DESALINATION: TECHNOLOGY, HEALTH AND ENVIRONMENT

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Keywords: Reverse Osmosis, Multiple Effect Distillation, Multistage Flash Distillation, Microfiltration, Nanofiltration, Ultrafiltration, Disinfection by-products, Beneficial Minerals, Environmental Impact Assessment

Contents

Summary

This book provides insights into desalinated drinking water production and treatment and the elements that should be addressed in that process, including health and environmental concerns, monitoring, and management approaches for assuring the quality and safety of desalinated drinking water.

Access to sufficient quantities of safe water for drinking, domestic uses, commercial and industrial applications, is essential for healthful living, enhanced quality of life, and for achieving human and economic development. Many world regions are grossly

deficient in the availability of water of sufficient quantity and quality, the availability of the limited quantities of fresh water continually decreases.

Most of the world's water is seawater or brackish water and saline groundwater unavailable for beneficial uses without the application of technologies capable of removing large portions of the dissolved solids. Desalination technologies were introduced around the 1960s and expanded access to water, but at high energy cost. New and improved technologies have now broadened opportunities to access large quantities of safe water. Desalination and wastewater reuse are the principal sources of "new" water in the world.

More than 15,000 desalination plants are in operation or under construction, daily producing about 68.2 million cubic meters of water. The capacity is growing rapidly as the need for freshwater supplies grows more acute, technologies improve and unit costs are reduced.

Desalination plants use waters impaired with salts as their sources. Performance, operating and quality specifications seem to have evolved virtually on a site-by-site basis. Most desalination applications use the World Health Organization's Guidelines for Drinking-water Quality (GDWQ) in some way as finished water quality specifications. Because desalination is applied to non-typical source waters and often uses non-typical technologies, existing national standards and guidelines may not fully cover the unique factors that can be encountered during production and distribution of desalinated water.

1. Health and Environmental Issues for Desalinated Drinking Water

From Joseph A. Cotruvo

This introductory section briefly describes technologies, management approaches, water quality issues, and health and environmental topics that are addressed in the document and in greater detail in Desalination Technology: Health and Environmental Impacts, J.A. Cotruvo et al eds. TD479.D473 2010. CRC Press, www.crcpress.com.

Most of the world's water is seawater or brackish water and groundwater that is high in total dissolved solids. These waters are either undesirable or unavailable for beneficial uses without technologies capable of removing large portions of the dissolved solids. Desalination technologies were introduced especially in the Arabian Gulf region around the 1960s, and they expanded access to water, but at high relative costs. New improved technologies have greatly broadened access to large quantities of safe water in many parts of the world. Costs are still significant compared to freshwater sources, but there have been major cost reductions; the desalination option is now much more widely available, and along with water reuse, the principal sources of 'new' water. Higher energy costs have halted overall price reductions, although technology efficiency continues to improve. Even so, when the alternative is no water or inadequate water quantity for needs, and harm to health and welfare can occur, greater cost is endurable in many circumstances.

Desalination of seawater and brackish water, along with planned water reuse for indirect potable and non-potable applications (e.g. irrigation) are the world's sources of 'new' water that have been growing rapidly in recent years. Planned reuse is a valuable companion to desalination and it improves cost effectiveness. The need to produce more water and efficiently use water to satisfy the needs of growing and more demanding populations has become acute. These technologies are more complex than more traditional technologies usually applied to relatively good quality freshwaters. As such, the cost of production is greater than freshwater sources, but they are being applied in areas where the need is also greater. This document focuses upon desalination and examines the major technologies and the health and environmental considerations that they bring in addition to water production from more traditional sources.

This section provides insights into drinking water production and treatment and the elements that are managed in that process, as well as integrated health and environmental concerns, and management approaches for assuring the quality and safety of drinking water at the consumer's tap.

Desalination Background

As of 2011, 15,300 desalination plants have been installed or under construction; almost 11,600 were in operation producing 68.2 million cubic meters (~18 billion US gallons) of water per day and an additional 10.6 million cubic meters of capacity are contracted(WDR, 2008). About 45% of the capacity exists in the West Asia Gulf region. North America has about 12%, Asia apart from the Gulf about 9.6% and North Africa and Europe account for about 6.5% and 12.5%, respectively, and Australia has 3.2% (WDR/DesalData, 2011). This distribution is changing as demand increases in Australia, Europe and North America. Capacity is expected to reach at least 94 million m^3/day by 2015 (WDRr, 2006). Desalination plant sizes and designs range from more than 1,000,000 m^3/day down to 20 to 100 m^3/day. Home sized reverse osmosis units produce a few liters per day, but these are applied to freshwaters with higher than usual total dissolved solids (TDS). Accelerated expansion worldwide is expected in 2011 to 2016 predominantly as seawater RO.

Any large scale facility brings with it potential for unintended collateral health and environmental upsets unless adequate consideration is given to their concerns during planning and before construction and operation. Many questions are not unique to desalination and some are already dealt with in WHO Guidelines for Drinking Water Quality (GDWQ).

- What are the principal technologies for desalination and what factors influence selection and performance?
- How can the aggressiveness of desalinated water and its corrosivity be managed?
- What should be the quality guidance for blending waters added post- desalination for stabilization?
- What is appropriate guidance for aesthetic and stability factors, e.g., TDS, pH, taste/odor, turbidity, corrosion indices, etc.?
- Should optimal finished water reflect potentially nutritionally desirable components that are removed during treatment, e.g., calcium, magnesium, fluoride?

- What are appropriate quality specifications and safety of chemicals and materials used in production and in contact with the water e.g., coagulants, disinfectants, pipe and surfaces in desalination plants, distribution systems, etc?
- How should monitoring of plant performance and water during distribution be designed, e.g., key chemicals, microbiological parameters, frequencies?
- What are environmental impact assessments relating to siting, marine ecology, ground water protection, energy production, and air quality?

Water quality, technology and health issues

Drinking water systems should strive to produce and deliver safe drinking water that meets all health and aesthetic quality specifications. The WHO Guidelines for Drinking-water Quality (GDWQ) provide comprehensive information and they apply to conventional or desalinated drinking water. Desalinated water provides some additional issues for potential chemical and microbial components. Some recommended augmentations to the GDWQ are suggested.

Aesthetics and water stability

Although not directly health related, aesthetic factors like taste, odor, turbidity, and TDS affect palatability and consumer acceptance, and indirectly health. Corrosion, hardness and pH have economic consequences and they affect the extraction of metals and other pipe components during distribution. Corrosion has potential negative health consequences; magnesium and calcium may have health benefits.

Blending waters

Blending is used to increase TDS and improve the stability of finished desalinated water. Microbial components of the blending water can affect the quality and safety of the finished water because it may not receive any further treatment beyond residual disinfection. Some contaminants are controlled by selection of or pretreatment of the blending water. Some of the microorganisms in the blending water could be resistant to the residual disinfectant, could contribute to biofilms, or could be inadequately represented by surrogate microbial quality measurements such as *E. coli* or heterotrophic plate counts (HPC).

Nutritionally Desirable Components

Desalinated water is stabilized by adding lime and other chemicals. The diet is the principal source of nutrient minerals that are removed by water treatment, but there is a legitimate question as to the optimal mineral balance of drinking water to assure quality and health benefits. Dietary calcium and magnesium are important health factors, as well as certain trace elements. Fluoride is considered to be beneficial for dental and possibly skeletal health by most authorities (Cotruvo, 2006; WHO, 2005; WHO, 2006). There is a public health policy and practical economic question as to whether and to what extent public or bottled drinking water should be reconstituted with removed nutritional elements; this question would be addressed differently in different dietary, political and social environments. It should be part of an Environmental Impact Assessment.

Chemicals and materials used in water production

Chemicals used in desalination processes are similar to those used in standard water production; however, they may be used in greater amounts and under different conditions. Governments are encouraged to utilize systems for specifying the appropriateness and quality of additives used in desalination, or to adopt existing international standards for those products tailored to desalination conditions.

Water quality and distribution system monitoring

Desalination processes utilize non-traditional water sources and technologies and produce drinking water that is different from usual sources and processes. Desalination may be practiced in locations with warm climates and longer distribution networks. Operators and authorities should select a small number of key parameters associated with source and process, included or in addition to the WHO GDWQ, that would be useful in particular circumstances, and utilize appropriate monitoring schemes.

Environmental quality and environmental impact assessments

Any major project can have significant effects on the environment during construction and operation. Procedures and elements of Environmental Impact Assessments (EIA) are provided to assist project designers and decision makers to anticipate and address environmental concerns to be considered when undertaking a project. Factors include: site considerations, coastal zone/marine protection regarding withdrawal and discharge, air pollution from energy production and consumption, groundwater protection from drying beds, leachates, and sludge disposal. This is discussed in detail in Desalination Technology: Health and Environmental Impacts Resource, and Guidance Manual for Environmental Impact Assessments (UNEP, 2008).

1.1. Drinking-Water Production and Health Issues

Drinking water delivery is divided into three broad categories:

- Source Water
- Treatment Technology
- Distribution System

Some factors distinguishing desalination from typical drinking water operations are:

Source Water

- Total dissolved solids (TDS) in the range of about 5,000 to 45,000 mg/liter
- High levels of particular ions including sodium, chloride, calcium, magnesium, bromide, iodide, sulfate
- Total organic carbon (TOC) type
- Potential petroleum contamination
- Saline water microbial contaminants

Treatment Technology

- Reverse Osmosis (RO)
- Thermal processes
- Leachates from system components

- Pretreatment and anti fouling additives
- Disinfection by-products (DBPs)
- Post-treatment blending with source waters

Distribution System Management

- Corrosion control additives
- Corrosion products
- Bacterial regrowth including non-pathogenic HPC, and pathogens like *Legionella*

Related issues:

- Are there risks from consumption of low TDS water, or from corrosivity toward the plumbing and distribution system?
- Environmental impacts of desalination operations and brine disposal.
- Microorganisms unique to saline waters.
- Monitoring source water, process performance, finished water and distributed water to assure consistent quality.
- Maintaining microbial and chemical quality in distribution systems in warm climates including presence of rooftop storage tanks.

1.2. Source Water Composition

Rivers, lakes, impoundments, or shallow or deep groundwaters are typical freshwater sources for drinking water. The water could be virtually pristine, contain natural contaminants, or impacted by agricultural and sewage waste discharges.

Even a pristine source may contain excess undesirable minerals and suspended particulates that affect taste, aesthetic quality or safety, and natural organic materials (Total Organic Carbon and Total Organic Nitrogen) that could affect the quality of finished water and challenge treatment processes. Mineralization of aesthetically desirable freshwaters could be from less than 100 mg/liter to about 500 mg/liter.

Microbial contamination can occur in pristine source especially surface water. Many are impacted by sewage discharges, agricultural or industrial wastes, and surface runoff, so virtually all surface waters require filtration and disinfection.

Groundwaters often benefit from natural filtration, but they can also be naturally contaminated (e.g. TDS, arsenic or excess fluoride). If ‘under the influence of surface water’ they can be contaminated by surface discharges of sewage, agricultural and industrial waste or spills if the overlaying soil does not retard migration of some contaminants. However, many groundwaters are sufficiently protected that they may be consumed without further treatment, or possibly only disinfection.

Seawaters and brackish waters are defined by the extent of mineralization. This includes minerals that are partly a function of location. They contain organic carbon and microbial contaminants, and they can also be impacted by waste discharges. Tables 1 and 1 are mineral composition of several saline waters.

Constituent	Normal Seawater	Eastern Mediterranean	Arabian Gulf At Kuwait	Red Sea At Jeddah
Chloride ($C1^{-1}$)	18,980	21,200	23,000	22,219
Sodium (Na^{+1})	10,556	11,800	15,850	14,255
Sulfate (SO_4^{-2})	2,649	2,950	3,200	3,078
Magnesium (Mg^{+2})	1,262	1,403	1,765	742
Calcium (Ca^{+2})	400	423	500	225
Potassium (K^{+1})	380	463	460	210
Bicarbonate (HCO_3^{-1})	140	--	142	146
Strontium (Sr^{+2})	13	--	--	--
Bromide (Br^{-1})	65	155	80	72
Boric Acid (H_3BO_3)	26	72	--	--
Fluoride (F^{-1})	1	--	--	--
Silicate (SiO_3^{-2})	1	--	1.5	--
Iodide (I^{-1})	<1	2	--	--
Other	1	--	--	--
Total Dissolved Solids	34,483	38,600	45,000	41,000

Table 1. Major ion composition of seawater (mg/liter) (Al-Mutaz, 2000)

Constituent	Design Value	Design Range
Calcium (Ca^{+2})	258	230 - 272
Magnesium (Mg^{+2})	90	86 - 108
Sodium (Na^{+1})	739	552 - 739
Potassium (K^{+1})	9	NK
Strontium (Sr^{+2})	3	NK
Iron (Fe^{+2})	< 1	0 - < 1
Manganese (Mn^{+2})	1	0 - 1
Bicarbonate (HCO_3^{-1})	385	353 - 385
Chloride ($C1^{-1}$)	870	605 - 888
Sulfate (SO_4^{-2})	1,011	943 -1,208
Nitrate (NO_3^{-1})	1	NK
Phosphate (PO_4^{-3})	< 1	NK
Silica (SiO_2)	25	NK
Total Dissolved Solids	3,394	2,849 - 3,450
pH	8.0	7.8 - 8.3
Temperature	75 °F	65 °F - 85 °F

Table 2. Major ion composition of a raw brackish water (mg/liter) (USBR, 1976)

1.3. Fresh Water Treatment Technologies

Treatment of freshwaters involves particulate removal and microbial inactivation; filtration and disinfection are the main technologies. These include coagulation, sedimentation, and rapid sand filtration, with chlorine or chlorine dioxide and possibly ultraviolet light for primary disinfection, and sometimes chloramines for secondary disinfection. Ozone is used for oxidation and disinfection. Some reduction of natural organics occurs in the coagulation/filtration process. Microfiltration and ultrafiltration are sometimes used, and powdered carbon and granular activated carbon for taste and odor and sometimes to reduce organics. Softening reduces calcium and magnesium hardness. Targeted technologies are used such as for arsenic or nitrate removals.

Home treatment technologies are usually applied as a polish on safe supplied water, however, some can provide disinfection or complete treatment. They include point-or-use (POU, end of tap), or point-of-entry (POE) that treats all of the water entering the home. Technologies are specific to the particular water problem; consumers should determine the problem before purchase. Technologies should be tested and certified by a credible independent organization as to claims. The most common systems involve ion exchange water softening, or activated carbon for chlorine taste and some organics, or iron removal. Some include UV light or membranes. Disinfection techniques are also available for home or traveller use.

1.4 Desalination Technologies

Desalination processes (distillation or membranes) remove dissolved salts from seawater and brackish water. Desalination is energy intensive and research is improving efficiency. Cogeneration facilities are now the norm for desalination projects.

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Bibliography

Ainsworth R,(2004) *Safe piped water: Managing microbial water quality in piped distribution systems*. IWA Publishing, London, for the World Health Organization. [A discussion on the role of distribution systems as sources of contamination of finished drinking water].

J.A. Cotruvo and J. Bartram, eds. (2009) *Calcium and Magnesium in Drinking Water: Public Health Significance*. ISBN 978 92 4 156355 0 World Health Organization. [WHO expert committee review and recommendations regarding beneficial minerals in drinking water].

J.A. Cotruvo N. Voutchkov, J. Fawell, P. Payment, D. Cunliffe, S. Lattemann, eds. (2010) *Desalination Technology: Health and Environmental Impacts*, TD479.D473 2010. CRC Press, www.crcpress.com. [A more detailed discussion of the contents of this EOLSS monograph from which this monograph was derived.].

Mickley MC (2006) *Membrane Concentrate Disposal: Practices and Regulation*. Second Edition, Desalination and Water Purification Research Program Report No. 123, US Bureau of Reclamation. [A review of techniques for managing concentrates from desalination processes].

Environmental Impact Assessment Training Resource Manual. 2nd Edition, (2002). Two Volumes (Manual 573 p.; transparency overheads 226 p.). Print version available at Earthprint (http://www.earthprint.com). Electronic version available at UNEP

(http://www.unep.ch/etu/publications). [EIA manuals for use in conjunction with large project development].

Sea Water Desalination in the Mediterranean: Assessment and Guidelines. MAP Technical Reports Series No. 139, Mediterranean Action Plan (MAP), Programme for the Assessment and Control of Pollution in the Mediterranean region (MEDPOL), Athens. [An early comprehensive review of impacts of desalination projects in the Mediterranean].

Resources and Guidance Manual for Environmental Impacts Assessments. (2008) http://www.unep.org.bh/Newsroom/pdf/EIA-guidance%20manwal.pdf [A detailed discussion of background and procedures for conducting Environmental Impact Assessments of desalination systems].

Desalting Handbook for Planners. 3rd Edition. (2003) Desalination and Water Purification Research and Development Report #72,. Denver, CO: United States Department of the Interior, Bureau of Reclamation, Water Treatment Engineering and Research Group. [A comprehensive and detailed discussion of desalination technologies and costs].

Voutchkov N (2006). Innovative Method to Evaluate Tolerance of Marine Organisms. *Desalination and & Water Reuse*, 16, no. 2: 28-34. [A discussion of techniques for evaluating the impact of desalination process discharges on marine organisms].

World Health Organization Guidelines for Drinking-water Quality, 3rd edition. Recommendations. Geneva, Switzerland. [Comprehensive discussions and recommended health based guidelines for drinking water].

World Health Organization Guidelines for Drinking-water Quality, (4th edition). Comprehensive discussions and recommended health based guidelines for drinking water. [An update of the 3rd edition to be released in July, 2011. Geneva, Switzerland].

Nutrients in Drinking Water and the Potential Health Consequences of Long-Term Consumption of Demineralized and Remineralized and Altered Mineral Content Drinking Waters. Roma, 11-13 November, 2003. WHO/SDE/WSH/04.01].

Cotruvo, JA, Dufour A, Rees G, Bartram J, Carr R, Cliver DO, Craun GF, Fayer R, Gannon VPJ,(eds.) Waterborne Zoonoses, Identification, Causes and Control. WHO and IWA Publishing, ISBN 1 84339 058 2. [A comprehensive review of pathogenic microorganisms in drinking water that are associated with animal origin].

References

Ainsworth R,(2004) *Safe piped water: Managing microbial water quality in piped distribution systems.* IWA Publishing, London, for the World Health Organization.

Adham S, Gagliardo P, Smith D, Ross D, Gramith K, Trussell R (1998) Monitoring the integrity of reverse osmosis membranes. Desalination 119 (1-3), 143-150.

Adham S, Trussell RS, Gagliardo, PF, Trussell, RR (1998) *Rejection of MS2 virus by RO Membranes*, JAWWA, 90, 9, 130-139.

Al Mutaz (2000) *Water Desalination in the Arabian Gulf Region, in Water Management Purification and Conservation Management in Arid Climates*, 245-265 M. F.A. Goosen and W.H Shayya eds. Technomic Publ.

Al-Rabeh (2005) Saudi Arabia Report on Desalination Water Quality Data.

AWWA Water Desalination Committee (2004a) *Water Desalination Planning Guide for Water Utilities*. John Wiley & Sons, Inc., Hoboken, New Jersey: 122-123.

AWWA & ASCE (1990) *Water Treatment Plant Design*, 4rd Edition, American Waterworks Association and American Society of Civil Engineers, McGraw-Hill.

AWWA Membrane Process Committee (2004b) Manual M53, *Microfiltration and Ultrafiltration Membranes in Drinking Water*, American Water Works Association, Denver, Colorado.

AWWA (1996) Rothberg, Tamburini and Winsor *Model for Corrosion Control and Process Chemistry*, American Water Works Association, Denver, Colorado.

American Water Works Association (AWWA, 2006) *Waterborne pathogens*. AWWA Manual of Practices, M48. Denver, Colorado, USA, American Water Works Association.

Bartram J, Balance R (1996) *Water quality monitoring: a practical guide to the design and implementation of freshwater quality studies and monitoring programs*. Published by E & FN Spon, London on behalf of the United Nations Educational, Scientific and Colvin CK, Acker CL, Marinas BJ,Lozier JC (2000) Microbial removal by NF/RO. American Water Works Association - Annual Conference, Denver, Colorado, USA, June 11-15 2000.

Bay S, Greenstein D (1992/93) Toxic Effects of Elevated Salinity and Desalination Waste Brine, in *SCCWRP Annual Report* (available online at scwrp.org/pubs/annrpt/92/93).

Birnhack L, Lahav O (2007) A New Post-Treatment Process for Attaining Ca^{+2}, Mg^{+2}, SO_4^{-2} and AlkalinityCriteria in *Desalinated Water. Water Research*, doi:10.1016/jwatres. 2007.06.007.

Block JC (1992) *Biofilms in drinking water distribution system*. pp. 469-485 In: Biofilms---science and technology. Melo LF, Bott TR, Fletcher M, Capdeville B (eds), Kluwer Academic Publishers, Dordrecht, The Netherlands.

AWWA (1999) *Manual of Water Supply Practices M46, Reverse Osmosis and Nanofiltration*, American Water Works Association, Denver, Colorado.

Bull RJ, Cotruvo JA (2006) A Research Strategy to Improve Risk Estimates for Bromate in Drinking Water. Bull RJ and Cotruvo JA eds. *Toxicology*, 221: 2-3, 135-248. Special issue. 17 April.

City of Carlsbad (2005) *Environmental Impact Report for Precise Development Plan and Desalination Plant* EIR SCH# 2004041081, May.

City of Huntington Beach (2005) Draft Recirculated Environmental Impact Report, Seawater Desalination Project at Huntington Beach, April.

Cotruvo, J.A. (2005) Water Desalination Processes and Associated Health Issues. Water Conditioning and Purification, January, 13-17. www.wcponline, Issue 47, #1.

Cotruvo (2006) Health Aspects of Calcium and Magnesium in Drinking Water. Water Conditioning and Purification, June , 40-44. www.wcponline, Issue 48, #6.

Craun GF, Calderon RL (2001) Waterborne disease outbreaks caused by distribution system deficiencies. *Journal of American Water Works Association* 93 (9), 64-75.

J.A. Cotruvo N. Voutchkov, J. Fawell, P. Payment, D. Cunliffe, S. Lattemann (2010) Desalination Technology: Health and Environmental Impacts, TD479.D473 2010. CRC Press, www.crcpress.com.

Dufour A., Snozzi M., Köster W, Bartram J, Ronchi E, Fewtrell L (2003) *Assessing microbial safety of drinking water: improving approaches and methods*. London, World Health Organization - Drinking Water Quality Series, IWA Publishing.

Elimelech (2006) *Environmental Science & Technology Online News*, May 3.

EMS (2006) Reuters .co.uk, July 24, 2006.

Escobar IC, Hong S, Randall AA (2000) Removal of assimilable organic carbon and biodegradable dissolved organic carbon by reverse osmosis and nanofiltration membranes. *Journal of Membrane Science* 175 (1), 1-18.

EU (1997) A guide to gender impact assessment. European Commission. Director General for Employment, Industrial Relations and Social Affairs. Available at: http://europa.eu.int/comm/employment_social/gender_equality/docs/gender/gender_en.pdf

EU (2001a) Guidance on EIA. Screening. European Commission. Office for Official Publications of the European Communities, L-2985 Luxembourg. Available at http://europa.eu.int/comm/environment/eia/eia-support.htm

EU (2001b) Guidance on EIA. Scoping. European Commission. Office for Official Publications of the European Communities, L-2985 Luxembourg. Available at http://europa.eu.int/comm/environment/eia/eia-support.htm

FAO (2005) Proceedings of the FAO Expert Consultation on Water Desalination for Agricultural Applications, 26-27 April 2004, FAO, Rome.

Fayer R, Graczyk TK, Lewis EJ, Trout JM, Farley CA (1998) Survival of infectious Cryptosporidium parvum oocysts in seawater and eastern oysters (Crassostrea virginica) in the Chesapeake Bay. *Applied and Environmental Microbiology* 64 (3), 1070-1074.

Fujioka RS, Yoneyama BS (2002) Sunlight inactivation of human enteric viruses and fecal bacteria. *Water Sciences and Technology* 46 (11-12), 291-295.

Gagliardo PF, Adham S, Trussell RR, Olivierie A W (1997). Membranes as an alternative to disinfection. Atlanta, GA, USA, AWWA - Annual Conference.

Gille, D (2003) Seawater Intakes for Desalination Plants. *Desalination*, 156: 249-256.

Gagliardo PF, Adham S, Trussell RR, Olivierie A W (1997). Membranes as an alternative to disinfection. Atlanta, GA, USA, AWWA - Annual Conference.

Graczyk TK, Thompson RC, Fayer R, Adams P, Morgan UM, Lewis EJ (1999) Giardia duodenalis cysts of genotype A recovered from clams in the Chesapeake Bay subestuary, Rhode River. *The American Journal of Tropical Medicine and Hygiene* 61 (4), 526-529.

GWI DesalData/IDA (2006)

Hong S, Escobar IC, Hershey-Pyle J, Hobbs C, Cho J (2005) Biostability characterization in a full-scale hybrid NF/RO treatment system. *Journal of American Water Works Association* 97 (5), 101-110.

Jiang SC, Fu W (2001) Seasonal abundance and distribution of Vibrio cholerae in coastal waters quantified by a 16S-23S intergenic spacer probe. *Microbiology Ecology* 42 (4), 540-548.

Jiang SC, Louis V, Choopun N, Sharma A, Huq A, Colwell RR (2000) Genetic diversity of Vibrio cholerae in Chesapeake Bay determined by amplified fragment length polymorphism fingerprinting. *Applied and Environmental Microbiology* 66 (1), 140-147.

Kim JH, Grant SB, McGee CD, Sanders BF, Largier JL (2004) Locating sources of surf zone pollution: a mass budget analysis of fecal indicator bacteria at Huntington Beach, California. *Environmental Science and Technology* 38 (9), 2626-2636.

Kitis M, Lozie, JC, Kim JH, Mi B, Marinas BJ (2002) Microbial removal and integrity monitoring of high-pressure membranes. Seattle, Washington, USA, American Water Works Association - Water Quality Technology Conference.

Kitis M, Lozier JC, Kim JH, Mi B, Marinas BJ (2003) Evaluation of biologic and non-biologic methods for assessing virus removal by and integrity of high pressure membrane systems. *Water Science and Technology: Water Supply* 3 (5-6), 81-92.

Kozisek F (2005) *Health risks from drinking demineralised water in Nutrients in Drinking Water*, November, WHO, Geneva www.who.int/water_sanitation_health

Larson T (1970) *Corrosion by Domestic Waters*, Illinois State Water Survey, Bulletin 56. Urbana, IL.

Li D, Daler D (2004) Ocean pollution from land-based sources: East China Sea, China. *Ambio* 33 (1-2), 107-113.

Louis VR, Russek-Cohen E, Choopun N, Rivera IN, Gangle B, Jiang SC, Rubin A, Patz JA, Huq A, Colwell RR (2003) Predictability of Vibrio cholerae in Chesapeake Bay. *Applied and Environmental Microbiology* 69 (5), 2773-2785.

Lovins WA, Taylor JS, Kozik R, Abbasedegan M, LeChevallier M, Ajy K (1999) Multi-contaminant removal by integrated membrane systems.Tampa, Florida, USA, American Water Works Association - Water Quality Technology Conference.

McGuire/Malcolm Pirnie (2006) Poseidon Resources Corporation Corrosion Pilot Study. Draft final report. McGuire/Malcolm Pirnie, 1919 Santa Monica Blvd. Suite 200, Santa Monica, CA 90404-1955

McGuire Environmental Consultants, Inc (2005) Final Report: Pharmacuticals, personal care products and endocrine disruptors-Implications for Poseidon Resources Corporation's proposed ocean desalination facility in Carlsbad. McGuire/Malcolm Pirnie, 1919 Santa Monica Blvd. Suite 200, Santa Monica, CA 90404-1955.

McGuire Environmental & Poseidon Resources (2004) Disinfection By-product Formation in Simulated Distribution System: Blending Desalinated Seawater from the Poseidon Resources Inc. Pilot Facility With Local Drinking Water Sources, March, Final Report.

McLaughlin, R (1998) Personal communication.

Mickley MC (2006) Membrane Concentrate Disposal: Practices and Regulation. Second Edition, Desalination and Water Purification Research Program Report No. 123, US Bureau of Reclamation.

Missimer TM (1994). *Water Supply Development for Membrane Water Treatment Facilities*. Lewis Publishers/CRC Press, Boca Raton, Florida.

Missimer TM (1999) Raw Water Quality – The Critical Design Factor for Brackish Water Reverse Osmosis Treatment Facilities. *Desalination and Water Reuse*, May/June, 9/1: 41-47.

Molley J, Edzwald J (1988) Oxidant effects on organic halidate formation and removal of organic halidate precursors. *Env Tech. Letters*, Vol. 9, pp.1089-1104.

Nasser AM, Zaruk N, Tenenbaum L, Netzan Y (2003) Comparative survival of Cryptosporidium, coxsackievirus A9 and Escherichia coli in stream, brackish and sea waters. *Water Sciences and Technology* 47 (3), 91-96.

Paul JH, McLaughlin MR, Griffin DW, Lipp EK, Stokes R, Rose, J.B. (2000) Rapid movement of wastewater from onsite disposal systems into surface waters in the Lower Florida Keys. *Estuaries* **23** (5), 662-668.

Paul JH, Rose JB, Brown J, Shinn EA, Miller S, Farrah, SR (1995a) Viral tracer studies indicate contamination of marine waters by sewage disposal practices in Key Largo, Florida. *Applied and Environmental Microbiology* 61 (6), 2230-2234.

Paul JH, Rose JB, Jiang S, Kellogg C, Shinn EA (1995b) Occurrence of fecal indicator bacteria in surface waters and the subsurface aquifer in Key Largo, Florida. *Applied and Environmental Microbiology* 61 (6), 2235-2241.

Paul JH, Rose JB, Jiang SC, Zhou X, Cochran P, Kellogg C, Kang JB, Griffin D, Farrah S, Lukasik J (1997) Evidence for groundwater and surface marine water contamination by waste disposal wells in the Florida keys. *Water Research* 31 (6), 1448-1454.

Peters T, Pinto, D (2006) Sub-seabed Drains Provide Intake Plus Pretreatment. *Desalination and & Water Reuse*, Vol. 16, No. 2, 23-27.

Prévost M, Laurent P, Servais P, Joret JC (2005) *Biodegradable organic matter in drinking water treatment and distribution*. Denver, Colorado, USA, American Water Works Association.

Reeves RL, Grant SB, Mrse RD, Copil Oancea CM, Sanders BF, Boehm A (2004) Scaling and management of fecal Indicator bacteria in runoff from a coastal urban watershed in Southern California. *Environmental Science and Technology* 38 (9), 2637-2648.

Rossum, JR and Merrill DT (1983) An Evaluation of the Calcium Carbonate Saturation Indexes. *J. AWWA* 75:2 (95-100).

Sessions WB and Hawkins NS (2006) Many Advantages to Working Offshore, *Desalination and Water Reuse*, Vol. 15/4; 22-29.

Schwartz, J (2000) *Beach Well Intakes for Small Seawater Reverse Osmosis Plants*, The Middle East Desalination Research Center, Muscat, Sultanate of Oman, August.

Seacord TF, Singley E, Juby G, Voutchkov N (2003) Post-treatment Concepts for Seawater and Brackish Water Desalination, American Water Works Association Proceedings, Membrane Technology Conference, Atlanta, Georgia.

Schock MR (1991) *Internal Corrosion and Deposition Control in Water Quality and Treatment*. McGraw Hill, New York.

Sinton LW, Finlay RK, Lynch PA (1999) Sunlight inactivation of fecal bacteriophages and bacteria in sewage-polluted seawater. *Applied and Environmental Microbiology* 65 (8), 3605-3613.

Tamburrini A, Pozio E (1999) Long-term survival of Cryptosporidium parvum oocysts in seawater and in experimentally infected mussels (Mytilus galloprovincialis). *International Journal for Parasitology* 29 (5), 711-715.

Tanaka S, Numata K, Kuzumoto H, Sekino M (1994) New disinfection method in RO seawater desalination systems. *Desalination,* 96: 191-196.

Taylor JS, Dietz JD, Randall AA, Hong SK, Norris CD, Mulford LA, Arevalo JM, Imran S, Le Puil M, Liu S, Mutoti I, Tang J, Xiao W, Cullen C, Heaviside R, Mehta A, Patel M, Vasquez PF, Webb D (2006) *Effects of blending on distribution system water quality*. American Water Works Association Research Foundation Report 91065F (Denver, Colorado, USA).

Taylor JS, Jacobs EP (1996) Reverse osmosis and nanofiltration pp. 9.18–9.22. In: *Water Treatment Membrane Processes*, (Eds.) Mallevialle, J., Odendaal, P.E. and Wiesner, M.R., McGraw-Hill, New York.

Thompson T et al (2004) *Draft Chemical safety of drinking-water: Assessing priorities for risk management*. Geneva, World Health Organization

UNEP (2002) *Environmental Impact Assessment Training Resource Manual*. 2nd Edition, Two Volumes (Manual 573 p.; transparency overheads 226 p.). Print version available at Earthprint (http://www.earthprint.com). Electronic version available at UNEP (http://www.unep.ch/etu/publications).

UNEP/MAP/MEDPOL (2003) Sea Water Desalination in the Mediterranean: Assessment and Guidelines. MAP Technical Reports Series No. 139, Mediterranean Action Plan (MAP), Program for the Assessment and Control of Pollution in the Mediterranean region (MEDPOL), Athens.

UNEP(2008) Resources and Guidance Manual for Environmental Impacts Assessments. http://www.unep.org.bh/Newsroom/pdf/EIA-guidance%20manwal.pdf
http://www.unep.org.bh/Publications/default.asp

USBR (1976) United States Department of Interior, Bureau of Reclamation. Solicitation No. DS-7186, Denver, Colorado, 33.

USBR (2003a) Desalting Handbook for Planners. 3rd Edition. Desalination and Water Purification Research and Development Report #72. Denver, CO: United States Department of the Interior, Bureau of Reclamation, Water Treatment Engineering and Research Group.

U.S. EPA National Recommended Water Quality Criteria, National Center for Environmental Publications and Information, 11029 Kenwood Road, Cincinnati, Ohio 45242, USA.

U.S. EPA (1984) Ambient Water Quality Criteria for Chlorine. EPA 440-5-84-030, Office of Water Regulations and Standards Division, Washington DC 20460.

van der Hoek JP, Hofman JAMH, Bonne PAC, Nederlof MM, Vrouwenvelder HS (2000) RO treatment: Selection of a pretreatment scheme based on fouling characteristics and operating conditions based on environmental impact. *Desalination* 127 (1), 89-101.

Voutchkov N (2004) Thorough Study is Key to Large Beach Well Intakes, *The International Desalination and Water Reuse Quarterly*, May/June, Vol. 14/No.1.

Voutchkov N (2004). Seawater Desalination Costs Cut Through Power Plant Co-location, *Filtration + Separation*, September.

Voutchkov N (2006). Innovative Method to Evaluate Tolerance of Marine Organisms. *Desalination and & Water Reuse*, Vol. 16, No. 2, 28-34.

Wait DA, Sobsey MD (2001) Comparative survival of enteric viruses and bacteria in Atlantic Ocean seawater. *Water Sciences and Technology* 43 (12), 139-142.

Watson IC et al. (2003). Desalination Handbook for Planners, Third Edition. Desalination and Water Purification Research Program Report No. 72, Bureau of Reclamation.

WDRr (2006) Water Desalination Report, Vol. 42, No. 35, September 25, 2006.

WDR/DesalData, 2011. Personal communication Tom Pankratz

WDR (2008) Water Desalination Report, Vol. 44, No. 33, 15 September, 2008.

WHO (2003) World Health Organization *Guidelines for Safe Recreational Waters*. Volume 1. Coastal and fresh waters. Geneva, Switzerland. ISBN: 92-4-154580-1.

WHO (2004) World Health Organization *Guidelines for Drinking-water Quality*, 3rd edition). Recommendations. Geneva, Switzerland.

WHO (1976) *Surveillance of drinking-water quality*. Geneva, World Health Organization

WHO (2004) *Guidelines for drinking-water quality*, 2^{nd} ed. Vol 1. Geneva, World Health Organization

WHO (2003) Nutrients in Drinking Water and the Potential Health Consequences of Long-Term Consumption of Demineralized and Remineralized and Altered Mineral Content Drinking Waters. Roma, 11-13 November, WHO/SDE/WSH/04.01.

WHO (2004a) *Waterborne Zoonoses, Identification, Causes and Control. Cotruvo*, JA, Dufour A, Rees G, Bartram J, Carr R, Cliver DO, Craun GF, Fayer R, Gannon VPJ,(eds.) IWA Publishing, ISBN 1 84339 058 2.

WHO (2004) T*he precautionary principle: protecting public health, the environment and the future of our children*. World Health Organization, Regional Office for Europe, Denmark. Available at http://www.euro.who.int/document/e83079.pdf

WHO (2005) Environmental Health Impact Assessment of Development Projects: A Practical Guide for the WHO Eastern Mediterranean Region. World Health Organization, Regional Office for the Eastern Mediterranean (EMWO), Regional Centre for Environmental Health Activities (CEHA), http://www.who.int/water_sanitation_health/resources/emroehiabook/en/index.html

WHO (2006) World Health Organization *Guidelines for Drinking-water Quality*, 3rd edition. Recommendations. Geneva, Switzerland.

WHO (2005) Nutrients in Drinking Water. World Health Organization. Joseph Cotruvo, John Fawell, Gunther Craun, eds. 2005, WHO Press, Geneva, ISBN 92 4 159398 9. www.who.int/water_sanitation_health/dwq/nutrientsindw/en

WHO (2005a) *Water Safety Plans. Managing drinking-water from catchment to consumer*. WHO/SDE/WSH/05.06. WHO, Geneva.

WHO (2009) *Calcium and Magnesium in Drinking-water: Public Health Significance*. JA Cotruvo and J Bartram ,eds.WHO Geneva. www.who.int/water_sanitation_health ISBN 978 92 4 156355 0.

WHO (2006a) http://www.who.int/oral_health/action/risks/en/index1.html

WHO (2005) *Water Safety Plans. Managing drinking-water from catchment to consumer*.

WHO/FAO JMPR (1988) http://www.inchem.org/documents/jmpr/jmpmono/v88pr03.htm

WHO/SDE/WSH/05.06. WHO, Geneva.

WHO (2005a) *Nutrients in Drinking Water*, November, Geneva www.who.int/water_sanitation_health

WHO (2006) Meeting of Experts on the Possible Protective Effect of Hard Water Against Cardiovascular Disease, Washington DC, 27-28 April 2006**,** published November 2006. www.who.int/water_sanitation_health

WHO (2007) *Chemical safety of drinking-water: Assessing priorities for risk management*

World Bank (1991) Environmental Assessment Sourcebook. Volume I (Policies, Procedures, and Cross-Sectoral Issues), Volume II (Sectoral Guidelines), Volume III (Guidelines for Environmental Assessment of Energy and Industry Projects) and with updates 1993, 1994, 1995-96, 1997, 1998-99, and 2002. Available at http://www-wds.worldbank.org/

WPC/WHO (2006) *Health Aspects of Plumbing Systems*, WHO and World Plumbing Council ISBN 4 156318 4, ISBN 978 92 4 156318 5.

Wright RR, Missimer TL (1997) *Alternative Intake Systems for Seawater Membrane Water Treatment Plants*, Proceedings of International Desalination Association, Madrid, 3: 407-422.

Yang ZB, Hodgkiss IJ (2004) *Hong Kong's worst "red tide" - causative factors reflected in a phytoplankton study at Port Shelter station in 1998*. Harmful Algae

Yermiyahu U, Tal A, Ben-Gal A, Bar-Tal A, Tarchitzky Jm Lahav O (2007) Rethinking Desalinated Water Quality and Agriculture. *Science*, 318, 920-921, 9 November.

Biographical Sketches

Joseph Cotruvo is President of Joseph Cotruvo & Associates. His doctorate is in physical organic chemistry. He was the first director of USEPA’s Drinking Water Standards Division, and was also Director of the Risk Assessment Division at USEPA. He was VP for Environmental Health Sciences with NSF International. He has been a long time coordinator of World Health Organization Guidelines for Drinking Water Quality, and has managed or participated in developing monographs on food process disinfection, aircraft water sanitation, calcium and magnesium in drinking water, zoonoses, Heterotrophic Plate Counts, pathogenic mycobacteria, desalination, Health Aspects of Plumbing and others. He has been principal or co-principal investigator on numerous studies involving drinking water quality and safety, regulatory policy, small systems and individual home water treatment, bromate metabolism water and serves on numerous scientific advisory panels for water recycling. He is currently engaged in several water, diet and health studies in Abu Dhabi, UAE.

David Cunliffe received a BSc with honors in microbiology from the University of Adelaide and a PhD from Flinders University. He is Principal Water Quality Adviser with the South Australian Dept. of Health and he has over 25 years regulatory experience dealing with public health aspects of drinking water and recycled water. Dr. Cunliffe has contributed to national and international guidelines including WHO and Australian for drinking water quality and recycled water. He has published on issues including water quality, rainwater, and management of water supplies. He is a member of the WHO and Australian water quality committees. He has received the Public Service Medal and the Premier’s Water Medal for services to water quality in Australia.

John Fawell comes from a toxicology background but has worked on drinking water quality issues for nearly 30 years. He has carried out research on a wide range of water contaminants and he was Chief Scientist at the UK Water Research Centre’s National Centre for Environmental Toxicology and is now an independent consultant. He works on drinking water standards and guidelines amongst a range of other topics and has been one of the coordinators of the WHO guidelines for drinking water quality since 1988. He is closely involved in the implementation of water safety plans and has also worked on the quality issues associated with new water sources including desalination.

Sabine Lattemann is a marine scientist specializing in environmental impact assessment (EIA) studies particularly of seawater desalination, offshore wind energy development, and maritime shipping impacts. She is a scientific official at the German Federal Environment Agency (Umweltbundesamt). She completed her PhD in 2009 with an EU funded project“ Membrane-based desalination, an integrated approach“ at the University of Oldenburg, Germany, and the UNESCO-IHE Institute for Water Education in Delft, The Netherlands. She is the principal author of the book Seawater Desalination: Impacts of Brine and Chemical Discharges on the Marine Environment, and Resources and Guidance Manual for the Environmental Impact Assessment of Desalination Projects published by the United Nations Environment Program.

Pierre Payment obtained his M.Sc. (Microbiology and Immunology) in 1971 and his Ph.D. (Microbiology and Immunology) in 1974 from the University of Montreal. His postdoctoral studies were done at the Baylor College of Medicine. During that period he became interested in microorganisms in water. Returning to Montreal in 1975, he became professor at Institut Armand-Frappier. He is now a full professor at this institution and has been active both in clinical microbiology and public health. He has been Head of the Electron Microscopy Laboratory and Head of the Veterinary Virology Diagnostic Services. Apart from his activities as a researcher, he was director of the Technology Transfer Unit at INRS-Institut Armand-Frappier and Director of the Intellectual Property Management Network of the University of Québec. He was also President of the Canadian Association of Clinical Microbiology and Infectious Diseases (CACMID) and the organizer of their annual meeting. He is knowledgeable on many aspects of water treatment and microbiology and his current research activities are centered on the health effects of drinking water. As an expert, he has participated to activities of the USEPA, WHO, Health Canada, OECD, the Walkerton Inquiry and was a member of the Advisory Scientific Committee of the Joint International Commission (Great Lakes).

Nikolay Voutchkov has over 25 years of experience in the field of seawater desalination and water treatment. Currently, he is an independent expert providing desalination project advisory services through his company, Water Globe Consulting, LLC. Mr. Voutchkov has published over 30 technical articles and co-authored several books on desalination, including technology and design guidelines for the American Water Works Association and the Australian Water Association. He is a registered professional engineer and a Board Certified Environmental Engineer by the American Academy of Environmental Engineers. Mr. Voutchkov serves on the Research Advisory Committee of the WateReuse Research Foundation and the Research Project Advisory Committees for the American Water Works Association and the Water Environment Federation. Mr. Voutchkov’s work in the field of desalination research and technology has been recognized with numerous awards including the 2006 Global Grand Prize for Innovation by the International Water Association.