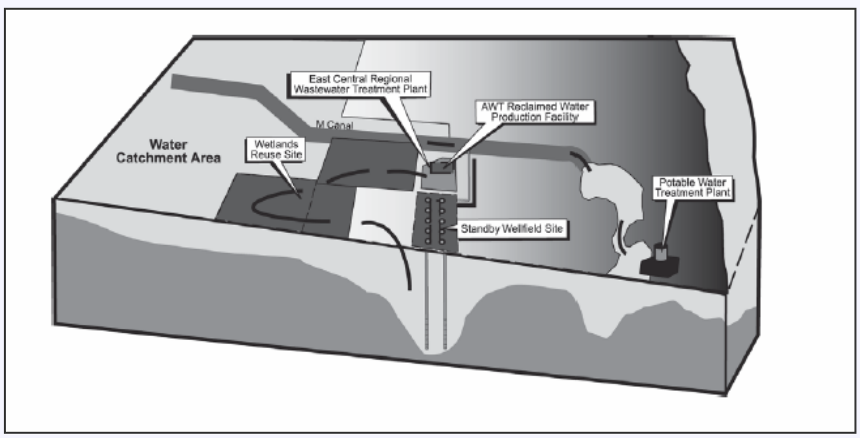

Figure 27: Wetlands Demonstration Project

Side by side operations of the two treatment trains allowed a performance and cost evaluation of the two treatment alternatives. Similarly, Ultraviolet Light [UV] was proposed as an alternative disinfection method for wastewater. Again, the parallel treatment process operation of UV disinfection with free chlorine disinfection allowed a cost and performance comparison. After travel through the wetlands, the water will be pumped to the City of West Palm Beach's well field where it will be recovered and pumped into the M-canal and eventually flow to the City Drinking Water Treatment Plant.

Table 30: Overview of IPR projects in the remainder of the United States

Plant name Location	Year	Size	O&M	Technology	Type of indirect potable	Objective	Outcome
City of Scottsdale Water Campus Scottsdale, AZ	1998	0.44 m^3/s IPR 2.7 m^3/s total	0.15 usd/1000l	MF RO Cl	Augmenting ground [drinking] water supply through vadose zone wells	Recharging to supply increasing demand and to comply with GMA	Water Factory 21 has demonstrated that highly treated reclaimed water can be used successfully for direct injection projects
Pima County's Roger Road Wastewater Treatment Facility Tucson, AZ	1983	0.38 m^3/s IPR 1.8 m^3/s total		Clarification Trickling bio filters Pressure filters Chlorination	Augmenting ground [drinking] water supply through vadose zone wells		
Northwest Water Reclamation Plant Mesa, AZ	1990	0.79 m^3/s IPR	0.16 usd/1000l	Secondary treatment with activated sludge Nitrification/de-nitrification Sand filtration Chlorination or UV	Stream augmentation [aquifer recharge], Augmenting ground [drinking] water supply through vadose zone wells	Maintain a 100-year water supply requirement for development	On schedule
East Central Region WWTP, West Palm Beach, FL	2003	0.44 m^3/s 2.4 m^3/s total	0.15 usd/1000l [RO] 0.10 usd/1000l [AWT]	De-nitrification Flocculation Clarifier Bridge sand filter UV	Augmenting ground [drinking] water supply through wetlands supplementation	Restore 1,400 acres of wetlands and recharge the city's adjacent well field	Wetlands habitat stabilized

8.5 Failed IPR project in Florida

8.5.1 Tampa Water Resource Recovery Project

Originally introduced in 1982, the concept of discharging highly treated wastewater into the Tampa Bypass Canal, which would eventually enter the potable water source, moved to the research stage. A pilot plant was constructed in 1984 to explore four different supplemental treatment regimes. The City of Tampa, the Florida Department of Environmental Regulation and the West Coast Regional Water Supply Authority, now Tampa Bay Water, conducted the four-year research project as a joint effort, which ran from 1987 through 1989.

The pilot plant facility's three processes that were evaluated each included traditional RO pretreatment [lime treatment, re-carbonation, and multi-media filtration]. This was followed by either granular activated carbon [GAC], RO, or ultra filtration [Figure 28]. All three processes were disinfected with ozone. The influent water for the pilot plant was withdrawn downstream from the Howard F. Cullen Advanced Wastewater Treatment Plant before chlorination. Applying the supplemental treatment to the denitrified, un-chlorinated effluent, rather than to the chlorinated effluent, provided a lower concentration of chlorinated organic compounds in the pilot plant's influent. This in turn limited the damage to the RO membranes by chlorine.

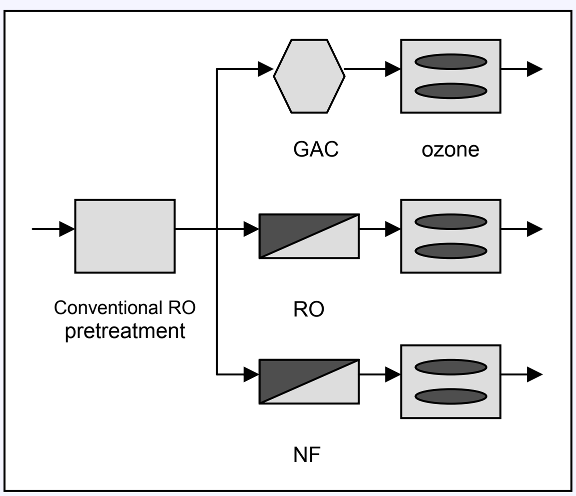

Figure 28: Process flow diagram Tampa Water Resource Recovery Project

Based on this research, the City of Tampa continued through the period of 1992-1998 with engineering feasibility studies of the Tampa Water Resource Recovery Project [TWRRP]. This project was expected to contribute approximately 1.5 m^3/s to the potable water supplies. Ecosystem Team Permitting then produced a draft permit for the project.

The plan received an official clean bill of health and the required permit, but it encountered public opposition [much of it from Pinellas County] that it could not survive. TWRRP was indefinitely postponed in a landmark decision when the Tampa Bay Water Board of Directors selected a 1.1 m^3/s desalination plant, the largest in the Western Hemisphere, and a reservoir in Hillsborough County as the future water sources to be pursued. The desalination plant has been off line for several months due to the clogging of the membranes by minuscule Asian green muscles. The membrane manufacturer blamed improper pretreatment as the cause.

Table 31: Overview of the Proposed IPR project in the remainder of United States

Plant name location	Year	Size	O&M	Technology	Type of indirect potable	Objective	Outcome
Tampa Water Resource Recovery Project Tampa, FL	1987	1.5 m^3/s IPR	GAC/O3: 0.20 usd/1000l [20 mgd] 0.15 usd/1000l [50 mgd]	Pre-aeration Lime clarification Re-carbonation Filtration RO or UF or GAC Ozone	Surface water augmentation	Contribute approximately 1.5 m^3/s to potable water supplies	Project was feasible, but was turned down by public opposition. 1.1 m^3/s Desalination plant was constructed instead.

8.6 Established NPR projects in the United States

Several Non-Potable Reuse [NPR] projects have been surveyed to complete the overview of water reclamation in the United States and to put IPR in perspective. Some of these plants are world renowned for their water reclamation, whereas others are considering IPR in the future.

8.6.1 San Diego, California: San Diego's North City Water Reclamation Plant

The North City Water Reclamation Plant [NCWRP] is the first large-scale water reclamation plant in San Diego's history and part of the single largest sewerage system expansion in the area in more than 35 years. This state-of-the-art facility can treat up to 1.3 m^3/s of wastewater, which is generated by Northern San Diego communities. Wastewater entering the plant undergoes primary and secondary sedimentation, tertiary filtering and chlorination, before it supplements the water supply of the region reserved for irrigation and industrial purposes. The City of San Diego is planning to use the tertiary effluent for advanced treatment for IPR [see 8.3.2].

8.6.2 San Jose, California: San Jose/Santa Clara Water Pollution Control Plant

The San Jose/Santa Clara Water Pollution Control Plant is one of the largest advanced wastewater treatment facilities in California. It treats and cleans the wastewater of over 1,5 million people in and around San Jose. The Water Pollution Control Plant has the capacity to treat 7.3 m^3/s of wastewater. It is located at the southern most tip of the San Francisco Bay. Originally constructed in 1956, the Plant had the capacity to treat 1.6 m^3/s and only provided primary treatment. In 1964, the Plant added a secondary treatment process to its system. In 1979, the Plant upgraded its wastewater treatment process to an advanced tertiary treatment system.

8.6.3 Malibu, California: Tapia Water Reclamation Facility

With no local water, Las Virgenes Municipal Water District provides 100% of potable supplies with water purchased from Metropolitan Water District [MWD]. The Las Virgenes Reservoir is filled with MWD supplies during periods of low demand and holds up to a six-month supply for emergency backup. Las Virgenes has long been active in promoting the use of recycled water to irrigate community and commercial green spaces. Recycled water from the district's Tapia Water Reclamation Facility has reduced demand for imported potable supplies by 20%. Comprehensive and innovative conservation programs have further contributed to reducing water use. Known for its environmental stewardship, the district is realizing its goal of total beneficial reuse of waste products with its composting facility. This facility also transforms bio-solids into rich garden compost and uses methane gas from bio-solids digestion to generate electricity, using fuel cells.

The discharge of the Tapia Water Reclamation Facility in the otherwise dry Malibu Creek has established an ecosystem, which the facility is now mandated to maintain. Stricter regulations regarding nitrogen concentrations have resulted in the recent implementation of a Nitrification/De-Nitrification treatment component.

8.6.4 St Petersburg, Florida: Water Reclamation System

St. Petersburg’s Water Reclamation System is not only the first to be built in the United States, but also remains one of the largest in the world. The city's innovative system provides more than 1.6 m^3/s to 10,483 customers for lawn irrigation. Reclaimed water is also an integral part of the city's overall water conservation effort. The initial reclaimed water distribution system, constructed in 1977, was limited to serving golf courses, parks, schools, and large commercial areas. Extensive biological research through the late 1970s and early 1980s resulted in approval by Florida Department of Environmental Protection [FDEP] and the Environmental Protection Agency [EPA] for the expansion of the reclaimed water system into residential areas. In 1986, a $10 million expansion system was completed to include service to a limited number of residential and commercial sites. Continued expansion of the reclaimed water system has significantly contributed to reducing potable water demands and made St Petersburg the largest community in the United States to achieve a zero-discharge into surface waters.

Excess reclaimed water is deeply injected through 10 injection wells into a saline zone. It was hoped for that the injected non-salient reclaimed water would form a bubble due to its buoyancy in the salient aquifer, such that it could be extracted in for [indirect potable] reuse if needed in the future. It was, however, observed that even after several years of injection there was still a mixture of reclaimed and saline water present and no water lens had formed.[43]

8.6.5 APRICOT Project, Florida: Regional Water Reclamation Facility

The Altamonte Springs Regional Water Reclamation Facility [RWRF] is a 0.55 m^3/s tertiary wastewater treatment facility accepting domestic sanitary sewage from the city, as well as neighboring municipal collection systems. Current flow averages 0.26 to 0.28 m^3/s. Primary treatment is accomplished with coarse screening, grit removal, fine screening, and primary clarification. Secondary treatment achieves biological nitrogen removal through the use of anoxic and aerated zones. Secondary clarification is followed by alum addition, flocculation, and denitrifying deep bed filters. The effluent is then re-aerated, disinfected, and passed on to a low-head transfer pump facility.

APRICOT [A Prototype Realistic Innovative Community Of Today] is the name given to the city of Altamonte Springs’ public-access reuse system. Collectively, it refers to the city’s tertiary wastewater treatment plant. On average, APRICOT delivers annually about 94 percent of its treated domestic wastewater for residential and commercial irrigation, cooling tower make-up, other commercial applications, and aesthetic uses. On a daily basis, between 0 percent and 175 percent of the domestic sanitary sewage flow is reused.

[43] Water Conservation, Reuse, and Recycling: Proceedings of an Iranian-American Workshop [2005]

8.6.6 Orange County, Florida: Eastern Water Reclamation Facility

Orange County Utilities [OCU], FL operates three major water reclamation facilities: the Eastern Water Reclamation Facility [EWRF], Northwest Water Reclamation Facility [NWRF], and South Water Reclamation Facility [SWRF]. These facilities serve the wastewater treatment needs of approximately 250,000 people within service areas totaling about nearly 2000 km^2. OCU's water reclamation facilities treat and reuse approximately 1.8 m^3/s wastewater. The total bio-solids production at OCU's water reclamation facilities is approximately 30 dry tons per day [200 wet tons per day].

The South Water Reclamation Facility [SWRF], with a design capacity of 1.35 m^3/s, is the largest of three water reclamation facilities owned and operated by Orange County Utilities [OCU]. The SWRF provides wastewater treatment for a service area that encompasses most of Orange County south of the city of Orlando. Effluent from the SWRF is reused in several ways, including groundwater recharge by rapid infiltration basins [IPR is not practiced as the ground water basin is not used as a drinking water source], citrus irrigation, and urban reuse. Because of these effluent reuses, the facility is required to meet Florida standards for both unrestricted reuse and groundwater recharge—5 mg/L total suspended solids [TSS], 10 mg/L nitrate nitrogen, and high level disinfection. The plant is also required to remove viruses and to limit the effluent concentration of numerous constituents to satisfy quality requirements stipulated in contracts with citrus growers.

Table 32: Overview of established non potable reuse projects in the United States

Plant name location	Year	Size	O&M	Technology	Type of non potable	Objective	Outcome
San Diego's North City Water Reclamation Plant San Diego, California	1997	1.3 m^3/s	--	Primary sedimentation NDN aeration Secondary sedimentation Tertiary filters Chlorination	Commercial irrigation and industrial	Supplement water supply	--
San Jose, California: San Jose/Santa Clara Water Pollution Control Plant	1956 1979 [tertiary upgrade]	7.3 m^3/s	--	Primary sedimentation NDN aeration Secondary sedimentation Tertiary filters Chlorination	Supplement to San Francisco Bay	Water pollution control in the San Francisco Bay	Below required limits
Tapia Water Reclamation Facility Malibu, California	1972	0.42 m^3/s	0.64 usd/1000l	Primary sedimentation NDN activated sludge Secondary sedimentation Tertiary filters Chlorination	Irrigation and stream flow maintenance	-Treat local wastewater to high quality recycled water -Beneficial use, limited water resources, and reduce local dependence on imported water	--
Water Reclamation System St. Petersburg, Florida [4 plants]	1977	1.8 m^3/s	0.23 usd/1000l	Preliminary Primary sedimentation NDN activated sludge Secondary sedimentation Coagulation/flocculation Tertiary filters Chlorination	Deep injection Residential and agricultural irrigation Toilet flushing	Supplement water supply to account for increase usage.	Stabilized potable water use despite increase in total usage
Regional Water Reclamation Facility Apricot Project, Altamonte Springs, Florida	?	0.44 m^3/s	--	Preliminary Primary sedimentation NDN aeration Secondary sedimentation Coagulation/flocculation Tertiary filters Chlorination	Residential and commercial irrigation	Supplement water supply to account for increase usage	--

	Eastern Water Reclamation Facility Orange County, Florida [SE and SW]	1986	1.35 m^3/s [0.41 m^3/s + 0.94 m^3/s]		Primary sedimentation NDN aeration Secondary sedimentation Tertiary filters Chlorination	Groundwater recharge [non potable] Urban and commercial irrigation	Supplement water supply to account for increase usage	Stabilized potable water use despite increase in total usage.

9.0 Established non-surveyed IPR and DPR Projects

9.1 United States

The following projects have not been surveyed yet do practice IPR in the United States. These projects are either milestones in IPR or are established in practicing IPR. They are not located in the California, Arizona, or Florida where IPR is predominantly practiced, but be worthy of referencing. A brief overview of each plant follows, while their characteristics are listed in the table at the end of this section.

9.1.1 Chanute, Kansas

In the summer of 1956 the Neosho River ceased to flow, which threatened Chanute's drinking water supply. The city considered several alternative sources and decided to re-circulate treated sewage, and on October 14, 1956 through March 1957, without public announcement, the city opened the valve permitting the mixing of treated sewage with water stored in the river channel behind the water works dam.

Further precautions were required, including the chlorination of the sewage treatment plant effluent, re-chlorination of raw water, installation of a continuous chlorine residual recorder at the softening plant, and more frequent sampling. The treated water had a pale yellow color and an unpleasant musty taste and odor. Initial public acceptance was good but gradually changed when stories appeared in the local paper. There were no known cases of adverse health effects

9.1.2 El Paso, Texas: Hueco Bolson Recharge Project

In order to decrease the rate at which the drinking water resources of the Hueco Bolson aquifer were being depleted, the El Paso water utilities had considered to artificially recharge the aquifer with tertiary treated wastewater effluent from the Fred Harvey Water Reclamation Plant. The Hueco Bolson aquifer provides 65 percent of the municipal water supply of El Paso and, injected into the aquifer, has been in effect since 1985. The recycled water meets drinking water standards before it is injected. Its residence time in the aquifer is estimated to vary between 5 and 15 years.

With a capacity of 0.53 m^3/s, the facility provides primary sedimentation, biological secondary treatment, lime treatment, filtration, and ozonation. The effluent is finally passed through Granular Activated Carbon filters to provide polishing before storage and injection. The cost of the injected water was estimated at 782 USD per km^3. in 1992.

Before the recharge project, water table levels were dropping at a rate of 0.5 to 2 meters per year because groundwater was being pumped at a rate 20 times faster than the aquifer's natural recharge rate. By 1990, the water level in the aquifer had risen 2.5 to 3 meters, which is higher than they would have been without the aquifer recharge project. Irrigation and industrial customers were subsequently added to the project.

9.1.3 Denver Potable Water Reuse Project

Denver began investigating the concept of IPR in 1968 and initiated a pilot plant [1970-1979], which was the precursor for The Denver Potable Water Demonstration Project This project evaluated the feasibility of Direct Potable Reuse [DPR] of secondary-treated municipal wastewater in 1985 with a multi barrier demonstration plant. It capitalized on a pilot plant from 1970-1979. Its influent was the Denver Metropolitan Wastewater Reclamation District's regional wastewater treatment facility's effluent, which was not nitrified.

The processes included high-pH lime treatment, sedimentation, re-carbonation, filtration, UV, carbon adsorption, RO, air stripping, ozonation, chloramination, and UF. Various configurations of the multiple-barrier redundancy approach were used to produce a highly reliable effluent, which met or exceeded Denver's drinking water standards for almost every contaminant. A health effects study was conducted and concluded that no adverse health effects were detected from lifetime exposure to any of the samples.

9.1.4 Fairfax, Virginia: Upper Occoquan Sewage Authority [UOSA] Reclamation Plant

The UOSA plant discharges its effluent to its own reservoir. From there, the water flows to a tributary channel of the Occoquan Reservoir, a principal water supply source for approximately one million people in Northern Virginia, located about 20 river miles upstream of the water treatment plant intake.

The UOSA Plant was originally created in 1978 to eliminate pollution of the Occoquan Reservoir by 11 small sewage plants. However, because of the highly reliable technology and the high quality produced water, regulatory authorities endorsed UOSA's request for expansion, in order to increase the yield of the reservoir. During normal precipitation, the UOSA effluent consists out of five percent of the total inflow to the reservoir, with significantly higher percentages during times of drought.

The Water Reclamation Plant consists of traditional primary and secondary treatment, high pH chemical treatment, two stage re-carbonation with intermediate settling, multimedia filtration, carbon absorption, ion exchange, and breakpoint chlorination. The initial capacity of 0.45 m^3/s has been increased to 1.4 m^3/s, making the 11 sewer plants obsolete. A $200 million expansion to 2.4 m^3/s is currently underway. In addition, the UOSA recycled water is now an essential part of the water supply strategies for the Washington metropolitan area.

9.1.5 More IPR projects operating successfully throughout the United States

The Clayton County Water Authority operates a land application system that has served the southern metropolitan Atlanta area for more than 20 years. Approximately 0.66 m^3/s is treated by this system and is discharged into nearby forestlands. The water percolates through the soils and flows into a creek that feeds a water supply reservoir for the area.

Since 1987 in suburban Dallas, the North Texas Municipal Water District operates an advanced wastewater treatment plant that has produced up to 1.1 m^3/s of water treated for return to the local watershed. The highly treated water flows into a lake which provides the influent to a drinking water facility serving the entire district.

Table 33: Overview of other non surveyed IPR projects

Plant name location	Year	Size	Cost	Technology	Type of IPR/DPR	Objective	Outcome
Chanute, Texas	1956	--	--	Extra chlorination	DPR	Supply local water supply	No adverse health effects
Hueco Bolson Recharge Project El Paso, Texas	1985	0.53 m^3/s	--	Sedimentation primary Biological secondary Lime clarification Filtration Ozonation GAC Chlorination	Augmenting ground [drinking] water supply by direct ground water injection	Protect Hueco Bolson aquifer by producing water that meets the U.S. EPA's drinking water standards	The FHWRP is effective in removing the priority pollutants entering the plant
Denver Potable Water Reuse Project Denver, CO	1985	--	--	Lime treatment, sedimentation, re-carbonation, filtration, UV irradiation, carbon adsorption, reverse osmosis, air stripping, ozonation,	DPR	Evaluate the feasibility of direct potable reuse of secondary treated municipal wastewater	Study has demonstrated that the multiple-barrier process can remove contaminants to non-detectable levels
Upper Occoquan Sewage Authority [UOSA], Millard H. Robbins, Jr. Water Reclamation Plant Fairfax, Virginia	1978	1.5 m^3/s	--	Primary-secondary treatment, high pH chemical treatment, two-stage re-carbonation multimedia filtration, carbon absorption, ion exchange, and breakpoint chlorination.	Surface water augmentation	-Eliminate pollution of the Occoquan Reservoir -Expansion to 2.4 m^3/s	Eliminated 11 small WWTPs and increased the yield of the Occoquan reservoir

9.2 Established IPR and DPR project outside the US

The following projects are two well established IPR plants outside the United States. They have been briefly reviewed to diversify and complement the representation of IPR for this thesis.

9.2.1 Singapore: NEWater Project

The newest indirect potable water purification project in the world is in the city-state of Singapore. The "NEWater" project produced sewer water purified to drinking water standards on a test basis for two years. Before it was fully operational in early 2003, the Prime Minister led the way by drinking the NEWater to show his citizens the high quality and safety of the new purified water. The project uses water purification processes similar to Orange County's Groundwater Replenishment System design. The NEWater project provides a safe, reliable source of high quality water for Singapore's 4.3 million residents and greatly diminishes the country's dependence on water imported across the channel from Malaysia.

The three-step purification process [micro filtration, RO, and UV disinfection] used to produce NEWater results in water is better than the World Health Organization's drinking water standards. NEWater also meets or is better than the standards set by the United States Environmental Protection Agency, which are considered an international benchmark for water quality.

With the purity and safety of NEWater endorsed by an international panel of world-renowned water quality experts, the long-term plan is to add NEWater to Singapore's reservoirs before piping it to residential homes and commercial industrial customers.

9.2.2 Namibia: Windhoek

In an effort to supplement the potable water supply, a system for reclaiming potable water from domestic sewage was pioneered in Windhoek, Namibia in 1968. Surface water sources and ground water extraction had been fully appropriated and direct reuse of reclaimed water was instituted just in time to avert a water crisis caused by drought The system has been producing acceptable potable water to the city ever since as part of a larger program to conserve water and manage water demand[44]. The reclamation plant has been operating on an intermittent basis to supplement the main supplies during times of peak summer demand or during emergencies. The facility is known to not intake any domestic, infectious hospital, abattoir and/or industrial wastewater.

This system has gone through some successful improvements over the years, accompanied by comprehensive chemical, bacteriological, virological, and epidemiological monitoring. The current sequence of treatment processes involves primary and secondary treatment at the Gammans wastewater treatment plant [primary settling activated sludge, secondary settling, and maturation ponds]. The secondary effluent is then directed to the Goreangab water reclamation plant, where treatment includes alum addition, dissolved air flotation, chlorination, and lime addition. This is followed by settling, sand filtration chlorination,

[44] Harhoff and van der Merwe, 1996

carbon filtration, and final chlorination. The final effluent is then blended with treated water from other sources before distribution.

Initially, the secondary effluent intake from the Gammans WWTP by the Goreangab Water Reclamation Plant was gradually raised from 3 to 18% of the total potable water distributed to the city. Water quality from the Goreangab dam has been deteriorating over the years because of heavy pollution due to run off and unauthorized settlements around the dam. Upon the completion for the new multi barrier system, raw water intake from the Gammans WWTP was 50%. Currently, that portion is 100% because the quality and quantity of the Goreangab dam has deteriorated beyond a point where it cannot be used anymore. Windhoek exports an excellent rated Namibian beer that is made using this same reclaimed water.

10.0 Results and discussions

10.1 Introduction

The results and discussions of this thesis will be discussed in this chapter and begin in the first section with a general overview of the trends in water reclamation and IPR. The more detailed legislative, public and technological response to the developments in IPR is discussed in the following three separate sections. In the final section, the inventoried plants will be quantitatively compared in two IPR categories.

10.2 Trends in water reclamation and IPR

Water reclamation in the form of IPR has come a long way in the United States with its first attempt back in 1954 in Chanute, Kansas. IPR has since then often been implemented unplanned yet successfully such as health studies have shown for the Chino Valley Basin [1950] and Montebello Forebay [1962]. These studies showed no adverse health effects of using filtered and disinfected secondary effluent for surface water recharge. Some of the planned versions of IPR in the late 80's and early 90's such as the East Valley Water Recycling Project [EVWRP, 1995], the San Diego Water Re-purification Project [SDWRP, 1985] and the Tampa Water Recourse Recovery Project [1987] encountered public resistance which eventually caused the project to fail. In some parts the public resistance was genuine and based upon health fears, and in other parts it appears that political candidates opposed the proposed projects during election campaigns, which elevated public concerns. An incorrect approach to educating the public, such as involvement only after project conception, was partly to blame as well. These projects failed to materialize although they were in most cases identical to existing, successful IPR projects, which demonstrate an inconsistency in decision making.

More recently implemented IPR projects such as the GWR System [2003], West Basin [1995], and The Scottsdale Water Campus [1998] seem to have found the appropriate formula for successful projects. Early and intensive outreach to the general public combined with highly advanced, proven technology insured the success of the project. These projects also relied upon favorable results from previous pilot projects in other locations, such as the Denver Potable Water Reuse Demonstration and the Lake Arrowhead Reclamation Pilot Study.

10.3 Legislative response

The decentralized governing system in the United States has its advantages and disadvantages. Disadvantages have displayed themselves in the early years of this century. Individual water rights and the doctrine of "first in time, first in right," in combination with the limited Federal influence have created a climate of complex or uncertain regulations governing new projects. Nearly every newly proposed water project encounters resistance from the public or environmental groups with issues such as dubious ownership of the water rights and environmental impacts. In some cases it is not clear who owns the wastewater and has the right to reuse it. The Colorado River compact is the largest example of ambiguous ownership.

The current Federal system requires public involvement which is appreciated but can result in delays of unimplemented water reclamation projects. Public involvement may increase the awareness for the need of IPR projects and therefore may increase the chances for successful implementation. California has predominantly set the standards for the rest of the United States for water reclamation regulations and indirectly for IPR. Many other States practicing water reclamation and IPR duplicate regulations set by California. This very aggressive and enterprising approach has made California the front runner [Porter Cologne, Title 22, CASDWA].

Public education has played a key role in the successful IPR projects. The dynamics of a passive and uninformed public and its subsequent overreaction upon becoming aware of the facts have usually halted IPR projects. The Chanute, Kansas project was shut down immediately when the public discovered that their drinking water was recycled. The EVWRP and the SDWRP were IPR projects accepted by the public until political candidates wrongly labeled projects as toilet-to-tap or as social injustice. Such overreactions have strengthened regulations for future projects and in some cases they have be become too stringent as revised contaminant action levels [NDMA, 1999] confirm. The following are examples of regulations that are too stringent:

- The United Stated has some of the most stringent regulations in the world, so stringent that the WHO blames the United States for not setting a more realistic example for countries that are struggling to meet the WHO regulations.
- The 2003 TMDLs' implementation was halted because it had been successfully challenged on a dozen occasions in court. The number of TMDLs had increased from 500 in 1999 to 3000 in 2002.
- The federal legislative branch is working towards a more integrated approach to the SDWA and CWA. The newly implemented Information Collection Rule [ICR] is a beginning in doing so.
- The 1986 amendments to the Safe Drinking Water Act [SDWA] mandated states to comply with regulations for 25 new contaminants every year for the next 5 years, brings the number from 75 contaminants to 200. A 1996 amendment had a more realistic approach by adding only 3 contaminants each year.
- The California Toxic Rule [CTR] was successfully challenged in court establishing its unstable foundation for its proposed new implementations. It would, for example, force the Tillman plant [see: 8.3.1] to install expensive membrane technology in order to comply with the newly proposed changes in the CTR.

10.4 Public response

Americans and Californians in particular are said to be very accepting of reclaimed water, yet several IPR have failed in the past. The public often understands the logic of using reclaimed water but refrains from using the water themselves. Even though water treatment technology in the US is highly advanced, public acceptance of water reuse has lagged. The influence of conflicting regulations and the limited ability of the governing agencies to cooperatively and successfully implement IPR is a major barrier to its development. In spite of these difficulties there is an overall growing awareness of the need of reclaimed water.

Studies conducted between 1972 and 2002 show that public's increasing awareness and knowledge of IPR is improving their ability to make more critical and informed decisions. The opposition to drinking recycled water has increased from 56% to 74% during this period. It must be noted that the respondents from earlier studies were less informed and educated on the subject of water reuse in general and IPR in particular.

The traditional approach of implementing water reclamation projects through the "decide-announce-defend" policy has clearly proven itself to be ineffective. Strategies in which public outreach and education happen after conception are also failing [EVWRP 1995, SDWRP, 1985] although alternative government systems might succeed [NEWater, Singapore 2003]. Newly proposed strategies are to engage stakeholders before project conception and to effectively communicate risks to the stakeholders. This has proven to be the successful approach [GWR System 2003].

The public that perceives a higher social pressure to recycle and has a higher level of awareness for the environment, and subsequently for the conservation of natural resources, is more likely to accept recycled water. Implementation of water reclamation projects encountered more difficulty in societies that do not adopt collective approaches to decision making and problem solving.

10.5 Technological response

The technical response to IPR has undergone major developments in recent years. When IPR started in the US in 1954 with Chanute, Kansas project, only chlorination was used as an additional process and there were no known adverse health effects. IPR facilities performing groundwater recharge through recharge basins in the 1950s later added tertiary filtration with chlorination to their secondary treatment processes. De-chlorination was added in the 70's when the need to protect aquatic species was realized. Macro nutrients [N and P] were next targeted for removal and many facilities converted their aeration tanks to NDN tanks by adding fine air bubble diffusers and anoxic or anaerobic zones . More stringent requirements surfaced in the late 80's when IPR facilities started to directly inject advanced treated wastewater into groundwaters which served as drinking water resources. This caused these facilities to use advanced treatment technologies such as lime clarification, ammonia stripping, activated carbon and granular media filtration. The rapid development in membrane technology has resulted in high rejection, lower pressure RO membranes of which its effluent complied with the stringent regulations for IPR. The success of RO eventually allowed lime clarification, ammonia stripping, and carbon adsorption to be phased out. The latest membrane technology for RO pretreatment is submerged MF. Submerged MF drastically shrinks the footprint of the plant as this is physically integrated with the activated sludge process. MF processes are now displacing granular media filters.

The most common form of disinfection, chlorination has virtually disappeared in water reclamation. Problems with chlorination disinfection byproducts have been known for more than 30 years. Chlorine gas is hazardous to handle and agencies responsible for managing hazardous waste are discouraging its transport. UV light is the most popular form of disinfection in today's water reclamation plant. It also avoids production of a popular emerging pollutant NDMA. UV light has also gained ground because advanced membrane technology provides a better effluent which practically eliminates the shading of potential suspended solids. Ozonation, which was popular for about a decade, is no longer being selected for economical reasons.

Newly emerging pollutants in wastewater are of growing concern. Although not routinely detected for by advanced wastewater treatment facilities, newly emerging pollutants have raised concern for their unknown health effects, fate and transport. They include heavy metals, endocrine disrupters, pharmaceuticals, hormones, antibiotics, anti-inflammatories and personal care products. Advanced oxidation techniques, of which hydrogen peroxide is the most widely encountered form, target these new pollutants. Current detection methods are a limiting factor in identifying these pollutants. A more detailed look will be taken at the evolution in treatment configuration and RO in the next few paragraphs.

- Evolution in configurations

A few standard configurations were consistently encountered in the inventoried facilities [see Chapter 8.0] Facilities performing groundwater recharge through the means of recharge basins often consisted of the following, which has been referred to in this theses as traditional tertiary treatment [see: Figure 18]:

- Preliminary treatment
- Primary sedimentation
- High rated processes
- Secondary sedimentation
- Coagulation and flocculation
- Multi media tertiary filtration
- Chlorination [and de-chlorination]

Advanced facilities using secondary or tertiary effluent as their influent and performed groundwater recharge through direct injection had their tertiary and/or advanced treatment configured in which reverse osmosis was placed central. Two standard configurations were consistently encountered of which one has been referred to as traditional RO pretreatment earlier in this thesis [see: Figure 19] and consisted of the following:

- Lime clarification
- [optional] Re-carbonation
- Multi media filtration

The second standard configuration that has been encountered consistently in facilities that used tertiary or secondary influent as their influent has been referred to in this thesis as contemporary advanced treatment [also see: Figure 20] and was configured as follows:

- [Submerged] Micro filtration
- Reverse osmosis
- Ultra violet

A few alternatives to and combinations of these treatment configurations have been encountered and have been illustrated separately for each relevant facility in Chapter 8.0.

- Evolution in RO

Membrane technology has changed over the years to become proprietary science. It is for that reason that the more interesting details were not available. It has become clear thought that RO membranes have changed their material from cellulose acetate to composite polyamides over the past few years increasing flux and decreasing fouling. The number of units per pressure vessels tends to increase from 6 at older facilities to 7 units at newer facilities. Increasing the overall size of the membrane [the MegaMagnum: see 7.5.5.3] in order to limit floor space is currently under development. Neutrally charged membranes seem to be a new development, although some manufacturers claim that membranes always have been neutrally charged. Manufacturers also expressed that the development of RO membranes will reach a ceiling in the near future.

- Up and coming: Submerged Micro Filtration

According to the visited membrane manufacturers, Submerged Micro Filtration [SMF] is the next hot item in membrane manufacturing. SMF [also see 7.5.2] will drastically limit floor space because it incorporates two treatment units [activated sludge and Micro Filtration] into one. Very little information was available on SMF because it is new and its information is proprietary. SMF for water reclamation has thus far, only been put to practice in the GWR System.

10.6 Plants and how well they performed

It has been clearly established that IPR through groundwater recharge can be achieved in two different ways. The first and most established form is through recharge basins. The contemporary form is injection into groundwaters, which requires less land and can be performed in developed areas. Both forms of groundwater recharge have undergone significant changes. Whereas the recharge basins have undergone a slow process of changes, direct injection has experienced a rapid development in new techniques. Plants that fall in either category have been reviewed and evaluated on the following parameters, in order of importance, to determine their probability in succeeding:

- Relative cost of the effluent [in relation to location and viable alternatives]
- Involvement of the public [before, during and after conception]
- Outcome of proposed goals
- Degree of updated technology
- Degree of establishment [in relation to years in production and recognition for its reliable production]
- Size of IPR component

Table 34 is an evaluation of the various IPR projects using fuzzy categories for relative successes and failures. Each of the above categories is listed in order of importance and is weighed in conformance with its rank from 6 to 1. Plants score 0 to 5 on these weighted factors for the worst and best representative. These scores are multiplied with the weight and added up to achieve a total score. The total possible score was 105. The GWR System [99] has most successfully developed these parameters and therefore sets the bar. Other facilities have often not developed these three parameters equally and score lower.

Table 34: Inventoried plants performing IPR through direct injection and surface water augmentation

Criteria	Size of IPR component	Degree of establish-ment	Degree of updated technology	Outcome of proposed goals	Public involve-ment	Relative cost of the effluent	Total Score
Weight factor	**1**	**2**	**3**	**4**	**5**	**6**	
Water Factory 21	3	5	4	5	4	4	**89**
GWR System	5	5	5	5	5	4	**99**
West Basin	1	4	4	5	4	4	**85**
Scottsdale Water Campus	1	4	5	5	3	4	**83**
San Diego Water Re-Purification Project [SDWRP]*	3	0	3	1	2	4	**50**
Tampa Water Recourse Recovery Project [TWRRP]*	4	0	3	1	2	4	**51**

[*] surface water augmentation

The GWR System, which is the follow-up on the Water Factory 21, leads in most aspects of the United States' plants performing direct injection. Its history, technology, size, and public involvement are cutting edge. Several expansions are planned in the next 20 years [see 8.2.1], including surface water recharge. It will be the first plant to perform surface water recharge while using RO as part of their treatment process. The SDWRP and the TWRRP have both failed in their attempts to augment surface water, which indirectly served as the supply for drinking water. Public involvement, or the lack thereof, and politics played a deciding role in the failure of these projects.

Table 35: Inventoried Plants Performing IPR through Recharge Basins

	Size of IPR component	Degree of establish-ment	Degree of latest technology	Outcome of proposed goals	Public involve-ment	Relative cost of the effluent	Total Score
	1	2	3	4	5	6	
Montabello Forebay	4	4	2	3	4	5	**80**
Chino Valley Basin	3	5	2	3	4	5	**81**
Victor Valley Water Reclamation Authority	3	4	2	4	3	4	**72**
Tucson Roger Road Wastewater	3	3	2	3	3	4	**66**
Mesa Northwest Water Reclamation Plant	3	3	3	3	3	4	**69**
East Central Region WWTP	3	2	3	3	3	4	**67**
East Valley Water Reclamation Project [EVWRP]	4	1	2	1	2	5	**56**

Chino Valley Basin is leading the plants when surface water recharge is performed with a slight edge over the Montabello Forebay mainly because of its establishment since the 1950's. The West Palm Beach Wetlands Demonstration Project has been included in this model in order to indicate that the cost for RO treatment for surface water recharge is difficult to justify. The EVWRP fell subject to the Los Angeles mayoral race and thus, politics were the deciding factor in the failing of this project. The EVWRP also fell short in the area of public involvement because of outreach after the project's conception. This project is currently under review by the City of Los Angeles for reinstatement. It is a near copy of existing projects, such as the Montabello Forebay and Chino Valley Basin, which creates hope for the future operation.

11.0 Conclusion

The fight for new water supplies in the United States is over. All water supplies have been allocated. The competition for reclaimed water is next. The technology for water recycling is well developed and this study shows that it was rarely a deciding factor in the success of IPR projects. IPR is becoming a greater integral section of water reclamation and therefore several of the older, failed projects are currently reevaluated. The most successful projects involved the general public before conception and maintained communications before, during, and after construction. The Ground Water Recharge System is the best example thereof. A common occurrence is for agencies to assume that the public is apathetic when they demonstrate little interest. This was the case in several projects with the San Diego Water Re-purification Project and the East Valley Water Reclamation Project. The survey showed that such cases led to project failure due to the public losing its apathy and opposing the project because they felt uninformed. Further study is needed to acquire definitive epidemiological and toxicological data regarding health risks associated with IPR are critical in order to assure the public of the IPR projects' validity and thus to increase the probability for success of future projects.

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13.0 Appendix

This appendix shows the water quality data that were collected during the survey. For each plant, the same set of constituents was provided and the full suite is shown for the first listed plant--Water Factory 21 in Table 36 and Table 37. There was no one facility that was able to provide all the data and some of the facilities were only able to provide a few of the constituents. In order to save space, the constituents that were not provided for each the plant are omitted from the list. In other cases, a less than [<] sign appears, which defines the measured values as below the plant's method detection limit.

13.1 IPR facilities in Southern California

Table 36: Water Factory [WF] 21, Fountain Valley, CA*

	Units	Influent	Effluent	Regulation: MCL
Conventional:				
Dissolved Oxygen	mg/L			
pH	mg/L	7.3	6.7	6.5-8.5
Chlorine	mg/L	237	18	250
Phenols	mg/L			
MBAS	mg/L			0.5
Cyanide	mg/L	14.7	8.1	0.15
TOC	mg/L	39	0.7	
BOD	mg/L			
COD	mg/L	10.2	3.0	
Temperature	C			
Turbidity 105	NTU	203	0.05	5
TSS	mg/L			
SS				
Oil and Grease	mg/L			
TOX	mg/L			
Nutrients:				
Nitrate [N03-N]	mg/L			
Nitrite [N02-N]	mg/L			
Kjeldahl Nitrogen	mg/L			
Ammonia [as N]	mg/L			
Organic-N [TKN]	mg/L			
Ortho-P	mg/L			
Total-P	mg/L			
Total N	mg/L	18.3	2.6	
Bacteriological:				
Total Coliform	mpn/100mL	1.5	<10E-6	<1
Fecal	mpn/100mL			
Streptococcus	mpn/100mL			
Enteroccocus	mpn/100mL			
Salts:				
Hardness mg/L [as CaCO3]	mg/L			180
Alkalinity mg/L [as CaCO3]	mg/L			
TDS	mg/L	936	60	500
Conductivity	umhos/cm	1,712	182	
Sulfate	mg/L	218	14	
Chloride	mg/L	237	18	
Fluoride	mg/L	1.0	0.2	2
Boron	mg/L			
Calcium	mg/L			
Magnesium	mg/L			
Sodium	mg/L			
Silica	mg/L			
Potassium	mg/L			
Metals:				

Aluminum	µg/L			200
Antimony	µg/L			6
Arsenic	µg/L			50
Barium	µg/L	51.2	1.2	1,000
Beryllium	µg/L			4
Cadmium	µg/L	3.0	ND-<1.0	5
Total Chromium	µg/L	1.6	ND-<1.0	50
Copper	µg/L	13.6	4.8	1,000
Iron	µg/L			
Lead	µg/L	1.2	0.2	15
Mercury	µg/L	<0.5	<0.5	2.0
Nickel	µg/L			100
Selenium	µg/L	4.8	<5.0	50
Silver	µg/L	0.6	1.0	100
Zinc	µg/L			5,000
Thallium	µg/L			2
Manganese	µg/L	43.9	2.0	50
Disinfection Byproducts				
NDMA	ppt	33.2	7.8	
Bromate	ppb			10
TTHM	ppb		12	80
HAA5	ppb			60
Trace Organic Compounds				
Endocrine Disruptors	ppb			
Pharmaceuticals	ppb			
Hormones	pbp			
Antibiotics	ppp			
Anti-inflammatories	ppb			
Personal Care Products	ppb			

[*]injection at Talbert Gap, March 2003

Table 37: Ground Water Replenishment [GWR] System, Fountain Valley, CA*

	Units	Influent	RO Influent	RO Effluent	% Removal	Regulation
Conventional:						
Chlorine	mg/L		1.9			250
MBAS	mg/L		0.23	0.03	87	0.5
Cyanide	mg/L		13	10	23	0.15
TOC	mg/L		9.42	1.23	87	
Nutrients:						
Ammonia [as N]	mg/L		25.2	2.3	91	
Organic-N	mg/L		1.3	0.2	85	none
Bacteriological:						
Total Coliform	mpn/100mL		<1			<1
Salts:						
Hardness mg/L [as CaCO3]	mg/L		203	9	96	180
Alkalinity mg/L [as CaCO3]	mg/L		36	18	50	
TDS	mg/L		890	61	92	500
Conductivity	umhos/cm		1570	155	--	
Sulfate	mg/L		378	15.5	96	
Chloride	mg/L		207	27	87	
Fluoride	mg/L		0.42	0.25	40	2
Boron	mg/L		0.34	0.32	22	
Calcium	mg/L		79.4	2.4	97	
Magnesium	mg/L		2.4	0.1	96	
Sodium	mg/L		187	21	89	
Silica	mg/L		15.5	3.5	77	
Potassium	mg/L		14.8	1.7	89	
Metals:						
Aluminum	µg/L		12.3	1.1	91	200
Antimony	µg/L					6
Arsenic	µg/L		<2.0	<2.0	0	50
Barium	µg/L		11	<1.0	>91	1,000
Beryllium	µg/L		--	--	--	4
Cadmium	µg/L		<1.0	<1.0	0	5
Total Chromium	µg/L		1.6	<1.0	>38	50
Copper	µg/L		8.5	1.5	82	1,000
Iron	µg/L		13	<1.0	>92	
Lead	µg/L		<1.0	<1.0	0	15
Manganese	µg/L		2.2	<1.0	>55	2.0
Mercury	µg/L		<0.5	<0.5	0	100
Nickel	µg/L		14.2	<1.0	>93	50
Selenium	µg/L		<5.0	<5.0	0	100
Silver	µg/L		<0.1	<0.1	0	5,000
Zinc	µg/L		<50	<50	0	2

[*] injection at Talbert Gap and Kreamer/Miller Basins

Table 38: West Basin Reclamation Project, El Segundo, CA

	Units	Influent	Effluent
Conventional:			
pH	mg/L	6.7 to 7.1	7 to 8
Chlorine	mg/L	<0.1	2 to 3
Phenols	mg/L		ND
MBAS	mg/L		ND
Cyanide	mg/L		ND
TOC	mg/L	10 to 15	0.2-0.4
BOD	mg/L	20 to 30	<3
Temperature	C	seasonal	seasonal
Turbidity 105	NTU	5 to 20	0.1 to 0.15
TSS	mg/L	15 to 25	<1
Nutrients:			
Nitrate [N03-N]	mg/L	<0.5 to 1	<0.1 - 0.1
Nitrite [N02-N]	mg/L	<0.5	<0.1
Kjeldahl Nitrogen	mg/L	30 to 40	1 to 2
Ammonia [as NL	mg/L	30 to 40	1 to 2
Organic-N [TKN	mg/L		<1
Ortho-P	mg/L	ND	<0.1
Bacteriological:			
Total Coliform	mpn/100mL	>1600	<2
Fecal	mpn/100mL	>1600	<2
Streptococcus	mpn/100mL		<1
Enteroccocus	mpn/100mL		<1
Salts:			
Hardness mg/L [as CaCO3]	mg/L		12 to 40
Alkalinity mg/L [as CaCO3]	mg/L	250 to 300	30 to 60
TDS	mg/L	?	20 to 50
Conductivity	umhos/cm	1300 to 1600	30 to 80
Sulfate	mg/L	90 to 120	<2 to 3
ChlorideL	mg/L	150 to 250	4 to 8
Fluoride	mg/L		<0.1 to 0.2
Calcium	mg/L		5 to 15
Magnesium	mg/L		<0.1
Sodium	mg/L		6 to 12
Potassium	mg/L		0.5 to 0.8
Metals:			
Antimony	µg/L		<5
Arsenic	µg/L		<2
Barium	µg/L		<100
Beryllium	µg/L		<1
Cadmium	µg/L		<1
Total Chromium	µg/L		<10
Copper	µg/L		<50
Lead	µg/L		<5
Mercury	µg/L		<1
Nickel	µg/L		<10
Selenium	µg/L		<5
Silver	µg/L		<1
Zinc	µg/L		<50

Thallium	µg/L		<1
Magnesium	µg/L		<100
Disinfection Byproducts			
NDMA	ppb	NA	NA
THM	ppb		1-3
HAA	ppb		<1
Bromate	ppb		<5
TTHM	ppb		1-3
Trace Organic Compounds			
Endocrine Disruptors	ppb		NA
Pharmaceuticals	ppb		1-3
Hormones	pbp		<1
Antibiotics	ppp		<5
Anti-inflammatories	ppb		1-3

Table 39: Pomona Valley, CA

	Units	Influent	Effluent	Regulations: MCL
Conventional:				
pH	mg/L		7.3	6.5-8.5
Chlorine	mg/L		<0.51	0
Phenols	mg/L		0.14	
MBAS	mg/L			0.5
Cyanide	mg/L			4.2
BOD5/20	mg/L		4	20
Temperature	C		24.4	
Turbidity 105	NTU		1.4	
TDS			545	750
SS			1	15
Nutrients:				
Nitrate [N03-N]	mg/L		1.15	
Nitrite [N02-N]	mg/L		1.89	1.0
Ammonia [as NH3-H]	mg/L		13.9	
Organic-N [TKN]	mg/L		2.0	
Ortho-P	mg/L		1.2	
Bacteriological:				
Fecal	mpn/100mL			<200 max
Fecal	mpn/100mL		<2	
Salts:				
Sulfate	mg/L		69	300
Chloride	mg/L		139	180
Boron	mg/L		0.47	1.0
Metals:				
Antimony	µg/L		<0.5-1.3	
Arsenic	µg/L		<1-2.4	
Beryllium	µg/L		<0.5	
Cadmium	µg/L		<0.4	5
Total Chromium	µg/L		<10	
Copper	µg/L		<8-14	
Lead	µg/L		<2-2	6.6
Mercury	µg/L		<0.04-<0.1	0.051
Nickel	µg/L		<20	
Selenium	µg/L		<1	
Silver	µg/L		<0.24-0.49	
Zinc	µg/L		60	
Thallium	µg/L		<1	
Disinfection Byproducts				
NDMA	µg/L		<1-<5	8.1

Table 40: San Jose East, CA

	Units	Influent	Effluent	Regulations
Conventional:				
pH	mg/L		6.9	6.0-9.0
MBAS	mg/L		<0.09	0.5
TOC	mg/L		6.0	
BOD5/20	mg/L		<3.0	20
COD	mg/L		21	
Temperature	C		79	100
Turbidity 105	NTU		0.9	2
TSS	mg/L		<2	15
TDS	mg/L		612	700
SS	mg/L		<0.1	0.1
Oil and Grease	mg/L		<4	10
Nutrients:				
Nitrate [N03-N]	mg/L		4.10	
Nitrite [N02-N]	mg/L		<0.081	1
Ammonia [as NH3-H]	mg/L		1.6	
Organic-N [TKN]	mg/L		1.4	
Bacteriological:				
Total Coliform	mpn/100mL		<1	2.2
Fecal	mpn/100mL		<2	
Salts:				
Hardness mg/L [as CaCO3]	mg/L		197	
Alkalinity mg/L [as CaCO3]	mg/L		152	
Sulfate	mg/L		122	250
Chloride	mg/L		148	250
Fluoride	mg/L		0.35	1.6
Calcium	mg/L		48.8	
Magnesium	mg/L		17.1	
Sodium	mg/L		138	
Potassium	mg/L		15.1	
Boron	mg/L		0.46	1
Metals:				
Arsenic	µg/L		1	50
Barium	µg/L		34	1000
Cadmium	µg/L		<0.4	5
Total Chromium	µg/L		<10	50
Copper	µg/L		<8	1300
Lead	µg/L		<3	15
Mercury	µg/L		<0.04	2
Nickel	µg/L		<20	100
Selenium	µg/L		<1	50
Silver	µg/L		<0.2	100
Zinc	µg/L		75	500
Iron	µg/L		95	300
Manganese	µg/L		27	50

Table 41: San Jose West, CA

		Units	Influent	Effluent	Limits
	Conventional:				
	pH	mg/L		7.1	6.0-9.0
A	MBAS	mg/L		<0.09	0.5
	TOC	mg/L		5.5	
	BOD5/20	mg/L		<3.0	20
	COD	mg/L		20	
	Temperature	C		79	100
	Turbidity 105	NTU		0.9	2
	TSS	mg/L		<2	15
	TDS	mg/L		532	700
	SS	mg/L		<0.1	0.1
	Oil and Grease	mg/L		<4	10
	Nutrients:				
	Nitrate [N03-N]	mg/L		5.48	
	Nitrite [N02-N]	mg/L		<0.096	1
	Ammonia [as NH3-H]	mg/L		2.8	
	Organic-N [TKN]	mg/L		1.5	
	Bacteriological:				
	Total Coliform	mpn/100mL		<1	2.2
	Fecal	mpn/100mL		<2	
	Salts:				
	Hardness mg/L [as CaCO3]	mg/L		190	
	Alkalinity mg/L [as CaCO3]	mg/L		166	
	Sulfate	mg/L		87.8	250
	Chloride	mg/L		108	250
	Fluoride	mg/L		0.60	1.6
	Calcium	mg/L		48.7	
	Magnesium	mg/L		14.0	
	Sodium	mg/L		110	
	Potassium	mg/L		<12.7	
	Boron	mg/L		0.50	1
	Metals:				
	Arsenic	µg/L		1	50
	Barium	µg/L		23	1000
	Cadmium	µg/L		<0.5	5
	Total Chromium	µg/L		<10	50
	Copper	µg/L		<8	1300
	Lead	µg/L		<2	15
	Mercury	µg/L		<0.04	2
	Nickel	µg/L		<20	100
	Selenium	µg/L		<1	50
	Silver	µg/L		<0.2	100
	Zinc	µg/L		91	500
	Iron	µg/L		60	300
	Manganese	µg/L		12	50

Table 42: Whittier Narrows WRP, CA

	Units	Influent	Effluent	Limits
Conventional:				
pH	mg/L		7.1	6.0-9.0
MBAS	mg/L		<0.09	0.5
TOC	mg/L		5.5	
BOD5/20	mg/L		<3.0	20
COD	mg/L		20	
Temperature	C		79	100
Turbidity 105	NTU		0.9	2
TSS	mg/L		<2	15
TDS	mg/L		532	700
SS	mg/L		<0.1	0.1
Oil and Grease	mg/L		<4	10
Nutrients:				
Nitrate [N03-N]	mg/L		5.48	
Nitrite [N02-N]	mg/L		<0.096	1
Ammonia [as NH3-H]	mg/L		2.8	
Organic-N [TKN]	mg/L		1.5	
Total Nitrate Nitrite			5.58	10
Bacteriological:				
Total Coliform	mpn/100mL		<1	2.2
Fecal	mpn/100mL		<2	
Salts:				
Hardness mg/L [as CaCO3]	mg/L		190	
Alkalinity mg/L [as CaCO3]	mg/L		166	
Sulfate	mg/L		87.8	250
Chloride	mg/L		108	250
Fluoride	mg/L		0.60	1.6
Calcium	mg/L		48.7	
Magnesium	mg/L		14.0	
Sodium	mg/L		110	
Potassium	mg/L		<12.7	
Boron	mg/L		0.50	1
Metals:				
Arsenic	µg/L		13	50
Barium	µg/L		31	1000
Cadmium	µg/L		<0.7	5
Total Chromium	µg/L		<10	50
Copper	µg/L		<8	1300
Lead	µg/L		<2	15
Mercury	µg/L		<0.04	2
Nickel	µg/L		<20	100
Selenium	µg/L		<1	50
Silver	µg/L		<0.2	100
Zinc	µg/L		91	500
Iron	µg/L		60	300
Manganese	µg/L		12	50

Table 43: Chino Valley Basin, Chino Hills CA*

	Units	Influent	Effluent	Limits?
Conventional:				
pH	mg/L	7.4/7.4		6.0-9.0
Phenols	mg/L		<1	
Cyanide	mg/L		<0.007	
TOC	mg/L		12	
BOD5/20	mg/L		<4	20
TSS	mg/L	277/290	1	15
TDS	mg/L	452/507		700
Nutrients:				
Ammonia [as NH4-H]	mg/L	23.7/29.3		
Organic-N [TKN]	mg/L	40.4/43.8		
Total Inorganic Nitrogen		24.4/42.3	12	
Salts:				
Hardness mg/L [as CaCO3]	mg/L		140	
Alkalinity mg/L [as CaCO3]	mg/L		144	
Sulfate	mg/L		62	250
Chloride	mg/L		102	250
Fluoride	mg/L		0.2	1.6
Calcium	mg/L		40	
Magnesium	mg/L		10.1	
Potassium	mg/L		93	
Boron	mg/L		0.34	1
Metals:				
Antimony	µg/L		<2 max	
Arsenic	µg/L		<5	50
Barium	µg/L		7	1000
Beryllium	µg/L		<2 max	
Cadmium	µg/L		<1	5
Total Chromium	µg/L		<1	50
Cobalt	µg/L		<4	
Copper	µg/L	57/67	<4	1300
Lead	µg/L	<13/<13	<2	15
Mercury	µg/L		<0.3	2
Nickel	µg/L		<3	100
Selenium	µg/L		<7	50
Silver	µg/L		<2	100
Zinc	µg/L		30	500
Thallium	µg/L		<2 max	
Iron	µg/L		85	300
Manganese	µg/L		5	50
Disinfection Byproducts				
NDMA	µg/L		<5 max	
TTHM	µg/L		<21	

[*] RP-1/RP-4, 2002: share the same point of discharge

Table 44: Victor Valley Water Reclamation Authority, Victorville CA *

	Units	Influent	Secondary Effluent	Tertiary Effluent	% Removal
Conventional:					
pH	mg/L		7.0	6.9	
MBAS	mg/L	9.7	0.11	0.15	
BOD	mg/L	385	6.8	1.8	99.7
COD	mg/L	873		23	
Temperature	C			23.9	
Turbidity 105	NTU			0.63	
TSS	mg/L	495	7.3		99.8
Nutrients:					
Nitrate [N03-N]	mg/L	<0.2	9.8	10.4	
Kjeldahl Nitrogen	mg/L	36.3	1.3	1.7	
Ammonia [as N]	mg/L	43.0	0.6	2.1	97.4
Salts:					
TDS	mg/L	400	368	1.6	
Sulfate	mg/L			58	
Chloride	mg/L			72	
Sodium	mg/L			97	
	mg/L				
Metals:					

[*]2004 avg:.:secondary effluent to ponds, tertiary to river

13.2 Failed IPR projects

Table 45: East Valley Water Recycling Project [EVWRP], Los Angeles, CA*

	Units	Influent [avg. 5]	Effluent [avg. 7]	Regulation
Conventional:				
pH	mg/L	6.9	7.2	6.0-9.0
Phenols	mg/L	ND		
MBAS max	mg/L		0.3	0.5
Cyanide	mg/L	ND	DNQ	2
BOD5	mg/L	382		
COD	mg/L	45		
Temperature	C	22	23	34
Turbidity 105	NTU			2 [5 max]
Nutrients:				
Nitrate [N03-N]	mg/L		0.76	
Nitrite [N02-N]	mg/L		0.29	2 [8 combined]
Ammonia [as NH3-N]	mg/L		17.4	
Organic-N [TKN]	mg/L		1.8	
Ortho-P	mg/L		1.43	
Total-P	mg/L	1.42	1.57	
Total N	mg/L	15.5 [total]	20.3	
PO4-P			1.7	
Bacteriological:				
Total Coliform	cfu/100mL		1870	
Fecal	cfu /100mL		467	
Salts:				
Hardness mg/L [as CaCO3]	mg/L		149	
TDS	mg/L		598	950
Conductivity	umhos/cm	1184	1056	
Sulfate	mg/L		105	300
Chloride	mg/L		139	190
Fluoride	mg/L		1	2
Metals:				
Antimony	µg/L	ND	ND	10
Arsenic	µg/L	18.0	5.7	1
Barium	µg/L	50	DNQ	1
Boron	µg/L	770	740	100
Cadmium	µg/L	ND	ND	1
Total Chromium	µg/L	24	ND	10
Copper	µg/L	94	DNQ	10
Nickel	µg/L	ND	DNQ	20
Silver	µg/L	6.00	DNQ	0.62
Zinc	µg/L	3.08	ND	10
Thallium	µg/L	ND	ND	5
Iron	µg/L	827	ND	100

Disinfection Byproducts

TTHM	µg/L	3.16	10.5

[*]Tillman plant, 2002: Balboa Lake: 720 m^3/s, Wildlife Lake: 250, plant outfall: 650, Japanese garden: 200, plant reuse: 390

Table 46: San Diego Water Re-purification Project [SDWRP], CA

	Units	Influent	Effluent	Regulation
Conventional:				
TOC	mg/L	71/68	1.1/15	
COD	mg/L	427/371	15/9	
Turbidity 105	NTU	96/69	NA/NA	
TSS	mg/L	209/211	2.7/1.3	
TS	mg/L	1008/1180	81/254	
Nutrients:				
Nitrate [N03-N]	mg/L	0.1	0.6	
Ammonia [as NH3-N]	mg/L	24.8	1.1	
Phosphate-P	mg/L	14.1	1.6	
Salts:				
Sulfate	mg/L	177	3.1	
Chloride	mg/L	195	16	
Calcium	mg/L	67.7	3.6	
Magnesium	mg/L	29.8	3.6	
Sodium	mg/L	127	11.3	
Metals:				
Arsenic	µg/L	2.5	1.6	
Boron	µg/L	260	230	
Cadmium	µg/L	2.8	1	
Chromium	µg/L	17	2	
Copper	µg/L	103	17	
Lead	µg/L	29	3	15 federal
Mercury	µg/L	1.2	10	
Nickel	µg/L	21	4	100
Selenium	µg/L	5	3	
Silver	µg/L	8	5	
Zinc	µg/L	109	8	
Magnesium	µg/L	See above		
Iron	µg/L	800	40	
Manganese	µg/L	97	15	

[*] Aqua II: pilot plant 87-89/90/92

13.3 IPR projects in Arizona

Table 47: Pima Roger Road Wastewater Plant Tucson, AZ

	Units	Influent	Effluent
Conventional:			
pH	mg/L		7.2
Chlorine	mg/L		<0.05
Phenols	mg/L		ND
Cyanide	mg/L		trace
BOD	mg/L	220	11
COD	mg/L		360
TSS	mg/L	238	12
Nutrients:			
Nitrate [N03-N]	mg/L		ND
Nitrite [N02-N]	mg/L		ND
Kjeldahl Nitrogen	mg/L		43.0
Ammonia [as NL	mg/L		21.3
Organic-N [TKN	mg/L		43.0
Ortho-P	mg/L		3.35
Total-P	mg/L		6.73
Bacteriological:			
E-coliforml	mpn/100mL		9
Salts:			
Hardness mg/L [as CaCO3]	mg/L		199
Alkalinity mg/L [as CaCO3]	mg/L		271
Conductivity	umhos/cm		1070
Sulfate	mg/L		109
Fluoride	mg/L		0.717
Calcium	mg/L		62.0
Magnesium	mg/L		10.8
Metals:			
Antimony	µg/L		0.8
Arsenic	µg/L		6.0
Barium	µg/L		116.1
Beryllium	µg/L		ND
Cadmium	µg/L		Trace
Total Chromium	µg/L		5.7
Copper	µg/L		59.4
Lead	µg/L		4.3
Mercury	µg/L		Trace
Nickel	µg/L		15.0
Selenium	µg/L		1.2
Silver	µg/L		4.9
Zinc	µg/L		164.7
Thallium	µg/L		ND

Disinfection Byproducts		
NDMA	ppb	ND
Bromate	ppb	trace
Trace Organic Compounds		
Endocrine Disruptors	ppb	ND
Pharmaceuticals	ppb	ND
Hormones	pbp	ND
Antibiotics	ppp	ND
Anti-inflammatories	ppb	ND
Personal Care Products	ppb	ND

Table 48: Mesa Northwest Water Reclamation Plant, AZ

	Units	Influent	Effluent
Conventional:			
Dissolved Oxygen	mg/L		3.45
Chlorine	mg/L		19
Phenols	mg/L		<2.5
Cyanide	mg/L		<20
Temperature	C		25
Nutrients:			
Nitrate [N03-N]	mg/L		4.99
Nitrite [N02-N]	mg/L		4.99
Kjeldahl Nitrogen	mg/L		1.42
Ammonia [as NL	mg/L		<0.10
Total-P	mg/L		error
Salts:			
TDS	mg/L		1068
Metals:			
Arsenic	µg/L		1.40
Beryllium	µg/L		<1.0
Cadmium	µg/L		<1.0
Total Chromium	µg/L		<10
Copper	µg/L		21
Lead	µg/L		<1.0
Mercury	µg/L		<0.2
Nickel	µg/L		<10
Selenium	µg/L		1.10
Silver	µg/L		<10
Zinc	µg/L		<50
Thallium	µg/L		<1.0
Boron	µg/L		450.0
Disinfection Byproducts			
NDMA	µg/L		2.5
TTHM	µg/L		0.2

13.4 IPR projects in Florida

Table 49: East Central Region WWTP* West Palm Beach, FL

	Units	MF Influent	RO Influent	RO Effluent	Total% Removal
Conventional:					
pH	mg/L	7.2	6.7	6.8	NA
TOC	mg/L	53	22	1	97.5
BOD	mg/L	8.27	1.18	<0.5	91.2
TSS	mg/L	7.84	0.79	<0.5	90.6
Nutrients:					
Nitrite [N02-N]	mg/L	0.030	0.026	0.072	66.4
Kjeldahl Nitrogen	mg/L	4.26	2.72	1.55	77.0
Ammonia [as N]	mg/L	0.36	1.15	0.61	39.6
Ortho-P	mg/L	0.053	0.032	0.014	72.9
Total-P	mg/L	0.53	0,36	0.14	73.4
Bacteriological:					
Fecal	mpn/100mL	851	5	3	98.9
Salts:					
Hardness mg/L [as CaCO3]	mg/L	158	203	92	53.7
TDS	mg/L	292	330	61	77.0
Sulfate	mg/L	58	73	17	77
Chloride	mg/L	58	67	10	80
Fluoride	mg/L	0.50	0.6	<0.01	84.4
Boron	mg/L	<0.2	<0.2	<0.2	NA
Calcium	mg/L	80	72	21	71.4
Magnesium	mg/L	25	22	6	83.3
Sodium	mg/L	51	68	19	57.0
Silica	mg/L	0.79	<0.1	<0.1	85.0
Metals:					
Arsenic	µg/L	7	<7	<1	NA
Barium	µg/L	<10	<10	<10	NA
Beryllium	µg/L	<4	<4	<4	NA
Cadmium	µg/L	32	<5	<5	65.6
Total Chromium	µg/L	<10	<10	<10	NA
Copper	µg/L	51	<10	<10	74.8
Iron	µg/L	310	<10	<10	95.0
Lead	µg/L	9	<1	<1	86.3
Manganese	µg/L	<10	<10	<10	NA
Mercury	µg/L	2	<0.2	<0.2	87.0
Nickel	µg/L	29	<20	<20	34.8
Selenium	µg/L	<1	<1	<!	NA
Silver	µg/L	<10	<10	<10	NA
Zinc	µg/L	774	1043	356	54.7
Thallium	µg/L	<2	<2	<2	NA
Silver	µg/L	<10	<10	<10	NA

Table 50: Tampa Water Recourse Recovery Project [TWRRP], Tampa, FL

	Units	Influent	Effluent
Conventional:			
Dissolved Oxygen	mg/L	1.49	20.56 w/ozone
pH	mg/L	6.52	7.02
Chlorine	mg/L	0	0
MBAS	mg/L	0	0
Cyanide	mg/L	<0.007	0.0006
TOC	mg/L	11.59	1.88
Temperature	C	27.1	24.5
Turbidity 105	NTU	1.8	0.05
TSS	mg/L	3.25	0.68
TOX	mg/L	103	13
Silica	mg/L	11.34	4.04
Nutrients:			
Nitrate [N03-N]	mg/L	1.36	1.3
Nitrite [N02-N]	mg/L	0.47	0.04 w/ozone
Kjeldahl Nitrogen	mg/L	1.64	0.34 “
Ammonia [as NL	mg/L	0.32	0.03 “
Organic-N [TKN	mg/L	1.32	0.31
Total-P	mg/L	5.78	0.17
Bacteriological:			
Total Coliform	mpn/100mL	53600	0.31
Fecal	mpn/100mL	17300	0.14
Salts:			
Hardness mg/L [as CaCO3]	mg/L	218	133
Alkalinity mg/L [as CaCO3]	mg/L	221	98
TDS	mg/L	576	461
Conductivity	umhos/cm	887	761
Sulfate	mg/L	92.9	95.6
ChlorideL	mg/L	141	138
Fluoride	mg/L	.073	.061
Magnesium	mg/L	10.11	3.35
Sodium	mg/L	100	100
Potassium	mg/L	12.64	12.63
Metals:			
Antimony	µg/L	ND	ND
Barium	µg/L	<0.02	0.011
Beryllium	µg/L	ND	ND
Total Chromium	µg/L	70.98	47.78
Copper	µg/L	<0.003	<0.002
Lead	µg/L	0.001	0.0004
Mercury	µg/L	3E-5	2E-05
Nickel	µg/L	0.005	0.005
Selenium	µg/L	ND	ND
Zinc	µg/L	0.022	0.008
Thallium	µg/L	ND	ND
Cobalt	µg/L	<0.006	ND
Iron	µg/L	0.015	0.026
Molybdenum	µg/L	0.016	0.01
Strontium	µg/L	0.33	0.18

Vanadium	µg/L	ND	ND
Disinfection Byproducts			
TTHM	ppb	9.7	2.84 w/ozone
TTHM	ppb	9.7	20.7 w/Cl

13.5 Established NPR facility

Table 51: San Diego North City Water Reclamation Plant, CA *

	Units	Influent	Effluent	MCL
Conventional:		64/Penasquitos		
pH	mg/L	7.61/7.54	7.47	
MBAS max	mg/L		0.16	0.03
Cyanide	mg/L	0.006/<0.002	0.0061	0.002/0.2
TOC	mg/L		8.2	0.250
BOD5	mg/L	223/253	<2	2
Turbidity 105	NTU	122/155	1.2	
TSS	mg/L	241/327	<1.6	
Bacteriological:				
Total Coliform	cfu/100mL		<2	
Salts:				
Hardness mg/L [as CaCO3]	mg/L		282.2	0.08
TDS	mg/L	1120/904	941.3	42
Sulfate	mg/L		203	0.5/300
Chloride	mg/L		228	7/228
Fluoride	mg/L		0.4	1/0.05
Calcium	mg/L	89.2	64.8	0.08
Magnesium	mg/L	40.3/34.5	29.2	0.02
Sodium	mg/L	221/170	59	-
Potassium	mg/L	17.3/17.9	13.2	2
Metals:				
Antimony	µg/L	5/7.05	3	23/6
Arsenic	µg/L	1.14/1.41	0.56	0.4/50
Barium	µg/L	111/122	38	10/1000
Boron	µg/L	366/370	373	15/700
Cadmium	µg/L	0.4/0.331	0.1	1/5
Total Chromium	µg/L	3.5/10.1	1.8	5/50
Copper	µg/L	151/124	44	4/-
Lead	µg/L	4/6.26	-	18
Mercury	µg/L	0.21/0.20	0.01	05/2
Nickel	µg/L	5/11.5	4	14/100
Selenium	µg/L	1.36/1.38	0.66	0.28/50
Silver	µg/L	3/3.44		6.6
Zinc	µg/L	120/118		4
Thallium	µg/L		ND	40/2
Manganese	µg/L	220/	88	4/50
Iron	µg/L		146	30/300

[*] 2004 reclaimed water portion only

Table 52: Tapia Water Reclamation Facility, Malibu, CA

	Units	Influent	Effluent	MCL
Conventional:				
pH	mg/L		8.14	
Chlorine	mg/L		2.2	4
TOC	mg/L		3.3	TT
Turbidity 105	NTU		0.17	0.3 [5 max]
Nutrients:				
Nitrate [N03-N]	mg/L		10	ND
Bacteriological:				
Total Coliform	cfu/100mL		0.10	5.0
Salts:				
Hardness mg/L [as CaCO3]	mg/L		135	
Alkalinity mg/L [as CaCO3]	mg/L		28	
TDS	mg/L		395	1000
Conductivity	umhos/cm		1600	557
Sulfate	mg/L		60	500
Chloride	mg/L		79	500
Fluoride	mg/L		0.2	2 ppm
Calcium	mg/L		28	
Magnesium	mg/L		16	
Metals:				
Arsenic	µg/L		ND	50 ppb
Boron	µg/L		270	
Disinfection Byproducts				
TTHM	µg/L		60	80
HAA5	µg/L		14.8	60

Table 53: Apricot Project, Altamonte Springs, FL

	Units	Influent	Effluent	Limits
Conventional:				
Dissolved Oxygen	mg/L		6	6
pH	mg/L		7.0	6.0-7.4
Chlorine	mg/L		0.01	0.01
BOD5/20	mg/L		5	8
SS	mg/L		5	30
Nutrients:				
Nitrate [N03-N]	mg/L		0.42	10
Organic-N [TKN]	mg/L		3	5
Salts:				
Fluoride	mg/L		0.999	4
Metals:				
Barium	µg/L		0.0111	2
Cadmium	µg/L		0.14	5
Copper	µg/L		0.867	1.3
Lead	µg/L		2.8	15
Disinfection Byproducts				
TTHM	µg/L		24	100

Table 54: Eastern Water Reclamation Facility [SW and SE], Orange County, FL

	Units	Influent	Effluent	Limits
Conventional:				
BOD5/20	mg/L	149	3.6/1.3	
TSS	mg/L		7.2/1.4	
Nutrients:				
Nitrate [N03-N]	mg/L		2.6/5.5	
Organic-N [TKN]	mg/L	35	4.7/1.6	
Total-P	mg/L	8	2.1/3.9	