AN ANALYSIS OF DIRECT POTABLE WATER REUSE ACCEPTANCE IN THE UNITED STATES: OBSTACLES AND OPPORTUNITIES

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EXECUTIVE SUMMARY

Extreme scarcity of freshwater resources for drinking water use in many areas of the world creates a dire situation that must be addressed. Establishing a method of supplying stable, sufficient, and safe drinking water to communities is imperative. A novel yet viable solution is direct potable reuse (DPR). This introduction of highly-treated waste water into the drinking water treatment process solves the problem of unreliable raw water resource availability due to water scarcity/water stress, population and demographic pressures, polluted freshwater sources, and costly deliverance of water from distant locations. In 1998, the National Resource Council Report stated that DPR was not a practical option for consideration. Since that time, however, tremendous advances in water treatment technology, water quality monitoring, constituent detection and health risk analysis systems have occurred.[1] Consequently, scientific and public health researchers, water industry specialists, policy makers and community stakeholders are taking a fresh look at DPR's viability. DPR acceptance is determined by identifying and resolving concerns regarding treatment train technology, health risks, regulatory issues, management and operational controls, public perception issues and cost.

This paper explores the history, drivers, mechanisms, and relevant case studies of DPR, and explores opportunities to further its acceptance in the United States. While technology and water quality monitoring systems can promise the delivery of safe, sufficient and secure drinking water through DPR, gaining public acceptance appears to be the major hurdle. It is the opinion of this author that more rigorous epidemiological research into the potential short and long term health effects of DPR would help ensure public trust. Included among the many opportunities detailed in this paper for developing increased DPR acceptance in the US are collaboration with leading risk communication specialists, implementation of research-based health communication

approaches, and analysis of Singapore's successful NEWater system. Many leading experts have commented that water will be the oil of the 21st century. Without doubt, the US has an obligation to aggressively seek out novel approaches to preserving precious water resources and to prepare judiciously for a future that assures safe drinking water delivery to all.

Note: The term Advanced Waste Water Treatment (AWWT), Advanced Drinking Water Treatment (ADWT) and Advanced Water Treatment (AWT) are used interchangeably throughout the literature. This paper will use the term ADWT.

GLOSSARY

ADWT – Advanced Drinking Water Treatment

AWT – Advanced Water Treatment

AWWT – Advanced Waste Water Treatment

AOPs – Advanced Oxidation Processes

BAC – Biological Activated Carbon

DBP – Disinfection Byproduct

DPR – Direct Potable Reuse

CECs – Chemicals of Emerging Concern

CWA – Clean Water Act

EDCs – Endocrine Disrupting Compounds

EPA – Environmental Protection Agency

GAC – Granular Activated Carbon

IPR – Indirect Potable Reuse

MBR – Membrane Bioreactors

MCLs – Maximum Contaminant Levels

MF – Microfiltration

NF – Nanofiltration

NGWRP – New Goreangab Water Reclamation Plant

NWRI – National Water Research Institute

OGWRP – (Old) Goreangab Water Reclamation Plant

PPCPs – Pharmaceuticals and Personal Care Products

PAC – Powdered Activated Carbon

RO – Reverse Osmosis

SDWA – Safe Drinking Water Act

TDS – Total Dissolved Solids

UF - Ultrafiltration

UV – UltraViolet Irradiation

WHO – World Health Organization

WWTP – Waste Water Treatment Plant

INTRODUCTION

To ensure a dependable supply of safe drinking water for their communities, stakeholders in water-challenged areas in the US are rethinking their water resource options. Conventional drinking water treatment is the status quo throughout most of the US. Indirect potable water reuse (IPR), a more sustainable option, has worked well for over 30 years in northern Virginia and was recently implemented in Orange County, California. However, the most sustainable option is direct potable reuse (DPR). DPR involves directly pumping highly treated wastewater into drinking water treatment systems for potable use as shown in *Appendix A*. Once considered unthinkable, this method now has scientific and public health researchers, policy makers, water agencies, environmentalists, social scientists and community stakeholders poring over its feasibility. This paper presents a survey of current literature on DPRs viability and its current standing. The intent of this review is to illuminate the problem of DPR acceptance and to report on opportunities to move this efficient, novel drinking water solution forward.

As background on this issue, this paper will explore potable water reuse definitions, drivers of DPR, treatment train processes used in its advanced water treatment, and three case studies. DPR progression/implementation will be discussed in terms of obstacles and opportunities for effectiveness and reliability of treatment train processes, health risk concerns, key regulatory issues, management and operational controls and, importantly, public perception issues. Cost analysis will not be covered in this paper due. It is critical to look for drinking water delivery through new paradigms that integrate sustainability, public participation and environmental morals.[1] The reality of DPR in the US is *when*, not *if*, and California is playing a critical role in its development. With recent advances in water treatment and monitoring technology, constituent detection, and health risk analysis encountering water availability, environment, population and cost pressures, DPR is emerging as a viable future option.

DESCRIPTION OF POTABLE WATER REUSE

Potable water reuse takes two forms; indirect potable reuse (IPR) and direct potable reuse (DPR) again shown in *Appendix A*. Planned IPR is the "planned incorporation of reclaimed water into a raw water supply, such as in potable water storage reservoirs or a groundwater aquifer, resulting in mixing and assimilation, thus providing an environmental buffer" which after a specified time period is withdrawn for drinking water treatment.[1(p.1346)] Ironically, unplanned IPR has occurred for decades in the US where treated wastewater effluent is discharged into a river source upstream from a drinking water treatment plant intake (aka. deFacto IPR). In many Midwestern cities, sewage overflows become active with wet weather, forcing untreated sewage into these waterways upstream from drinking water treatment intakes. DPR "refers to the introduction of highly treated reclaimed water either directly into the potable water supply distribution system downstream of a water treatment plant, or into the raw water supply immediately upstream of a water treatment plant."[1(p.1346)] DPR occurs without intervening storage and is also known as "pipe to pipe." Of important distinction is the existence and use of this IPR "environmental barrier" which serves as a spatial and temporal buffer between treated wastewater effluent and drinking water treatment.

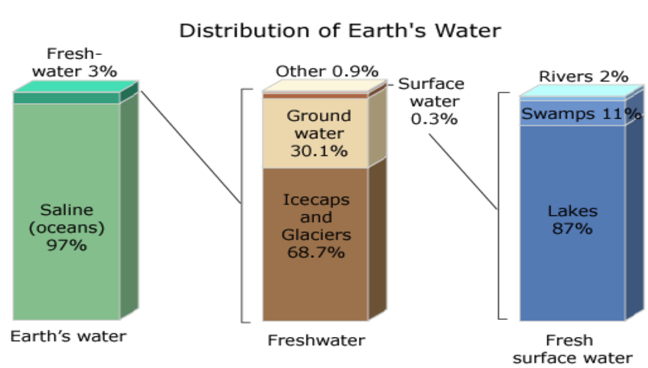
DPR has been recommended as a better alternative to IPR due to its efficiency (recycling the water where needed in the amounts needed), cost (avoiding storage, pumping and retreatment costs), and purity (piping highly treated wastewater effluent directly into enhanced drinking water treatment trains avoids potential contamination of highly purified water in environmental barriers).[2] Additionally, IPR through groundwater recharge requires a suitable aquifer and IPR through surface water augmentation requires reservoir site availability.[3]

DRIVERS OF DPR *(Appendix B)*

GLOBAL WATER SITUATION

Awareness of the critical need for accessible drinking water is global. The United Nation's 58th General Assembly proclaimed 2005 to 2015 to be the International Decade for Action, "Water for Life," to focus on water-related issues and address collaborative efforts to reach the Millennium Development Goal (MDG) for Water and Sanitation.[4] MDG Target 7.C is to "halve, by 2015, the proportion of people without sustainable access to safe drinking-water and basic sanitation."[5] The Global Annual Assessment on Sanitation and Drinking-Water specifically reports on this MDG progress and gives decision-makers tools for comprehensive, global analysis.[5] Increases in population growth and agricultural irrigation have significantly increased global water use in the past 50 years. This is simply unsustainable.[6] Global freshwater availability is illustrated *in Figure 1*.[7] A mere 3% of earth's water is freshwater, 30% of this is ground water and 0.3% surface water. Of this surface water, 89% is available for human use in rivers and lakes, comprising just 1/150th of 1% of total water.[7]

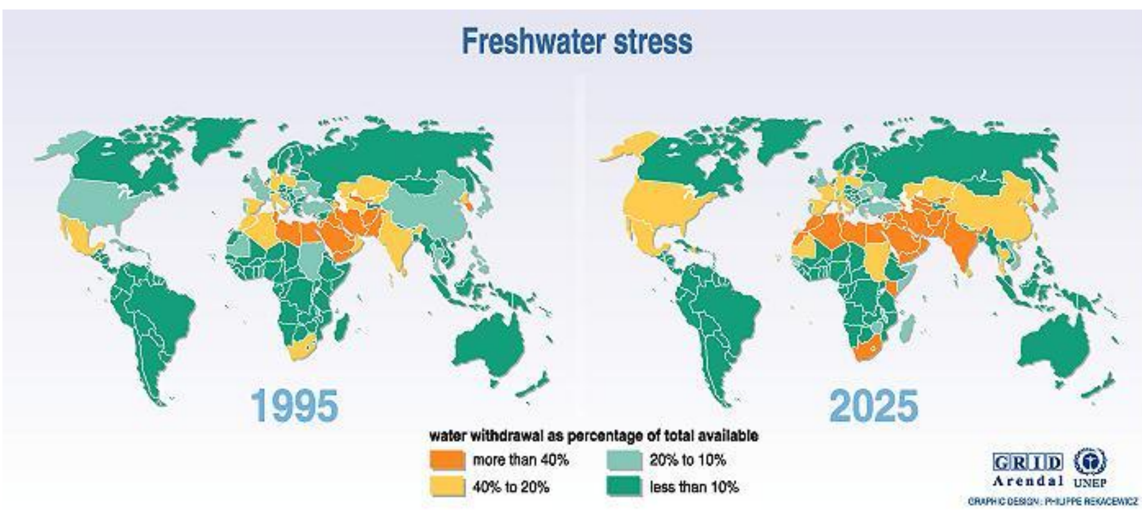
Figure 1 – Distribution of the Earth's Water[7]



WATER-SCARCE / WATER-STRESSED AREAS

The World Water Council warns of a water crisis. Soaring demand for water in many locales is fueled by population growth, concurrent industrialization and urbanization.[8] Specific areas have limited water resources. Water-scarcity and water stress occur in areas where annual water supplies are less than 1000 m^3 per per person and below 1700 m^3 per per person, respectively.[6] Models indicate that by 2050, approximately 40% of the projected global population will live in water-scarce or water-stressed areas, comprised of 54 countries with 4 billion people.[6] *Figure 2* shows global freshwater stress projections.[9] In 1995 the US as a whole experienced freshwater stress from 10-20%. By 2025 it will approach 20-40%.[9]

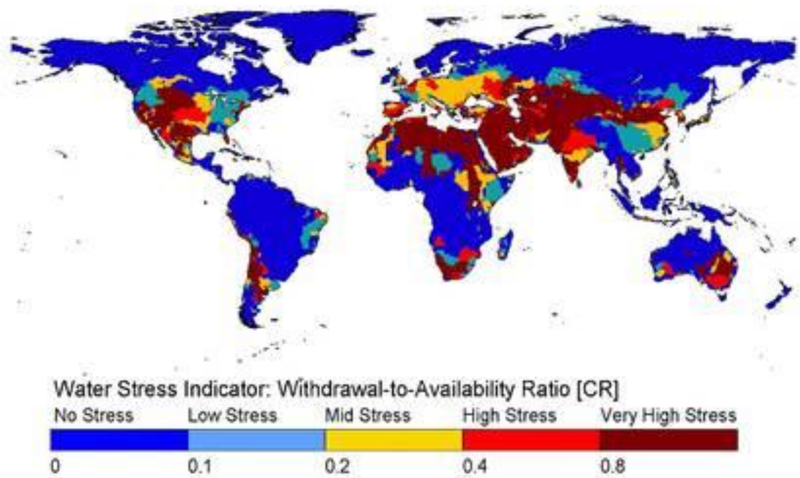
Figure 2 - Freshwater stress projections worldwide:[9]



Source: Global environment outlook 2000 (GEO), UNEP, Earthscan, London, 1999.

Figure 3 illustrates 1995 global water stress.[8] Areas in the US Midwest, Southwest and Florida state already experience high to very high water stress.[8] This creates unique water management issues.

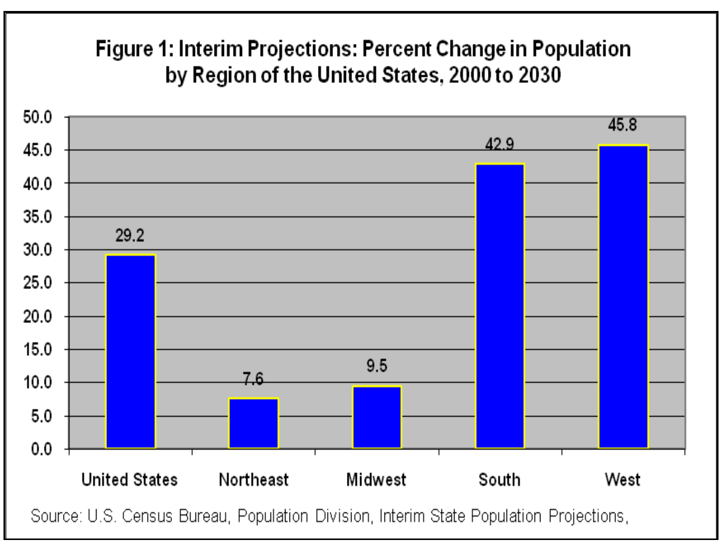
Figure 3 - The 1995 world view of water stress:[8]



POPULATION INCREASES / DEMOGRAPHIC SHIFTS

In the first half of the 21st century the world population is expected to increase by an additional 40-50%.[8] Large population increases in the South and Western US are illustrated *in Figure 4.*[10] In the US, demographic shifts toward the Sunbelt regions, areas already experiencing water resource depletion due to scarcity, contamination, and other environmental impacts, have resulted in economic/urban growth pressures to increase water usage.[11]

Figure 4 – Interim Projections of US Regional Population Percent Changes, 2000 to 2030[10]



ENVIRONMENTAL IMPACTS

Environmental degradation and destruction of natural resources drives DPR. The World Commission on Water for the 21st Century reported that "More than one-half of the world's major rivers are being seriously depleted and polluted… threatening the health and livelihood of people who depend upon them for …drinking water."[12] The new journal, *Water and Climate Change*, highlighted climate change as a driver for drinking water and sanitation improvements.[13] Greenhouse gas emissions have led to environmental changes including diminishing glaciers, severe floods, protracted draughts and powerful heat waves.[14] Water and sanitation infrastructure and management systems are susceptible to these factors where, for example, floods can impact source water quality, damage infrastructure and affect supply demands.[13] Dr. Christine Moe warns that based on such water shortages more efficient use of water is critical and increasing reuse of water will be essential.[15]

RIGHT TO WATER

On September 30, 2010, the United Nation's Human Rights Council affirmed the "right to water." The right to water and sanitation falls within the right to an adequate standard of living, as defined by many international human rights treaties.[16] This first ever declaration affirming the right to water and sanitation is of great historical importance, justifies this right as a legally binding and enforceable global agreement, and serves as authoritative validation for future water-related actions. Although not directly driving DPR, this right to water will push the advancement of more efficient mechanisms for delivering safe, sufficient and accessible water.

ADDITIONAL DRIVERS

Significant increases in water's value, existence of essentially unregulated de facto IPR (urban storm water, highway, and agricultural runoff), existing infrastructure constraints, increased environmental regulations for secondary treatment, and technology advancement are additional drivers of DPR.[17]

TREATMENT TRAIN FOR ADWT – MULTIPLE BARRIER SYSTEM

To ensure that a water agency consistently produces safe potable water, sequential multiple barriers are installed to remove constituents of concern.[1] Technological redundancy enhances reliability of safe water production. Current advances in real-time monitoring technology and robustness of existing and new technologies, such as enhanced membrane systems and advanced oxidation processes, offer nearly complete elimination of trace contaminants.[1] Multiple barrier systems also include nontreatment and operational components, inserting safety barriers based on associated constituent risk to end user.[1]

Current technologies allow for high quality water production greatly surpassing current drinking water standards via Advanced Drinking Water Treatment (ADWT).[1] *Appendix C* conceptualizes the ADWT flow diagram. ADWT is focused on trace constituent removal from reclaimed water beginning with secondary effluent from a conventional Waste Water Treatment Plant (WWTP), applying tertiary treatment, and then dissolved constituent removal, conditioning and disinfection. Bacteria, viruses and protozoa are treated with filtration and disinfection. Inorganics are treated with membrane bioreactors (MBR) and reverse osmosis (RO). Endocrine Disrupting Compounds (EDCs) and Pharmaceuticals and Personal Care Products (PPCPs) are targeted by MicroFiltration (MF), RO and UltraViolet Irradiation (UV).[18,19] See *Appendix D*. Selection of treatment steps depends on multiple factors including source water composition, and with DPR, end potable use drives selection. Common ADWT treatment trains include MF, RO, PAC/GAC, AOPs and chlorination or UV treatment.[20] Not all systems use all of these technologies at once. A typical treatment train in IPR systems is conventional treatment followed by MF, RO and UV followed by conventional DWT. Key technologies follow.[1]

POWDERED, GRANULAR, BIOLOGICAL ACTIVATED CARBON (PAC, GAC, BAC) -MBRs

In the activated sludge process, PAC is added to secondary effluent. GAC, further down the treatment line, uses gravity or pressure filtration. These remove solution substances, trace constituents, by their adsorption onto solid phase activated carbon. They reduce priority pollutants, remove color and ammonia, and improve sludge settling.[1] Examples of readily adsorbed organics include Benzene, Toluene, BCPs, DDT, Atrazine, Carbon tetrachloride, and Chloroform as well as various dyes, gasoline and amines.[1] In addition to refractory organic constituent removal, residual inorganic constituents (i.e., nitrogen, sulfides and heavy metals) and odor compounds are also removed. BAC filtration incorporates GAC with biological activity and is used to treat organic matter and disinfection byproduct (DBP) removal. Pretreatment with ozonation or advanced oxidation enhances performance.

REVERSE OSMOSIS (RO) - MBR

RO technology is used for dissolved constituent removal including salts, many EDCs and PPCPs, pesticides, industrial chemicals, metals, and inorganics.[18] These spiral wound or hollow fiber membrane configurations utilize a high pressure system and small pore size to concentrate such constituents while permitting passage of water and solvents.[1] Pretreatment of feed stream by surface filtration, MF/UF or dissolved air floatation reduces certain constituents and minimizes membrane fouling/scaling for optimal RO efficiency.[1]

ION EXCHANGE

Ion exchange removes dissolved ionic constituents by displacing different (given) ions from solid phase material. It is primarily used for water softening, and removing nitrogen, heavy metals and total dissolved solids, including Na+, Cl-, SO_4^{2-}, NH_4^+ and NO_3^-, Ca_2^+ and Mg_2^+ as well as barium, radium, arsenic, perchlorate, and chromate.[1]

ADVANCED OXIDATION PROCESSES (AOPs)

AOPs remove residual trace constituents. The highly active oxidant, hydroxyl radical, destroys trace organic constituents in a chemical oxidation process.[1] Tertiary effluent contains low concentrations of natural and synthetic chemicals that must be removed or destroyed before potable application. AO usually follows RO to manage such trace constituents and is nonselective in its approach. Benefits of AO are the lack of secondary waste stream production and associated management costs, and operation at normal temperatures and pressures.[1]

NANOFILTRATION (NF) - MBR

NF removes dissolved constituents, salts, most microorganisms and organics. It operates at lower pressures and higher recovery rates than RO. Spiral wound and hollow fiber membrane configurations remove small molecules, bacteria, viruses and proteins in the 0.001-0.01 µm range.[1] Disinfection typically follows to safeguard against membrane defects.

MICROFILTRATION (MF) and ULTRAFILTRATION (UF) – MBRs

MF and UF remove suspended solids, large organic molecules, large colloidal particles and many microorganisms including protozoan cysts, oocysts and helminthes ova. MF removes particles in the 0.008 – 2.0 µm range and UF removes particles in the 0.005-0.2 µm range. Greater removal is achieved with UF than MF but at the expense of pressure. UF is often used prior to disinfection for many reuse applications, including Namibia's DPR treatment train.[1]

CHLORINE, OZONE AND ULTRAVIOLET RADIATION (UV) DISINFECTION

Disinfection in water reuse applications is necessary to target pathogenic organisms of greatest public health consequence, namely bacteria, protozoan oocysts and cysts, helminthes, and viruses.[1] The goal of disinfection is organism destruction or inactivation. The selection of a disinfection method depends on factors such as availability, interaction with extraneous material, nontoxicity to higher life forms, safety, solubility, stability, toxicity to microorganisms and measurement in reclaimed water.[1] Chlorine and its compounds and ozone are the primary chemical compounds used for reclaimed water disinfection while UV use is rapidly increasing. Chlorine is applied through baffled serpentine contact chambers or long pipelines to the permeate fluid.[1] In terms of effectiveness, chlorine gas and sodium hypochlorite are “excellent” at disinfecting bacteria and viruses but “fair to poor” at disinfecting protozoa. Ozone is administered in a contact chamber by bubbling ozone gas through the permeate liquid. In terms of effectiveness, ozone is “excellent” at disinfecting bacteria and viruses and “good” at disinfecting protozoa. Open and closed channel reactors are used for UV lamp irradiation of microorganisms and pressure and intensity parameters capitalize on the very short contact time. UV is “good” at disinfecting bacteria and viruses and “excellent” at disinfecting protozoa.[1] For all three disinfection choices, contact time is critical and correlates with greater destruction of organisms. Concentration of chemical disinfectant, temperature, intensity/ nature of physical agent, types of organisms, nature of suspending liquid and effect of upstream treatment processes are important performance-affecting factors.[1]

CASE STUDIES

WINDHOEK, NAMIBIA

The only location in the world utilizing DPR is Windhoek, Namibia. Located in Africa’s southwest region, Namibia experiences relentless droughts, is ranked as sub-Saharan Africa’s most arid country and is fed by two distant perennial rivers, both over 700 kilometers from

Windhoek.[21] Ephemeral river-based surface water is a highly unreliable water source and groundwater is sparse. In response, the Goreangab Water Reclamation Plant (OGWRP) was constructed and opened in 1969 to utilize final effluent from the city's waste water treatment plant (GWCW) which processed domestic (not industrial) wastewater. Initially, reclaimed water from GWCW was blended with well field water for OGWRP raw source water.[22] Final effluent from the OGWRP was mixed with other potable water and sent directly into the distribution line.[1] DPR was born. The OGWRP underwent numerous upgrades but in 2002, the New Goreangab Water Reclamation Plant (NGWRP) was built and commissioned with cutting-edge technology, a "multiple barrier" approach as shown *in Figure 5*, the water reclamation process.[1]

Figure 5 – Water Reclamation Process for (a) OGWRP and (b) NGWRP[1(p.1355)]

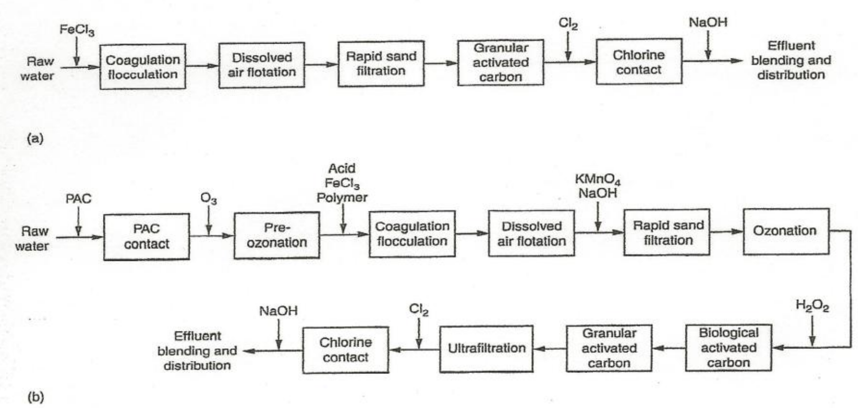


Figure 24-2
Water reclamation process flow diagrams for the Goreangab Water Reclamation Plant in Windhoek, Namibia. (a) 1997 upgrade of the Goreangab process train. (b) The new Goreangab process train. (Adapted from du Pisani, 2005; Lahnsteiner and Lempert, 2005.)

Oversight and involvement by three leaders in the drinking water treatment world (Veolia Water, Berlinwasster International and VA TECH WABAG) for 20 years is conditioned by the loan.[22] The NGWRP now utilizes 90% reclaimed water as its raw water source and consistently produces 21,000 m^3/d of high quality drinking water, providing up to 25% of the city's daily potable water needs.[21]

Since specific water quality guidelines for reclaimed potable water do not currently exist, the NGWRP utilized guarantee values from drinking water standards including the WHO Guidelines, Rand Water (South Africa) Potable Water Quality Criteria and the Namibian Guidelines for Group A water as final water quality guidelines.[1] Under normal conditions, approximately 35% of water in the distribution system is reclaimed, but it can operate safely at a 50% level during periods of draught and high water demand.[22] This completely automated process utilizes the Supervisory Control And Data Acquisition (SCADA) system. To ensure water quality, Intermediate Treated and Treated Water Criteria are benchmarked against Target and Absolute Values which, if not met, results in performance failure penalties, water delivery stoppage, and forced recycle mode.[21,22] See *Appendix E*.

The citizens of Windhoek have successfully overcome negative public perceptions regarding drinking recycled water. Lack of alternatives strongly drove this acceptance.[1] They express pride in utilizing water from the world's only DPR operation. No adverse health effects have been reported attributable to drinking reclaimed water and no waterborne disease outbreaks have occurred.[1] The city has a safe, secure, economically feasible, and reliable source of water for the region through DPR.

DENVER, COLORADO – DIRECT POTABLE REUSE DEMONSTRATION PROJECT/ STUDY

In the 1960s the Denver Water Department realized a water crisis was imminent. Population increases, insufficient surface water and non-sustainable transmountain diversions of water pressured the recognition that a sustainable water source was needed. To utilize sewage effluent for DPR as drinking water, Denver prioritized research and development to prove it possible to produce water of similar or better quality than Denver's current drinking water. A 1970 AWWT pilot plant was constructed to draw secondary effluent from the Metropolitan

Denver Sewage Disposal District Number 1 facility and serve as the research and design template for the Denver Potable Water Demonstration Project of 1985. The plant-scale 5-year demonstration project was necessary prior to full-scale implementation to assure safety, reliability and quality standards while assessing cost.[23] Research and design data were amassed through 1979 along with economic, legal, and marketing feasibility studies including U.S. Environmental Protection Agency participation, analytical quality testing, and health effects research.[24] A study of public opinion showed that 84% of Denver customers would accept DPR if water quality met or exceeded their current drinking water parameters and if safety was certain.[24]

Appendix F illustrates this demonstration plant's multiple barrier treatment train approach.[23(p.54)] Real-time monitoring, rigorous sampling and analyses were done throughout to monitor and ensure water quality. For almost every constituent of concern the final effluent met or exceeded U.S. EPA Drinking Water Standards for physical, general mineral, microbiological, organic, metals and others.[23] A two year health effects study was an integral component and multiple chronic toxicology studies showed no adverse health effects detected using exposure to reclaimed water supplies.[25] DPR was not implemented due to fragmented political consensus.

SINGAPORE – NEWater

Geographically water-challenged Singapore has emerged as a current leader in the water recycling world. Decreasing freshwater sources, escalating trans-country water importation costs, the 2011 expiration of Malaysia's water supply agreement, and population pressures pushed the Public Utilities Board (PUB) to predict this crisis and to begin plans in the 1970s for utilizing the city's sewage for drinking water purposes. This reclaimed, highly treated water, called NEWater, is produced by DPR treatment trains, bottled as drinking water, but is currently used via IPR for Singapore's tap drinking water. The 1998 Singapore Water Reclamation Study proved that NEWater could supplement the country's water supply safely as an additional raw water source.[26] As of 2010, five NEWater plants meet 30% of Singapore's water demand and by 2011 2.5% of drinking water demand will be furnished through IPR NEWater.[27,28]

Through the Water Reclamation Study and an international panel of experts, more than 65,000 analyses investigating over 290 parameters demonstrated that NEWater is cleaner than local drinking water.[28,29] NEWater also meets or surpasses USEPA and WHO drinking water standards throughout quality parameters, as shown in *Appendix G*.[28] NEWater technology consists of a multiple barrier treatment train, a process perfected by Singapore's scientists over a 30 years period.[28,26] Used water is first sent through a conventional wastewater treatment process, treated to global standards and then treated with MF, RO and UV disinfection.[26,28,30] It is used for direct non-potable purposes by commercial buildings and industries and in 2002, NEWater was also approved for planned IPR.[28] Although using DPR for tap drinking water is not currently practiced in Singapore, NEWater is bottled for public consumption (from DPR), and technology is in place to introduce safe and reliable NEWater directly into the drinking water distribution system once infrastructure and public policy permit.[26]

Recent prestigious awards highlight NEWater's cutting edge contribution to water reuse, and ultimately DPR's future. Singapore's PUB recently received the National Water Research Institute Award of Excellence.[28] The 2010 Sembcorp NEWater Plant is the world's largest water recycling plant built on top of a water reclamation plant. This plant collects and treats used water from Singapore's eastern half and then transports it "upstairs" for NEWater purification processes. This successful public/private partnership recently won the Global Water Award 2010 Water Reuse Project of the Year validating its considerable achievement internationally.[27]

CURRENT DIALOGUE ON U.S. DPR IMPLEMENTATION

MEDIA / GOVERNMENT

Public dialogue about DPR is increasing. A 2008 news article titled "It's Time To Drink Toilet Water – Recycling sewage is safe and efficient, so why aren't we doing it?" heightened public awareness in San Diego of the quality, safety, cost, and environmental benefits of DPR.[31] To address increasing water supply demands from population, environmental and drought pressures, the Orange County Water District of So. California recently completed the nation's largest water reclamation plant utilizing IPR to supply 10% of its daily need.[32] Overcoming this large hurdle certainly paves the way for DPR consideration. Peter Silva, head of EPA's Office of Water, addressed the June 2009 AWWA meeting commenting on the new intersection of issues between the drinking and waste water factions. Regarding how water is supplied amidst environmental pressures, he stated that "even direct potable reuse is being considered."[33]

SCIENTIFIC / PUBLIC HEALTH RESEARCHERS

Increased inputs by scientific and public health researchers are highlighting DPR's real possibility as a future water source solution by addressing various elements of concern. California stakeholders are focusing efforts to pursue DPR. The 2010 National Water Research Institute (NWRI) White Paper regarding Regulatory Aspects of DPR in California and the September 2010 DPR Workshop Report furthered California's progression by setting timelines for key investigations.[34,35] Three Johns Hopkins Bloomberg School of Public Health researchers presented "Reuse of Wastewater: Contaminants of Concern, Potential Human Exposure and Treatment" at the March 2009 International Conference on Environmental Health. They addressed drivers for water reuse, water quality considerations for reuse, routes of exposure for contaminants and advanced treatment options for specific "constituents of concern."[18]

WATEREUSE ASSOCIATION

The WateReuse Association is a collection of international organizations and individuals committed to the advancement of efficient water resource practices for local water supply management.[36] Its mission is "to advance the beneficial and efficient uses of high-quality, locally produced, sustainable water sources for the betterment of society and the environment through advocacy, education and outreach, research, and membership."[36] Presentations at Water Reuse Symposiums have increasingly included DPR feasibility. George Tchobanoglous, from UC Davis – Dept of Civil and Environmental Engineering, spoke at the September 2009 24th Annual WateReuse Symposium on "Direct Potable Reuse: Why Not?"[17] He discussed drivers for DPR, public perception issues, defacto IPR, and infrastructure issues limiting conventional reuse strategies (expensive infrastructure is required and large storage sites are difficult to permit for IPR in developed areas). He concluded that IPR, DPR and new infrastructure approaches represent the future.[17] Mike Wehner of the Orange County Water District presented "Direct Potable Reuse – Its Time Has (nearly) Come" at the same symposium.[2] He addressed why potable reuse is difficult to accept, its urgent need, current technological ability to produce safe potable reuse water and reasons to proceed with DPR rather than IPR.[2] At the 2010 California Water Policy Conference, a session on "Direct Potable Reuse? How Thirsty Do We Have to Be?" detailed that "now, caught between the pressures of increasing demand and tighter water supplies, water agencies are beginning to take another look at options once considered off the table. One of these is DPR."[37] The May 2010 Water Reuse & Desalination Research Conference included a presentation on "The Path from Indirect to Direct Potable Reuse – Ready for Prime Time?" by Jorg Drewes, Professor at the Colorado School of Mines.[38] He evaluated IPR's environmental buffer and reached the critical conclusion that blending and retention functions normally served by IPR's environmental buffer can be substituted through an engineered solution.[38] The WateReuse Foundation's strong research arm includes DPR and has called for abstracts for its second Potable Reuse Conference in November 2011.[36]

DETERMINANTS OF DPR ACCEPTANCE *(APPENDIX H)* - OBSTACLES AND OPPORTUNITIES

EFFECTIVENESS AND RELIABILITY OF TREATMENT TRAIN UNIT PROCESSES

OBSTACLES:

Obstacles are inherent in all ADWT treatment train processes. *PAC and GAC* obstacles include logistical difficulties with transporting large volumes of materials, high media replacement costs, contactor space requirements, and sensitivity to pH, temperature and flow rate.[1] Obstacles arising from *NF and RO* use include imperative analysis of RO feed water and selection of an appropriate pretreatment system given that RO membranes are highly sensitive. Membrane fouling, cleaning, and lifespan as well as operating and maintenance costs are persistent issues. Efficient *Ion exchange* is highly dependent upon on levels of particulate and colloidal matter, solvent, and organic polymer presence. These can cause "blinding" of the ion exchange surfaces and thus require chemical pretreatment for clarification to optimize performance.[1] *Advanced oxidation processes* produce brominated byproducts but can be managed by pH control or ammonia addition. Additional byproducts are carbon dioxide and mineral acids. Bicarbonate, carbonate, pH, and metal ions affect AO performance and must be corrected for at the outset.[1] *MF/UF* endure typical membrane obstacles including life, performance, operating efficiency, flux maintenance and increased operating costs.[1] Each disinfection procedure has associated obstacles. With *chlorine disinfection,* byproducts (trihalomethanes and haloacetic acids) are formed and total dissolved solids (TDS) increase. After disinfection, dechlorination is necessary to reduce chlorine levels to acceptable environmental levels. Use of *ozone disinfection* creates DBPs, although they are not chlorinated; the type created depends on bromide's presence or absence in the effluent.[1] Effectiveness of *UV disinfection* depends on certain permeate parameters, particularly chemical/microorganism characteristics, particle presence, microorganism regrowth potential post treatment, and the UV system's physical state.[1]

The ADWT separation process generates waste stream concentrates of technological, management and economic concern. Waste products created during purification of secondary effluent include concentrated rejected constituents from liquid waste (regeneration brines, backwash), concentrated trace constituents saturating media during adsorption phases (retentate), and chemicals added to the process and concentrated from precipitate compounds.[1]

OPPORTUNITIES:

The 1998 National Research Council report on potable reuse concluded that DPR was not a practical option to consider at that time due to unresolved issues regarding microbial and chemical constituents of concern, treatment train effectiveness and monitoring water quality for health effects.[39] Since that time, an escalation in research and development has attempted to prove otherwise by investigating such issues including reclaimed water and multiple barrier treatment reliability.[39] It is beyond the scope of this paper to elucidate all pertinent research, however investigating important chronological research into treatment train processes and chemical constituents of concern illustrates this point. EDCs and PPCPs at trace levels are of important public health concern, especially when considering potential DPR application. Conventional WWTPs do not remove EDCs and PPCPs in their entirety.[20] Thus ADWT processes must be effective in removal prior to DPR acceptance. In 2004, researchers found that 98% of bisphenol A was removed with membrane bioreactors and RO.[40] In 2006, researchers reported efficient removal of natural steroid hormones from wastewater using direct contact membrane distillation and forward osmosis.[41] Investigators in 2007 published an updated review on EDC removal by photocatalysis and ultrasound oxidation from wastewater.[42] A 2007 paper investigated the removal of antibiotics in AWWT, in particular MF/RO product water, and implications for wastewater recycling.[43] Researchers in 2009 reported on pharmaceuticals and EDCs removal from water using a photocatalytic reactor membrane pilot system achieving great efficiency in the UV/ H_2O_2 mode.[44] A 2009 paper reported that ozone/UV used together do not promote bromate production yet do achieve effective PPCP removal.[45] In 2010 evaluation of UV/H_2O_2 treatment for pharmaceutical oxidation in wastewater, found an influence by effluent organic matter levels.[46] Investigators in 2010 found the removal of pharmaceuticals, caffeine and DEET in wastewater treatment plants in China very effective with MF/RO processes.[47] Rigorous research has escalated in many other areas regarding ADWT individual processes.

The 2010 DPR Workshop report highlighted opportunities to address treatment barrier diversity and constituent reduction. Determining necessary treatment processes by number, type and reliability, identifying Chemicals of Emerging Concern (CECs) surrogates and "sufficient" barrier criteria, and validating barrier effectiveness against benchmarks were recommended.[35]

HEALTH RISK CONCERNS

OBSTACLES:

Few epidemiologic and toxicological potable reuse health effects studies have been conducted over the past 30 years to investigate the public health impact of IPR and DPR as detailed in *Appendix I*. The Windhoek, Namibia DPR project utilized epidemiological and toxicological studies to find no relationship observed between drinking water source and diarrheal disease cases.[48] The Denver, Colorado potable water reuse demonstration project published the only other DPR study.[34] A two year toxicological health effects study used in vivo studies for chronic and reproductive effects and found no adverse health effects using exposure to reclaimed water supplies.[1] All other health effects studies to date have evaluated IPR with toxicological studies, the most recent being the 2007 IPR Singapore Water Reclamation Study which did not show any health effects in fish or mice.[34] Although these studies revealed no obvious health effects, design shortcomings, age of studies, and technology's rapid advancement over the past decade are factors worthy of important consideration in interpretation and extrapolation.[49] The 1998 NRC report on "Issues in Potable Reuse: The Viability of Augmenting Drinking Water Supplies with Reclaimed Water" considered only IPR. While significant IPR findings detailed below are encouraging, the jump from IPR to DPR requires careful consideration of potential short and long term health effects:

- "Current projects and studies have demonstrated the capability to reliably produce water of excellent measurable quality.
- In communities using reclaimed water where analytical testing, toxicological testing, and epidemiological studies have been conducted, significant health risks have not been identified (and long-term effects cannot yet be known).
- Best available current information suggests that risks from IPR projects are comparable to or less than risks associated with many conventional supplies."[49(p4.16)]

The NRC recommends that retrospective cohort studies or case-control studies are needed to elucidate health outcomes and exposure data in relation to IPR and ultimately DPR.[34]

Microbiological and chemical constituents are effectively diminished in ADWT, including waterborne pathogens of significant concern such as bacteria (Campylobacter, Escherichia coli, Salmonella, Yersinia, Vibrio, Legionella, Aeromonas, Mycobacterium, Shigella and Pseudomonas); viruses (Hepatitis A, Reovirus, Calicivirus, Enterovirus, Coxsackievirus, Adenovirus, Echovirus and Poliovirus); and protozoa (Giardia, Cryptosporidium, Entameoba, Microsporidium).[18] However, CECs are health risk obstacles to DPR acceptance. In California, a 2009 "blue-ribbon" panel charged experts to investigate the current status of CEC scientific knowledge, and potential environmental/public health risks from recycled water. While targeted to landscape irrigation with IPR, many aspects apply to DPR.[34] The 2010 final report gave guidance for prioritizing CEC inclusion in recycled water monitoring programs with data interpretation formats.[50]

OPPORTUNITIES:

To explore the water-health connection, a new journal, *Water Quality, Exposure and Health* was launched in 2009.[51] Synthesized organic compounds now surpass half a million and 10,000 new compounds are added annually. The likelihood of identifying all possible health effects is slim. However, tremendous research and significant findings on water quality and health effects over the past few decades give hope to narrowing the margin and protecting public health from adverse health consequences.[51] Christine Moe and Richard Rheingans from Emory University's Center for Global Safe Water, Rollins School of Public Health urge researchers to carry out epidemiologic studies of potential health risks associated with potable water reuse as reuse practices become increasingly prevalent and tools to protect public health continue to develop.[6] Examples of research needs include identification of which treatment technologies provide the most meticulous and reliable treatment for waste water intended for reuse projects and which monitoring strategies best identify chemical contaminants and microbial pathogens in effluent from reuse systems serving the public drinking supply.[6]

The 2010 DPR Workshop Report highlighted many important gaps that function as opportunities to address health risk concerns. The main components are mentioned here.[35] *Water quality treatment performance goals* require clarification of monitoring, ensuring adequacy of treatment to warrant environmental buffer elimination, water quality standardization with performance standards potentially incorporated for ADWT, justification of required monitoring level and characterization of monitoring strength for QA/QC. *Performance monitoring* will reveal if routine, automated and periodic monitoring for indicators, surrogates and specific contaminants, respectively, can together validate treatment performance goals continuously.[35] Expanding surrogate research, evaluating incorporation of a Hazard Analysis Critical Control Point type program, determining real-time online monitoring feasibility to capture parameters of concern, considering rapid feedback methodology and assessing ability to incorporate rapid bioassays are necessary.[35] *Monitoring for public health assurance* through drinking water requirements, additional sampling and constituent monitoring, online real-time monitoring and enhanced CEC procedures are imperative. By *investigating diversity of treatment barriers* for constituents, the number, type, order and reliability levels can be determined to guarantee that constituents are reduced to appropriate drinking water levels.[35]

The need for a global data base to catalogue wastewater biological contaminant load and the need to characterize public health protection in terms of water reuse are both critical to inform policy and decision making.[52] WHO guidelines and the European Union Council Directive 98/83/EC are trending away from the absolutism of pathogen-free drinking water to providing that which is free of numbers and concentrations of microorganisms, parasites and chemicals which could potentially endanger public health; in other words, acceptable risk.[52] Monte-Carlo techniques for probabilistic health risk and exposure assessments are beginning to have application for quantifying human exposure to contaminants for ADWT systems.[53] Mathematical modeling of risk reduction from pathogen/chemical concentrations as well as Quantitative Microbial Risk Assessment utilizing indicator data and treatment strategies with the standard hazard identification, dose-response, exposure assessment and risk characterization will be helpful in further addressing water quality and public health protection from DPR.[52] Risk extrapolation for carcinogens depends upon unverifiable assumptions, varying results from model selection and lack of models to evaluate very low doses of carcinogens.[1] To estimate risk from lifetime (70-year) carcinogen exposure in drinking water, a default linearized multistage model is currently used.[1]

KEY REGULATORY ISSUES TO BE ADDRESSED PRIOR TO DPR

CURRENT STATUS WATER QUALITY GUIDELINES / STANDARDS

International attention on water and wastewater is established. The WHO has issued guidelines for safety in wastewater use since 1973, most recently the 2006 WHO Guidelines for Safe Use of Wastewater in Agriculture.[1] Based on public health protection, WHO drinking water guidelines were established in 1983.[54] The 2008 3rd ed. of WHO's Guidelines for Drinking Water Quality include a rolling revision on microbial aspects, guideline applications, chemical safety, and monitoring which are comprehensive in scope yet adaptable to unique settings worldwide.[54] In 2004, the IWA issued the Bonn Charter for Safe Drinking Water as a quality management framework utilizing risk assessment and reduction throughout the water supply system.[55] Potable reuse guidelines are currently non-existent in WHO, particularly with DPR. Country-specific reuse regulations are growing, notably in Australia and Spain.[56]

The U.S. Safe Drinking Water Act (SDWA) of 1974 with amendments in 1986 and 1996 regulates the U.S. drinking water supply to protect public health.[57] It gives authority to the U.S. EPA to set national standards for drinking water, National Primary Drinking Water Regulations, which include maximum contaminant levels (MCLs), required treatment processes, and mandatory testing parameters for contaminants. These enforceable parameters are based on risk science to protect the health of vulnerable populations and to assure consistent water quality.[57] Based on ongoing EPA evaluation of constituent risk, a Contaminant List for potential future regulation, the National Contaminant Occurrence Database, and the Unregulated Contaminant Monitoring Regulation monitor drinking water contaminants.[58,59] For prevention, SDWA requires source water analysis from states and water suppliers, including Underground Injection Control to monitor waste injection into ground water.[57] Since the SDWA assumes source water is relatively uncontaminated and the Clean Water Act (CWA) uses water quality limits that are not in line with drinking water parameters to protect the nations' waters, these two regulatory acts are presently insufficient to deal with public health concerns associated with municipal wastewater as source water for drinking water treatment in DPR.[1]

U.S. federal regulations do not currently exist for governance of water reuse practices.[60] The U.S. EPA suggests certain IPR guidelines in their 2004 Guidelines for Water Reuse, but to date have not suggested DPR guidelines as shown in *Appendix J*.[1] IPR guidelines address treatment techniques, reclaimed water quality guidelines and water monitoring and setback distances for the three types of IPR (groundwater recharge by spreading into potable aquifers, groundwater recharge by injection into potable aquifers and augmentation of surface supplies). The EPA is currently developing the next Guidelines for Water Reuse which may include a chapter on DPR systems due to advances in interest, industry, and technology.[61]

Many individual states have passed legislation for their state water reuse practices. Conservation, non-potable uses, and in a few states, IPR, are defined by state regulations which vary considerably in their parameters and type of reuse application.[60] These regulations are conservative in nature with "public health protection being the most important consideration."[62(p1)] As of 2002, four states had regulations and guidelines governing IPR; California, Florida, Hawaii, and Washington state. These vary in treatment and monitoring parameters but all operate under the assumption that minimal to no additional treatment will be required following discharge to the environmental buffer prior to drinking water treatment abstraction.[60] Florida and California have the most specific regulations for treatment and quality criteria for potable reuse.[62] Currently, there are no state regulations or guidelines for DPR.

OPPORTUNITIES

The state of California is a world leader in developing specific criterion for both IPR and DPR.[1] Pushing forward to assess DPR's feasibility as a safe potable water source for Californians, a 2010 NWRI white paper evaluated the regulatory aspects of DPR in California and identified existing regulations applicable to DPR as well as specific issues requiring evaluation for DPR progression.[34] Specifically, they investigated the various domains of regulatory authority and their interactions including the State Water Resources Control Board and its Recycled Water Policy, the Regional Water Quality Control Boards, and the California Department of Public Health (CDPH). The September 2010 DPR Workshop Report pushed the NWRI paper a step further calling for stronger evaluation of such regulatory aspects to identify current limitations.[35] Their detailed opportunities follow:

- investigating how existing statutes, regulations and policies currently used with IPR can be adapted to DPR;
- determining how evaluation tools for drinking water regulations can be adapted to DPR through the various state governmental water and health departments

- delineating the point at which water transitions from Water Code authority to Health and Safety Code authority for DPR proposals;
- evaluating the need for water rights regulation changes for DPR;
- evaluating if operator certification changes are needed for DPR treatment plant operators; establishing approaches for concentrate/residual permitting, treatment and disposal.[35]

Based on these findings, they recommended optimal regulatory scheme identification, CEC evaluation approach development, environmental buffer needs assessment, and development of source control strategy, communications protocol and treatment performance standards.[35] Moving forward, a Work Plan will be issued by the National Water Research Institute, WateReuse-California, and the California Urban Water Agencies in early 2011 outlining candidate organizations, individual study issue leaders, and timeline for completion.[35] This may well serve as a model for other states and federal attention.

PUBLIC PERCEPTION ISSUES

OBSTACLES

Public perception issues are the largest hurdles to overcome in DPR acceptance. Drinking water that once contained human excreta is perceived as "dirty." Without a separation step, between sewage effluent and influent to the drinking water treatment plant, public DPR acceptance will be difficult.[1] Even San Diego's costly IPR project was recently halted despite its safe, technologically feasible and cost effective parameters due to a dive in public perception after the term "toilet to tap" surfaced.[63] The perception that water is everywhere, and therefore DPR is unnecessary, is another major public perception obstacle. DuPisani's 2006 analysis of DPR at Windhoek's, Namibia's NGWRP concludes that public perception is the main obstacle and DPR will only succeed if no other options exist for the community or region.[21]

OPPORTUNITIES:

It is now commonly recognized that public perceptions and acceptance are critical for a water reuse project's success. A 2003 literature review of factors influencing public perceptions and behavioral acceptability of water reuse revealed the following target opportunities:

- Disgust or "Yuck" factor
- Perceptions of risk associated with using recycled water
- The specific uses of recycled water
- The sources of water to be recycled
- The issue of choice
- Trust and knowledge
- Attitudes toward the environment
- Environmental justice issues
- The cost of recycled water
- Socio-demographic factors[63(p.14)]

The 2010 DPR Workshop Report identified and prioritized five key tasks necessary to address public perception issues prior to implementing DPR in California.[35] To *develop appropriate terminology,* water recycling terminology and images should be consistent throughout regulations and understandable by stakeholders to inspire product confidence and trust.[35] S*urveying stakeholders* requires researching attitudes and analyzing results to elucidate reasons for DPR support or opposition, understanding of the IPR/DPR difference, public perception of DPR necessity, and terminology impact.[35] *Developing messages* by including appropriate terminology and stakeholder perspective results, targets unique audiences. Message content should include success and safety of current IPR projects, public health and DPR safety parameters, risk communication, and supply/environmental/cost drivers.[63] *Developing a communications strategy* by incorporating lessons learned from successful IPR projects, embracing human nature ("yuck" factor, empowerment), and providing useful information that is simple, accurate, informative and accessible aids informed decision making. Using a hands-on approach (i.e., important stakeholders drinking bottled product water), working with opponents and developing trust enhance the communications strategy.[35]

Establishing and maintaining public trust and confidence is of the highest importance in effecting behavioral and attitudinal change.[63] A top-down approach does not work.[64] The Recycled Water Task Force urges community involvement prior to any reuse project's conception to build successful and sustainable participation.[63] Flinders University's Dr. June Marks describes people's active trust in the willingness to drink recycled water as developed on their understanding of laws and regulations governing safety, belief in adherence to those standards, proposal familiarity, information transparency and belief in involved institutions' good governance.[64] A 2008 paper on drivers of communities' decisions and behaviors regarding wastewater reuse identified "trust" as the strongest influencing factor.[65] It is wise to engage the skills of a risk communication specialist to promote this aspect of trust.

MANAGEMENT AND OPERATIONAL CONTROLS - OBSTACLES / OPPORTUNITIES:

Obstacles related to operations and management of DPR systems are best viewed through the opportunities they present. Improvements over the last decade in wastewater and water management and operational controls have been advanced by real-time process monitoring and control strategies development.[1] The 2010 DPR Workshop Report identified several related areas to investigate before justifying DPR progression.[35] *Consideration of system design* includes analysis and preparation for system failure, immediate response planning including discharge diversion and storage use, organization of emergency water supply and security issues, and analysis of compensation for loss of retention/reaction time (i.e., IPR requires 6 months).[35] It is necessary to evaluate the n*eed for enhanced source control programs* to reduce or remove the entrance of certain chemicals into the wastewater collection system. This would include aspects of monitoring, permitting, and physical/program design steps. Evaluation of *data reporting tasks* includes internal protocol planning and external reporting of monitoring results to regulatory agencies and the public. *Operational guideline* development is required to assure DPR plant system reliability and includes identifying changes to operator certification requirements and monitoring changes in the distribution system. Proper *concentrate and residual management* will be guided by NPDES permitting development and CWA amendments. Finally, *monitoring for environmental impacts* of DPR requires delineation.[35]

CONCLUSION

Direct potable reuse is a viable option for future water resource management as cities and regions struggle to ensure a dependable supply of safe drinking water amidst growing population, environmental and cost pressures. DPR's acceptance depends upon stakeholders, policymakers, scientific researchers and public health professionals investigating opportunities and solving problems present in DPR's treatment train processes, health risk concerns, key regulatory issues, management and operational controls and public perception issues. Cost-benefit analysis of DPR versus IPR is essential, but already appears positive.[2] Of great importance is the vital need for stronger epidemiological research, including observational epidemiology such as case/control and retrospective and prospective cohort studies, and potentially clinical trials with NEWater or Namibia's DPR water, to mitigate health effects concerns. Running new toxicological studies with current state of the art DPR treatment train technology and various endpoints would add strength to existing toxicological studies. California's diligent, systematic pursuit of DPR acceptance will serve as a model to states such as Florida, Texas and Arizona. They are exemplifying the ethos of good resource stewardship. As professor Malin Falkenmark of the Stockholm International Water Institute and Resilience Center reported "Humanity finds itself on the threshold to a new era related to its dependence on, and interaction with, the global water cycle, the bloodstream of the biosphere. This new era demands that we further develop our thinking and approaches so that we adequately prepare for a better future and lay the basis for successfully coping with the increasingly complex challenges that will face our children and grandchildren."[66]

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APPENDIX A - IPR (UNPLANNED / PLANNED) AND DPR DIAGRAM

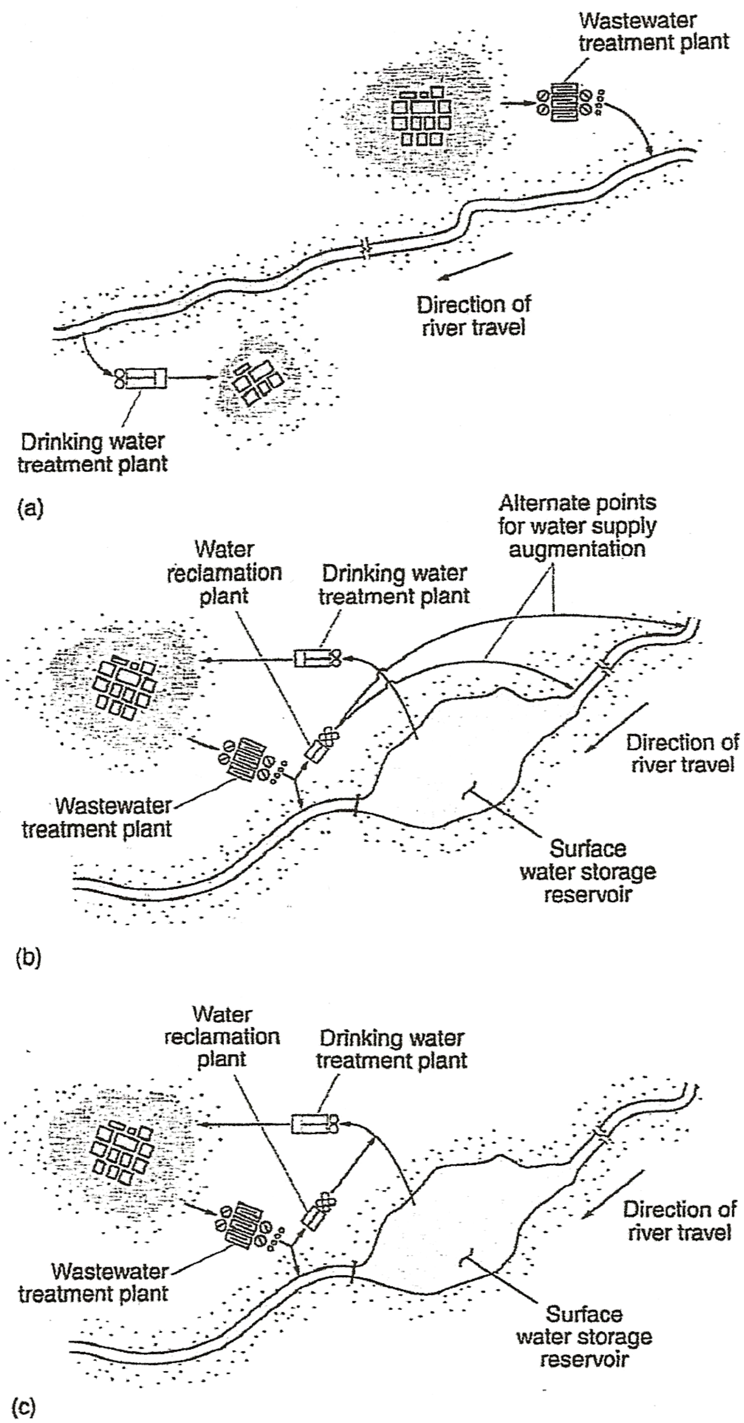
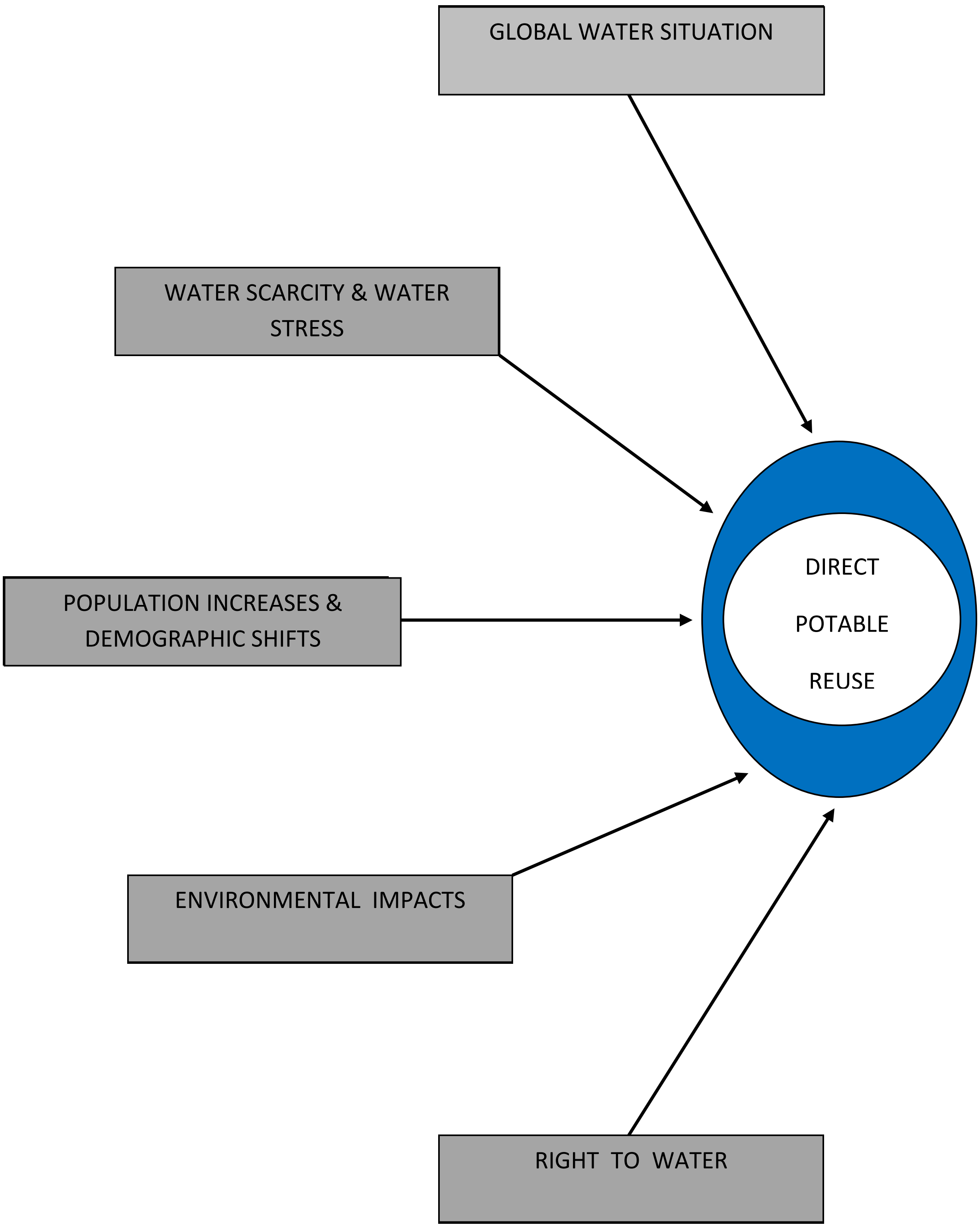


Figure 23-2 Schematic diagrams of water reuse schemes: (a) incidental (*de facto*) indirect potable reuse, (b) planned indirect potable reuse, and (c) direct potable reuse.

Source: Water Reuse [1(p.1307)]
IPR = Indirect Potable Reuse; DPR = Direct Potable Reuse

APPENDIX B - DRIVERS OF DIRECT POTABLE REUSE - CONCEPTUAL DIAGRAM



APPENDIX C - AWT FLOW DIAGRAM EXAMPLE

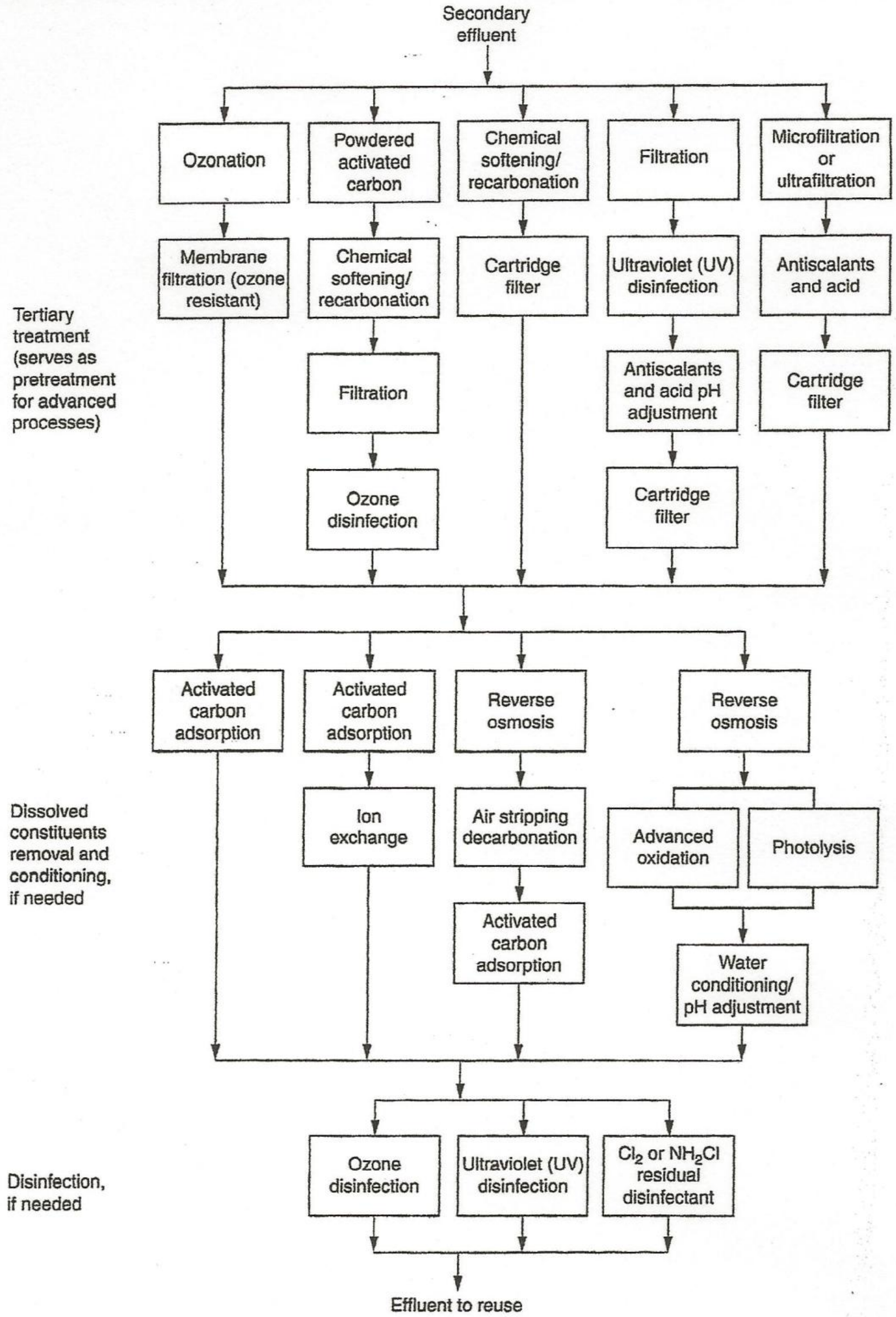


Figure 10-1
Examples of flow diagrams used for advanced treatment for water reclamation.

Source: Water Reuse [1(p. 530)] *AWT = Advanced Water Treatment*

APPENDIX D - CONSTITUENT REMOVAL PER TREATMENT PROCESS

WASTEWATER CONSTITUENT REMOVAL (mg/L) AND % REDUCTION IN AWT

	Raw Concentration	Primary Effluent Conc	Secondary Effluent Conc	Tertiary Effluent Conc	AWT Effluent Conc	Overall % Reduction
Conventional						
CBOD	185	149	13	4.3	NA	98
TSS	219	131	9.8	1.3	NA	99+
TOC	91	72	14	7.1	0.6	99+
TS	1452	1322	1183	1090	43	97
Turb. (NTU)	100	88	14	0.5	0.27	99+
Ammonia-N	22	21	9.5	9.3	0.8	96
Nitrate-N	0.1	0.1	1.4	1.7	0.7	0
TKN	31.5	30.6	13.9	14.2	0.9	97
Phosphate-P	6.1	5.1	3.4	0.1	0.1	98
Nonconventional						
Arsenic	0.0032	0.0031	0.0025	0.0015	0.0003	92
Boron	0.35	0.38	0.42	0.31	0.29	17
Cadmium	0.0006	0.0005	0.0012	0.0001	0.0001	83
Calcium	74.4	72.2	66.7	70.1	1.0	99
Chloride	240	232	238	284	15	94
Chromium	0.003	0.004	0.002	0.001	0.001	83
Copper	0.063	0.070	0.043	0.009	0.011	83
Iron	0.60	0.53	0.18	0.05	0.04	94
Lead	0.008	0.008	0.008	0.001	0.001	91
Magnesium	38.5	38.1	39.3	6.4	1.5	96
Manganese	0.065	0.062	0.039	0.002	0.002	97
Mercury	0.0003	0.0002	0.0001	0.0001	0.0001	67
Nickel	0.007	0.010	0.004	0.004	0.001	89
Selenium	0.003	0.003	0.002	0.002	0.001	80
Silver	0.002	0.003	0.001	0.001	0.001	75
Sodium	198	192	198	211	11.9	94
Sulfate	312	283	309	368	0.1	99+
Zinc	0.081	0.076	0.024	0.002	0.002	97

Source: Adapted from Water Reuse [1(p. 109)]

AWT = Advanced Water Treatment

APPENDIX D – (con't)

LOG REMOVAL OF TYPICAL MICROORGANISMS BY WASTEWATER TREATMENT PROCESSES						
	Removal of organism for given treatment process, log units					
	Primary	Secondary		Tertiary		Advanced
Organism	Plain Sedimentation	Activated sludge	Trickling filter	Depth filtration	Microfiltration	Reverse osmosis
Fecal coliforms	<0.1 - 0.3	0 - 2	0.8 - 2	0 - 1	1 - 4	4 - 7
Salmonella	<0.1 - 2	0.5 - 2	0.8 - 2	0 - 1	1 - 4	4 - 7
Mycobacterium tuberculosis	0.2 - 0.4	0 - 1	0.5 - 2	0 - 1	1 - 4	4 - 7
Shigella	<0.1	0.7 - 1	0.8 - 2	0 - 1	1 - 4	4 - 7
Campylobacter	1	1 - 2		0 - 1	1 - 4	4 - 7
Cryptosporidium parbum	0.1 - 1	1		0 - 3	1 - 4	4 - 7
Entamoeba histolytica	0 - 0.3	<0.1	<0.1	0 - 3	2 - 6	>7
Giardia lamblia	<1	2		0 - 3	2 - 6	>7
Helminth ova	0.3 - 1.7	<0.1	1	0 - 4	2 - 6	>7
Enteric viruses	<0.1	0.6 - 2	0 - 0.8	0 - 1	0 - 2	4 - 7

Source: Water Reuse [1(p.101)]

APPENDIX D – (con't)

PERCENT EDCs, PPCPs REMOVAL BY AWT UNIT PROCESSES													
Group	Classification	Reverse Osmosis	BAC	Activated Carbon	Nanofiltration	Biodegradation	Advanced Oxidation	Photodegradation	Activated Sludge	UV	Cl2/CLO2	Softening	Coag/Floc
EDCs	Pesticides	E	E	E	G	v	L-E	E	v	E	v	G	P
	Industrial Chems	E	E	E	E	G-E	F-G	v	v	E	P	P-L	P-L
	Steroids	E	E	E	G	L-E	E	v	v	E	E	P-L	P
	Metals	E	G	G	G	P	P	v	E	P	P	F-G	F-G
	Inorganics	E	F	P-L	G	P-L	P	P-L	P-L	P	P	G	P
	Organometallics	E	G-E	G-E	G-E	L-E	L-E	L-E	L-E	F-G	P-F	P-L	P-L
PHACs	Antibiotics	E	E	F-G	E	E	L-E	G-E	v	F-G	P-G	P-L	P-L
	Anti-depressants	E	G-E	G-E	G-E	G-E	L-E	G-E	G-E	F-G	P-F	P-L	P-L
	Anti-inflammatory	E	G-E	E	G-E	E	E	v	v	E	P-F	P-L	P
	Lipid regulators	E	E	E	G-E	P	E	v	v	F-G	P-F	P-L	P
	X-ray contrast media	E	G-E	G-E	G-E	E	L-E	E	v	F-G	P-F	P-L	P-L
	Psychiatric control	E	G-E	G-E	G-E	G-E	L-E	G-E	G-E	F-G	P-F	P-L	P-L
PCPs	Synthetic musks	E	G-E	G-E	G-E	E	L-E	v	v	E	P-F	P-L	P-L
	Sunscreens	E	G-E	G-E	G-E	G-E	L-E	G-E	G-E	F-G	P-F	P-L	P-L
	Antimicrobials	E	G-E	G-E	G-E	v	L-E	F	v	F-G	P-F	P-L	P-L
	Detergents	E	E	E	E	L-E	F-G	v	v	F-G	P	P-L	P-L

E = excellent (>90%); G= good (70-90%); F= fair (40-70%); L= low (20-40%); P= poor (<20%); v= variable

Source: Adapted from Snyder, S.A; Westerhoff, P; Yoon, Y and Sedlak, DL; 2003 [19(p.450)]

APPENDIX E – WINDHOEK'S DPR INTERMEDIATE CRITERIA AND TREATED WATER SPECIFICATIONS

INTERMEDIATE TREATED WATER CRITERIA for DPR - WINDHOEK, NAMIBIA				
Parameter	Unit	Target values	Target values	Absolute values
After DAF				
Turbidity	NTU	1.5 (exceeded by no more than eight readings in one day) 5.0 (exceeded by no more than four readings in one day)	5.0 (exceeded by no more than four readings in one day)	8.0 (absolute maximum peak reading)
After rapid sand filters				
Turbidity	NTU	0.2 (exceeded by no more than four readings in one day)	0.35 (exceeded by no more than four readings in one day)	0.5 (absolute maximum peak reading)
Manganese	mg/L	0.03	0.05	N/A
Iron	mg/L	0.05	0.05	N/A
After ozonation				
Ozone	ng/L	-	-	0.1 minimum (absolute minimum registered by on-line monitoring)
COD	mg/L	25	25	N/A
DOC	mg/L	15	15	N/A
Microbiological quality, disinfection byproducts	-	According to treated water specification		
After GAC filters				
DOC	mg/L	5	5	8

Adapted from Water Reuse, Table 24-3 [1(p. 1361)]
DPR = Direct Potable Reuse

APPENDIX E - (con't)

TREATED WATER SPECIFICATIONS for DPR IN WINDHOEK, NAMIBIA			
Parameter	Unit	Target values	Absolute values
Physical and organoleptic constituents			
CCPP	mg/L as $CaCo_3$	N/A	must be btwn 0 and 8
Chemical oxygen demand	mg/L	10	15
Color	mg/L Pt	8	10
Dissolved organic carbon	mg/L	3	5
Total dissolved solids	mg/L	Greater of 1000 or 200 above raw water	Greater of 1200 or 250 above raw water
Turbidity	NTU	0.1	0.2
UV_{254}	Abs/cm	N/A	0.06
Macro elements			
Aluminum	mg/L	N/A	0.15
Ammonia	mg/L	N/A	0.1
Chloride	mg/L	Not removed by process	
Iron	mg/L	0.05	0.1
Manganese	mg/L	0.01	0.025
Nitrite and Nitrate	mg-N/L	Not removed by process	
Sulfate	mg/L	Not removed by process	
Microbiological indicators			
Heterotrophic plate cts	count/mL	80	100
Total coliform	count/100 mL	N/A	0
Fecal coliform	count/100 mL	N/A	0
E. Coli	count/100 mL	N/A	0
Coliphage	count/100 mL	N/A	0
Enteric viruses	count/10 L	N/A	Grtr of 0 or 4 log removal
Fecal streptococci	count/100 mL	N/A	0
Clostridium spp.	count/100 mL	N/A	0
Clostridium viable cells	count/100 mL	N/A	0
Giardia	count/100 L	Grtr of 0 or 6 log removal	Grtr of 0 or 5 log removal
Cryptosporidium	count/100L	Grtr of 0 or 6 log removal	Grtr of 0 or 5 log removal
Chlorophyll A	ug/L	N/A	1
Disinfection byproducts			
Total THMs	ug/L	20	40

Source: Water Reuse, from Table 24-2 [1(p.1359)]
DPR = Direct Potable Reuse

APPENDIX F - DENVER, COLORADO'S PILOT DPR TREATMENT TRAIN

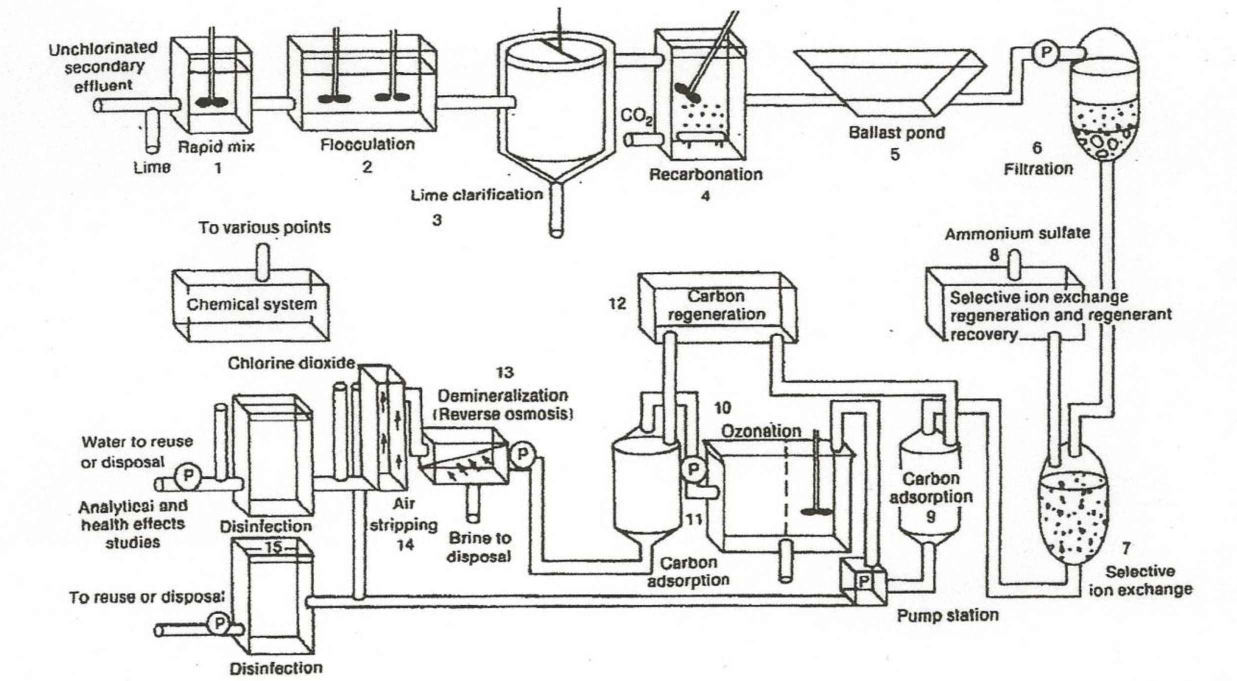


Figure 1. Water reuse treatment process

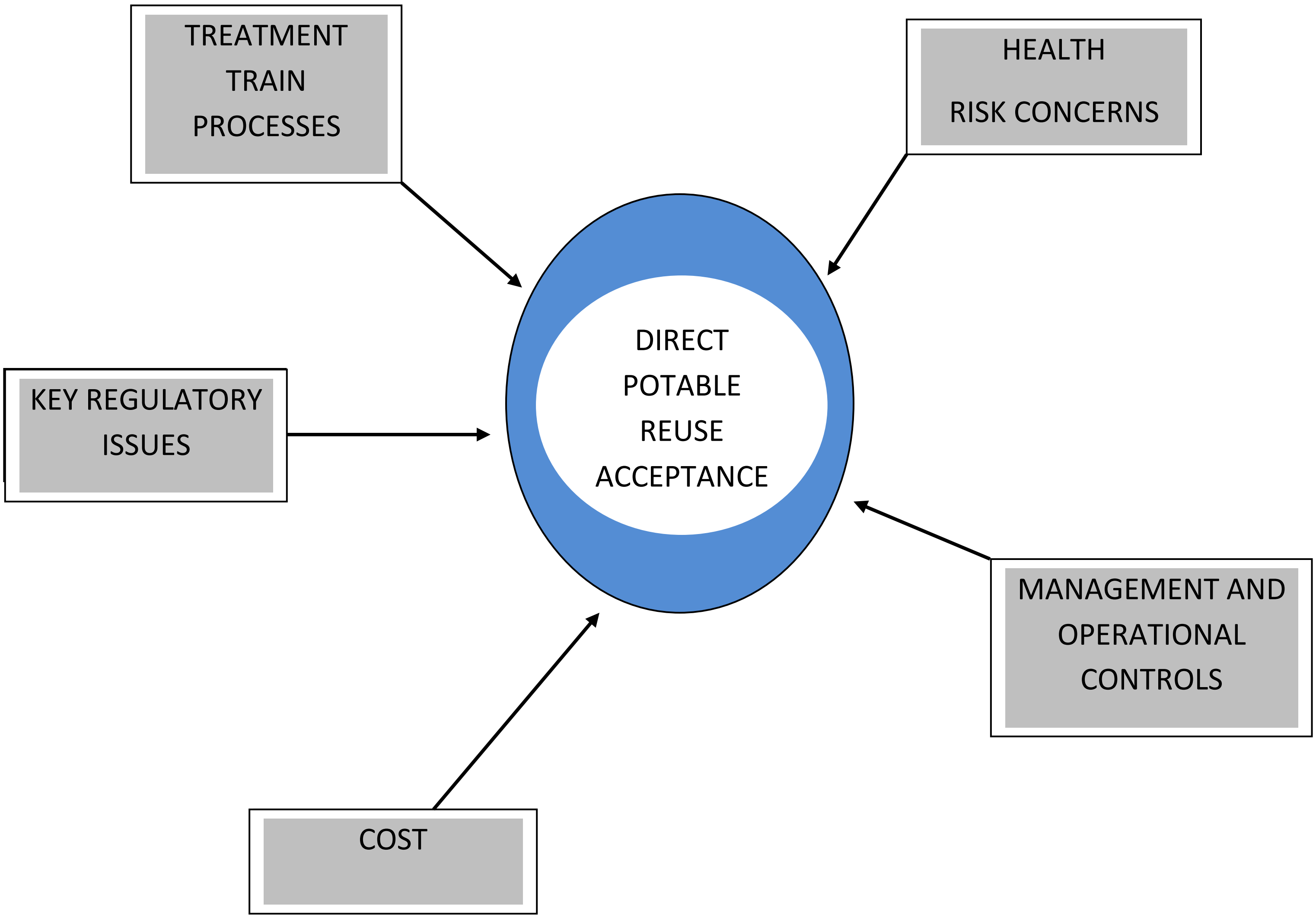
Source: Lauer, W.C.; Rogers, S.E. and Ray, J.M., The Current Status of Denver's Potable Water Reuse Project. [23(p.54)]
DPR = Direct Potable Reuse

APPENDIX G - SINGAPORE'S NEWater QUALITY PARAMETERS, USEPA AND WHO DRINKING WATER STANDARDS

Potable Water Quality Parameters				
Water Quality Parameters	Units	NEWater	USEPA Standard	WHO Standard
A) Physical				
Turbidity	NTU	<5	5	5
Colour	Hazen units	<5	15	15
Conductivity	uS/cm	<250	-	-
pH Value		7.0 - 8.5	6.5-8.5	-
Total Dissolved Solids	mg/L	<150	500	1000
Total Organic Carbon	mg/L	<0.5	-	-
B) Chemical				
Ammoniacal nitrogen (as N)	mg/l	<1.0	-	1.2
Chloride (Cl)	mg/l	<20	250	250
Fluoride (F)	mg/l	<0.5	4	1.5
Nitrate (NO3)	mg/l	<15	10	11
Silica (SiO2)	mg/l	<3	-	-
Sulphate (SO4)	mg/l	<5	250	250
Residual Chlorine (CL, Total)	mg/l	<2	4	5
Total Trihalomethanes	mg/l	<0.08	0.08	-
C) Metals				
Aluminium	mg/l	<0.1	0.05-0.2	0.2
Barium (Ba)	mg/l	<0.1	2	0.7
Boron (B)	mg/l	<0.5	-	0.5
Calcium (Ca)	mg/l	4-20	-	-
Copper (Cu)	mg/l	<0.05	1.3	2
Iron (Fe)	mg/l	<0.04	0.3	0.3
Manganese (Mn)	mg/l	<0.05	0.05	0.4
Sodium (Na)	mg/l	<20	-	200
Strontium (Sr)	mg/l	<0.1	-	-
Zinc (Zn)	mg/l	<0.1	5	3
D) Bacteriological				
Total Coliform Bacteria	counts/100 ml	ND	ND	ND
Enterovirus		ND	ND	ND
Heterotrophic Plate Count	CFU/ml, 35°C, 48h	<300	<500	-

Non specified indicated by "-". Not detectable indicated by "ND"
Source: Adapted from www.pub.gov/sg [28]
USEPA = United States Environmental Protection Agency; WHO = World Health Organization

APPENDIX H - DETERMINANTS OF DIRECT POTABLE REUSE ACCEPTANCE



APPENDIX I - MAJOR EPIDEMIOLOGICAL AND TOXICOLOGICAL POTABLE REUSE HEALTH EFFECTS STUDIES TO DATE – KEY FINDINGS

DPR = Direct Potable Reuse; IPR = Indirect Potable Reuse

1979-1992 **Denver Potable Water Demonstration Project, Denver, CO (DPR)**[1]

- AWT processes (high pH lime clarification, recarbonation, filtration, activated carbon adsorption, RO, or UF, air stripping, ozonation, and chloramination) consistently produce product water that satisfies current (1992) and proposed US EPA drinking water standards.
- Two year (lifetime exposure) chronic toxicity and carcinogenicity study on reclaimed water in relation to Denver drinking water. No adverse health effects detected.
- Two generation reproductive studies on reclaimed water in relation to Denver drinking water. No adverse health effects detected.
- Reclaimed water subjected to physical, chemical, and microbiological testing. Purity surpassed domestic water supplies and microbiological and chemical assessment revealed no parameters approaching regulatory limits.
- Public acceptance positive if safety and need were guaranteed.

Late 1970s-1996 **City of San Diego, CA Total Resources Recovery Project (IPR)**[1]

- Health Effects Study validated AWT treatment train (coagulation, filtration, RO, air stripping and GAC) produces product water equal to or better than the current Miramar raw water supply.

2002 **Singapore Water Reclamation Study (IPR), (DPR)**[67]

- The Health Effects Testing Programme (HETP) used long-term chronic toxicity studies on mice and fish with NEWater in relation to PUB raw water.
- No tissue abnormalities or health effects detected in mice when exposed for 3-months, 12-months or life-long-24 months.
- Long-term chronic toxicity and estrogenic potential (reproductive and developmental) with no evidence of health effects in first or second generation fish exposed to NEWater.

Spring 2011 (anticipated) **Identifying Health Effects Concerns of Water Reuse Industry and Prioritizing Research Needs for Nomination of Chemicals for Research to Appropriate National and International Agencies. (WRF-06-004)**[36]

TBD **Bio-analytical Techniques to Assess the Potential Human Health Impacts of Reclaimed Water. (WRF-10-07)**[36]

APPENDIX J - SUGGESTED GUIDELINES FOR WATER REUSE, 2004 (NOTE IPR ONLY, NO SUGGESTED GUIDELINES FOR DPR)

Types of Reuse	Treatment	Reclaimed Water Quality [2]	Reclaimed Water Monitoring	Setback Distances [3]	Comments
Groundwater Recharge By spreading or injection into aquifers not used for public water supply	• Site-specific and use dependent • Primary (minimum) for spreading • Secondary [4] (minimum) for injection	• Site-specific and use dependent	• Depends on treatment and use	• Site-specific	• Facility should be designed to ensure that no reclaimed water reaches potable water supply aquifers • See Section 2.5 for more information. • For spreading projects, secondary treatment may be needed to prevent clogging. • For injection projects, filtration and disinfection may be needed to prevent clogging. • See Section 3.4.3 for recommended treatment reliability.
Indirect Potable Reuse Groundwater recharge by spreading into potable aquifers	• Secondary [4] • Disinfection [6] • May also need filtration [5] and/or advanced wastewater treatment [16]	• Secondary [4] • Disinfection [6] • Meet drinking water standards after percolation through vadose zone	Includes, but not limited to, the following: • pH - daily • Coliform - daily • Cl_2 residual - continuous • Drinking water standards - quarterly • Other [17] - depends on constituent • BOD - weekly • Turbidity - continuous	• 500 ft (150 m) to extraction wells. May vary depending on treatment provided and site-specific conditions.	• The depth to groundwater (i.e., thickness to the vadose zone) should be at least 6 feet (2 m) at the maximum groundwater mounding point. • The reclaimed water should be retained underground for at least 6 months prior to withdrawal. • Recommended treatment is site-specific and depends on factors such as type of soil, percolation rate, thickness of vadose zone, native groundwater quality, and dilution. • Monitoring wells are necessary to detect the influence of the recharge operation on the groundwater. • See Sections 2.5 and 2.6 for more information. • The reclaimed water should not contain measurable levels of viable pathogens after percolation through the vadose zone. [12] • See Section 3.4.3 for recommended treatment reliability.
Indirect Potable Reuse Groundwater recharge by injection into potable aquifers	• Secondary [4] • Filtration [5] • Disinfection [6] • Advanced wastewater treatment [16]	Includes, but not limited to, the following: • pH = 6.5 - 8.5 • ≤ 2 NTU 8 • No detectable total coli/100 ml [9,10] • 1 mg/l Cl2 residual (minimum) [11] • ≤ 3 mg/l TOC • ≤ 0.2 mg/l TOX • Meet drinking water standards	Includes, but not limited to, the following: • pH - daily • Turbidity - continuous • Total coliform - daily • Cl_2 residual - continuous • Drinking water standards - quarterly • Other [17] - depends on constituent	• 2000 ft (600 m) to extraction wells. May vary depending on site-specific conditions.	• The reclaimed water should be retained underground for at least 9 months prior to withdrawal. • Monitoring wells are necessary to detect the influence of the recharge operation on the groundwater. • Recommended quality limits should be met a the point of injection. • The reclaimed water should not contain measurable levels of viable pathogens after percolation through the vadose zone. [12] • See Sections 2.5 and 2.6 for more information. • A higher chlorine residual and/or a longer contact time may be necessary to assure virus and protozoa inactivation. • See Section 3.4.3 for recommended treatment reliability.
Indirect Potable Reuse Augmentation of surface supplies	• Secondary [4] • Filtration [5] • Disinfection [6] • Advanced wastewater treatment [16]	Includes, but not limited to, the following: • pH = 6.5 - 8.5 • ≤ 2 NTU [8] • No detectable total coli/100 ml [9,10] • 1 mg/l Cl2 residual (minimum) [11] • ≤ 3 mg/l TOC • Meet drinking water standards	Includes, but not limited to, the following: • pH - daily • Turbidity - continuous • Total coliform - daily • Cl_2 residual - continuous • Drinking water standards - quarterly • Other [17] - depends on constituent	• Site-specific	• Recommended level of treatment is site-specific and depends on factors such as receiving water quality, time and distance to point of withdrawal, dilution and subsequent treatment prior to distribution for potable uses. • The reclaimed water should not contain measurable levels of viable pathogens. [12] • See Sections 2.6 for more information. • A higher chlorine residual and/or a longer contact time may be necessary to assure virus and protozoa inactivation. • See Section 3.4.3 for recommended treatment reliability.

Source: Guidelines for Water Reuse, Table 4-13,[60(p.169)]
IPR = Indirect Potable Reuse; DPR = Direct Potable Reuse