RECLAMATION

Managing Water in the West

Literature Review of Desalination Research Priorities

DRAFT REPORT

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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14. ABSTRACT *(Maximum 200 words)* The Bureau of Reclamation's Oklahoma-Texas Area Office (OTAO) spearheaded this effort as a means of helping OTAO allocate resources at the local level in support of Advanced Water Treatment (AWT)-related research that is relevant and beneficial to OTAO's water supply Project partners across Texas, Oklahoma, and Kansas. After initiating this literature review, we discovered that Reclamation was beginning an update of its agency-wide desalination roadmap to help prioritize desalination-related needs and to guide allocation of agency resources. We subsequently shifted the focus to help guide Reclamation's desalination roadmap by identifying and summarizing desalination-related research and priorities at various organizational levels both nationally and internationally. The results are by no means exhaustive considering the abundance of information and organizations involved with desalination across the world. However, we expect the information to provide value to OTAO as it allocates resources at the local level, while also helping OTAO and water purveyors alike assess areas where desalination-related resources could be leveraged that build on existing work and prevent duplication of effort.			
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Executive Summary

The transfer of advanced water treatment technology from research to application is often limited by the opportunity to implement research concepts prior to full scale design. Pilot and demonstration studies are used to evaluate treatment options and benchmark performance to aid in design. At the pilot and demonstration scale, the opportunity exists to integrate research concepts into design and consider a mixture of proven and emerging technologies.

Reclamation area and regional offices are often approached by municipalities and consultants to participate in pilot desalination studies as a means of augmenting water supplies in their region. There are often components of these types of studies which overlap with Reclamation research interests, but there is no Reclamation framework to facilitate this participation. Pilot programs can include numerous study objectives that align with the recommendations of the National Research Council's *Desalination: A National Perspective*. These objectives include evaluating the environmental impacts of concentrate disposal, the treatment of brackish groundwater, and the coupling of renewable energy sources with desalination facilities. By implementing design based research objectives, experimental design, and novel technologies at the pilot scale, demonstrators have the opportunity to advance the research field during piloting.

The Oklahoma-Texas Area Office (OTAO) spearheaded this effort as a means of helping OTAO allocate resources at the local level in support of Advanced Water Treatment (AWT)-related research that is relevant and beneficial to OTAO's water supply project partners across Texas, Oklahoma, and Kansas. After initiating this literature review, we discovered that Reclamation was beginning an update of its agency-wide desalination roadmap to help prioritize desalination-related needs and guide allocation of agency resources. We subsequently shifted the focus to help guide Reclamation's desalination roadmap by identifying and summarizing desalination-related research and priorities at various organizational levels both nationally and internationally.

Twelve key desalination-related papers from seven states outlined some type of state desalination research and implementation priority. Furthermore, twelve key desalination-related papers from eight national level organizations and institutions outlined their respective desalination research and implantation priorities. As well, three papers from countries/international organizations outlined their respective desalination research and implantation priorities. Websites also are catalogued where appropriate. All references are summarized in Appendices A - C and summarized in tables by research category for ease of reference. Table ES-1 provides a complete list of these sources.

Table ES-1: A list of desalination-related papers and websites at various organizational levels.

Entity:		**Reference**
State	Arizona	• Salinity Management and Desalination Technology for Brackish Water Resources in the Arid West (2007) • Desalination in Arizona – a growing component of the state's future water supply portfolio (2011) • Information found on the http://www.cap-az.com/ website (2014)

Entity:		Reference
State	California	• Seawater Desalination: Opportunities and Challenges (2003) • Desalination, with a Grain of Salt: a California Perspective (2006) • An Ecological-Economic Research Program for Desalination (2011) • Direct Potable Reuse: A Path Forward (2011) • 2014 Water Desalination Proposal Solicitation
	Florida	• Desalination in Florida: Technology, Implementation, and Environmental Issues (2010)
	Nevada	• Information found on the http://www.snwa.com/ website (2014)
	Texas	• Desalination Research at Texas Universities —A Brief Overview (2004) • 2012 Biennial Report on Seawater Desalination
	Utah	• The Water-Energy Nexus in Utah (2012)
	Virginia	• The Feasibility of Using Desalination to Supplement Drinking Water Supplies in Eastern Virginia (2004)
National	U.S. Environmental Protection Agency, Office of Water (EPA)	• National Water Program Research Strategy 2009 – 2014 (2009) • Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management (2013)
	National Research Council of the National Academies (NRC)	• Desalination: A National Perspective (2008) • Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater (2012)
	National Water Research Institute (NWRI)	• Desalination Research & Development Workshop Report (2001)
	Bureau of Reclamation (Reclamation)	• Desalination and Water Purification Research and Development Program – Report to Congress (2001) • Desalination and Water Purification Research and Development (DWPR) Pre-Proposal Solicitation for Fiscal Year 2014
	Reclamation/ Sandia National Laboratories (Sandia)	• Desalination and Water Purification Technology Roadmap – A Report to the Executive Committee (2003)
	Sandia	• Inland Desalination: Challenges and Research Needs (2005)
	Sandia/ Water Research Foundation (WRF)/ WateReuse Research Foundation (WRRF)	• Implementation of the National Desalination and Water Purification Technology Roadmap: Structuring and Directing the Development of Water Supply Solutions (2010)
	Western Governors' Association (WGA)	• Water Needs and Strategies for a Sustainable Future: Next Steps (2008)
	WRRF/ WRF/ Reclamation	• Desal Dialog: A Regulatory Workshop on Critical Issues of Desalination Permitting (2013)

Entity:		Reference
Countries/ International Organizations	Australia	• Australian Desalination Research Roadmap (2012)
	Egypt	• Desalination Technology Roadmap 2030 (2007)
	Middle East Desalination Research Center (MEDRC)	• Information found on the www.medrc.org website (2014)
	South Africa	• National Water Resource Strategy – National Desalination Strategy (2011)

Contents

Introduction

Much of the Western U.S. continues to be in severe drought, which highlights the need to expand water supply portfolios that take advantage of treating impaired supply sources such as seawater, brackish water, and wastewater effluent. The Oklahoma-Texas Area Office (OTAO) has jurisdiction over 11 reservoir projects across Texas, Oklahoma, and Kansas, which together deliver more than 650,000 acre-feet of municipal, industrial, and irrigation water annually to about 3 million customers, and which also provide fish and wildlife, recreation, and flood control benefits. Currently, six of its 11 reservoirs are below 50 percent conservation pool elevation, with two reservoirs all but completely dry. This situation is being repeated across the nation, and entities have a compelling need to develop new water supplies to help supplies traditionally provided by reservoirs during severe droughts.

Reclamation's Advanced Water Treatment (AWT) program, operating under umbrella programs such as WaterSMART and Research & Development, offers a unique opportunity to help address these needs, utilizing its labs, facilities, and resources to conduct research that covers the entire spectrum of technology development, from: (1) Concept: generating a new concept resulting in new or improved technology that can be applied to increase water supplies; to (2) Experimentation: conducting experiments and proof-of-concept laboratory testing to validate a treatment process or application; to (3) Development: testing the concept at the pilot scale to gain real-time operating data in a field setting; to (4) Maturation: demonstrating the concept on a larger scale to verify scalability, economic feasibility, and technical validity; to (5) Usage: incorporating successful concepts into engineering design activities, full-scale treatment plants, and deploying commercial products.

On a broad level, Reclamation's desalination investments are guided by institutional knowledge, and by key publications such as the *Desalination and Water Purification Technology Roadmap* (2003) and *Desalination: A National Perspective* (2008). An internal Reclamation AWT "Community of Practice" also exists, which serves as a means of creating a network of agency staff interested in AWT at various levels (area and regional offices, Technical Services Center, Research and Development, etc). However, a need exists to refine Reclamation's approach based on current data and resources, both locally and agency wide; to this end, Reclamation is in the initial stages of developing a desalination roadmap to help identify needs and prioritize research. The following literature review serves as one positive step in that direction; However, until the roadmap is completed, OTAO will use this information to not only help guide its resource allocation at the local level, but also to assess areas where resources could be leveraged that build on existing work and prevent duplication of effort. Three sections follow:

1) State Research Priorities
2) National Research Priorities
3) International Research Priorities

State Research Priorities

This section describes twelve papers and two websites from seven states: Arizona, California, Florida, Nevada, Texas, Utah, and Virginia. These states identified some type of state desalination-related research and implementation priority, all of which are categorized in Table 1 to indicate areas where priorities overlap across states. States that were evaluated but lacked published documentation that identify desalination research and implementation priorities include: Alaska, Colorado, Georgia, Hawaii, Idaho, Louisiana, Maryland, Massachusetts, Montana, New Jersey, New Mexico, New York, North Carolina, Oregon, South Carolina, Washington, and Wyoming. The states searched were based on best professional judgment and limited resources and time; all other states were not searched. References are summarized in Appendix A.

Table 1: Priority areas identified for each state.

Priority Desalination Research Areas	State
Intake Improvements	
• Evaluate feedwater intake technology and impacts	• California
• Study mixing zone turbulence entrainment	• California
• Improve thin-layer mixing models as part of far-field plume modeling	• Texas
• Research ecosystem impacts from water withdrawal and water intake structure	• Virginia
Pretreatment and Anti-Fouling Technologies	
• Evaluate implementation and cost of various pre-treatment strategies to allow greater RO water recovery before the onset of scaling	• Arizona
• Reduce RO membrane fouling through feed water pretreatment and coupling of RO systems to ion exchange processes or nanofiltration. Other approaches include membrane improvements and mechanical or chemical ways to inhibit scaling.	• Arizona
• Evaluate the relative efficacies of the various commercially available anti-scalants and identify a standard testing protocol by which these and future products in the market can be comparatively rated	• Arizona
• Evaluate feedwater treatment processes and strategies	• California
• Decrease membrane fouling	• Nevada
• Improve pretreatment and anti-fouling technologies	• Texas
• Develop new membrane materials that work efficiently at high temperatures	• Texas
Energy Efficient Technologies	
• Refine and retest the DewVaporation technology based on the findings of the study done by the City of Phoenix and U.S. Bureau of Reclamation if appropriate	• Arizona
circumstances arise where brine generation occurs proximate to a waste or cheap heat source (e.g., power plant cooling water stream)	• Arizona
• Improve energy use	
• Investigate renewable power coupling to the desalination treatment process (e.g., wave energy)	• Arizona
• Determine how to achieve energy sustainability for desalination through minimizing energy consumption through investment in energy-efficient pumps and other	• California
equipment, purchasing renewable energy credits that offset the greenhouse gas loading of the electricity consumed by the facility, and investing in greenhouse gas-reducing projects, from new renewable energy projects to carbon storage projects	• California
• Determine any synergistic effects caused by combining desalination's high salinity discharge with the high temperatures and dead biomass in power plant discharge	
• Evaluate energy price risk, including year-to-year variation and trends over time, in the revenue requirement of water utilities that invest in or purchase water from	• California
ocean desalination	• California
• Perfect promising low-energy technologies (i.e., capacitive deionization) and alternative energy sources (i.e., wind and solar)	
• Recover energy from reverse osmosis processes used for desalination	• Texas
• Use new technology (nanotechnology, energy efficient pumps, alternative energy sources, use of 'waste heat') to reduce the costs to operate and maintain	• Texas
desalination processes like membrane filtration and, equally important, reduce the carbon footprint	• Florida
• Evaluate co-location at steam electric power plants or large municipal wastewater treatment plants can reduce the energy, capital, and operational costs	• Florida
• Develop a statewide plan for water/energy resource planning to assist local and regional shareholders with a framework for coordination	• Utah
• Develop a mechanism for enhanced cooperation between water utilities and power companies to make existing and future desalination plants more cost-competitive	• Virginia

Priority Desalination Research Areas	State
Treatment Improvements	
• Conduct combined basic and applied research on the potential for incorporating novel membrane functionalities, such as electromagnetic membranes, biomimetic membranes, and ion-specific electrodialysis membranes	• Arizona
• Evaluate the impacts of treatment train and process operation modifications to enhance the performance and reliability of secondary, tertiary, and advanced treatment systems	• California
• Evaluate new and alternative integrated technologies for optimizing seawater desalination plant design and operating concepts	• California
• Evaluate blending requirements for purified water	• California
Brine Disposal Alternatives	
• Investigate feasible strategies for and means of encouraging centralized ion exchange media regeneration (vis-à-vis in-home regenerative water softeners) to minimize water consumption and brine disposal impacts	• Arizona
• Evaluate, at the scoping level, the potential for use of the Sacaton Pit and other regional scale options for waste brine disposal	• Arizona
• Improve concentrate management	• Arizona
• Pursue development of selective precipitation as a means for beneficial product recovery from the brine residuals particular to Arizona waters that are likely to be subject to RO treatment	• Arizona
• Undertake a preliminary feasibility, impact, and cost study of the potential for development of a salt marsh in the Gila River channel south of Phoenix	• Arizona
• Evaluate concentrate issues and options	• California
• Improve brine/concentrate management and disposal	• California
• Investigate injecting reject waters into depleted oil and gas fields	• Texas
• Characterize benthic fauna in areas that will be affected by concentrate discharges	• Texas
• Determine the salinity tolerance of key aquatic species along the Texas Gulf Coast which may potentially be affected by desalination concentrate discharges	• Texas
• Model currents and tides to determine impact on concentrate dispersion	• Texas
• Improve brine disposal and cost effectiveness of various brine disposal and management technologies, such as Zero Liquid Discharge and brine reuse potential	• Virginia
Vegetation Use	
• Develop and/or identify halophytes with commercial value that can be grown in lined facilities irrigated with RO brines	• Arizona
Distribution System integration	
• Develop the capability for case specific, systems-level evaluation of complete process schemes for desalination and brine management, including development of the necessary modeling tools and metrics	• Arizona
• Determine the impacts of desalinated product water, which can be corrosive or damaging, on the distribution systems	• California
• Develop design considerations for sizing engineered storage buffers	• California
• Investigate integrating desalinated seawater into existing drinking water distribution networks	• Texas
Institutional and Regulatory Concerns	
• Establish a program by which new membranes, membrane treatment related products, and alternative desalination technologies are independently and comparatively tested under the conditions and constraints relevant to the arid west	• Arizona
• Investigate regulatory and economic means to discourage the use of in-home regenerative water softeners	• Arizona
• Document regulatory permitting issues associated with seawater desalination	• California
• Establish a combined basic and applied research program to improve the efficiency and decrease the cost of capacitive deionization.	• Arizona

Priority Desalination Research Areas	State
Institutional and Regulatory Concerns (continued)	
• Analyze the public aspects of desalination projects, including environmental impacts, mitigation, and protection.	• California
• Refine or advance desalination technology affecting regulatory parameters	• California
• Document equivalency of advanced wastewater treatment trains and processes for direct potable reuse	• California
• Develop standard terminology, messaging, and communication materials for planning and implementation of direct potable report	• California
• Identify the concerns about building a new supply source and improve public perception	• California
• Develop comprehensive public relations/public education programs	• California
• Evaluate source-water issues in relation to potential cost and fatal flow issues	• California
• Develop a better understanding of the ecological-economic impacts and provide a clearer and stronger framework for public review	• California
• Ensure technology transfer for government agencies and utilities in Florida	• Florida
• Exchange information on environmental issues associated with desalination	• Florida
• Revise regulatory bacteria and virus removal credits for reverse-osmosis membranes	• Texas
• Teach water resources managers about best management practices	• Texas
• Evaluate the effects of the operation of desalination plants on the environment	• Texas
• Develop a comprehensive database of available water resources in eastern Virginia, viable regional water supply, and allocation plan based on the scientific evaluation of existing water resources and the potential for developing impure water sources such as saline water	• Virginia
• Coordinate and expedite permit reviews between various federal and state agencies for the implementation of future desalination plants	• Virginia
• Develop a strategic plan for future use of large-scale desalination technologies in eastern Virginia and identify potential sites to locate desalination facilities	• Virginia
Water Quality Concerns	
• Investigate the benefits of targeting quality of the output given the quality of the input water	• Arizona
• Assess future waste loads and waste stream through analysis of long-term growth patterns, degree of incorporation of reuse in new development and sub-divisions, and household- level water harvesting that will affect wastewater volumes, and thereby, wastewater salinities	• Arizona
• Explore advanced wastewater treatment processes such as high-pressure membrane filtration and advanced oxidation to address trace organic contaminants persisting through conventional treatment processes	• Nevada
Monitoring Improvements	
• Enhance monitoring techniques and methods for direct potable reuse	• California
• Develop protocols for sampling, testing, analysis, and monitoring	• California
Cost/Benefit Analysis	
• Determine economic and social benefits of drought-proof water supplies	• California
• Develop policy on public and private roles and development of a new project delivery process to minimize costs and maximize performance	• California
• Identify, optimize, and control the complexity and experience level required for the large number of minor cost components for seawater desalination projects	• California
• Understand the relationship between finished-water quality specifications and plant design/cost	• California
• Develop a methodology to facilitate an assessments of desalination options and total benefits	• California
• Explore ways to reduce associated energy consumption and operational costs	• Nevada

National Research Priorities

This section describes twelve papers from eight national level organizations and institutions describing their respective desalination-related research and implantation priorities. These organizations include:

- Bureau of Reclamation (Reclamation)
- National Research Council of the National Academies (NRC)
- National Water Research Institute (NWRI)
- Sandia National Laboratories (Sandia)
- U.S. Environmental Protection Agency, Office of Water (EPA)
- Western Governors' Association (WGA)
- Water Research Foundation (WRF)
- WateReuse Research Foundation (WRRF)

Table 2 summarizes research priorities for each organization/institution. References are provided in Appendix B.

Table 2: Priority areas identified for each national institutions and organizations and year the paper was published.

Priority Desalination Research Areas	National Institution/ Organization
Intake Improvements	
• Develop improved intake methods at coastal facilities to minimize impingement of larger organisms and entrainment of smaller ones	• NRC (2008)
• Use existing data from desalination environmental impact assessments, cooling water intake studies, and brine discharge monitoring associated with National Pollutant Discharge Elimination System permitting to analyze the environmental impacts of seawater desalination, identify data gaps, and develop monitoring protocols (including factors to consider in defining a baseline)	• Sandia/WRF/ WRRF (2010)
• Assess information that can be used to adequately examine intake options	• Sandia/WRF/ WRRF (2010)
• Develop a methodology for quantification of Impingement & Entrainment (I&E) of desalination plant intakes	• WRRF/WRF/ Reclamation (2013)
• Develop a methodology for determination of the biological significance of I&E	• WRRF/WRF/ Reclamation (2013)
• Develop a methodology for assignment of I&E reduction credits to intake technologies	• WRRF/WRF/ Reclamation (2013)
• Develop a methodology for development of I&E mitigation	• WRRF/WRF/ Reclamation (2013)
• Develop a methodology for assigning pathogen removal credits to desalination intake wells	• WRRF/WRF/ Reclamation (2013)
Pretreatment and Anti-Fouling Technologies	
• Improve pretreatment for membrane desalination	• NRC (2008)
• Develop better methods of preventing membrane fouling	• Sandia (2005)
• Model current oxidative conditioning of water to develop alternative pretreatments for conditioning seawater	• Sandia/WRF/ WRRF (2010)
• Develop process and feedback control mechanisms that lead to design guidelines for pretreatment systems	• Sandia/WRF/ WRRF (2010)
• Identify naturally occurring geo- and bio-polymers in seawater	• Sandia/WRF/ WRRF (2010)
• Identify organic fouling control mechanisms and develop real-time sensing tools	• Sandia/WRF/ WRRF (2010)
• Reduce or eliminate fouling so that existing membrane systems can be operated at a higher throughput	• Sandia/WRF/ WRRF (2010)
• Facilitate operational adjustments (feedback) at the pretreatment process that enable membrane operations/performance adjustments	• Sandia/WRF/ WRRF (2010)
Energy Efficient Technologies	
• Energy conservation and renewable energy sources	• EPA (2013)
• Energy reduction for desalination plants	• NWRI/Reclamation (2001)
• Reducing energy consumption and integrating renewable energy into desalination processes	• Reclamation (2014)
• Demonstrate energy-recovery technology candidates for concentration of membrane concentrate streams	• Sandia/WRF/ WRRF (2010)
• Provide cost-effective concentrate disposal solution by using low-cost power and/or providing industrial feed water through co-siting facilities	• Sandia/WRF/ WRRF (2010)
• Evaluate alternative energy use in desalination	• Sandia/WRF/ WRRF (2010)
• Identify differential energy needs of desalination relative to existing water supplies	• Sandia/WRF/ WRRF (2010)

Priority Desalination Research Areas	National Institution/ Organization
Treatment Improvements	
• Optimization treatment for cost savings in energy, maintenance, manpower, and other plant operating costs	• EPA (2013)
• Improve membrane system performance	• NRC (2008)
• Improve existing desalination approaches to reduce primary energy use	• NRC (2008)
• Develop novel approaches or processes to desalinate water in a way that reduces primary energy use	• NRC (2008)
• Develop a better understanding of pathogen removal efficiencies and the variability of performance in various unit processes and multi-barrier treatment and develop ways to optimize these processes	• NRC (2012)
• Improve membrane process technology	• NWRI/Reclamation (2001)
• Look outside-the-box for innovative (desalting technology) solutions	• NWRI/Reclamation (2001)
• Improve the fundamental understanding of membrane science	• NWRI/Reclamation (2001)
• Evaluate membrane bioreactor applications to reduce the costs and increase the efficiency of systems	• Reclamation (2001)
• Develop innovative membrane test bed for seawater desalination	• Reclamation (2001)
• Evaluate low cost, small system, desalination using evaporation	• Reclamation (2001)
• Demonstration of clathrate seawater desalination	• Reclamation (2001)
• Develop and test flexible use systems for treating waters of significantly varying salinities	• Reclamation (2014)
• Reduce the cost of desalination processes	• Reclamation (2014)
• Expand scientific understanding of desalination processes	• Reclamation (2014)
• Improve the quality and suitability of treated water for reuse	• Reclamation (2014)
• Develop membrane technologies (technologies that desalinate and purify water by pushing it through a semi-permeable membrane that removes contaminants)	• Reclamation/ Sandia (2003)
• Develop alternative technologies (technologies that desalinate and purify water that take advantage of non-traditional methods)	• Reclamation/ Sandia (2003)
• Develop thermal technologies (technologies that rely on boiling or freezing water and then capturing the purified water while the contaminants remain behind)	• Reclamation/ Sandia (2003)
• Develop reuse/recycling technologies (often membrane or alternative technologies that must be designed to handle increased contaminant loads due to their postconsumer application)	• Reclamation/ Sandia (2003)
• Improve low temperature thermal desalination to increase affordability for small systems where infrastructure is lacking	• Sandia (2005)
• Develop better designs for membrane modules that efficiently transport water to the membrane surface, and waste salts away from it	• Sandia (2005)
• Develop approaches that employ low temperature distillation processes driven by waste heat sources to reduce the volume of RO concentrate and increase fresh water recovery	• Sandia (2005)
• Improve technologies for removing organic and biological contamination, as well as dissolved salts, that will allow for the substantial recycling of water and will reduce strain on our limited resources in the face of increasing demand	• Sandia (2005)
• Develop alternatives to spiral membrane systems	• Sandia/WRF/ WRRF (2010)
• Identify new techniques and evaluate existing alternatives for removing boron during seawater RO	• Sandia/WRF/ WRRF (2010)

Priority Desalination Research Areas	National Institution/ Organization
Treatment Improvements (continued)	
• Investigate the use of improved membranes, soluble salts control (for brackish water), and system design improvements. Research additional secondary recovery strategies such as electro-deionization and selective adsorbents	• Sandia/WRF/ WRRF (2010)
• Evaluate arrays, vessel configuration, variation in type(s) of membranes, etc. (e.g., staged feeding, modified arrays, varying type of membrane from front to back of system due to differential loadings)	• Sandia/WRF/ WRRF (2010)
• Develop hybrid systems that can treat very difficult brackish source waters	• Sandia/WRF/ WRRF (2010)
• Demonstrate the scalability of membrane distillation	• Sandia/WRF/ WRRF (2010)
• Develop a forward osmosis desalination process that can operate at a lower cost and recover than RO	• Sandia/WRF/ WRRF (2010)
• Investigate biomimetic membrane filtration in synthetic systems	• Sandia/WRF/ WRRF (2010)
• Improve membrane productivity, rejection, selectivity, and manufacturing reproducibility (consistency of project)	• Sandia/WRF/ WRRF (2010)
Brine Disposal Alternatives	
• Develop cost-effective approaches for concentrate management that minimize potential environmental impacts	• NRC (2008)
• Balance increasing the production of potable water and reducing the cost of the ultimate disposal of concentrate	• NWRI/Reclamation (2001)
• Develop concentrate management technologies	• Reclamation/ Sandia (2003)
• Quantify the potential benefits and applicability of integrating treatment of brackish water concentrate and seawater	• Sandia/WRF/ WRRF (2010)
• Compile existing information on additives typical of desalination facility operations, including naturally derived additives, and identify knowledge gaps in our current understanding of additive fate, transport, and risk (human health and environmental)	• Sandia/WRF/ WRRF (2010)
• Develop a better understanding of concentrate impacts on the environment and reevaluate the current methods used to determine these impacts	• Sandia/WRF/ WRRF (2010)
• Evaluate hybrid techniques for zero-liquid discharge	• Sandia/WRF/ WRRF (2010)
• Develop a geomaterial liner (possibly with additives) that incorporate concentrate components to self-seal (heal) liners	• Sandia/WRF/ WRRF (2010)
• Reduce land requirements for concentrate management by providing an additional treatment tool to maximize evaporation rates in evaporation ponds	• Sandia/WRF/ WRRF (2010)
• Develop a better understanding of the impact of concentrates on WWTP unit operations, particularly as the volume of these concentrates increase	• Sandia/WRF/ WRRF (2010)
• Evaluate the ability to remove selective contaminants to produce saleable projects	• Sandia/WRF/ WRRF (2010)
• Develop novel nano-materials that can rapidly and effectively remove silica from solutions	• Sandia/WRF/ WRRF (2010)
• Develop understanding and system design for minimizing use of anti-scalants and biocides and with impact on concentrate	• Sandia/WRF/ WRRF (2010)
• Develop selective precipitation and purification methods for common RO concentrate salts and identify potential regional markets for beneficial reuse	• Sandia/WRF/ WRRF (2010)
• Create new concentrate disposal options and improve public perception by applying concentrates in health spa or environment/recreation improvements	• Sandia/WRF/ WRRF (2010)

Priority Desalination Research Areas	National Institution/ Organization
Brine Disposal Alternatives (continued)	
• Identify ways to mitigate adverse impacts of brine disposal	• WGA (2008)
• Develop an information and decision tree for characterization of desalination plant discharges	• WRRF/WRF/ Reclamation (2013)
• Characterize the toxicity impacts of desalination plant discharges	• WRRF/WRF/ Reclamation (2013)
• Develop standard methods for laboratory analysis of concentrate	• WRRF/WRF/ Reclamation (2013
• Develop, verify, and certify salinity dispersion models tailored for seawater discharge	• WRRF/WRF/ Reclamation (2013)
• Develop a database of permitting practices for brackish concentrate disposal	• WRRF/WRF/ Reclamation (2013)
Vegetation Use	
• Develop a better understanding of contaminant attenuation in environmental buffers	• NRC (2012)
• Examine the potential for contributions from biotechnology and the biologic sciences contributing to the production of potable water at useful scales	• Sandia/WRF/ WRRF (2010)
• Identify, develop, and demonstrate new agricultural-based methods to promote cost-effective and sustainable concentrate management	• Sandia/WRF/ WRRF (2010)
• Evaluate the impacts of a typical brine stream on commercial agriculture and horticulture	• Sandia/WRF/ WRRF (2010)
• Investigate integrated biological processes for salinity control	• Sandia/WRF/ WRRF (2010)
Distribution System Integration	
• Evaluate green infrastructure effectiveness and integration with water reuse and reclamation at the watershed scale	• EPA (2009)
• Develop guidelines for integrating desalinated water into the water distribution system	• WRRF/WRF/ Reclamation (2013)
Institutional and Regulatory Concerns	
• Assess environmental impacts of desalination intake and concentrate management approaches	• NRC (2008)
• Analyze the human health impacts of boron to expedite water-quality guidance for desalination process design	• NRC (2008)
• Address critical gaps in the understanding of health impacts of human exposure to constituents in reclaimed water	• NRC (2012)
• Assess the potential impacts of environmental applications of reclaimed water in sensitive ecological communities	• NRC (2012)
• Examine the public acceptability of engineered multiple barriers compared with environmental buffers for potable reuse	• NRC (2012)
• Develop a better understanding of the formation of hazardous transformation products during water treatment for reuse and ways to minimize or remove them	• NRC (2012)
• Analyze the need for new reuse approaches and technology in future water management	• NRC (2012)
• Develop and education and public relations strategy to facilitate the implementation of desalination projects	• NWRI/Reclamation (2001)
• Establish a national water policy to streamline regulations for development of desalination	• NWRI/Reclamation (2001)
• Establish a national advisory panel for developing water purification technologies to increase water supplies	• NWRI/Reclamation (2001)

Priority Desalination Research Areas	National Institution/ Organization
Institutional and Regulatory Concerns (continued)	
• Understand the environmental impacts of desalination and develop approaches to minimize these impacts relative to other water supply alternatives	• Reclamation (2014)
• Understanding the environmental impacts of desalination and developing approaches to minimize these impacts relative to other water supply alternatives	• Reclamation (2014)
• Establish acceptable levels for boron, chloride, and sodium for plants common to households, yards, and open space in the United States as well as selected soil types and climates where seawater desalination is a viable candidate water source. The results from this research would allow utilities to use alternative water supplies with a quantitative understanding of potential landscaping impacts.	• Sandia/WRF/ WRRF (2010)
• Develop tools and standards to determine and assess the capacity of alternative water supply methods	• Sandia/WRF/ WRRF (2010)
• Develop a portfolio approach to water supply planning to reflect the different risks and benefits of desalination relative to alternative water supply options	• Sandia/WRF/ WRRF (2010)
• Summarize regional case studies of policy modifications regarding water rights	• Sandia/WRF/ WRRF (2010)
• Develop information necessary to achieve changes in regulatory requirements for use by Federal and State Governments	• Sandia/WRF/ WRRF (2010)
• Compile unsuccessful project case studies to allow barriers to be anticipated and potential policy changes to be implemented to streamline desalination implementation	• Sandia/WRF/ WRRF (2010)
• Develop guidelines for desalination that address technical and institutional aspects of implementing desalination	• Sandia/WRF/ WRRF (2010)
• Provide outreach and education for permitting processes and network water professionals	• WRRF/WRF/ Reclamation (2013)
• Study salinity tolerance of target sensitive marine species	• WRRF/WRF/ Reclamation (2013)
• Map United States ocean shorelines for “near-shore” outfall zones	• WRRF/WRF/ Reclamation (2013)
• Develop a surrogate-based method for assessment of algal toxin removal	• WRRF/WRF/ Reclamation (2013)
• Develop a methodology for implementing NSF/ANSI 61 Standard for desalination projects	• WRRF/WRF/ Reclamation (2013)
Water Quality Concerns	
• Remove nutrients and recover resources including energy and nutrients	• EPA (2013)
• Remove chemical contaminants, such as EDCs and PhACs	• EPA (2013)
• Pilot studies treating agricultural return flows containing elevated levels of TDS and selenium to be conducted at the San Luis Demonstration Treatment Plant near Firebaugh, California, within the San Joaquin River Water Quality Implementation Program (SJRIP) reuse area in Panoche Drainage District	• Reclamation (2014)
• Evaluate and test treatment approaches for problem contaminants	• Sandia/WRF/ WRRF (2010)
• Develop and verify framework/model to describe and predict rejection of trace organic compounds	• Sandia/WRF/ WRRF (2010)
• Study of survivability of regulated human pathogens in saline waters	• WRRF/WRF/ Reclamation (2013)

Priority Desalination Research Areas	National Institution/ Organization
Monitoring Improvements	
• Improve emergency preparedness of WWTPs to deal with pandemics, new strains of viruses and bacteria, or spill incidents	• EPA (2013)
• Develop mitigation strategies for treatment plants after natural calamities	• EPA (2013)
Monitoring Improvements (continued)	
• Improve prevention and preparedness for bioterrorism	• EPA (2013)
• Strengthen waterborne disease surveillance, investigation methods, governmental response infrastructure, and epidemiological research tools and capacity	• NRC (2012)
• Quantify the relationships between polymerase chain reaction detections and infectious organisms in samples at intermediate and final stages	• NRC (2012)
• Develop improved techniques and data to consider hazardous events or system failures in risk assessment of water reuse	• NRC (2012)
• Identify better indicators and surrogates that can be used to monitor process performance in reuse scenarios and develop online real-time or near real-time monitoring techniques for their measurement	• NRC (2012)
• Standard method for online nanofiltration and RO integrity testing	• WRRF/WRF/ Reclamation (2013)
• Substantially enhance acceptability of desalinated water by developing quantitative guidelines linking post-treatment stabilization to water quality goals	• WRRF/WRF/ Reclamation (2013)
Cost/Benefit Analysis	
• Quantify the non-monetized costs and benefits of potable and non-potable water reuse compared with other water supply sources to enhance water management decision making	• NRC (2012)
• Determine the value of water for different water users	• NWRI/Reclamation (2001)
• Develop approaches to lower the financial costs of desalination so that it is an attractive option relative to other alternatives in locations where traditional sources of water are inadequate	• Reclamation (2014)
• Identify case study examples of alternative water supply evaluations that have been completed and used by decision makers to prioritize and justify investments in new water supplies	• Sandia/WRF/ WRRF (2010)
• Develop a documented process for using a normalized spreadsheet-based desalination cost model	• Sandia/WRF/ WRRF (2010)
• Provide an inventory of capital and operations and maintenance costs for different qualities of product water for use by utilities and planners	• Sandia/WRF/ WRRF (2010)
Miscellaneous Topics	
• Assess the quantity and distribution of brackish water resources nationwide	• NRC (2008)
• Quantify the extent of de factor (or unplanned) potable reuse in the United States	• NRC (2012)
• Assess the conceptual feasibility for energy reduction, process productivity improvements, or environmental mitigation potential of offshore intakes and offshore desalination	• Sandia/WRF/ WRRF (2010)
• Investigate the availability and use of brackish waters to meet future water needs, particularly those of rural communities without other readily available sources of supply	• WGA (2008)
• Develop a methodology for performing sanitary surveys and applying drinking water standards to desalination projects	• WRRF/WRF/ Reclamation (2013)
• Survey of existing brackish groundwater sources water blending practices	• WRRF/WRF/ Reclamation (2013)

International Research Priorities

The literature search identified three desalination-related papers and one website from the following: Australia, Egypt, Middle East Desalination Research Center (MEDRC), and South Africa. Table 3 categorizes research priorities by entity. Countries that were evaluated but which lacked published documentation related to desalination-related research and implementation priorities include: Canada, Cyprus, India, Israel, Oman, Qatar, Saudi Arabia, Singapore, and Spain. References are provided in Appendix C.

Table 3: Priority areas identified for each international country and organizations.

Priority Desalination Research Areas	Country/International Organization
Intake Improvements	
• Optimize intakes and outfalls	• Australia
• Management of entrainment of small marine organisms in SWRO intakes	• Australia
• Establish management of entrainment of small marine organisms in SWRO intakes	• Australia
• Improve procedures for selecting appropriate intake and outfall systems based on the site conditions and development of new intake and out-fall systems	• MEDRC
Pretreatment and Anti-Fouling Technologies	
• Determine optimal use of chemicals	• Australia
• Identify and research specific issues for pre-treatment in rural and remote areas relating to seasonal and location variability in feedwater composition	• Australia
• Improve anti-fouling technologies and membranes and oxidant resistant membranes	• Australia
• Improve pretreatment methods and scale and fouling fundamentals	• MEDRC
Energy Efficient Technologies	
• Evaluate preheating using waste heat or renewable energy and the use of lower-pressure membranes	• Australia
• Investigate direct use of renewable energy via kinetic, electrical, or thermal means	• Australia
• Couple water production with renewable energy	• Australia
• Develop solar ponds for energy and concentrate management	• Egypt
• Develop solar poly vinyl-reverse osmosis (PV- RO) systems	• Egypt
• Develop energy recovery in RO processes	• MEDRC
• Reduce energy consumption and the use of cheap alternative energy sources	• MEDRC
• Expand the application of renewable energy sources for desalination	• MEDRC
• Support research into and the development of more energy efficient desalination technologies	• South Africa
Treatment Improvements	
• Improve membrane materials to reduce operating pressure while maintaining or increasing flux rates and maintaining ion rejection	• Australia
• Optimize contaminant removal without the need for second-pass RO	• Australia
• Optimize operations of RO desalting for plant simplification	• Australia
• Develop novel technologies, including those for direct agricultural and industrial use	• Australia
• Develop low-maintenance, reliable evaporative technologies using waste heat or renewable energy	• Australia
• Pilot real-world situations and breakthrough near commercial desalination technology	• Australia
• Design reliable, robust small-scale systems	• Australia
• Design and manufacture of solar stills	• Egypt
• Apply reflection reduction solution to the glass of solar desalination units	• Egypt
• Manufacture of stand-alone small desalination units (1.0 - 20 m3/day)	• Egypt
• Develop an integrated complex for the production of water (solar stills), electricity (wind, solar, bio mass), food (greenhouses self-sufficient of irrigating water, rabbit, sheep and birds breeding), and salts (chemical salts, artemia & fish nutrients)	• Egypt
• Provide continuous improvement in material enhancement for solar desalination unit	• Egypt

Priority Desalination Research Areas	Country/International Organization
Treatment Improvements (continued)	
• Enhanced evaporation through multistage condensation evaporation cycle	• Egypt
• Study the biology of salty water, including understanding environmental impacts, using bacteria for beneficial treatment	• Egypt
• Develop ionization of salty water for irrigation	• Egypt
• Develop performance improvements for thermal desalination processes	• MEDRC
• Develop new membranes, membrane module and process design, and process and ancillary equipment design	• MEDRC
• Develop new concepts for non-traditional desalination and those that have not been fully explored	• MEDRC
• Improve operation, efficiency, and reliability of the many conventional desalination plants now in operation	• MEDRC
• Improve desalination processes for reducing and/or disposing of effluents and include the assessment of the composition of desalination plant effluents	• MEDRC
• Develop hybrid desalination processes for reduction in capital, operation and maintenance costs	• MEDRC
• Identify treatment for acid mine drainage and other saline mine waters	• South Africa
• Develop treatment for mining and industrial process effluents	• South Africa
Brine Disposal Alternatives	
• Develop novel zero liquid discharge processes	• Australia
• Minimize/optimize produced waste based on value added and beneficial use	• Australia
• Develop new materials for lower-cost corrosion management	• Australia
• Explore extraction of desalted water at source or concentrate injection	• Australia
• Utilize energy efficiency in concentrate management, such as: waste heat, energy recovery, co-siting, and evaporator technologies.	• Australia
• Develop solar ponds for energy and concentrate management	• Egypt
• Improve secondary treatment of brine for salt production	• Egypt
• Investigate the technical and environmental feasibility of desalination and provide guidelines for the establishment of saline surface pans or lakes as regional facilities for brine disposal	• South Africa
• Investigate the technical and financial feasibility of recovering useful and saleable products from desalination waste streams	• South Africa
Distribution System Integration	
• Optimize water stabilization and water health for integration with existing infrastructure	• Australia
Institutional and Regulatory Concerns	
• Identify appropriate disposal or reuse of spent membrane cartridges	• Australia
• Develop public perception analysis and improvement through education and communication	• Australia
• Identify policy developments to better understand energy-water interdependence	• Australia
• Develop a centralized understanding of national desalination deployment, performance, and lessons learnt	• Australia
• Develop a detailed understanding of the salinity and toxin tolerance of marine species in the vicinity of SWRO outflows	• Australia
• Develop, sustain, and support Alexandria Desalination Academy – ADA - the first elearning institute in both Arabic & English languages	• Egypt
• Develop procedures for assessment of environmental impact of desalination plant effluents	• MEDRC

Priority Desalination Research Areas	Country/International Organization
Institutional and Regulatory Concerns (continued) • Promote the development and use of appropriate codes of practice and standards in materials, systems, operation and maintenance	• MEDRC
Monitoring Improvements • Improve real-time monitoring and classification of potential foulants	• Australia
Cost/Benefit Analysis • Develop a total life cycle analysis and sustainability assessment of desalination against other water sources	• Australia
Miscellaneous Topics • Characterize groundwater and seawater sources and map those to best fit desalination technologies	• Australia

Conclusion

Significant overlap exists across the desalination-related research and implementation priorities identified through this literature review. The priorities summarized in Tables 1-3 are divided into ten general areas: intake improvements, pretreatment and anti-fouling technologies, energy efficient technologies, treatment improvements, brine disposal alternatives, distribution system integration, institutional and regulatory concerns, monitoring improvements, cost/benefit analyses, and miscellaneous topics. Key similarities and differences between organizational levels both nationally and internationally are identified in this section within these ten general areas.

Energy efficient technologies, brine disposal alternatives, and institutional and regulatory concerns appear more significant to states than other general areas based on the number of desalination-related research and implementation priorities identified. Although geographic location does not appear to affect the overlap among priorities across states, it is clear that whether states have inland or coastal desalination opportunities defines similarities more than eastern or western regions and climate. States appear more concerned with institutional and regulatory issues than national-level organizations and institutions due to their role in approval processes. Many similarities are also present among the states in their conscientious goals of protecting the environment.

National-level organizations and institutions appear to prioritize technology development as the most important research need based on this literature review. Many similarities exist across organizations and institutions, particularly across organizations and institutions that co-sponsor or co-develop publications. Overall, desalination goals at the national level are more diverse than those detailed by the states within the ten general areas.

Country/international organizations, although only four were identified, appear to prioritize development of energy efficient technologies, treatment improvements, brine disposal alternatives, and public education and perception related institutional and regulatory concerns. Egypt's and South Africa's priorities are focused exclusively on these four areas. MEDRC prioritized these four areas, as well as intake improvements. Australia's priorities are very comprehensive and align more closely with the national-level organizations and institutions.

This effort was constrained by limited time and resources, so the results are by no means comprehensive. More extensive searches could be completed for each entity identified and unidentified in this report. More extensive searches could provide more compelling priorities and also identify additional collaborators for desalination-related research and implementation.

Appendix A: State Research Priorities Summaries

Table A-1: List of state desalination-related papers and websites that were identified and included in this literature review.

Entity:		Reference
State	**Entity:**	**Reference**
	Arizona	• Salinity Management and Desalination Technology for Brackish Water Resources in the Arid West (2007) • Desalination in Arizona – a growing component of the state's future water supply portfolio (2011) • Information found on the http://www.cap-az.com/ website (2014)
	California	• Seawater Desalination: Opportunities and Challenges (2003) • Desalination, with a Grain of Salt: a California Perspective (2006) • An Ecological-Economic Research Program for Desalination (2011) • Direct Potable Reuse: A Path Forward (2011) • 2014 Water Desalination Proposal Solicitation
	Florida	• Desalination in Florida: Technology, Implementation, and Environmental Issues (2010)
	Nevada	• Information found on the http://www.snwa.com/ website (2014)
	Texas	• Desalination Research at Texas Universities —A Brief Overview (2004) • 2012 Biennial Report on Seawater Desalination
	Utah	• The Water-Energy Nexus in Utah (2012)
	Virginia	• The Feasibility of Using Desalination to Supplement Drinking Water Supplies in Eastern Virginia (2004)

Publication Title: Salinity Management and Desalination Technology for Brackish Water Resources in the Arid West (2007)

Organization: Arizona Water Institute (AWI) and Bureau of Reclamation

Summary:
Each year the Central Arizona Project (CAP) and the Salt River Project "import" over 1,000,000 tons of salt along with the water supplied from the Colorado and Salt-Verde River systems. Arizonans use up the critical water resource but the salt remains and builds up salinity in the area's aquifers and reclaimed water resources. Yet salt-affected waters are needed to achieve a sustainable water supply for drinking and other uses. The only viable solution to removing the salt is desalination, but the cost of both treatment and residuals management is high. AWI invited experts to develop a roadmap for applied research on these problems leading to sustainable use of saline water resources.

- Evaluate implementation and cost of various pre-treatment strategies to allow greater RO water recovery before the onset of scaling. These strategies should specifically utilize waters from or representative of the CAP canal water, Salt River water, or other Arizona source waters with average TDS greater than 600 ppm. The pre-treatment strategies of immediate interest are:
    - Ion exchange
    - Nanofiltration softening (with and without microfiltration particle removal)
    - Chemical softening
    - Combined and hybrid versions of these approaches
- Pursue development of selective precipitation as a means for beneficial product recovery from the brine residuals particular to Arizona waters that are likely to be subject to RO treatment
- Undertake a preliminary feasibility, impact and cost study of the potential for development of a salt marsh in the Gila River channel south of Phoenix
- Evaluate the relative efficacies of the various commercially available anti-scalants and identify a standard testing protocol by which these and future products in the market can be comparatively rated
- Evaluate, at the scoping level, the potential for use of the Sacaton Pit and other regionalscale options for waste brine disposal
- Evaluate the efficiency, shortcomings and energy costs associated with direct implementation of VSEP™ technology for increasing water recovery from an RO process applied in typical inland, arid west conditions.
- Investigate feasible strategies for and means of encouraging centralized ion exchange media regeneration (vis-à-vis in-home regenerative water softeners) to minimize water consumption and brine disposal impacts.
- Investigate regulatory and economic means to discourage the use of in-home regenerative water softeners.

- Develop the capability for case specific, systems-level evaluation of complete process schemes for desalination and brine management, including development of the necessary modeling tools and metrics.
- Develop and/or identify halophytes with commercial value that can be grown in lined facilities irrigated with RO brines.

The following projects are recommended to address long-term desalination challenges and provide potentially large, yet longer horizon, payback on investment.

- Establish a program by which new membranes, membrane treatment related products, and alternative desalination technologies are independently and comparatively tested under the conditions and constraints relevant to the arid west desalination situation.
- Establish a combined basic and applied research program to improve the efficiency and decrease the cost of capacitive deionization.
- Assess future waste loads and waste stream through analysis of long-term growth patterns, degree of incorporation of reuse in new development and sub-divisions, and household- level water harvesting that will affect wastewater volumes, and thereby, wastewater salinities.
- If the results of the short-term scoping study recommended above are positive, undertake detailed cost and feasibilities studies of using the Sacaton Pit and/or a Gila River Salt Marsh as brine disposal options.
- Conduct combined basic and applied research on the potential for incorporating novel membrane functionalities, such as electromagnetic membranes, biomimetic membranes, and ion-specific electrodialysis membranes
- If appropriate circumstances arise where brine generation occurs proximate to a waste or cheap heat source (e.g., power plant cooling water stream), refine and retest the DewVaporation technology based on the findings of the study done by the City of Phoenix and U.S. Bureau of Reclamation.

Publication Title: Desalination in Arizona – a growing component of the state's future water supply portfolio (2011)

Organization: The University of Arizona

Summary:

- **Efficiency Losses:** Each approach to desalination has specific challenges, generally related to scaling or fouling of operating parts and the resulting reduction in efficiency. Fouling is caused by organic constituents in the feed water, while scaling is caused by inorganic constituents. Because RO technology has been favored in the United States for desalination, research has focused on ways to reduce membrane fouling and thereby increase efficiency. Feed water pretreatment and coupling of RO systems to ion exchange processes or nanofiltration are some of the ways researchers are attempting to reduce RO membrane fouling. Other approaches include membrane improvements and mechanical or chemical ways to inhibit scaling.
- **Brine or 'Concentrate' Management:** Brine management continues to be the single largest challenge facing engineers, regardless of how desalination is approached. According to the journal Desalination, there simply are no cost-effective solutions to concentrate management for inland desalination plants. Nationally, the most common method of concentrate management has been discharge into surface waters. Sewer discharge is the next most common method, followed by deep well injection. Evaporation, reuse and land discharge together are employed for only about 15 percent of the concentrate produced nationally.
- **Regulatory Issues:** Utilities planning to construct and operate a desalination plant must first obtain permits from the State and often from local county or municipal government agencies.
- **Desalination Costs:** Building a desalination facility is a major undertaking that requires huge capital inputs and years of planning and construction before ribbon-cutting. The source of the water, distribution system needs, concentrate discharge options, and an electrical supply are important considerations when selecting a plant location and design. Identifying the desired end use for the product water is necessary as well. A fundamental question to ask is what is the target quality of the output given the quality of the input water?
- **Energy Use:** Energy requirements for desalination are large. Reliance upon fossil fuel powered plants creates additional disincentives to build desalting plants.

Website: Central Arizona Project (website, 2014)

Organizations: Central Arizona Project

Summary:
Central Arizona Project (CAP) has been investing in desalination, essentially removing salts from water, research for the past decade in its efforts to meeting the state's growing water needs. This is one strategy in CAP's water augmentation program aimed at boosting water supplies to meet future water needs in Arizona.

CAP's desalination research focuses on brackish (briny) groundwater desalination within Arizona and seawater desalination as part of projects in Mexico and California. In cooperation with the Bureau of Reclamation, Metropolitan Water District of Southern California (MWD) and Southern Nevada Water Authority, CAP has been piloting operations at the Yuma Desalting Plant. There, the research partners are evaluating optimal treatment technologies to improve efficiency—essentially, getting the most water using the least amount of energy and chemicals, for the lowest price. The results of these studies are guiding discussions on ways to conserve more than 100,000 acre feet a year from unused agricultural drainage in the Yuma area.

Regarding seawater desalination, CAP has participated by studying plants in Mexico, in the Rosarito area of Baja, California, as well as evaluating options for projects from the Sea of Cortez in Sonora. These binational projects have the potential to generate new water supplies for CAP via exchange for existing Colorado River uses. Currently CAP is participating as part of the Minute 319 project. CAP is also developing a scope of work in cooperation with Mexico, as part of the implementation of Minute 319, to study desalination and reuse options for new water exchanges in the Sea Cortez and Mexicali Valley region of Mexico.

And finally, CAP is also conducting a study in cooperation with MWD on opportunities to develop new water supplies via exchange with MWD from reuse and desalination in southern California. This study will consider costs, constraints and opportunities; and is slated to be completed in the spring of 2014. The effort is part of the "next steps" portion of the Colorado River Basin Water Supply & Demand Study released in late 2012, which projected a future long-term imbalance between existing water supplies and new water needs in the Colorado River system.

Publication Title: Seawater Desalination: Opportunities and Challenges (2003)

Organization: National Water Research Institute (NWRI) in Cooperation with Metropolitan Water District of Southern California and Member Agencies

Summary:
The workshop was based on the Nominal Group Technique (NGT), which was developed by Andre Delbecq, Ph.D., at the University of Santa Clara. Since 1992, NWRI has used the NGT format as a process for identifying, prioritizing, and developing approaches to address critical local, state, and national water issues. The NGT process is rigorous and robust, and its protocol provides a controlled environment that allows every voice to be heard regardless of perspective. The ability of the workshop participants to focus on a single question allowed for the maximum use of time and energy. The participants attending were invited because of their expertise and credibility in their respective fields.

Priority 1	Regulatory Permitting Issues Associated with Seawater Desalination
Priority 2	Concentrate Issues and Options Analyses
Priority 3	Regional Planning: When Do You Build a Desalination Plant As a Supply Source?
Priority 4	Public Information and Outreach of Seawater Desalination
Priority 5	Push the Boundaries: Evaluate New and Alternate Integrated Technologies for Optimizing Seawater Desalination Plant Design and Operating Concepts
Priority 6	Policy on Public and Private Roles and Development of a New Project Delivery Process to Minimize Costs and Maximize Performance
Priority 7	Source-Water Issues and Options Analysis
Priority 8	Desalination in the Context of State Water Planning
Priority 9	Work with Ratepayers to Find Particular Seawater Desalination Projects They Perceive As Reasonable to Fund, If Any
Priority 10	Providing Funding for Seawater Desalination Plants
Priority 11	Total Cost of Seawater Desalination Includes a Relatively Large Number of Minor Cost Components That Must Be Identified, Optimized, and Controlled
Priority 12	Understand the Relationship between Finished-Water Quality Specifications and Plant Design/Costs
Priority 13	What Should Be the Federal Role in Desalination?
Priority 14	Rapid Improvement in Technology Will Potentially Result in Significant Savings for a Seawater Desalination Project
Priority 15	New Water Projects: Same questions, Good Answers—Perhaps
Priority 16	Scaling Pilot Testing to Full-Scale Desalination Plant Design and

Publication Title: Desalination, with a Grain of Salt: a California Perspective (2006)

Organizations: Pacific Institute for Studies in Development, Environment, and Security

Summary:
In this report, the Pacific Institute provides a comprehensive overview of the history, benefits, and risks of ocean desalination, and the barriers that hinder more widespread use of this technology, especially in the context of recent proposals for a massive increase in desalination development in California. Although a majority of the conclusions and recommendations were institutional for immediate implementation, several items were identified for additional research as listed below:

- More energy is required to produce water from desalination than from any other water-supply or demand-management option in California. The future cost of desalinated water will be more sensitive to changes in energy prices than will other sources of water.
    - Project proponents should estimate and publicly disclose the full energy requirements of each proposed project and provide details of energy contracts.
    - Project proponents should explicitly evaluate energy price risk, including year-to-year variation and trends over time, in the revenue requirement of water utilities that invest in or purchase water from ocean desalination.
- More research is needed to fill gaps in our understanding, but the technological state of desalination is sufficiently mature and commercial to require the private sector to bear most additional research costs.
    - Public research funds should be restricted to analyzing the public aspects of desalination projects, including environmental impacts, mitigation, and protection.
- Desalination can produce water that is corrosive and damaging to water distribution systems.
    - Additional research is needed to determine the impacts of desalinated product water on the distribution system.
    - Water-service providers must ensure that distribution systems are not adversely affected.
- Co-location of desalination facilities at existing power plants offers both economic and environmental advantages and disadvantages. Additional research is needed to determine whether there are synergistic effects caused by combining desalination's high salinity discharge with the high temperatures and dead biomass in power plant discharge.

Publication Title: An Ecological-Economic Research Program for Desalination (2011)

Organization: Brent M. Haddad, PhD - University of California, Center for Integrated Water Research

Summary:
The research topics proposed in this document are intended to address how desalination technology can be better integrated into existing urban water systems. Progress has already been made on every question posed here so it is a question of building on existing research foundations. Building a better understanding of the ecological-economic impacts of will help regions understand better the impacts they can expect by pursuing desalination technology, providing a clearer and stronger framework for public review, and hopefully speeding up the process of project review so that regions can undertake approved projects or move on from rejected projects without the wasteful multi-year interlude of rancorous review that is too often the fate of such proposals. This research agenda takes one well beyond the purview of water agencies to the realm of coordinated ocean policy involving state and federal legislative and regulatory bodies and the myriad public and private parties engaged in ocean policy. Among the questions to be asked in this agenda are:

- What other uses of the coastal ocean have similar impacts to desalination?
- What is the scale and location of those impacts?
- What are the costs and benefits of those uses and how do the costs and benefits compare to increased desalination?
- Who controls whether and how many other impacts occur?
- How would one scale back on those impacts?
- How does one institutionally generate a trade-off that decreases the impacts of other activities so that desalination can increase without ocean impacts?

The second has to do with whether the use of desalination can introduce changes to coastal management that will improve the health of the ocean more than the desalination process degrades it. The issue of energy sustainability can also be folded into this approach through a combination of:

- minimizing energy consumption through investment in energy-efficient pumps and other equipment;
- purchasing renewable energy credits that offset the greenhouse gas loading of the electricity consumed by the facility; and
- investing in greenhouse gas-reducing projects, from new renewable energy projects to carbon storage projects.

Publication Title: Direct Potable Reuse: A Path Forward (2011)

Organization: WateReuse Research Foundation and WateReuse California

Summary:
In light of the interest in DPR, the purpose of this report is to provide a general overview current knowledge related to DPR and to identify the information that must develop through targeted studies to inform the public, public and private water agencies, and regulatory agencies regarding the feasibility of implementing DPR as viable water supply management option. Although the background information on DPR and the needed research identified in this report are applicable across the country and throughout the world, the primary focus is on providing information as that the feasibility of DPR can be evaluated in California.

The specific research topics are:

1. Design considerations for sizing of engineered storage buffer;
2. Impacts of treatment train and process operation modifications to enhance the performance and reliability of secondary, tertiary, and advanced treatment systems;
3. Evaluation of blending requirements for purified water;
4. Enhanced monitoring techniques and methods for DPR;
5. Equivalent advanced treatment trains and processes for DPR;
6. Develop standard terminology, messaging, and communication resources for planning and implementation of DPR; and
7. Effect of prior knowledge on acceptance of planned potable reuse in California.

Publication Title: 2014 Water Desalination Proposal Solicitation

Organization: State of California Department of Water Resources

Summary:
Research projects are projects intended to advance the knowledge base of desalination technology, related infrastructure, and by-products treatment and disposal. For the purpose of this PSP, research projects will be restricted to developing information that will address regulatory permitting issues for desalination projects. The research should fulfill data or information needs by regulatory agencies in establishing standards, regulations, policies, or guidelines. Research projects can serve specific project needs but cannot be for the sole purpose of assessing a specific project. Applications must include documentation from a regulatory agency on how the proposed research will fulfill an identified need. Funded research projects will be expected to interface with third-party advisory committees as established by DWR. Research topics of potential regulatory significance may include, but are not limited to:

1. Feedwater intake technology and impacts
2. Feedwater treatment processes and strategies
3. Brine/concentrate management and disposal
4. Studies of mixing zone turbulence entrainment
5. Protocols for sampling, testing, analysis, and monitoring
6. Other applied investigations to refine or advance desalination technology affecting regulatory parameters
7. Renewable power coupling to the desalination treatment process (e.g., wave energy)

Publication Title: Desalination in Florida: Technology, Implementation, and Environmental Issues (2010)

Organization: Florida Department of Environmental Protection, Division of Water Resource Management

Summary:
This report was prepared in response to the interest in the development of alternative water supplies and specifically desalination in Florida. It is an assessment of current technologies and its application in the state. Recommendations are provided to effectively implement environmentally and fiscally sound desalination technologies that will hopefully help meet current and long-term potable water supply demands of the state's growing population. The report conclusions are provided below.

- Thermal Distillation, while a dominant technology in the world, is a minor component of the U.S. desalination and non-existent in Florida. The primary reason is energy needs compared to other technologies. Reverse Osmosis is by far the dominant technology used in the state. This may change as technology provides new options.
- The 2005 Legislature created the Water Protection and Sustainability Program to encourage and partially fund the development of alternative water supplies to meet the future potable water needs of the state. In the first three years of the program (2005-2008), the program provided funding assistance for the construction of 344 projects. Of these, brackish water desalination projects are expected to provide 234 million gallons of potable water per day. Continued funding of the program would provide additional incentive for the development of alternative water supplies in Florida, including desalination.
- The costs associated with desalination can vary greatly depending on the source water, typically increasing in cost when moving from the use of brackish groundwater to open seawater. However, the costs for environmentally safe disposal at some locations may offset the cost savings of using of lower-salinity source water. Co-location at steam electric power plants or large municipal wastewater treatment plants can reduce the energy, capital and operational costs.
- Use of new technology (nanotechnology, energy efficient pumps, alternative energy sources, use of 'waste heat') should continue to reduce the costs to operate and maintain desalination processes like membrane filtration and, equally important, reduce the carbon footprint.
- Technology transfer is vital for government agencies and utilities in Florida. Partnering with existing desalination organizations, such as the American Membrane Technology Association (AMTA), Affordable Desalination Collaboration (ADC), WaterReuse Foundation, and International Desalination Association (IDA), is needed to remain abreast of innovative technologies and to exchange 'lessons learned'.
- Similar to technology transfer, an exchange of information is needed on environmental issues associated with desalination. This information would help to minimize the potential risks associated with development of new desalination facilities.

Website: Southern Nevada Water Authority (website, 2014)

Organizations: Southern Nevada Water Authority

Summary:

Advanced Wastewater Treatment Processes:
Along with six other agencies, SNWA researchers are exploring advanced wastewater treatment processes such as high-pressure membrane filtration and advanced oxidation to address trace organic contaminants persisting through conventional treatment processes.

Membrane Fouling Reduction:
Aimed at decreasing membrane fouling, a significant obstacle in desalination as well as water purification and reuse processes, this pilot-scale project also will explore ways to reduce associated energy consumption and operational costs.

Publication Title: Desalination Research at Texas Universities —A Brief Overview (2004)

Organization: Texas Water Development Board. The fourth chapter contains an inventory of desalination-related research at Texas universities, including leading researchers' contact information.

Summary:

In order to meet the water needs of Texas, the following principles should be incorporated into an action plan:

- State and local agencies must work together with universities to obtain federal funds for research and development,
- Local, regional, state, and federal agencies must work together to help communities evaluate opportunities to meet pending water shortages through the use of desalination and other non-conventional methods (i.e., water conservation, wastewater reuse, rainfall harvesting, brush control to improve streamflows, and water marketing).
- Under the continued leadership of TWDB, universities, agencies, and communities should continue to meet together to discuss strategies to meet water challenges.

In addition, the following high priority technical issues must be addressed through research, outreach, and education:

- Perfecting pretreatment and anti-fouling technologies,
- Developing new membrane materials that work efficiently at high temperatures,
- Recovering energy from reverse osmosis processes used for desalination,
- Perfecting promising low-energy technologies (i.e., capacitive deionization) and alternative energy sources (i.e., wind and solar),
- Injecting reject waters into depleted oil and gas fields,
- Evaluating the effects of the operation of desalination plants on the environment,
- Teaching water resources managers about best management practices.

With leadership from TWDB and other state and federal agencies, Texas universities can make a significant contribution to desalination technologies and management systems. The greatest potential lies in developing a coordinated network of university researchers and agency specialists to quickly and effectively mobilize needed research and development in support of communities throughout Texas.

Publication Title: 2012 Biennial Report on Seawater Desalination

Organization: Texas Water Development Board

Summary:
Seawater desalination projects are notably driven by site-specific conditions. In regions where there is a lack of experience or precedent, such as the case in the Texas Gulf Coast, there is a need for studies to fill gaps in our knowledge concerning potential environmental effects and projected performance of desalination facilities. A TWDB-funded study of regulatory issues undertaken by the Brownsville Public Utilities Board (Brownsville Public Utilities Board, 2011) identified a list of research needs specific to Texas, including the following topics named in the 2010 Biennial Report, that remain relevant today:

1. Characterizing benthic fauna in areas that will be affected by concentrate discharges
2. Determining the salinity tolerance of key aquatic species along the Texas Gulf Coast which may potentially be affected by desalination concentrate discharges
3. Modeling currents and tides to determine impact on concentrate dispersion
4. Improving thin-layer mixing models as part of far-field plume modeling
5. Integrating desalinated seawater into existing drinking water distribution networks
6. Revising regulatory bacteria and virus removal credits for reverse-osmosis membranes

Publication Title: The Water-Energy Nexus in Utah (2012)

Organizations: Utah Division of Water Resources

Summary:

Similarly, energy has not often been considered of primary importance, or viewed simply as an operations and maintenance cost, when considering new water projects. Without planning for the energy-intensity of water over a longer time horizon, it could quickly become a more expensive resource. As an example, research conducted by Stokes et al. analyzed different energy and greenhouse gas impacts of meeting California's water demand in 2030 using different sources – from minimally energy intensive recycled water, to highly energy intensive desalination[1]. Their conclusions suggested that if California tried to meet their future water demand strictly with more energy-intensive options, the proportion of their energy budget devoted to water supply would rise from 19 percent (as it currently stands) to approximately 52 percent by 2030 – over half of the state's energy use consumed just by the water sector. They suggested a more palatable alternative would be the increased use of recycled and brackish water. This strategy would limit energy increases to only 22 percent of the state's energy budget, a substantially less energy-intensive path for meeting future water demand.

To this end, Utah policy makers and water and energy planners should look for ways to manage the two together or jointly to optimize their full potential. The development of a statewide plan for water/energy resource planning may assist local and regional shareholders with a framework for coordination. Likewise, convening broad-based stakeholder meetings amongst local water and utility managers, state, federal, academic and other interested agencies could facilitate greater integration. Such meetings would further inform water and energy managers of what challenges lie ahead in terms of availability, meeting future demand and mitigating possible climate impacts. At the same time Utah water managers could convey to their academic and research counterparts what their needs are in terms of basic data gathering and models that would benefit both day-to-day and long-horizon water and energy plant operation[2].

[1] Stokes, J., Horvath, A. (2009). "Energy and Air Emission Effects of Water Supply." Environmental Science & Technology, 43(8), 2680-2687.
[2] Western Governor's Association, (2006). "Water Needs and Strategies for a Sustainable Future." Denver, Co.

Publication Title: The Feasibility of Using Desalination to Supplement Drinking Water Supplies in Eastern Virginia (2004)

Organization: Virginia Water Resources Research Center

Summary:
Technologies are available for desalination of brackish and seawater. These technologies are implemented worldwide, and further research and development of more cost-effective desalination technologies are underway. Advanced brackish water desalination technologies are already implemented in the Hampton Roads area with acceptable cost to the public. Therefore, technology is not a factor in implementing desalination in eastern Virginia. However, there are issues related to availability of water sources, institutional needs, and ecosystem impacts that need to be addressed.

Water Source Inventory Need

At present a comprehensive and reliable database of surface and groundwater resources in eastern Virginia is not available. A better inventory of surface and groundwater resources is needed for optimal site selection of desalination plants.

- Legislative guidance and state government leadership is needed to develop a comprehensive database of available water resources in eastern Virginia to be followed by a viable regional water supply and allocation plan based on the scientific evaluation of existing water resources and the potential for developing impure water sources such as saline water.

Institutional Needs

There is a significant need for regional collaboration for successful implementation of desalination and to meet future water demand.

- Legislative guidance is needed to form a regional utility task force that will coordinate activities of numerous utilities in the region and to develop a strategic plan for future use of large-scale desalination technologies in eastern Virginia. The task force should determine where the needs are and identify potential sites to locate desalination facilities.
- Legislative guidance is needed to form an inter-governmental task force that will coordinate and expedite permit reviews between various federal and state agencies for the implementation of future desalination plants.
- Energy costs are a major factor in the production cost for desalination plants, particularly when using high salinity waters such as tidal and seawater. There is a need to develop a mechanism for enhanced cooperation between water utilities and power companies to make existing and future desalination plants more cost-competitive.

Research Needs for Ecosystem Management

Less is known about various effects of desalination plants on receiving waters and coastal ecosystems. Research is needed to provide science-based information that can facilitate science-based permitting and developing regulatory guidelines.

Legislative action is needed to provide funds that can support research for developing environmentally sound desalination practices. Research is needed to address ecosystem impacts such as effects of water withdrawal, water intake structure and brine disposal;

and cost effectiveness of various brine disposal and management technologies, such as Zero Liquid Discharge and brine reuse potential.

Appendix B: National Research Priorities Summaries

Table B-1: List of national desalination-related papers that were identified and included in this literature review.

Entity:		Reference
National	EPA	• National Water Program Research Strategy 2009 – 2014 (2009) • Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management (2013)
	NRC	• Desalination: A National Perspective (2008) • Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater (2012)
	NWRI	• Desalination Research & Development Workshop Report (2001)
	Reclamation	• Desalination and Water Purification Research and Development Program – Report to Congress (2001) • Desalination and Water Purification Research and Development (DWPR) Pre-Proposal Solicitation for Fiscal Year 2014
	Reclamation/ Sandia	• Desalination and Water Purification Technology Roadmap – A Report to the Executive Committee (2003)
	Sandia	• Inland Desalination: Challenges and Research Needs (2005)
	Sandia/ WRF/ WRRF	• Implementation of the National Desalination and Water Purification Technology Roadmap: Structuring and Directing the Development of Water Supply Solutions (2010)
	WGA	• Water Needs and Strategies for a Sustainable Future: Next Steps (2008)
	WRRF/ WRF/ Reclamation	• Desal Dialog: A Regulatory Workshop on Critical Issues of Desalination Permitting (2013)

Publication Title: National Water Program Research Strategy 2009 – 2014 (2009)

Organization: U.S. Environmental Protection Agency, Office of Water

Summary:
The National Water Program Research Strategy was developed to more completely define the Water Program's research needs, organize them around EPA's Strategic Goals and Sub-objectives, and communicate them to potential research partners.

The Water Executive Committee for Research discussed a variety of approaches to organize, prioritize, and present research needs to potential collaborators. The approaches (including the selected themes and tiers approach, budget percentages, immediacy, etc.) were all examined for how well each would communicate to the target audiences. The group also discussed the common research priority themes found in the Administrator's recent budget testimony, the EPA Science Advisor's research priorities, the 2009-2014 Draft Agency Strategic Plan, and the OW's process of categorizing research activities into defined bins. The agreed to priority Themes are (in no priority order): healthy watersheds and coastal waters research needs, safe drinking water research needs, sustainable water infrastructure research needs, and water security research needs.

To organize the research needs within each theme and communicate them more clearly to collaborators, the specific research needs identified in the 2008 Compendium were grouped within one of five technical tool areas:

- aquatic life health effects
- human health effects
- method development
- occurrence and exposure
- treatment technologies and effectiveness

Finally, the research needs within each technical tool area were sorted into three tiers to communicate the relevant driver and urgency:

- Tier 1 - On critical path to satisfy a statutory, regulatory, court ordered, or Agency/Office strategic obligation
- Tier 2 – Supports, augments, or improves existing and adequate tools, guidance, or policy, or would enhance new critical path research products
- Tier 3 - Investigates potential environmental concerns of the future, or takes advantage of a serendipitous opportunity to leverage resources or an initiative

Publication Title: Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management (2013)

Organization: U.S. Environmental Protection Agency (prepared under contract by Tetra Tech, Inc.)

Summary:

Science and research are critical to advancing EPA's mission to protect human health and the environment. This chapter (7) focuses on the relevant research needs in the areas of specific technologies that may have a significant impact on wastewater treatment and wet weather flow management, such as achieving higher levels of pollutant removal while minimizing operation and maintenance costs of the treatment system, thereby improving the contributions of the industry to sustainability.

The application of new concepts and technologies to enhance the long-term sustainability of wastewater management can be expedited by promoting research needed to develop and demonstrate these concepts and technologies.

Research and technical issues are grouped into the following areas:

- Upgrading older WWTPs
- Nutrient removal and recovery
- Removal of other contaminants
- Security of water systems
- Energy conservation and renewable energy sources
- Wastewater and solids treatment optimization

Publication Title: Desalination: A National Perspective (2008)

Organization: Committee on Advancing Desalination Technology; National Research Council of the National Academies (partially funded by Reclamation)

Summary:
Long-term research goals are outlined for advancing desalination technology and improving the ability of desalination to address U.S. water supply needs. A strategic national research agenda is then presented to address these goals. This research agenda is broadly conceived and includes research that could be appropriately funded and conducted in either the public or private sectors.

The committee identified research topics as part of a strategic agenda to address the two long-term research goals articulated earlier. This agenda is driven by determination of what is necessary to make desalination a competitive option among other water supply alternatives.

- Goal 1: Understand the environmental impacts of desalination and develop approaches to minimize these impacts relative to other water supply alternatives
  - Assess environmental impacts of desalination intake and concentrate management approaches
  - Develop improved intake methods at coastal facilities to minimize impingement of larger organisms and entrainment of smaller ones
  - Assess the quantity and distribution of brackish water resources nationwide
  - Analyze the human health impacts of boron to expedite water-quality guidance for desalination process design
- Goal 2: Develop approaches to lower the financial costs of desalination so that it is an attractive option relative to other alternatives in locations where traditional sources of water are inadequate
  - Improve pretreatment for membrane desalination
  - Improve membrane system performance
  - Improve existing desalination approaches to reduce primary energy use
  - Develop novel approaches or processes to desalinate water in a way that reduces primary energy use
- Goal 1 and 2 Crosscuts
  - Develop cost-effective approaches for concentrate management that minimize potential environmental impacts

All of the topics identified are considered important, although three topics were deemed to be the highest priority research topics: (1) assessing the environmental impacts of desalination intake and concentrate management approaches, (2) developing improved intake methods to minimize impingement and entrainment, and (3) developing cost effective approaches for concentrate management that minimize environmental impacts. These three research areas are considered the highest priorities because this research can help address the largest barriers (or showstoppers) to more widespread use of desalination in the United States.

Publication Title: Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater (2012)

Organization: Committee on the Assessment of Water Reuse as an Approach to Meeting Future Water Supply Needs; National Research Council of the National Academies (partially funded by Reclamation)

Summary:
In the committee's review of a wide range of issues affecting the application of nonpotable and potable reuse, the committee did not identify any technological hurdles that were holding back the application of reuse to address local water supply needs. In fact, in its review of water reclamation technologies, the committee found the state of technology to be quite advanced, with room for improvements but no major limitations to their use. However, additional research could enhance the performance and quality assurance of existing processes and help address public concerns over the safety of reuse to human health and the environment.

A total of 14 priority research areas were developed within two broad categories:

- Health, Social, and Environmental Issues
  - Quantify the extent of de factor (or unplanned) potable reuse in the United States
  - Address critical gaps in the understanding of health impacts of human exposure to constituents in reclaimed water
  - Enhance methods for assessing the human health effects of chemical mixtures and unknowns
  - Strengthen waterborne disease surveillance, investigation methods, governmental response infrastructure, and epidemiological research tools and capacity
  - Assess the potential impacts of environmental applications of reclaimed water in sensitive ecological communities
  - Quantify the nonmonetized costs and benefits of potable and nonpotable water reuse compared with other water supply sources to enhance water management decision making
  - Examine the public acceptability of engineered multiple barriers compared with environmental buffers for potable reuse
- Treatment Efficiency and Quality Assurance
  - Develop a better understanding of contaminant attenuation in environmental buffers
  - Develop a better understanding of the formation of hazardous transformation products during water treatment for reuse and ways to minimize or remove them
  - Develop a better understanding of pathogen removal efficiencies and the variability of performance in various unit processes and multibarrier treatment and develop ways to optimize these processes
  - Quantify the relationships between polymerase chain reaction detections and infectious organisms in samples at intermediate and final stages
  - Develop improved techniques and data to consider hazardous events or system failures in risk assessment of water reuse
  - Identify better indicators and surrogates that can be used to monitor process performance in reuse scenarios and develop online real-time or near real-time monitoring techniques for their measurement

- Analyze the need for new reuse approaches and technology in future water management

Improved coordination among federal and nonfederal entities is important for addressing the long-term research needs related to water reuse. Addressing the research needs will require the involvement of several federal agencies as well as support from nongovernmental research organizations.

Publication Title: Desalination Research & Development Workshop Report (2001)

Organization: National Water Research Institute in cooperation with United States Bureau of Reclamation

Summary:
During this workshop, 27 experts in the field of desalting/desalination science, technology, economics, environment, and public policy considered the question: *What are the highest priority issues that need to be addressed now to speed the installation of cost-effective desalting/desalination facilities?* These experts intially identifed 96 issues, which were then grouped together to form 18 major categories. Each workshop participant then ranked his or her perception of the ten most important major issue areas in decending order of importance. The concensus major issue areas were as follows:

1. Research and development to improve membrane process technology
2. Develop and education and public relations strategy to facilitate the implementation of desalination projects
3. National desalting and water quality improvement act
4. Develop a comprehensive framework to guide the decision-making process for potential desalination users
5. Concentrate and waste management
6. Energy reduction for desalination plants
7. Look outside-the-box for innovative solutions
8. Determine the value of water for different water users
9. Improve the fundamental understanding of membrane science
10. Establish a national advisory panel for developing water purification technologies to increase water supplies

A report was developed by a working group for each of the ten major issue areas selected. These reports included an issue description, rationale, approach, and identified individuals and/or organizations best able to address and resolve each issue.

Publication Title: Desalination and Water Purification Research and Development Program – Report to Congress (2001)

Organization: Bureau of Reclamation

Summary:
This report to Congress fulfills the requirements of P.L. 104-298: Water Desalination Act of 1996: *As soon as practicable and within three years after the date of enactment of this Act, the Secretary shall recommend to Congress desalination demonstration projects or full-scale desalination projects to carry out the purposes of this Act and to further evaluate and implement the results of research and studies conducted under the authority of this section. Recommendations for projects shall be accompanied by reports on the engineering and economic feasibility of proposed projects and their environmental impacts.*

The program's research, studies, and pilot-scale findings strongly indicate the recommended demonstration projects are feasible. While the recommended technologies proved successful so far, they have not been extensively tested in the field.

The recommended demonstration projects are as follows:

- Membrane bioreactors
- Innovative membrane test bed for seawater desalination
- Low cost, small system, desalination using evaporation
- Clathrate desalination

For each recommended demonstration project a description of the technology is provided, along with potential benefits and recommended activities.

Publication Title: Desalination and Water Purification Research and Development (DWPR) Pre-Proposal Solicitation for Fiscal Year 2014

Organization: Bureau of Reclamation

Summary:
The purpose of the DWPR program is to fund research and development projects that will serve to augment the supply of usable water in the United States by developing more environmentally sensitive, cost-effective and technologically efficient means to purify and desalinate water. Through this program, Reclamation forms partnerships with private industry, universities, water utilities, and others to conduct projects which address a broad range of desalting and water purification needs such as reducing costs, improving operation and reliability, and developing innovative materials and processes.

The program has three major goals:

- Augment the supply of usable water in the United States
- Understand the environmental impacts of desalination and develop approaches to minimize these impacts relative to other water supply alternatives
- Develop approaches to lower the financial costs of desalination so that it is an attractive option relative to other alternatives in locations where traditional sources of water are inadequate

The pre-proposal solicitation identifies three research priorities for fiscal year 2014:

- Research and pilot studies conducted at the Brackish Groundwater National Desalination Research Facility
- Developing and testing flexible use systems for treating waters of significantly varying salinities
- Pilot studies treating agricultural return flows containing elevated levels of TDS and selenium to be conducted at the San Luis Demonstration Treatment Plant near Firebaugh, California, within the San Joaquin River Water Quality Implementation Program (SJRIP) reuse area in Panoche Drainage District

Specific tasks have been developed to accomplish the DWPR objectives for Research and Laboratory Studies (Task I, II, III, IV and V). Each task is followed by a list of possible projects falling under that task.

- Task I: Reducing environmental impacts
- Task II: Reducing energy consumption and integrating renewable energy
- Task III: Reducing costs
- Task IV: Expanding scientific understanding of desalination processes
- Task V: Improving the quality and suitability of treated water for reuse
- Task VI: Pilot-scale systems

Publication Title: Desalination and Water Purification Technology Roadmap – A Report to the Executive Committee (2003)

Organizations: Bureau of Reclamation & Sandia National Laboratories

Summary:
The primary technological method of generating additional water supplies is through desalination and enhanced water reuse and recycling technologies. The efficiency of desalination and water purification technologies currently evolves at a rate of approximately four percent per year. Continuing along this path will result in future evolutions of current-generation technologies that continue to produce water that is too expensive for many applications. Thus, the primary goal of the Roadmap is to chart a series of research and development activities that will result in cost-effective, efficient revolutionary desalination and water purification technologies that can meet the nation's future needs. The Roadmap's secondary goal is to establish development activities that will accelerate the rate of improvement of current-generation desalination and water purification technologies, thus allowing these technologies to better meet the near-term needs of the nation.

The Desalination and Water Purification Technologies Roadmap traces the connection between the nation's water supply needs and the future of water desalination science and technology. It defines a research and development path for desalination technologies, beginning today and continuing through the year 2020, that, if implemented, will help find solutions to the nation's water supply needs by advancing the state-of-the-art in desalination and water purification technologies.

The Roadmapping Team identified five Technology Areas where R&D is needed in order to create the next-generation desalination technologies:

- Membrane Technologies (technologies that desalinate and purify water by pushing it through a semi-permeable membrane that removes contaminants),
- Alternative Technologies (technologies that desalinate and purify water that take advantage of non-traditional methods),
- Thermal Technologies (technologies that rely on boiling or freezing water and then capturing the purified water while the contaminants remain behind),
- Concentrate Management Technologies, and
- Reuse/Recycling Technologies (often membrane or alternative technologies that must be designed to handle increased contaminant loads due to their postconsumer application).

The Roadmap identifies a suite of research activities that, in concert with other activities as discussed earlier, can provide technological solutions to the nation's future water needs. However, application of these technologies will not occur in a vacuum – their implementation will be guided by national- and state-level policies and regulations.

Publication Title: Inland Desalination: Challenges and Research Needs (2005)

Organization: Sandia National Laboratories

Summary:
There are at least three major concerns for inland desalination. These include variable and site-specific water composition, concentrate disposal (since it is impossible to put saline concentrate into a large reservoir like the ocean), and inefficient economies of scale (since most inland plants will not be as large as their seawater counterparts).

- Chemical Composition
- Concentrate Disposal
- Economies of Scale

In order to minimize concentrate volume, energy consumption, and the overall costs of desalinated water, significant improvements in current technologies will have to take place. Fortunately, there is the potential for significant improvements in membrane technologies, as well as advances in engineering designs and construction materials that can bring other desalination technologies within the reach of current needs.

- Thermal Desalination
- Membrane Processes
- Hybrid Systems - Hybrid systems that take advantage of the complementary efficiencies of different desalination processes may also provide a significant improvement in water recovery, energy use, and concentrate minimization.
- Water Reuse. Finally, wastewater recovery and reuse represents the most sustainable, efficient, and in many cases, the lowest cost alternative for making limited resources go further. This is true since the wastewater has a low inherent salinity and has a low osmotic pressure to overcome in RO operations.

Publication Title: Implementation of the National Desalination and Water Purification Technology Roadmap: Structuring and Directing the Development of Water Supply Solutions (2010)

Organizations: Sandia National Laboratories, Water Research Foundation, and WaterReuse Foundation

Summary:
The objective of the National Desalination and Water Purification Roadmap and this Implementation document is to establish a coordinated national desalination research agenda that identifies high-impact and non-replicative research, thereby hastening the rate at which desalination technologies are developed and implemented to provide new water.

Created in response to a desire for a unified approach to advancing the technology of desalination and water purification, this Implementation document has two objectives: Hasten the rate of technological advance and reduce the cost of desalination technologies. This will be accomplished by cultivating and coordinating multiple research efforts at a national level with the goal of meeting current and projected real-world, user-generated needs. This document complements the Desalination and Water Purification Technologies Roadmap but differs from it by identifying specific research projects critical to the growth of desalination.

The document identifies four National Research Areas, which are each composed of numerous Research Agendas. Potential research projects are also identified for each Research Agenda item.

- Membrane Technologies
  - Pretreatment
  - Membrane Performance/Properties
  - Fouling
  - Post-Treatment Research Agenda: Operations
  - Other
- Alternative Technologies
  - Biological Treatment
  - Hybrid Systems
  - Alternative Membranes
  - Offshore Desalination
- Concentrate Management Technologies
  - Disposal, Fundamental Research
  - Disposal, Applied Research
  - Beneficial Use, Fundamental Research
  - Beneficial Use, Applied Research
  - Energy Consumption and Recovery
- Institutional Issues
  - Energy Cost Reduction
  - Environmental Considerations
  - Alternative Water Supplies and the Role of Desalination
  - Regulatory/Policy Considerations
  - Outreach to Water Professionals
  - Improving the Understanding of the Technology
  - Understanding the Economics of Desalination
  - Consumer Outreach
  - Determine Benefits of Desalination

Publication Title: Water Needs and Strategies for a Sustainable Future: Next Steps (2008)

Organization: Western Governors' Association

Summary:

Desalination Findings:

1. The primary constraints for desalination are construction and operational costs, especially energy costs, pre-treatment costs, and disposal of the brines produced.
2. Desalination costs for seawater have dropped from about $2,500 per acre-foot to the $800 to $1,400 range, with costs to treat brackish water at $50 to $500 per acre-foot.
3. As the cost of more traditional water supplies rise and desalination costs continue to fall due to technological advances, future opportunities for desalination will expand, particularly in coastal and rural areas with brackish water resources.
4. There are regulatory and other barriers to collocating desalination and coastal energy plants so as to take advantage of production synergies.

Next Steps:

1. Federal water management agencies should encourage further research and development of desalination treatment technologies.
2. The Administration and the Congress should continue to support spending for desalination research and development, including cost sharing where there is a significant national or regional benefit.
3. Federal agencies should continue to investigate the availability and use of brackish waters to meet future water needs, particularly those of rural communities without other readily available sources of supply, and to identify ways to mitigate adverse impacts of brine disposal.

Publication Title: Desal Dialog: A Regulatory Workshop on Critical Issues of Desalination Permitting (2013)

Organization: Water Reuse Research Foundation and cosponsors Water Research Foundation and Bureau of Reclamation.

Summary:

A significant barrier to implementing desalination technology in the United States is uncertainty regarding how environmental impacts are addressed in permitting processes. The primary objective of this outreach effort, called the Desal Dialog, was to conduct a national workshop for key desalination stakeholders, including utilities, regulators, and associations. The goal of the workshop was to facilitate a common understanding of desalination permitting issues and identify areas of common ground and agreement.

In preparation for a 2-day workshop for the participants, the project team prepared and circulated 12 technical White Papers that addressed 4 main permitting categories: source water issues, product water quality, discharge impacts, and membrane technology performance and reliability. The results of their recommendations are presented below.

1. Impingement & Entrainment (I&E) of Aquatic Organisms by Open Intakes
   a. Methodology for Quantification of Impingement & Entrainment (I&E) of Desalination Plant Intakes
   b. Methodology for Determination of the Biological Significance of I&E
   c. Methodology for Assignment of I&E Reduction Credits to Intake Technologies
   d. Methodology for Development of I&E Mitigation
2. Source Water Quality Characterization
   a. Study of Survivability of Regulated Human Pathogens in Saline Waters
   b. Methodology for Performing Sanitary Surveys and Applying Drinking Water Standards to Desalination Projects
   c. Methodology for Assigning Pathogen Removal Credits to Desalination Intake Wells
3. Product Water Quality and Public Health & Product Water Quality and Non-Consumptive Use
   a. Guidelines for Integrating Desalinated Water into the Water Distribution System
4. Blending of Source and Brackish Desalinated Waters
   a. Survey of Existing Brackish Groundwater-Source Water Blending Practices
5. Characterization of Discharges
   a. Information and Decision Tree for Characterization of Desalination Plant Discharge
   b. Characterization of Toxicity Impacts of Plant Discharges
   c. Development of Standard Methods for Laboratory Analysis of Concentrate
6. Seawater Concentrate Water Quality
   a. Survey of Existing Desalination Plant Discharge Permitting Practices
   b. Development, Verification, and Certification of Salinity Dispersion Models Tailored for Seawater Discharges
7. Alternative SWRO Concentrate Disposal Methods

   a. Study of Salinity Tolerance of Target Sensitive Marine Species
   b. Mapping of U.S. Ocean Shorelines (“Near-shore Outfall Zone”)
8. Alternative BWRO Concentrate Disposal Methods
   a. Database of Permitting Practices for Brackish Concentrate Disposal
9. RO Membrane Pathogen Removal Credits and Integrity Testing
   a. Standard Method for Online Nanofiltration and Reverse Osmosis Integrity Testing
10. Removal of Algal Toxins by SWRO Membranes
   a. Surrogate-based Methods for Online Nanofiltration and Reverse Osmosis Integrity Testing
11. NSF Certification of Equipment, Chemicals, and Membranes for Potable Use
   a. Methodology for Implementing NSF/ANSI 61 Standard for Desalination Project

Appendix C: International Research Priorities Summaries

Table C-1: List of international desalination-related papers and websites that were identified and included in this literature review.

Entity:		Reference
Countries/ International Organizations	Australia	• Australian Desalination Research Roadmap (2012)
	Egypt	• Desalination Technology Roadmap 2030 (2007)
	Middle East Desalination Research Center (MEDRC)	• Information found on the www.medrc.org website (2014)
	South Africa	• National Water Resource Strategy – National Desalination Strategy (2011)

Publication Title: Australian Desalination Research Roadmap (2012)

Organization: National Centre of Excellence in Desalination Australia (NCEDA)

Summary:
The roadmap process identified potential technology improvement opportunities for the Centre to pursue. This task was the focus of collaborative effort in a roadmapping workshop, where opportunities were identified by small groups and subsequently validated by industry experts and the Roadmap Advisory Group. Improvement opportunities are grouped into thematic research focus areas where strategy, benefit, and prerequisite are described. The 29 thematic research focus areas described are further detailed into 132 specific research strategies within the document. The thematic research focus areas are as follows:

- Pretreatment
  - Preheating using waste heat or renewable energy and the use of lower-pressure membranes
  - Optimal use of chemicals
  - Specific issues for pre-treatment in rural and remote areas relating to seasonal and location variability in feedwater composition
  - Characterization of groundwater and seawater sources and mapping those to best fit desalination technologies
  - Optimizing intakes and outfalls
- Reverse osmosis desalting
  - Anti-fouling technologies and membranes and oxidant resistant membranes
  - New membrane materials that reduce operating pressure while maintaining or increasing flux rates and maintaining ion rejection
  - Contaminant removal without the need for second-pass RO
  - Direct use of renewable energy via kinetic, electrical, or thermal means
  - Real-time monitoring and classification of potential foulants
  - Operational optimization
- Novel desalting
  - Novel technologies including those for direct agricultural and industrial use
  - Low-maintenance, reliable evaporative technologies using waste heat or renewable energy
  - Coupling water production with renewable energy
  - Piloting in real-world situations breakthrough near commercial desalination technology
  - Reliable, robust small-scale systems
- Concentrate management
  - Novel zero liquid discharge processes
  - Waste minimization based on value adding
  - New materials for lower-cost corrosion management
  - Extraction of desalted water at source or concentrate injection
  - Energy efficiency in concentrate management
- Social, environmental, and economic issues
  - Appropriate disposal or reuse of spent membrane cartridges

- Total life cycle analysis and sustainability assessment of desalination against other water sources
- Public perception analysis and improvement through education and communication
- Policy development
- Centralized understanding of national desalination deployment, performance, and lessons learnt
- Detailed understanding of the salinity and toxin tolerance of marine species in the vicinity of SWRO outflows
- Management of entrainment of small marine organisms in SWRO intakes
- Post-treatment

Publication Title: Desalination Technology Roadmap 2030 (2007)

Organization: Center for Future Studies, Egyptian Cabinet Information and Decision Support Center

Summary:
This project aims at identifying the future needs for desalination technology development, charting a series of research and development activities that will result in cost-effective, efficient revolutionary desalination technologies that can meet the national future needs, and providing short and long term action agenda to guide desalination research and investments in Egypt till the year 2030.

Egypt's main national needs with respect to water are categorized as:

- Cost-effective water
- Drinkable water
- Water fits for its uses
- Sustainable water

Table 3 of the Roadmap outlines Near Term Critical Objectives (2015) and Mid/Long Term Critical Objectives (2030) for each of the four national need categories. Table 4 of the Roadmap lists suggested R&D projects to meet the Near Term Critical Objectives, along with an estimate of the project duration and cost. Table 5 of the Roadmap lists suggested R&D projects to meet the Mid/Long Term Critical Objectives, along with an estimate of the project duration and cost.

The Roadmap also identifies three main technology areas where R&D is needed in order to create the next-generation desalination technologies. These technologies are:

- Solar/Thermal Technologies
- Membrane Technologies
- Other Technologies

Table 6 of the Roadmap summarizes the main R&D activities associated with each technology area in order to fulfill the previously described national needs.

Website: Middle East Desalination Research Center (website, 2014)

Organization: Middle East Desalination Research Center

Summary:
The Center is directed to focus on priority research, training and communication needs, in order to achieve the objectives defined by its Establishment Agreement. As a result, each year the Center will re-evaluate its overall program to continually enrich its activities and maintain close proximity to the changing needs of desalination technologies. Each year, a revised Program Framework and Profile (PFP) will be presented to the Research Advisory Council (RAC) for their review and input for a technical agenda for the upcoming year.

The Center's Research Program is based on Seven Research Program Goals:

- Decrease the cost of desalination
- Develop productive partnerships and cooperation
- Develop sustainable desalination technologies
- Improve communications in the desalination community
- Develop human resources for application of desalination and foster international cooperation in research activities, particularly among regional experts
- Utilize limited regional and international research resources
- Maximize technology transfer

For a systematic approach to research planning and management, the Center has defined ten Topic Areas into which projects are tendered. The Center's Research Advisory Council annually reviews the previous and recommends new projects for each of the following ten areas of research.

- Thermal Desalination
- Membrane Desalination
- Non-Traditional or Alternative Desalination
- Operation and Maintenance
- Intakes & Outfalls
- Energy Issues
- Environment Issues
- Hybridized Systems
- Certification Programs
- Assessment Studies

Publication Title: National Water Resource Strategy – National Desalination Strategy (2011)

Organization: Department of Water Affairs, Republic of South Africa

Summary:
Appendix C of the South Africa National Water Resource Strategy is the National Desalination Strategy.

The Department of Water Affairs (DWA) will work with the Water Research Commission (WRC), the Department of Science and technology (DST) and the Department of Trade and Industry (DTI) to support the development of desalination technologies where South Africa has comparative advantages, particularly in desalination processes related to mining and industry, including investigating the establishment of a center of expertise and excellence at one or more universities. The objective of the research and development will be to develop technologies and processes that can be commercialized and applied to the different scales of desalination projects.

Particular attention will be paid to the following areas:

- Acid mine drainage and other saline mine waters
- Mining and industrial process effluents
- Investigating the technical and environmental feasibility and providing guidelines for the establishment of saline surface pans or lakes as regional facilities for brine disposal
- Investigating the technical and environmental feasibility and providing guidelines for brine disposal to deep underground mining voids and workings
- Investigating the technical and financial feasibility of recovering useful and saleable products from desalination waste streams
- Supporting research into and the development of more energy efficient desalination technologies