State of the World Report 2015

Water Challenges

Fédération Internationale des Ingénieurs-Conseils
International Federation of Consulting Engineers
Internationale Vereinigung Beratender Ingenieure
Federación Internacional de Ingenieros Consultores

State of the World Report 2015

The **FIDIC State of the World Report 2015** was commissioned by the FIDIC Executive Committee, comprising: Pablo Bueno, Typsa, Spain (President); Jae-Wan Lee, Sekwang Engineering Consultants, Korea (President Elect); Alain Bentéjac, Artelia, France (Vice President); Chris Newcomb, McElhanney Consulting Services, Canada; Kaj Möller, SWECO, Sweden; Exaud Mushi, Norplan, Tanzania; William Howard, CDM Smith, USA; Moncef Ziani, CID, Morocco; Kiran Kapila, ICT, India.

The Report was compiled by William Howard, from CDM Smith, and co-authors April Gu (Northeastern University) and Miguel Mondria Garcia from Typsa (Spain). In addition, Dr. Mark Patterson (Northeastern University) and Ms Emily Izzo (Northeatern University) provided input on Oceans and the Role of Students, respectively.

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FIDIC is the international Federation of national Member Associations of consulting engineers.

FIDIC was founded in 1913 by three national associations of consulting engineers within Europe. The objectives of forming the Federation were to promote in common the professional interests of the Member Associations, and to disseminate information of interest to their members. Today, FIDIC membership covers more than 95 countries from all parts of the globe and encompassing most consulting engineers in private practice.

FIDIC is charged with promoting and implementing the consulting engineering industry's strategic goals on behalf of Member Associations. Its strategic objectives are to: represent world-wide the majority of firms providing technology-based intellectual services for the built and natural environment; assist members with issues relating to business practice; define and actively promote conformance to a code of ethics; enhance the image of consulting engineers as leaders and wealth creators in society; and promote the commitment to sustainability.

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Procurement
Risk management
Quality management
Business integrity
Project sustainability
Capacity building
Professional liability
Project management
Consultant selection
Scope of services
Quality of construction
Environmental management
Insurance
Transfer of technology
Information technology

Forward

The FIDIC 2015 State of the World Report on Water is the third in a series of "State of the World" reports. The first was a 2009 report on Infrastructure and the second was a 2012 report on Sustainability. FIDIC produces these reports as a service to our 100 member associations and global partners to examine some of the world's most challenging issues, which the engineering community can help address. Water is clearly one of these challenges. Thus, the issuance of this report is most timely.

As noted in the document, the world now faces a multi-faceted complex "water" problem. If more well-planned actions are not taken soon, we will have a water crisis. While engineers can and should play a leadership role in tackling our water woes, they additionally need to work with and actively involve other professionals and stakeholders in the effort. And, we are all stakeholders–as we will all be affected by the results.

This report consists of an executive summary followed by various sections about a particular subject and conclusions. It was produced under the leadership of the main author CDM Smith's William (Bill) Howard, P.E., BCEE, FACEC, FASCE (a member of FIDIC's Executive Committee) with contributions on many issues from Dr. April Gu, Associate Professor and Director of Graduate Studies, Department of Civil Engineering, Northeastern University, Boston Massachusetts, and Dr. Miguel Mondria Garcia, the Chief Technology Officer of Typsa, Spain. In addition, Dr. Mark Patterson, Professor of Marine and Environmental Sciences at Northeastern University contributed much of the material on Oceans with some assistance on micro-plastics from Ethan Edson, a recent Northeastern University Environmental Sciences graduate. Also, Ms. Emily Izzo, the valedictorian of Northeastern's class of 2014 and whose major was International Affairs and Anthropology with a minor in Environmental Studies, contributed to the section on the Role of the Today's Students and Other Professionals.

Much of the material here reflects information produced over the last few years in numerous professional journals and books, periodicals produced for more general audiences, and information from various Internet resources.

A significant effort was put forth to balance brevity with information. This was not a simple task since the amount of material available on each of our water challenges is extensive, to say the least. One of the strategies we used to limit the size of the document was to describe a certain issue in a few paragraphs and intersperse these with descriptions of real world projects to clarify some of the issues and point us toward possible solutions. Hopefully, this technique has at least been moderately successful.

Every effort was made to credit the various authors of books and journals used to produce this narrative. In the event a source was omitted or a reference listed incorrectly, we apologize.

Finally, while producing this report, it quickly became apparent how much attention water is getting. Professional journals and text books are being produced every month on the subject. More information on water is appearing in the media as well. Most importantly, many very bright people are dedicating part or all of their careers on one or more elements of our water challenges.

Many of them are listed in the Bibliography section at the end of the document. This is most encouraging news because it is creating global awareness of our water problems that will hopefully lead to more action.

Acknowledgements

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Michele and Daryl improved the document tremendously. So, if you find it readable and enlightening, we have them to thank.

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List of Acronyms

AOPs	Advanced Oxidation Processes
ASCE	American Society of Civil Engineers
AWWA	American Water Works Association
BIM	Building Information Modelling
BMPs	Best Management Practices
CAD	Computer Aided Design
CECs	Contaminants of Emerging Concern
CFD	Computerized Fluid Dynamics
CHP	Combined Heat and Power
CRADA	Cooperative Research and Development Agreement
CREAT	Climate Resilience Evaluation and Awareness Tool
CO_2	Carbon Dioxide
CSO	Combined Sewer Overflow
EDC	Endocrine Disrupting Chemical
EEA	European Environmental Agency
EWB	Engineers Without Borders
FIDIC	International Federation of Consulting Engineers
FIMS	FIDICs Integrity Management System
FOG	Fats, Oils and Grease
GHG	Greenhouse Gas
Gm^3/day	Giga Cubic Meters Per Day
ha	10,000 Square Meters
hm^3	Cubic Hectometers
IAM	Infrastructure Asset Management
IFI	International Funding Institution
I/I	Infiltration and Inflow
IPCC	Intergovernmental Panel on Climate Change
IWA	International Water Association
IWMI	International Water Management Institute
IWRM	Integrated Water Resource Management
km^3	Cubic Kilometers
LEED	Leadership in Energy & Environmental Design
LPCD	Liters Per Capita Per Day
m^3	Cubic Meters
MBR	Membrane Bioreactor
MDG	Millennium Development Goal
MF	Microfiltration
NOAA	U.S. National Oceanic and Atmospheric Administration
OCSD	Orange County Sanitary District
OECD	Organization for Economic Cooperation and Development
O&M	Operations and Maintenance
PPCP	Pharmaceuticals, Personal-Care Products
PW	Present Worth
RO	Reverse Osmosis
RWPF	Raw Water Production Facility
SRT	Sonar, Seismic Resurgence Testing
SSET	Sewer Scanner and Evaluation Technology
SSOs	Sanitary Sewer Overflows
STEM	Science, Technology, Engineering and Math
SWNs	Smart Water Networks
USACE	U.S. Army Corps of Engineers
UNESCOs	United Nation's Educational, Scientific and Cultural Organization
UF	Ultrafiltration
UWC	Urban Water Cycle
USEPA	United States Environmental Protection Agency
WCIT	Water Contaminant Information Tool
WEF	Water Environment Federation
WHO	World Health Organization
WRF	Water Research Foundation
WSUD	Water Sensitive Urban Design
WSSCC	Water Supply and Sanitation Collaborative Council

Executive Summary

Global Challenges

It seems that everyone is talking about water, perhaps most people are, considering its importance and the many global challenges associated with it. Volumes are being written about it in all types of publications. This is good news because the world is heading towards a water crisis and significant preventative actions from the global community are required to avoid it.

According to the United Nations, water scarcity affects every continent. Almost 20% of the world's population live in areas of physical scarcity and 500 million are approaching this situation. Another 25% face economic water shortage (http://www.un.org/waterforlifedecade/scarcity.shtml).

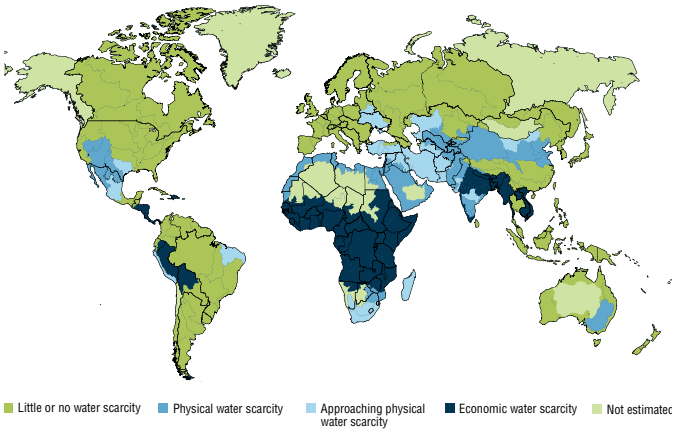

Figure 1 – Global Physical and Economic Water Scarcity: World Water Development Report 4 – Assessment Program March 2012, http://www.un.org/waterforlifedecade/scarcity.shtml.

More than 10% of the world's population still does not have reasonable access to clean water and twice as many don't have access to basic sanitation. This tragedy contributes to disease and about 3 million early deaths each year. One child dies from diarrhea every 17 seconds. This is equivalent to ten jumbo jets crashing every day (Bixler et al., 2015).

Less than 3% of the water on our planet is fresh and most of that is frozen. Less than 1% is generally available for use. While this percentage may seem low, if the fresh water falling to the Earth each year, which does not evaporate or freeze was evenly distributed across the planet, there would be plenty of fresh water for everyone. Of course, this is not the case and never can be. As a result, some parts of the world have too much water (e.g., floods) and others too little (e.g., droughts). Climate change and population growth will exacerbate this situation.

Energy, Food and Water

Energy and food requirements also have an enormous impact on water challenges. Thus, we need to recognize the water-energy-food nexus. Regarding energy and water, large amounts of one are generally required to produce and distribute large amounts of the other. Regarding agriculture, 70% of the world's fresh water demand is associated with food. Growing populations, increased wealth in developing countries, and the need to provide energy and food to those without adequate access to them now are resulting in increasing demands for both.

"The spread of prosperity across the world, especially in China and India, is driving an increased demand for meat, eggs and dairy, boosting pressure to grow more corn and soybeans to feed more cattle, pigs and chickens. If these trends continue, an additional problem of population growth and richer diets will require us to roughly double the amount of crops we grow by 2050" (Foley, 2014).

Improved drop-per-crop values and better decisions on what to grow and where to grow it, could lower agriculture water demands per unit of food. More dialogue about water footprints and virtual water trade may help the global community address agricultural water use as the world's population and the demand for more food increases, especially protein with a generally high water footprint.

Carbon dioxide (CO_2) emissions from fossil fuels (a significant contributor to climate change and global warming) have been increasing for more than a century—and at a much faster rate in the last 50 years. While energy related CO_2 emissions from some areas (e.g., North America and Europe) may decline, emissions from other areas will likely increase as countries in these geographies strive to meet growing energy needs, at least in part by using fossil fuels. Thus, we can expect that the world will continue to depend on fossil fuels to generate much of its electricity in the foreseeable future.

Sea level rise is affecting coastal populations along with water, wastewater and stormwater facilities adjacent to shorelines. The effectiveness of pollution and flood control programs as well as the increased energy costs to pump water are a few of the problems coastal utilities face as a result. Ocean warming and acidification is contributing to more intense storms and impacting aquatic life and food supplies.

Quantity and Quality

Despite advances in treatment technology, contaminated wastewater is still being discharged to receiving waters in large quantities. Adding to the strain are contaminants of emerging concern (CECs), which are appearing in waters around the globe. The ability of current treatment technologies to remove them are mixed.

The European Environmental Agency (EEA) has projected that about 7 trillion cubic meters (m^3) of fresh water will be needed by the global community by 2030—a deficit of about 3 trillion m^3. Overuse of surface and groundwater supplies is occurring throughout the world now, which is unsustainable. Reducing the demand for fresh water and capital expenditures for new facilities will both be necessary to close the demand vs. need gap and avoid a worldwide water crisis. Reducing the amount of fresh water required for agriculture, reducing potable water use, addressing the pricing of water and reusing water all can contribute to lowering demand.

We must also recognize fresh water in all forms (e.g., water, wastewater, stormwater) as a valuable resource that needs to be effectively used and reused. This requires a shift in thinking. More localized systems to distribute clean water, treat wastewater, capture stormwater and recharge aquifers are needed. Piping wastewater even when treated or stormwater to oceans should be minimized.

Valuable constituents within wastewater, including potential energy, biosolids and nutrients, can be harnessed, recovered and used. The good news is that significant progress is being made in all of these areas. Wastewater plants are becoming net energy generators, not users; biosolids are being captured to produce heat, electricity or fertilizer; and more technologies to recover nutrients and other valuable constituents are being developed.

Stormwater is increasingly being captured locally to build wetlands and recharge aquifers. In addition, more high sustainability scoring decentralized or hybrid systems are being developed for water, wastewater and stormwater, often reducing the need for costly pipelines.

Infrastructure

Significant new water infrastructure is needed in developing countries. The water infrastructure in developed countries is suffering from age; design life's are being exceeded and investments to address this problem are inadequate. Thus, every year the situation deteriorates. It is estimated that $17.5 trillion is required to meet all water infrastructure needs (maintenance and new) by 2030. While this is a staggering number, it is less than 2% of the World's GDP on an annualized basis.

New technologies and approaches can lower this cost. Cost-effective new technologies are being researched and new approaches are being implemented throughout the world. One very promising relatively new approach, integrated resource management, addresses many elements of a challenge simultaneously, thereby reducing overall costs and the potential that solving one problem generates another one.

Whether planning for new infrastructure or addressing aging facilities, sustainability, resiliency and other non-monetary factors need to be considered. This compounds the challenges associated with alternative analyses, which historically were evaluated based on financial considerations, like present worth. Fortunately, tools are being developed to facilitate their consideration thereby increasing the probability that the right projects will be selected for each specific situation.

The Role of Government

Water knows no boundaries, but waterways often form them. This has encouraged countries, even those unfriendly to each other, to have dialogue about water. About 450 transboundary agreements have been reached between governments since 1820. In addition to working with these agreements and developing new ones, when appropriate, governments can help address water issues by developing fit-for-purpose treatment regulations, streamlining procurement and permitting, and by working with non-governmental organizations and International Funding Institutions (IFIs) to develop innovative financing approaches and to address the special needs of the poor. Perhaps most importantly, governments need to show leadership in encouraging investment in water infrastructure.

The Role of Engineer, Students and other Professionals

More engineers will be needed to address the world's water challenges and they will need more diverse skills such as leadership and communication to do so effectively. Technical knowledge alone will not be adequate. Engineers will need to function as trusted advisors to their clients as well as technical and non-technical stakeholders, helping to ensure that the right projects are selected and that they are done right.

Engineers must also advocate for increased infrastructure investments and for better use of the funds made available via more effective up-front planning. It is in the preliminary planning phase when the best engineering is often done. The right projects do not always involve expensive capital programs. Good engineering during the planning stage often reduces the cost and extent of capital programs and sometimes eliminates them altogether. To execute increasingly complex projects faster and cheaper, engineers and scientists will need to become more adept at working in teams, remotely and with more and more sophisticated technical tools like building information modelling (BIM).

Addressing the world's water challenges will require enormous effort from the entire global community — not just those with science, technology, engineering and math (STEM) careers.

Others, including students and non-STEM professionals interested in water issues, must be welcomed by water professionals and be encouraged to get involved so their diverse skills can be used effectively.

The following statement, credited to UNESCO's International Program, highlights this point: "It is recognized that water problems cannot be solved by quick technical solutions. Solutions to water problems require the consideration of cultural, educational, communication and scientific aspects. Given the increasing political recognition of the importance of water, it is in the area of sustainable fresh water management that a major contribution to avoid/solve water related problems including future conflict can be found" (http://www.ukessays.com/essays/environmental-sciences/what- threatens-water-management-strategies-environmental-sciences-essay.php#ixzz3hQMhHGax).

Growing Awareness, Priorities and Actions

It is encouraging that more people are aware of the water challenges the world is facing. For example, in 2015, the World Economic Forum included "water crises" in their top 10 global risks (Cann, 2015). In addition, the Water Supply and Sanitation Collaborative Council (WSSCC) has established a "Vision 21", which calls for "A clean and healthy world: A world in which every person has safe and adequate water and sanitation and lives in a hygienic environment" (http//:www.thewaterpage.com/basic needs). This increased awareness may well turn out to be the most important contributor to addressing the water challenges we face.

In addition, not only do non-STEM professionals (e.g., policy experts, community engagement specialists and policymakers) show strong interest, but also there is more dialogue occurring among younger adults—especially in social media. This is creating keen interest among arguably the most educated and connected generation to date. They are already motivated since they will inherit and live with the consequences of the water problems we don't solve.

In the process of addressing water challenges, it is not difficult to be overwhelmed by their number and complexity. Thus, it is beneficial to consider the most important water challenges. FIDIC suggests these four:

- Providing everyone access to clean water and basic sanitation
- Closing the demand gap
- Planning for climate change
- Adequately investing in infrastructure (aging and new)

Consulting engineering firms practicing in the water field should consider what role they can play in addressing these challenges. All firms should strive to build on the growing awareness of the world's water issues and help direct the world community toward solutions. Large global firms may be able to reach out to many governments and institutions in an effort to keep water challenges on the agenda. Smaller local firms might consider how best to address issues that they are tasked with resolving in ways that meet local needs and also help their neighbors and/or the global community. Sharing lessons learned via presenting papers at universities and at professional organizational conferences should be encouraged by all firms, as this is one of the best ways to transfer knowledge and avoid repetitive problems. All firms can support professional organizations in their efforts to draw attention to critical issues and educate their members and other stakeholders.

Experienced engineers can volunteer to help groups such as FIDIC's Young Professionals, Engineers Without Borders or Water For People. Younger engineers and students interested in water should be encouraged to join and participate with such groups. Professional engineering firms should consider how their senior people can, as trusted advisers, influence decision makers to spend the time and money to plan projects properly and execute them well. Considering the magnitude of the estimated required investments for water infrastructure, this planning should be broad (sometimes going beyond governmental boundaries) and address as many issues as possible to increase the probability that resolving one series of challenges does not create others. Also, in this era of limited funds, firms should support initiatives that encourage innovative research, "fit for purpose" treatment options, reuse and programs associated with considering all elements of water as a resource to be used and reused.

All firms also should consider working with clients and potential clients to strengthen integrity programs while simultaneously streamlining procurement times and selecting firms for assignments based on their qualifications and approach, and not on cost. Finally, everyone in the water engineering profession must encourage other professionals and students to get involved in addressing our water challenges. Using everyone's skills in a collaborative environment will dramatically increase the probability of success.

There is ample reason to be optimistic. The seriousness of our water issues, the growing awareness of the challenges we all face, the general acceptance by many that diverse skills are needed to succeed, and the fact that there is a large population of highly motivated and trained citizens ready and able to help should take us to where we need to go—to a world where everyone has access to clean water and basic sanitation and where sustainability is accepted as a way of life. Working together, we will address our water issues successfully.

Global Water Issues

The World's Water

Many books, reports and scientific papers have been written about the water challenges the world is now and will be soon facing. Many believe that water will be a major issue in the 21st century. At any given time, some geographies will have too much and others too little. Some areas will experience both phenomena at different times (e.g. Texas, USA). A number of countries in all continents now have water shortages as well as, in some cases, deterioration of the quality of the supplies they do have. Climate change is exacerbating this situation via more intensive weather events, sea level rise and global warming.

In July 2010, the United Nations General Assembly recognized the right of every human being to have access to sufficient, safe and affordable water for personal and domestic uses. While progress is being made (the world has met the Millennium Development Goal (MDG) for drinking water) more needs to be done. The MDG goal for sanitation will likely not be met and some parts of the world including the sub Saharan region of Africa did not do as well in achieving clean water goals as others.

About 96.5% of the world's water is in the oceans, about 1.7% is frozen in glaciers, ice caps and permanent snow, and about another 1.7% is in the ground over half of which is saline. The amount of fresh water in lakes and rivers is about 0.0072% of the world's total water volume (Shiklomanov, 1993).

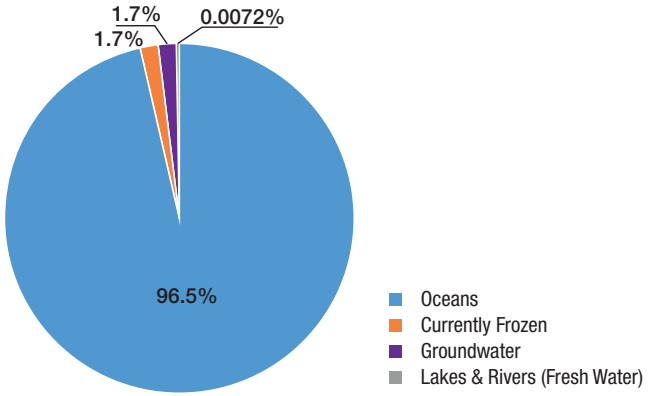

Figure 2 - The World's Water. Developed from Igor Shiklomanov's chapter "World Freshwater Resources" in Peter Gleik's 1993 Edition Water in Crisis: A Guide to the World's Fresh Water Resources (Oxford University Press, New York). percentages are approximate.

Oceans

Climate Change and Sea Level Rise

Sea levels have been rising due to warming of ocean temperature and ice melt. While the amount and rate of future sea level rise is unknown, we do know from the U.S. National Oceanic and Atmospheric Administration (NOAA) that ocean levels have been observed to be rising since 1880 after being relatively stable for about 2,000 years. Recently, the rate of rise has been more accurately measured by NOAA at about 3mm per year. Under various scenarios, NOAA projects a range of additional rise by 2100 of 0.2m to 2.0m. It should be noted that the extent of sea level rise, as well as the impact to adjacent land, is expected to vary throughout the globe. Table 1, shows global sea level rise scenarios for the U.S. National Climate assessment.

Scenario	SLR by 2100 (m)
High	2.0
Intermediate High	1.2
Intermediate Low	0.5
Lowest	0.2

Table 1 – Global Sea Level Rise Scenarios. US National Oceanic and Atmospheric Administration. Global Sea Level Rise Scenarios for the United States National Climate Change Assessment Dec. 6 2012 (NOAA, USGS, SERD, USACE)

While nobody is predicting it, ocean levels would rise by more than 65m if all of the world's ice melted (Folger, 2013).

It is indeed fortunate that we are a long way from a total global ice melt, as such a disaster would submerge lands along coasts populated by millions of people and totally submerge some countries and large portions of others. However, even under much lower sea level rise scenarios, coastal cities, like Venice, Italy, are at risk of being claimed by the ocean.

The impact of sea level rise is far reaching. Many coastal communities, which are already struggling financially, are concerned about increased electrical costs to pump wastewater and stormwater against higher heads, minimizing property damage due to flooding and even population disruptions. Currently, water and wastewater

pumping is the single largest municipal electrical demand in some cities. In the United States, it is estimated that 2% to 4% of electric usage is for water and wastewater treatment and pumping (Dyballa and Hoffman, 2015).

Extraordinary property damage is occuring already due to intense storms and population displacement, which currently appears to be happening in some parts of Bangladesh and is being considered as a long-term planning action in the Maldives. More than 2 million people in Florida, USA, where a Dutch development company is considering a floating village (i.e. units can rise and fall with the water levels), live within 4 feet of current high tide elevations (Parker, 2015). The floating village concept has already been implemented in the Netherlands where floating houses have been built on a lake in East Amsterdam (Folger, 2013). The flooding problems associated with coastal communities with land subsidence issues such as Manila, Calcutta, Dhaka and Ho Chi Minh City are even more challenging (Folger, 2013).

It is also feared that rising sea levels will, in some instances, exacerbate the already alarming problem of saltwater intrusion into groundwater. This is a particularly challenging problem in geographies with porous soils.

Wetlands

Damage to wetlands is a growing concern with many coastal communities. It should be a worry for all of us. As the planet warms, wetlands will be directly affected through sea level rise and changes in the hydrologic cycle. The diversity of wetlands (e.g., floodplains, mangroves, saltmarshes, arctic wetlands, peatlands, freshwater marshes, forests) makes generalizations tenuous, with one exception: wetlands constitute 12% of global carbon pools. Whether they will act as sinks or sources for carbon under future warming scenarios is currently unknown (Intergovernmental Panel on Climate Change (IPCC) 2001, Erwin 2009). In aggregate, wetlands store 10 times more carbon than temperate forests and 50 times more carbon than tropical forests. Unlike terrestrial ecosystems, this blue carbon (the carbon captured by the world's oceans and coastal ecosystems) is stored for centuries in the form of soils.

Ecosystem services provided by wetlands are enormous (Barbier et al., 2011). Their role in flood mitigation from storms, nursery habitats for commercially and ecological important species, and filtration and sequestration of harmful substances produced by society will only increase in importance. As noted in IPCC 2014: "Magnitudes and rates of climate change associated with medium- to high-emission scenarios pose an increased risk of abrupt and irreversible regional-scale change in the composition, structure and function of marine, terrestrial and freshwater ecosystems, including wetlands (medium confidence)." Planners using wetlands for the societal needs will need to evaluate how changes in the hydro-period and the frequency of extreme events impact natural, maintained or restored areas.

Pollution

The problems associated with some of the world's largest cities still discharging untreated or inadequately treated sewage into waterways and oceans remain daunting due to the serious impact to downstream users and aquatic food supplies. Coastal eutrophication has grown exponentially over the last 40 years, with virtually no coastal areas (with the exception of Antarctica) spared. Much of the coastal eutrophication can be traced to the success of fertilizer applications to farmland (often far from the ocean) in increasing crop yields. The double impact of crop production and nitrogen inputs from cities by the sea, with significant inputs into coastal areas from car and truck emissions, make reduction of the extent and duration of dead zones an international priority.

Even success stories, such as the Deer Island wastewater treatment facility in Winthrop, Massachusetts, USA, credited correctly for cleaning up and restoring ecosystem services in the Boston Inner Harbor, required a deep water effluent diffuser designed to, among other things, remove nitrate and other nutrients from the shallower harbor.

The scale of nutrient input to coastal waters is enormous. For example, 1.1 to 3.0 billion liters per day of treated sewage enters the Gulf of Maine, creating a substantial nitrogen input.

Endocrine-disrupting compounds are also introduced into coastal ecosystems through sewage effluent, with unknown concentrations and effects on developing fishes, birds, marine mammals, and invertebrate larvae. We expect greater societal and regulatory focus in these areas in the coming years.

Combined sewer overflow (CSO) systems are another troubling issue in coastal ecosystems. When CSOs dump directly into the coastal zone without benefit of a living shoreline or vegetated bed, bacterial contamination often skyrockets above levels that would permit shellfish harvesting or beach going. CSO inputs also introduce organic pollutant contamination that accumulates in the food chain and in coastal sediments. Many coastal cities have developed plans for CSO mitigation with newer designs incorporating holding facilities to dampen out flow peaks rather than bypassing the treatment plants and directly discharging to a sensitive coastal ecosystem.

Marshes

Recent work has shown that the collapse of coastal saltmarshes is often attributable to excess nitrogen, and that the nitrogen is entering from the coastal ocean

waters, not from the land side (Deegan et al. 2012). The saltmarsh cordgrass becomes "top-heavy" through excessive growth of above ground shoots relative to rooting systems. This leads to toppling of plants in chunks along waterways, reducing the effectiveness of the wetland to provide storm protection and ecosystem services. For wetlands located near urban areas, CSOs are likely the major source of episodic nutrient pulses contributing to this problem.

Along many coasts, tide gates manage flows into wetlands. Improper operation of these gray infrastructures in a green system can lead to manifold problems affecting coastal resilience. These include invasion of a freshwater tolerant grass (Phragmites australis) that increases fire risk during dry seasons, compromise of ecosystem services of the marsh through inadequate exchange with the nearshore area, and flooding of property adjacent to the wetland during extreme events if closure of the gate is not properly managed. Sensorization of tide gates, and smart systems to manage them, will be needed near-term as sea-level rise will increase the rate at which these structures are added to wetlands for flood control during extreme events.

Floatables

Floating plastic debris in oceans is being increasingly recognized as a problem. As plastics are broken down through mechanical action and ultraviolet (UV) light exposure, the plastic particles become small enough to be ingested by a host of marine organisms, such as copepods, filter feeding fishes and whales, bivalves, pelagic tunicates, salps, jellyfish, and corals.

Figure 3 - Floating Debris in Oceans. http://marinedebris.noaa.gov

These so-called microplastics (< 5 mm size) are an emerging environmental contamination issue. Most of the plastic compounds adsorb organic contaminants present, concentrating them many-fold (often many orders of magnitude) above concentrations in the water. Thus once ingested by a marine organism, depending on its trophic level, they can further biomagnify up the food chain, posing direct health threats to top predators, including humans.

Figure 4 – Common Millimeter Sized Micro-Plastics Pulled Up in an Open Net Tow. Sea Education Association

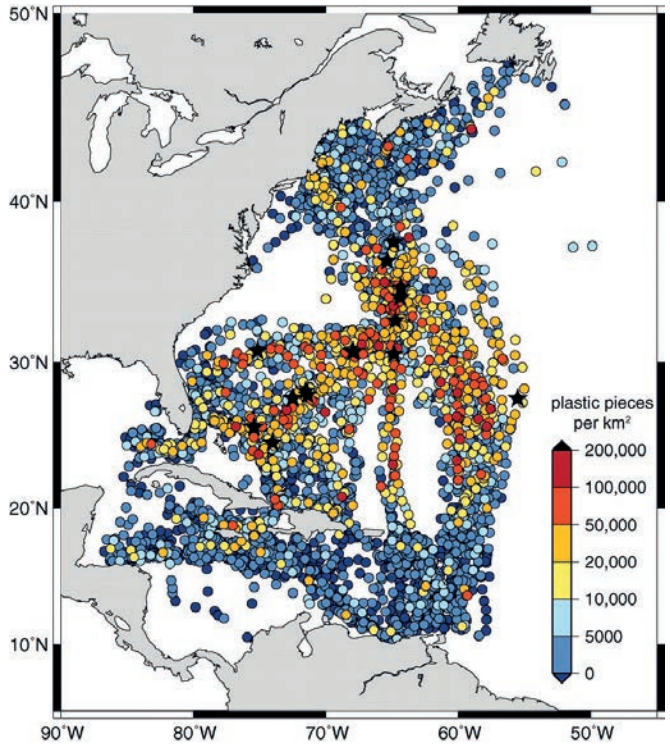

Figure 5 – Map Showing Concentration Trends in Open Ocean Micro-Plastics off the Atlantic Coast. Law, K. L., S. Moret Ferguson, N.A. Maximenko, G. Proskurowski, E.E. , Peacock, J. Hafner, And Reddy, C.M., Reddy 2010 Plastic Accumulation In The North Atlantic Subtropical Gyre. Science 329:1185 - 1188

Reportedly, Albatrosses lose as much as half their offspring in the Pacific Ocean near Midway Island after they inadvertently feed them plastics thinking it is food (Dyson, 2014).

Coral Reefs

Coral reefs are being damaged throughout the world due to ocean warming and acidification caused by increased CO_2 absorption—the "other CO_2 problem." Local economies depend on these reefs for food, recreation and coastal protection. Their economic value has been estimated to be $30 billion per year and they directly impact about 500 million people (Walsh, 2014).

Coral reefs are the first major ecosystem directly imperiled by the global changes we are experiencing. Some experts are projecting reef extinction within the next century as calcification becomes physic-chemically difficult, and reefs suffer annual episodes of bleaching (induction of loss of the symbiotic algae living in corals that facilitate their growth).

Reefs are a source of protein for many people, serve as the focus of the tourism industry in a number of tropical locations, provide protection from coastal erosion of shorelines, and mitigate impacts of tropical cyclones on shores. Sea level rise threatens the existence of low-lying island nation states such as Kiribati, Tuvalu and the Maldives built atop coral atolls.

The Caribbean basin coral reefs have severely degraded over the last 30 years from a combination of coral bleaching, overfishing and disease outbreaks. These trends are expected to expand globally.

Near Shore Ecosystems

Near-shore ecosystems in temperate and arctic latitudes will experience range-shifts and extinctions of many plant and animal species, given the speed of warming, which is faster by an order of magnitude than anything in life's geologically recent past. Calcifying organisms other than corals will be affected by the projected 30% increase in free hydrogen ion availability in seawater over the next century. Much of the nearshore secondary production occurs through bivalve and gastropod population turnover. These organisms are primary food sources for many economically and ecologically important fish and crustacean species. As calcification becomes more difficult, loss of key species may occur with unknown consequences for nearshore food-webs. The timing of reproduction for key species may shift as well, as was observed during an unprecedented warming of the Gulf of Maine during summer 2012, which appears to have impacted some aquatic life in the area.

While it is difficult to associate aquatic life changes to ocean warming alone due to other impacts like overfishing, there are indications that changes are occurring. For example, the cod population off the shores of Maine appear to be moving north and east while some shell fish such as the blue crab are appearing for the first time in waters north of Cape Cod (Massachusetts, USA). Also, during the 2012 warming event in the Gulf of Maine, the lobster crop was robust.

If phytoplankton or forage species reproduce out of phase with their consumers as warming increases, there is the potential for a chronic mismatch in trophic transfer in marine food webs.

Increased warming will lead to increased stratification of the water column at all latitudes. This will have consequences for the development and persistence of oxygen minimum zones, which occur naturally and unnaturally in overly eutrophied areas nearshore. Coastal upwelling zones dependent on the location of lower pressure areas and prevailing winds may be negatively or positively affected by climactic shifts.

Much of the high value fisheries occur in upwelling areas near coastlines. In addition, changes to near shore ocean waters may deleteriously effect shoreline facilities such as desalination plants and cooling systems.

> "SEA LEVEL RISE AND OCEAN WARMING INCLUDE DELETERIOUS IMPACTS TO POWER PLANT OCEAN WATER COOLING SYSTEMS AND INCREASED ALGAL BLOOM FREQUENCY THAT MAY DECREASE CAPACITY OF SEAWATER DESALINATION PLANTS" (URICH ET AL.).

Potential Economic Losses

According to the United Nations, "Globally, the market value of marine and coastal resources and industries is estimated at $3 trillion per year or about 5% of the world's GDP, and an estimated 63% of global ecosystem services are provided by marine and coastal systems" (http://www.undp.org/content/undp/en/home/ourwork/environmentandenergy/focusareas).

Due in part to projected sea level rise, the potential economic losses in 2050 if an extreme weather event overwhelmed protective structures around some coastal cities could range from $95 billion in Ho Chi Minh City to $250 million in Guangzhou, China, to more than $275 billion in Miami, Florida, USA (Hallegatte et al., 2013). Also, by 2050, without upgrading protective systems, damages to coastal communities due to flooding and storms could approach $1 trillion (Hallegatte et al., 2013). In the United States, the Federal Emergency Management Agency (FEMA) expects the number of flood insurance policies to increase in the future as well as the loss per policy (*Journal AWWA* April, 2014). The Organization for Economic Cooperation and Development (OECD) estimates that by 2070, 150 million people and $35 trillion in property will be at risk of coastal flooding (Folger, 2013). "In the coming decades, the World Bank predicts rising seas could invade major river deltas, poisoning them with salt water and destroying some of the world's richest agricultural land" (Parker, 2015).

There are likely other impacts associated with sea level rise and ocean warming, about which we have yet to learn.

After all, as Mr. Dan Dastel, director of the Ocean Genome Legacy Project at Northeastern University, has stated, "Life started in the oceans. It has been only the last 15% of the history of life that things crawled up on the land."

FRESH WATER

Quality

Fresh water issues are equally challenging and are perhaps even more important to the wellbeing of the global community.

Depending on location, water quality problems can include untreated or inadequately treated wastewater; combined sewer overflows; deterioration of watersheds due to development, deforestation and natural disasters like fires and floods; the emergence of contaminants of emerging concern (CECs), some of which are difficult to treat; and naturally occurring constituents such as salinity and metals including arsenic.

It is estimated that 2 million tons of untreated sewage, industrial waste and agricultural runoff is discharged to the world's waterways annually. This problem contributes to 2.2 million deaths from diarrhea each year, mostly with children under five and millions of cases of trachoma caused blindness (http://www.the waterpage.com/basic_needs.htm).

In 2006, the UNEP estimated that 80% or perhaps even 90% of sewage entering the sea from developing countries was untreated and that governments should be investing $56 billion each year to address the problem.

Region	Estimated Percentage of Untreated Wastewater Entering the Sea
Caspian Sea	60%
Latin America/Caribbean	86%
East Asia	89%
South East Pacific	83%
West and Central Africa	80%
Mediterranean	53%

Table 2 – Untreated Wastewater Entering Selected Seas. http://www.scidev.net/global/pollution/news/un-agency-issues-warning-over-untreated-sewage.html

Arsenic is a particularly troubling natural contaminant in developing countries that use groundwater for drinking. It affects millions of people who cannot afford the cost to adequately treat the water to remove this toxin. Recently, the University of Florida conducted successful bench scale tests on the effectiveness of iron impregnated wood char to remove arsenic at low cost. The technology may also be effective in nutrient removal and CO_2 sequestration (Landers, February 2015).

Contaminants of Emerging Concern (CECs)

Since the mid-1990s, there has been an increasing concern raised from the recognition that a large number of unregulated yet widely used chemicals pose risk to our aquatic ecosystem and water supplies. Such chemicals are referred to as CECs.

These CECs include both new emerging pollutants, such as nano-materials and antibiotic-resistant genes, and existing chemicals with recently recognized health impacts, including pharmaceuticals, personal-care products (PPCPs) and endocrine-disrupting chemicals (EDCs).

Their harmful effects on human, animal and aquatic lives have already become manifest and it is possible that additional unknown harmful impacts are occurring because of them.

There is a large and ever-increasing number of CECs (i.e., more than 87,000 CEC candidates have been identified by the USEPA), making the conventional labor- and resource-intensive methods of monitoring water quality neither feasible nor economical. Although great progress has been made toward better understanding of the occurrence, sources and potential environmental and health effects from these CECs, one remaining challenge that remains is the lack of a realistic method for assessing and quantifying the harmful effects and risks exerted by these pollutants in water. This greatly hampers the development and implementation of effective regulations, strategies and technologies to control and eliminate their harmful effects.

While they compound the many health issues in developing countries, they are also presenting developed countries with challenges. This is due to the limited effectiveness of existing treatment processes in removing them from wastewater streams. Traditional water and wastewater treatment processes are not designed to eliminate most of the CECs, especially at the trace levels often present in drinking water and the aquatic environment.

Figure 6 – Many Bangladeshi Villages Have Wells With Naturally High Levels of Arsenic. http://en.wikipedia.org/wiki/waterissuesindevelopingcountries

Various treatment technologies have been explored and advanced oxidation processes (AOPs), such as

CEC	Ultrafiltration	MBR	RO	UF/RO	MBR/RO	MF	UV
Acetaminophen	6	0	90	95	100		
Atrazine	15				0		
Carbamazepine	16		99	99	99	8	0
Diclofenac	3		97	95	82	-20	0
Dilantin			99	99	95	-3	0
Estradiol					0	-27	0
Estrone			90	97	97	-15	0
Galaxolide			99	99		4	9
Hydrocodone	14		99	99	97	6	0
Ibuprofen	8	-59			100	-32	0
Iopromide	-5		98	95	0	-3	0
Meprobamate	6	-106	100	100	99	16	0
Naproxen	13	86	94	95	100	-20	17
Oxybenzone	84	0	96	98	99	36	66
Progesterone	98				95		
Sulfamethoxazole			98	99	99	2	47
TCEP			95	95	96	9	65
Testosterone					96		
Triclosan			90	97	99	53	0
Trimethoprim	18		99	99	99	8	0
DEET			99	99	99	23	50

Table 3 – Effectiveness of Some Treatment Processes in Removing Selected Contaminants of Emerging Concern (CECs). April Gu, Northeastern University

photocatalysis, ozonation, chlorine dioxide, Fenton-based processes and other strong oxidants, have been reported as promising for effective degradation of CECs. In consideration of the energy and cost, and within the economically reasonable range of doses and reaction time commonly applied, the mineralization rates (i.e. TOC removal) by AOPs are generally low, generating byproducts often with higher polarity and solubility than the parent compounds. In some cases, the resulting consequence of this is that, although the targeted parent chemical treated may be reduced, the generated transformation products with higher solubility and polarity in the water may exert toxicity higher than the removed parent chemical.

CEC removal is an active area of global research and development. Great scientific and engineering challenges exist in addressing the water quality problems associated with CECs in terms of understanding their harmful impact and risk, and developing cost-effective remediation technologies.

Two of the six AWWA Water Research Foundation's (WRF) priorities are associated with some CECs (endocrine disruptors and pharmaceuticals). The other four being the water energy nexus, Cr+6, water system infrastructure assessment and advancing the science of water. The December 2013 *Journal AWWA* notes that the University of Bath in the UK is looking at using sea shells to polish wastewater effluent and remove undesirable substances, such as hormones, pharmaceuticals and fertilizers.

Scarcity

The world's population is expected to grow from today's slightly more than 7 billion to 9 billion, eventually peaking around 9.4 billion by 2070 and then decline to around 9 billion by 2100, according to population projections from IIASA researchers, published in a book, World Population and Human Capital in the 21st Century. Alternative scenarios included in the projections range from 7 billion to almost 13 billion by 2100 (http://phys.org/news/2014-10-world-population-peak.html).

Much of this growth will occur in cities that are already struggling to meet the needs of their current populations. Even now, access to water is limited in many areas and the infrastructure we rely on to deliver it and provide for sanitation is deteriorating.

The European Environmental Agency (EEA) has projected that the demand for fresh water could approach 7

trillion cubic meters by 2030–a deficit of about 3 trillion cubic meters (m^3). In 2009, the 2030 Water Resources Group made a similar estimation of 4.5 trillion m^3 in 2009 to 6.9 trillion m^3 in 2030 (Charting Our Water Future). Most of the growth in demand is likely to be in developing countries and associated with more and wealthier people in these geographies.

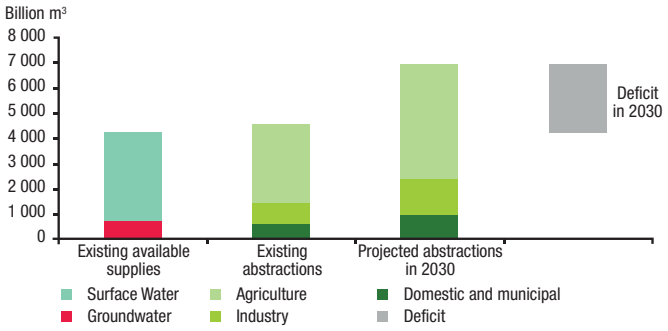

Figure 7 – EEA Projected Demand For Fresh Water. http://www.eea.europa.eu/data-and-maps/figures/forecast-of-global-water-demand

According to the United Nations, water scarcity affects every continent: 1.2 billion people live in areas of physical water scarcity and 500 million are approaching this situation.

About 1.6 billion face economic water scarcity (http://www.un.org/waterforlifedecade/scarcity.shtml). In addition, "in a growing number of countries, water has become the single most important constraint to increased food production" (Seckler, 1998). In an effort to define water scarcity, a study by Falkenmark, Lundqvist, and Widstrand, indicated that 1,700 m^3 per capita per year of available water supply or more is the level above which shortages will be local and rare; below 1,000 m^3 per capita per year, water supply begins to hamper health, economic development, and human well-being; and at less than 500 m^3 per capita per year, water availability is a primary constraint to life." The UN has listed the minimum water needed for personal and domestic uses as 50 to 100 liters per person per day.

Also, according to the Seckler report, about 108,000 cubic kilometers (km^3) of water precipitates annually on the earth's surface. About 60 % (61,000 km^3) evaporates directly back into the atmosphere. If the remaining 47,000 km^3 were evenly distributed, which, of course, is far from the case, it would equate to approximately 6,700 m^3 per person per year, which would be more than enough.

Virtual Water

While fresh water cannot be evenly distributed across the globe, emerging concepts like "water footprints" (i.e., a measure of the amount of water used to produce the goods and services an individual, community, business, or nation utilizes), "virtual water" (i.e., the amount of water that is embedded in the production of food or other products) and "virtual water trade" have the potential to mitigate some of the consequences of uneven distribution. These concepts can encourage individuals to conserve and countries, industries and the agricultural community to consider the global impacts of their water use decisions. For example, countries with arid climates may be encouraged to import water intensive foods and products from countries with wetter climates.

In some developed countries, water demand could actually decrease (at least from a per capita standpoint) due to a focus on conservation and the overall attention being paid globally to water footprints and sustainability. According to the United States Geological Survey (USGS), total potable water demand has in fact declined in the United States since 2005 by 13% and per capita demand has declined to 337 liters per capita per day (LPCD) from 379 LPCD (*Journal AWWA*, January 2015). Dyballa and Hoffman report a reduction of public and self-supplied domestic use in the United States of about 16%, since 1990. However, unless more substantial fresh water demand reduction strategies are implemented, especially those related to agriculture, population growth and increased wealth in developing countries will likely overwhelm efforts to reduce water consumption, resulting in a continued increase in the global demand for fresh water.

Overuse

The International Water Management Institute (IWMI) reports that in some parts of the world, including the semi-arid regions of Asia and the Middle East, the groundwater table is falling at an alarming rate (Seckler, 1998). IWMI believes there is an urgent need to focus the attention of both professionals and policy makers on the problems of groundwater depletion wherever it is occurring. Reportedly, more than 40% of the world's current population live in countries that are over pumping aquifers. Some of this over pumping is from "fossil aquifers" that do not have a significant, if any, recharge mechanism (Brown, 2013). A continuation of this trend could negatively impact food supplies at a time when substantial increases are predicted to be needed.

The severe drought in California is resulting in increased groundwater extraction that is causing concern about recharge, declining groundwater tables, reduced groundwater quality and sinking land (Hasselgrove, 2014). Consistent with sustainability principals, we should not be consuming more water than can be replenished for future generations. The mining of groundwater supplies and excessive withdrawals from surface supplies must stop, unless a compelling sustainable case can be made for continuance. Falling groundwater tables not only reduce available supplies for future users, but also can cause lowering of ground surfaces, and, in concert with rising sea levels, can exacerbate salt water intrusion problems along some coastlines.

Similarly, safe yields of reservoirs should not be exceeded and the impacts of climate change must be considered. Rivers need minimum flow and should not be allowed to run dry due to human causes. To achieve these objectives, we need to consider the big picture and take well planned aggressive action.

Total Supply Planning

On a rational level, the need to consider groundwater aquifers as a component of a hydraulic resource system is accepted. However, sometimes this element of water resource management is not given adequate consideration. Groundwater is everywhere, which often means it can be the cheapest and most convenient component. However, it still seems that more thorough studies into the benefits of integrating groundwater into a given water resource system are required, providing that such integration does not lead to the over pumping problems noted above.

Figure 8 – Mijares River Basin, Spain. Millars (Wikimedia Commons)

The Mijares River Basin on Spain's Mediterranean coast is an excellent example of the combined alternate use of surface and underground resources. The system has three reservoirs with a net capacity of 178 cubic hectometers (hm^3). Two have serious leaks, with average losses of about 45 hm^3 a year, but those leaks contribute to the recharge of the Plana de Castellón groundwater aquifer. Approximately one third of the 35,000 ha area uses surface water for irrigation; another third uses groundwater for urban and industrial demands; and the remaining third uses sources alternately, depending on the availability of surface water. Traditional irrigation using surface water generates return flows that also recharge the aquifer.

Consequently, surplus water levels protect the aquifer from salt water intrusion. In years of heavy rain, as the availability of surface water increases, reservoir and river losses also increase, enhancing aquifer recharge. It has been estimated that variations in the aquifer volume can exceed 700 hm^3, which is more than three times the storage capacity of the reservoirs (Sahuquillo et al., 2010).

Users manage resources in such a way that supply problems even in periods of severe drought are minimal.

Capital Programs

Serving the needs of those without clean water now, projected increases in water demand, deteriorating quality, more stringent regulations and excessive withdrawals all are driving the need for capital programs to increase the sustainable supply of clean water. Basic water treatment will be required for those in need and advanced treatment, such as desalinization, will be needed where raw water quality has become brackish, has other wise deteriorated or where oceans need to be used to supply arid coastal areas. Reservoirs, wells, dams, pipelines and ancillary facilities will all be required as well.

In addition, basic sanitation needs to be provided to all who need it as soon as possible. Wastewater conveyance and treatment systems will also be required to address population growth and ongoing pollution issues associated with inadequately treated wastewater polluting receiving waters or contaminating groundwater aquifers.

Membranes are particularly attractive for meeting future treatment needs due to improvements in process technology and effectiveness. Some of the world's largest desalinization plants are in the Middle East - Jubail Saudi Arabia (800,000m^3 per day) and Jebel Ali in the United Arab Emirates (2.13 billion liters per day). Membrane systems, effective in desalination, are also cost effective in treating brackish water and, as we have seen, in treating some CECs.

As drinking water regulations become more challenging and more sophisticated—and expensive treatment processes are developed to meet them—we should rethink the need to treat to potable water standards the water that is not used for drinking, bathing or cleaning.

More direct and indirect reuse options will be part of the solution to our water challenges as will conservation programs aimed at reducing waste and per capita potable water consumption.

As the cost to transport and treat wastewater increases and the global community's ability to properly fund these efforts declines, we must consider less costly local or decentralized options.

Energy-Water-Food Nexus

Most of us have heard of the energy–water nexus. Simply put, large amounts of one are usually required to produce and distribute large amounts of the other. Recently food has been added to the nexus since about 70% of global fresh water use is associated with agriculture.

Currently, it is estimated that more than 1.5 billion people do not have reasonable access to electricity. Addressing this need, along with the expected increased demand from those that do, will result in energy being a major global issue in this century. Meeting this demand will likely further stress fresh water supplies.

The vast majority of the world's energy, in the vicinity of 80%, is produced from fossil fuels, which are a major source of CO_2 emissions—a major contributor to global warming as well as the rising and acidification of our seas. Despite the increasing use of alternative energy generation, the world will likely remain dependent on fossil fuel for much of its energy for the foreseeable future. According to the USEPA, CO_2 makes up 77% of the greenhouse gases in the world's atmosphere, with about 75% of that emanating from fossil fuels. Methane and nitrous oxide make up almost all of the remainder. CO_2 emissions have been increasing over the past century – more rapidly in the last half.

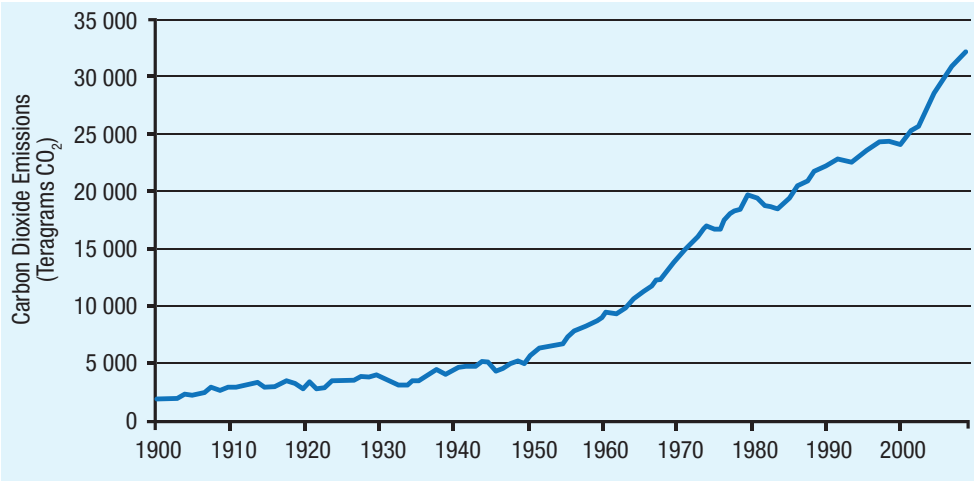

Figure 9 – Source of data: Boden, T.A., G. Marland, and R.J. Andres (2010). Global, Regional, and National Fossil-Fuel CO2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2010.

While this trend is alarming, there is significant global activity that might result in a reduction of CO_2 emissions, or at least a dampening of the rate of increase in the future. Countries all over the world are taking action to reduce CO_2 emissions through more use of renewable energy and people are becoming more aware of the need to use global resources more sustainably. Also, technologies are evolving, such as sequestration to capture CO_2 before it discharges to the atmosphere.

A somewhat recent challenging issue in some countries is the emergence of more sophisticated and effective hydraulic fracturing techniques for oil and gas development, which is creating regulatory challenges. Recently, the USEPA issued an advance notice of rulemaking related to hydraulic fracturing, which is proposed to apply to government land in the United States.

A major reason for the new regulations on hydraulic fracturing is the concern about possible impacts to groundwater quality. A similar concern has been expressed about certain types of CO_2 sequestration.

The challenges associated with agriculture are quite significant as well. The demand for agricultural water could also increase as the global population grows and more middle classes emerge, along with their desire for richer diets. The developing world's demand for meat has tripled in the last four decades, while egg consumption has increased seven fold (Foley, 2014). The developing world's demand for meat will put more pressure on the agricultural community to produce food in sustainable ways. Consideration of "what to grow and where to grow it" will become more prevalent. Such decisions, which are already politically and economically difficult, will likely become even more complex as our climate changes. Thus, the need for advances in techniques to use fresh water more effectively for agriculture, which is already critical and will become even more so in the future.

A Call For Action

Growing populations, increasing wealth and providing basic needs to the poor will place even more pressure on already stressed and overly used fresh water supplies. The world needs to address this from every direction possible. This should include more focus on reducing fresh water demand; rethinking how we supply fresh water; changing how we treat, distribute and collect water, wastewater and stormwater; and ensuring that reasonable climate change mitigation strategies are implemented. Potable and agricultural fresh water demand reduction, localized facilities, considering all elements of water as a resource, addressing infrastructure needs, sustainability considerations and better big picture planning will all have a role in effectively addressing our water challenges before they become our water crisis.

Demand Reduction

Overview

While large capital programs will be necessary to address our global water challenges, their number and cost can be minimized through fresh water demand reduction. Techniques to do this are less agricultural use, potable water demand reduction, including addressing the cost of water, and reuse.

Agricultural Demand Reduction

Improvements to irrigation efficiency, crop management (especially what to grow and where to grow it) along with more reuse should all play a role in agricultural fresh water demand reduction.

According to IWMI Report 19, "There is a wide range of irrigation practices and technologies available to increase irrigation water productivity, ranging from the conjunctive use of aquifers and better management of water in canal systems, to the use of sophisticated basin-level sprinkler and drip irrigation systems" (Seckler, 1998).

Water footprints and virtual water trade are particularly germane to agriculture fresh water use issues. If one country exports a water intensive product to another country, it exports water in virtual form. In this way some countries support other countries in their water needs." (Zimmer, 2013). Water scarce and water rich countries could both benefit by trading water-intensive products and in so doing improve water use efficiency, water supply security and reduce global fresh water demand.

A significant amount of research is being conducted on virtual water trade. While the details are beyond the scope of this document, Figure 10 provides some graphic indication of the amount of fresh water (blue - surface or groundwater, green - rainwater, and grey - fresh water required for pollution assimulation) that could be involved in virtual water trade associated with agriculture.

The "numbers" are significant and indicate the potential of virtual water trade concepts to help governments address the agricultural element of fresh water demand reduction.

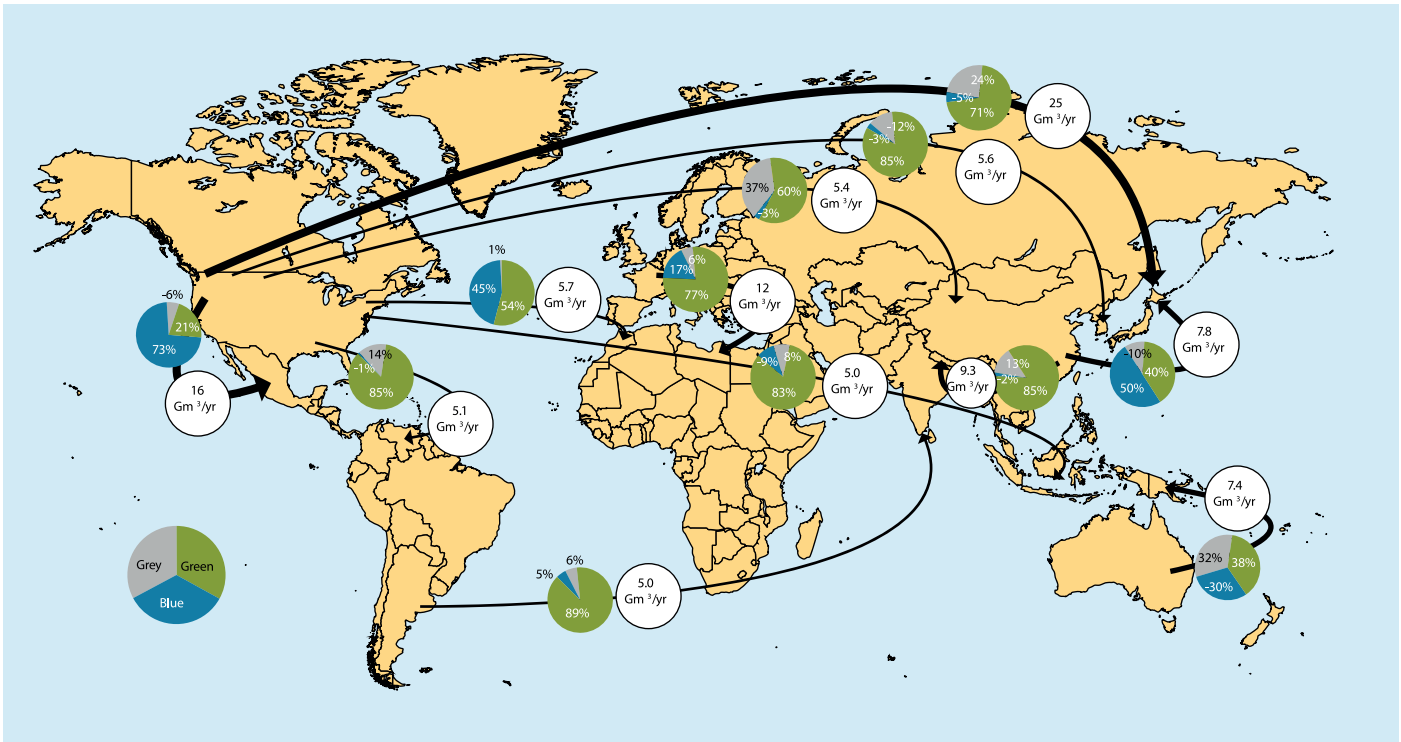

Figure 10 – Global Water Savings Associated with International Trade in Agricultural Products (1996-2005). The United Nations World Development Report 4. "Managing Water Under Uncertainty and Risk" Mekonnen and Hoekstra 2011, p. 24. Note: Only the biggest water savings >5 Gm^3 per year are shown.

Dialogue about water footprints and virtual water are evolving and figures related to the water used to produce a product are best estimates and contain myriad assumptions. Values of water footprints can also vary by geography, but regardless of location, the magnitude of water footprint values is, in some cases, startling. Tables 4, 5 and 6 list the water footprint for a variety of goods, for energy production, and for countries, respectively.

Item	Global Average Water Footprint
Peaches	910 liters/kg
Oranges	560 liters/kg
Olives	3,015 liters/kg
Egg	196 liters
Cotton shirt	2,495 liters/250 gm
Chicken	4,330 liters/kg
Beer	74 liters/250 ml
Milk	250liters/250ml glass
Cup of Coffee	140 liters
Beef	15,400 liters/kg
Chocolate	17,196 liters/kg

Table 4 – Selected Water Footprint Values for Various Items. http://waterfootprint.org/en/resources/interactive-tools/product-gallery/

M^3/GJ	
Natural Gas – 0.11	Wind – 0
Coal – 0.16	Solar – 0.27
Crude Oil – 1.06	Hydro – 22
Uranium – 0.09	Biogas – 70 (Range 10-250)

Table 5 – Average Global Water Footprints for Energy Production http://temp.waterfootprint.org./?page=files/Water_energy

Country	Average Water Footprint M3/capita/year	Part of Footprint Falling Outside of the Country Percent %
USA	2,483	19%
Greece	2, 389	35%
Spain	2,325	36%
France	1,875	37%
Australia	1,393	18%
Brazil	1,381	8%
UK	1,245	70%
Global Average	1,243	–
Japan	1,153	64%
India	980	2%
South Africa	931	22%
Bangladesh	896	3%
Haiti	848	1%
China	702	7%
Ethiopia	675	1%

Table 6 - Global Water Footprint for Selected Countries. www.waterfootprint.org.

There are a number of articles written about virtual water, footprints and virtual water trade. Many are mentioned in the bibliography. Readers interested in learning more are encouraged to peruse the referenced articles and authors as a starting point.

Potable Water Demand Reduction

In water distribution systems, demand reduction can be subdivided into two major elements: minimizing non-revenue water and reducing consumption. Two other strategies to reduce potable water demand are establishing appropriate water rate structures and reuse.

Non Revenue Water and Consumption Reduction

The World Bank has estimated non-revenue water to range from 15 to 40%, reaching as high as 60 to 70% in some developing countries (Cahn, 2014). Sources of non-revenue water include inaccuracy or absence of meters and unauthorized use, leakage and system maintenance, such as flushing.

Well planned metering and operations and maintenance (O&M) programs can be effective in reducing non-revenue water. To assist utilities in this endeavor, the International Water Association (IWA) and AWWA have developed a Water Audit Method - M36 (Jernigan, 2014).

Some utilities are implementing smart water networks (SWNs) to reduce demand and to manage other elements of their systems, including water quality and energy usage, which can be as much as 30% of a utility's cost. Many SWNs use remote sensing to detect meter inaccuracy and leaks thereby allowing them to rectify problems early. SWNs also often use automated pressure regulation systems to lower energy costs and reduce leakage volume. It is estimated that SWNs could save U.S. customers $12.5 billion per year (Cahn, 2014).

At the residential level, a Water Smart Software system developed by Peter Meyer, founder of Water Demand Management, has reportedly been used to create individualized water scores for households, creating peer pressure to reduce consumption. In addition to providing a water score, advice can be provided to homeowners regarding consumption reduction techniques (Hasselgrove, 2014).

Another common demand reduction strategy is to reduce outside use. Rules prohibiting the use of potable water for plant and lawn watering except on designated days are becoming more common. Incremental water rate structures that charge a premium for external household usage also has the potential to reduce consumption by encouraging consumers to more efficiently irrigate, reduce areas that need it and limit car washing activities. In an effort to help consumers maximize the efficiency of their irrigation

systems, Atkinson (2015) reports that hydrogels are potentially attractive as soil additives.

"HYDROGELS ... HELP RETAIN WATER (AND CAN) ABSORB 400 TIMES THEIR WEIGHT IN WATER AND NUTRIENTS, AND THEN RELEASE 96% BACK INTO THE ROOT SYSTEM" (ATKINSON).

Society's growing awareness of the need to be less wasteful, is by itself, contributing to domestic potable water demand reduction. One utility's consumer rebate program to encourage the use of water efficient appliances resulted in reduced overall consumption just due to increased awareness. In short, customers realized that "if the utility is paying us to conserve water, the need to do so must be very important" (Pushard and Michael, 2014).

In addition, the severity of the drought in California has resulted in government driven consumption reduction mandates, which appear to be getting the desired results.

Water Rates

Most people who work in the water and wastewater field agree that, with the exception of the poorest among us, water is generally underpriced. This encourages overuse. At the September 2013 Singapore International Water Week, Water Utility Leaders Forum, one topic of discussion was the need to communicate to stakeholders that the cost of not sufficiently investing in a water service is far greater than the cost of the service itself.

Consumer understanding of the need to increase our investment in water and wastewater systems is an important element in attacking the underpricing problem. If people were better informed, they would likely be more supportive of increased rates and fees for water service.

"ACCORDING TO THE WORLD BANK, THE AVERAGE (MEAN) GLOBAL WATER TARIFF IS $0.53 PER CUBIC METER. IN DEVELOPED COUNTRIES THE AVERAGE IS $1.04, WHILE IT IS ONLY $0.11 IN THE POOREST DEVELOPING COUNTRIES."

When discussing the price of water, affordability should be considered for all customers, not just the most needy. In the United States, the USEPA has suggested affordability rates of 2.0% to 2.5% of median household income for water and wastewater service. The United Nations has suggested 3%. The actual costs could be 7% or higher for some poorer consumers." (Smets,2009). Actual average expenditures in developed countries are often well below the 2.5% figure.

"IN INDONESIA, A REGULATION ADOPTED IN 2006, PRESCRIBES THAT DOMESTIC EXPENSES FOR THE FULFILLMENT OF THE STANDARD OF BASIC NEEDS FOR DRINKING WATER SHOULD NOT EXCEED 4% OF THE INCOME OF THE USER…" (SMETS, 2009).

Historically, many utilities have established declining rate structures where unit charges decrease as usage increases. In California, that trend has reversed and more utilities, in an effort to reduce consumption, have implemented inclining rate structures. At some time in the future, if this trend continues, affordability may well be an issue in this state (Gaur et al., 2015).

It is encouraging that, in addition to the UN General Assembly, many countries have policies establishing everyone's right to clean water at an affordable price. Except for the extremely poor, consumers should pay for the actual cost of water, including maintenance. This is consistent with the most basic of sustainability principals.

To encourage conservation, utilities should consider protecting and perhaps even subsidizing for the very poor the water rates for basic indoor needs (washing, bathing, cooking, and laundry) with more "optional" outdoor uses such as lawn irrigation charged at rates above the cost of service (Day et al., 2014).

Two South American Country Approaches

Two countries in South America have notable approaches to water rates, considering household income. The Colombian system divides users into residential (by socio economic strata) and non-residential (industrial, commercial, official and special) categories.

The users in the middle stratum pay an equilibrium tariff (neither paying nor receiving a subsidy) while the richest stratum pays surcharges to benefit the poorest stratum. There is a first basic block of 20 m^3 per account per month, for the three subsidized residential strata, and a second non-basic block for use that exceeds 20 m^3.

Chile's subsidies for the poor, funded by the central government, are administered by municipalities who inform drinking water and sanitation companies of selected users' incomes. The amount to be paid by the user and the amount to be paid directly by the municipality are shown separately on the invoice. The percentage subsidized varies between 25% and 85% of the total consumption value (CEPAL-UN, 2013).

Revenue Issues

It should be noted that water revenue shortages can be exacerbated by successful demand reduction programs. Without increasing water rates, reduced usage translates into reduced revenue—at a time when increased revenue is needed to meet maintenance and capital needs. This issue is likely a particular concern in cities whose demographics and economies have changed due to population shifts or reduced heavy manufacturing. Some of these cities are dealing with stranded or excess capacity water assets, which are much larger than what is currently needed, but must be maintained or otherwise dealt with.

This is a particularly challenging issue in southeast Michigan, USA. The region's water distribution and wastewater collection system was designed for a different era when heavy manufacturing was robust. A water master planning study is underway to consider options to reduce the costs associated with managing the systems for current and future water needs.

> "THE DILEMMA FOR WATER UTILITIES IS THAT THEY ALREADY HAVE THE INFRASTRUCTURE IN PLACE, WHICH NEEDS TO BE MAINTAINED AND UPGRADED IRRESPECTIVE OF THE AMOUNT OF WATER SOLD TO THEIR CUSTOMERS" (QURESHI, 2014).

While not complete, the study projects life-cycle savings in excess of $750 million by reducing total water treatment capacity to a projected maximum day demand of about 3.8 million m^3/day and from a design value of about 6.4 million m^3/day, repurposing a water treatment facility to a high lift pump station, converting a raw water tunnel to transport finished water, and reducing booster pump station capacity. Non-revenue water will be reduced from 30 % to 15 % through improved production and customer metering, retirement of under-utilized distribution mains, and an accelerated program for water distribution main replacement.

Direct and Indirect Reuse

Reuse is a particularly attractive strategy for potable water demand reduction. Wastewater is reused directly after advanced treatment, or indirectly after discharge to local surface water bodies or groundwater aquifers, and then recycled back into the water supply. Currently, indirect reuse is more prevalent than direct reuse. Beyond demand reduction, reuse helps utilities reduce the expense of removing nutrients at wastewater treatment plants to meet increasingly stringent discharge limits for nitrogen and phosphorous compounds. Water reuse concepts are being implemented worldwide for a variety of purposes. See Figure 11.

Local systems with various available and emerging membrane treatment processes, including microfiltration, ultrafiltration and reverse osmosis systems, are advancing reuse because of their superior reliability and improving cost-effectiveness. The automated nature of such systems makes them amenable to remote monitoring and operation which can facilitate the operation of decentralized systems. An increasing number of local waste treatment systems are separating gray water from black water and reusing it at the same location in a variety of ways, such as toilet flushing, nutrient capture, and creation of building materials from solids. Other conventional reuse systems are recreational impoundments, golf course irrigation, crop irrigation, snow making, street cleaning, boiler cooling, groundwater enhancement, and stream flow augmentation. Innovative approaches to reuse are occurring throughout the world.

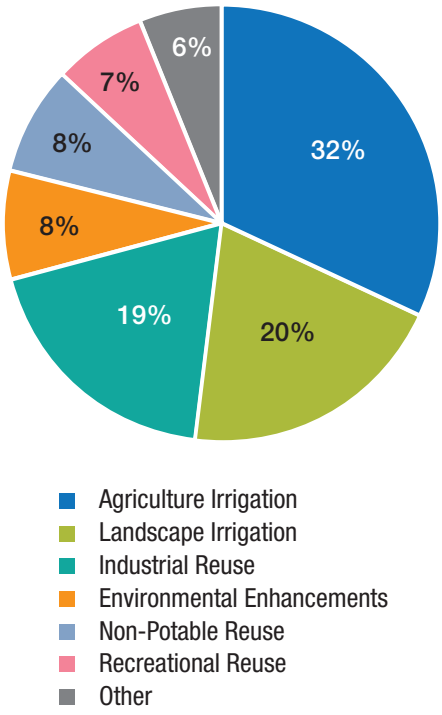

Figure 11 - After Advanced Treatment, Water Is Reused Globally For a Variety of Applications. GWI, and Lautze et al., 2014

The Orange County, California Groundwater Replenishment District (USA) treats wastewater treatment plant effluent to better than drinking water standards. The treated water is used for two purposes: a well injection system that serves as a barrier to saltwater intrusion and as a groundwater recharge system.

After receiving treated wastewater from the Orange County Sanitary District (OCSD), this facility further

purifies the water through microfiltration, reverse osmosis and UV light with hydrogen peroxide.

Figure 12 - Orange County Ground Water Replenishment District. http://gwrsystem.com/images/stories/About GWRS/GWRS%20Technical%20Brochure.pdf

Approximately 113,000 m^3 of the final product water is conveyed by a barrier pump station to injection wells along the seawater intrusion barrier. The remaining final product water is pumped to recharge basins.

At a raw water production facility (RWPF) in Big Springs, Texas, USA, filtered effluent from the city's conventional wastewater plant is treated with advanced technologies, delivered to the raw water pipeline system and then sent to five conventional water treatment plants (Salveson et al., 2014).

The reuse program in the Murcia region of Spain is especially effective, 90% of all wastewater in this area is treated and reused for irrigation.

Driven by its dry climate and population growth, the city of Windhoek, the capital of Namibia, has been using direct reuse for over 30 years (Nagel, 2015). Having served its design life, their plant was recently replaced with more unit processes to enhance water quality. A key element of their program since inception has been public outreach (http://sheffy6marketing.com/index.php?page=namibia).

In the developing world, untreated wastewater is often directly reused as fertilizer by the agricultural community because of the high nutrient value of domestic waste.

While this direct use of wastewater can create public health issues, the overall concept is beneficial. The World Health Organization (WHO) recognizes this and provides guidelines focused on mitigation as opposed to prohibition. As financial resources permit, these practices will hopefully evolve into fit-for-use treatment schemes, resulting in the agricultural community still receiving nutrients but from treated wastewater to mitigate health issues (Lautze et al., 2012).

Regulations and Public Health Considerations

The major barriers for widely implementing water reuse are more related to regulation, policy, cost and public concerns about health – not technical feasibility. These barriers must be addressed before closed urban water systems will be more widely accepted by the public.

Regarding public health, in addition to the conventional water contaminants such as pathogens, heavy metals and priority pollutants, another concern is the accumulation of CECs, which can enter the urban water cycle from a variety of sources, including sewage discharge, compounds leached from landfills, industrial wastes, agricultural and stormwater run-off, CSOs and sanitary sewer overflows (SSOs).

As noted previously, currently there is limited information regarding their toxicological effect and significance, and their discharge limits for water or wastewater effluent have not yet been fully established by regulatory agencies. These uncertainties complicate communication with the public and hinder acceptance of direct or indirect wastewater reuse.

While public acceptance of reuse (especially direct reuse) remains a challenge, the trend is toward acceptance due to increasing need and technical research results. Regarding the latter, reportedly one third of the water used in the United States can be recycled back into water supplies (Miller, 2015).

There is tremendous and diverse activity throughout the world on water reuse. More information can be found in the USEPA 2012 Cooperative Research and Development Agreement (CRADA) project report, titled "Reuse Guidelines."

It is indeed encouraging to see so much global reuse activity because of its potential to close the need vs. availability gap. Reuse is also becoming a broader consideration as more water professionals are looking at water in all forms as a valuable resource to be used and reused and not wasted. This is the subject of the next section.

Water as a resource
A paradigm shift

Overview

Water stress, the demand for basic sanitation facilities, and clean water for everyone not only pose great challenges for the technical community, but also are becoming more strategic issues for regulatory agencies, planners and other elements of government. To address the challenges in an environment of limited financial resources, climate change and population growth, we need a paradigm shift in our vision of water infrastructure and to consider all elements of it as a resource.

Global stakeholders must come together and adapt to changing circumstances to ensure the widest possible access to basic sanitation in the least damaging way. Thus, when thinking of water as a resource, we must address environmental and public health issues for both the wealthy and the poor. Addressing these problems will require engineers to work closely with social, ecological, legal, and financial experts and with all levels of government.

WEF HAS CHANGED THE TERM WASTEWATER TREATMENT FACILITIES TO WATER RESOURCE RECOVERY FACILITIES IN ALL ITS PUBLICATIONS (GUNDERSON, 2015).

There are many technical aspects to this paradigm shift, including centralized, decentralized and hybrid systems; domestic wastewater source separation; stormwater catchment; and using wastewater for energy generation and nutrient recovery.

Centralized vs Decentralized Systems

Urban water management systems can be classified as centralized, decentralized or hybrid. In a centralized system, potable water is produced and wastewater is collected for treatment at a central location before being distributed to users or discharged to the environment. By contrast, a decentralized system supplies water and treats wastewater locally. Hybrid systems incorporate elements of both by providing a centralized water and wastewater system backbone, connected with decentralized systems at selected locations. Purely centralized systems are often used by larger communities with high population densities, while fully decentralized systems are more suitable for more distributed communities. Even for larger urban areas, where centralized systems have been the norm, trends toward hybrid approaches are emerging.

Advantages of traditional centralized wastewater systems include the potential for large-scale biosolids processing, treatment and bio-energy recovery, as well as peak flow/demand attenuation.

In addition, basic treatment can be provided more cost-effectively at a central treatment plant but more advanced treatment (when necessary) can often be provided more cost-effectively at the local level.

Hybrid systems combined with reuse and resource recovery have multiple advantages. They offer the potential for increased water system security, resource recovery and sustainability. These are achieved by providing significant reuse opportunities, reducing conveyance costs, optimizing resource consumption through customizable and targeted treatment to meet local needs (instead of treating all water to the same high potable standards), and improving system security by reducing the impact of an event to a local area.

In addition, hybrid integrated urban water management systems can be phased in over time as areas within a specified urban area are developed and re-developed.

Household Source Separation

Perhaps the ultimate decentralized system is source separation at the household level. Instead of discharging all household used water to sewers, technology is currently available to separate household wastes into three streams: yellow water (urine), black water (other toilet wastes) and grey water (water from bathing and clothes washing). Each stream has significantly different characteristics and volumes, and separation of these streams allows them to be treated more economically for resource recovery and reuse. A good example of household separation is shown in Figure 13.

Urine waste has a very small volume compared to the

two other streams, but it contains the majority of the nutrients, such as nitrogen and phosphorus, and many CECs, such as some pharmaceuticals. Urine waste can be stored to allow for self-sterilization and degradation of CECs and then processed to produce fertilizer. Black water contains most of the degradable organic matter and therefore can be anaerobically treated to produce biogas, which in turn, might be used for hot water heating. Grey water, which has the greatest volume but contains less contaminants, can be economically treated for non-potable reuses such as landscape and garden irrigation and toilet flushing. Household source separation scores high in sustainability as it is compatible with potable water demand reduction, using waste water as a resource, and treatment cost reduction.

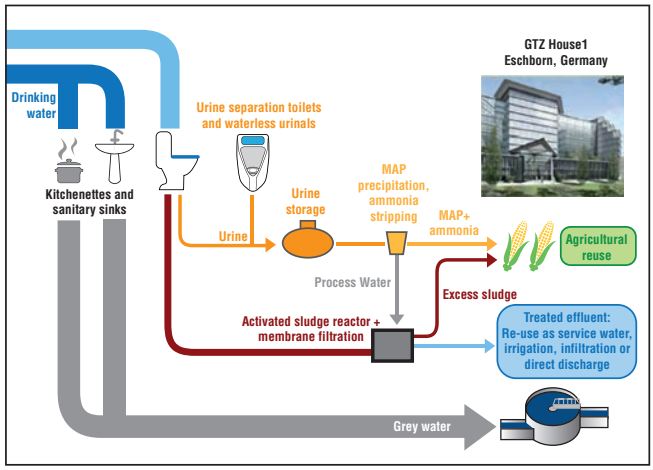

Figure 13 – Household Source Separation. Novotny, Vladimir, et al., 2010

Toilets that separately collect urine and fecal matter are now available, and approaches for incorporating them into overall wastewater management systems are being evaluated. For developing countries and rural areas in developed countries where new sewer systems are being contemplated, the infrastructure to support waste source separation and decentralized or hybrid wastewater management systems should be considered.

These types of systems are particularly suited for communities in very cold climates such as Alaska. The Alaska Department of Conservation (ADEC) has initiated an "Alaska Challenge" to encourage and accelerate research to provide household treatment systems to villages without centralized or decentralized treatment systems. Given the arctic conditions and fiscal constraints, ADEC believes there is a "potentially enormous demand for a decentralized technology to provide indoor water and sewer service, which will function reliably under harsh conditions and which has minimal operating and capital costs."

Satellite Systems

Hybrid or satellite/local treatment systems are especially attractive for new developments located a significant distance from a central conveyance system and treatment plant. Such systems can save energy, reduce conveyance costs, and reuse rainwater, groundwater and black water. One example of a satellite system is the Dockside Green Development in Victoria, British Columbia Canada. The master plan for Dockside Green, a mixed development, calls for treating all of its wastewater onsite.

Figure 14 - The Master Plan for Dockside Green. http:www.terrain.org/unsprawl/25, graphiccourtesyVancity/DocksideGreen

This community historically discharged primary treated wastewater into the adjacent Straits of Juan de Fuca. A sustainable development program, including Leadership in Energy & Environmental Design (LEED) certification, treated wastewater reuse, green infrastructure, water efficient appliances and stormwater capture/recharge was developed. The plan includes using plant effluent after membrane treatment for toilet flushing, irrigation and industrial use. The development also includes many water efficient appliances.

A large amount of stormwater is also captured locally via permeable paving systems, terraced ponds and greenways.

Comprehensive Stormwater Management Systems

Overview

Stormwater transports a variety of contaminants, such as particulates, nutrients, heavy metals, degradable organic matter, toxic organic pollutants and pathogens to receiving waters. Piped stormwater systems are increasingly seen as costly and performing somewhat poorly from a sustainability viewpoint. Consequently, alternative measures to reduce runoff and associated pollutant loads entering pipelines as well as to collect stormwater for supplemental water supply in drought stricken areas have been increasingly discussed. These discussions hinge around the concept of making stormwater a resource.

Best management practices (BMPs) for stormwater management provide opportunities for improving social, educational and environmental conditions in urbanized and surrounding areas. Recent low-impact stormwater management approaches incorporate various BMPs to harvest rain water then treat it for use as a local water resource for groundwater recharge.

Comprehensive stormwater management systems of the future will likely combine source control and end-of-pipe measures and include both structural and non-structural components. Many will be multifunctional: reducing flood risk, improving stormwater quality, enhancing groundwater supplies and providing urban green-spaces for recreation and wildlife. The use of source control in stormwater management aims to reduce the excessive runoff and the pollutant loads entering into the drainage system. These systems could include non-structural approaches such as alternative layouts of roads and buildings, minimizing imperviousness and maximizing the use of soils and vegetation, contaminant reduction, and educational programs to reduce stormwater pollution or structural measures, such as constructed wetlands, swales, rain barrels and similar stormwater capture facilities. The contribution of science and research to the areas of stormwater quantity and quality monitoring, collection and treatment technologies are continuously enabling a better understanding of stormwater characteristics and their effects on ecosystems and water resources.

Figure 15 - Innovative Stormwater Management Program - Philadelphia, Pennsylvania. Philadelphia Water Department - CDM Smith

While decentralized stormwater management systems score high on sustainability scales, the extent of decentralization needs to be balanced considering ecological as well as flooding factors. This requires comprehensive planning and dialogue among all stakeholders. Decentralization should not be a convenient way to free local authorities from the costly obligation of maintaining their stormwater infrastructure.

Figure 16 - Rain barrel Used For Collection and Storage of Stormwater. http://phillywatersheds.org/what_were_doing/green_infrastructure/tools

A good example of the advances being made in stormwater management is Philadelphia, Pennsylvania, USA. The city of Philadelphia is implementing a comprehensive approach to urban wet weather management, including stormwater management and control of combined sewer overflows in a sustainable manner with minimization of structural solutions.

The plan incorporates BMPs for vacant properties, city schools, recreation centers and other public properties. The program includes conceptual design of a low-discharge stormwater management system for a housing project redevelopment site. These BMPs have included seepage trenches, sand filters, bio-retention basins, porous pavement, swales, and subsurface storage and rain barrels, which can collect and store stormwater runoff from rooftops. The collected rain water can be used for irrigation to water lawns, gardens, window boxes or street trees.

Developing Country Stormwater Challenges

Although sustainability is currently a driving force in the evolution of water policy in developed countries, the more specific challenges of flooding and public health hazards are still the major issues in developing countries. Climate change, sea level rise and, in some cases, lower ground surface elevations are posing increasing challenges in stormwater management and policy making.

These issues are complex and will require investment and time for developing economies to address. One of the many strategies which should be considered is the concept of eco cities for planning urban areas in the developing world.

Eco-Cities and Zero-Waste Systems

The concept of the "eco-city" was proposed by an organization founded by Richard Register in Berkeley, California, in 1975. The concept is applicable to developed and developing economies. The ultimate goal of eco-cities is to eliminate all carbon waste, to produce energy entirely through renewable sources, and to incorporate the environment into the community.

Eco-cities offer various benefits, including stimulating economic growth, reducing poverty, organizing cities to have higher efficiency, and improving health. Water infrastructure and management is a crucial element of the eco-city.

Figure 17 - Eco City, Tianjin, China

An array of technologies and BMPs are included in the eco-city concept such as rainwater harvesting, smart irrigation (xeriscaping), and sustainable urban drainage and sewer systems. These help to reduce the amount of water needed for irrigation and to minimize the energy and resources required to deliver water supply and to minimize pollution.

THE ULTIMATE GOAL OF ECO-CITIES IS TO ELIMINATE ALL CARBON WASTE, TO PRODUCE ENERGY ENTIRELY THROUGH RENEWABLE SOURCES, AND TO INCORPORATE THE ENVIRONMENT INTO THE COMMUNITY.

There are about 170 eco-cities currently in the world, including Tianjin, China, Freiburg, Germany, and Stockholm, Sweden.

Improvements to the concept of eco-cities have been made over time. Currently, one hears a good deal about "Smart Cities", which utilize our ability to manage "big data" of all kinds and in all sorts of ways along with technological advancements and lessons learned over the years to create "Cities of Tomorrow". Much more information is available in many documents including FIDIC's "Rethink Cities" published in 2013. Some communities who are actively exploring smart city concepts include the Songdo International Business District on the waterfront of Inchon, South Korea, Rio de Janeiro, Brazil and Santander, Spain (Reid, 2015).

Valuable Contents of Wastewater

In addition to organic matter, wastewater contains nutrients (e.g., phosphorus and nitrogen) and other valuable substances. When concentrated sufficiently, organic matter can be combusted or converted into biogas and used for heat and electricity production through combined heat and power (CHP) systems. New technologies like microbial fuel cells can convert the energy value of organic matter into electricity. Heat can also be extracted directly from the wastewater stream and upgraded for a variety of uses using heat pump technology. Many other technologies are evolving to recover nutrients, generate energy and extract other valuable constituents from municipal wastewater.

Energy Generation

Urban water and wastewater management systems have the potential to be energy-neutral or even net energy producers, considering the potential energy contained in the wastewater. Energy use for a typical urban water management system (drinking water and wastewater) in the United States is around 15 to 20 watts/person, while the energy available in the organic matter and nitrogen contained in the wastewater stream is on the order of 35 to 40 watts/person (Daigger, 2009).

Nearly half of the energy consumption related to drinking water and wastewater systems is for water conveyance and collection. Proper planning and the prudent use of new technology can greatly reduce conveyance energy requirements, generate energy and capture heat. In so doing, it is possible to create energy-neutral systems (Daigger, 2009) via energy recovery from wastewater by biogas production, heat recovery, microbial fuel cells and other emerging technologies.

Through innovation and optimization, the 23,700 m^3/d Strass treatment plant east of Innsbrook, Austria, actually produces more energy (8,650 kW-h/d) than it consumes (7,870kW-h/d). (Wilson and Whitlock, 2014). A sludge plant at the Suzhou industrial park in China operated by the Sino French Water Development Company Ltd. produces 10GWh of excess energy from sludge, the ash from the sludge is used by the cement industry and much of its wastewater stream is recycled. A description of this facility was contained in materials prepared for the Singapore Water Week-Water Utility Leaders Forum event in September 2013.

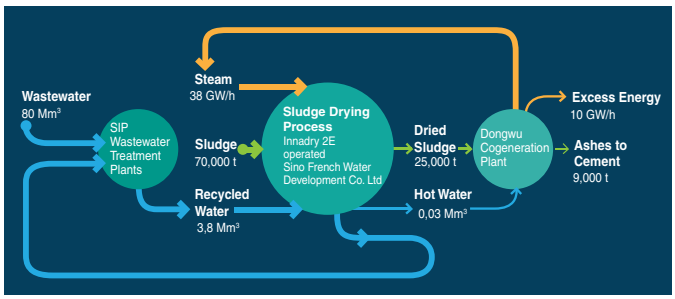

Figure 18 – Example of Energy Recovery at the Suzhoe Industrial Park in China. Page 12 of the document "Pushing The Water Management Envelope" – Insights From the Singapore International Water Week Water Utility Leaders Forum held in Singapore on September 18 and 19, 2013.

Anaerobic Treatment

Anaerobic treatment is commonly used to treat more concentrated waste streams, such as industrial wastes, or to stabilize biosolids. Research projects on anaerobic treatment technologies are providing new approaches in the co-digestion of other types of organic matter, including fats, oils, and grease (FOG); food waste; and industrial waste, with the aim to increase biogas production. Produced biogas can be used, after appropriate cleaning, in CHP systems, or further cleaned to remove CO_2, moisture and other undesirable impurities to produce natural gas. Recently, the application of anaerobic treatment processes involving granular sludge or anaerobic membrane bioreactors for direct treatment of wastewater have been demonstrated.

An anaerobic lagoon at a beef processing plant in Queensland, Australia, is reducing its dependence on natural gas and improving its carbon footprint. The plant is expected to pay for itself in 5 years. See Figure 19.

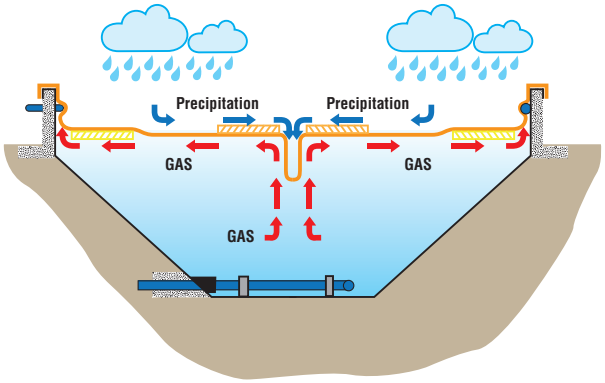

Figure 19 - Anaerobic Lagoon in Australia. Journal AWWA, May 2014, Pg. 97.

Energy Recovery Via Heat

Because a significant amount of energy is available with only a modest change in water temperature, heat can be directly extracted from a flowing wastewater stream for a variety of purposes, including district heating systems. Organic matter removed from the wastewater can also be treated in thermal processes to produce excess heat energy for direct use or for electricity production. Thermal processes can also be used to gasify these solids, with the gas subsequently used for energy production. In the process, heat is removed by heat exchange and converted into more useful forms using heat pumps. Although applications are currently limited, use of these technologies is increasing.

Microbial Fuel Cells

Microbial fuel cells are a developing concept for converting organic matter and nitrogen contained in wastewater into electrical energy (Logan et al., 2006). Bacteria extract electrons from organic matter and nitrogen and transfer them to oxygen, producing water. Extensive laboratory-scale research has been completed with this technology, and the scale-up to practical application is on-going.

Biofuel Production From Algae

Biofuels derived from microalgae is considered to be a promising emerging technology. Coupling algal cultivation with wastewater treatment is an environmentally friendly way to produce biofuel. The large quantities of freshwater and nutrients required for algae growth can be provided by various wastewater streams (e.g., agricultural run-off, industrial and municipal wastewater), while at the same time remediating wastewater.

Figure 20 - Biofuel Production from Algal Cultivation Using Wastewater. http://www.sciencedaily.com/releases/2015/04/150402132800.htm E. Siemann/Rice University

Moreover, the algal cultivation can be used for carbon-neutral fuel production if combined with other CO_2 sources (e.g. power plant or other emissions), thereby providing an effective carbon recycle and sequestration system to generate carbon credits and reduce greenhouse gas (GHG) emissions. An integrated algal cultivation and wastewater treatment system can provide both biofuel production and wastewater treatment for biochemical oxygen demand, nitrogen and phosphorous removal and recovery.

However, before advanced wastewater-based algal biofuel production technologies can be widely implemented, more research is needed to improve system tolerance and stability, develop more efficient and cost-effective algae harvesting and conversion technologies, and design economical integrated bio-refinery processes.

Nutrient Recovery

Recovery of nutrients, particularly phosphorus, from wastewater has been of interest because of the deleterious effect nutrient enriched wastewater and runoff has on receiving waters, potentially leading to eutrophication, especially in lakes, and its value as

a fertilizer. Phosphorus is also a limited resource with demand expected to exceed the supply in the future. It is estimated that about 15 to 20% of world demand for phosphate rock could be satisfied by recovering phosphorus from wastewater streams.

Lake Eutrophication

Lake Eutrophication is presenting challenges throughout the world. It is considered to be one of the most wide-spread environmental problems in the world's inland waters. As an example, the Albufera de Valencia lagoon in Spain was clear to the bottom in the 1960s. In the 1980s, the lake became one of the most eutrophic ecosystems in the world, reaching chlorophyll concentration peaks of 800 mg/l. A restoration program has been underway since 1991. Another example of nutrient related problems is the 2014 water ban in Toledo, Ohio, USA, caused by a blue green algae induced microcystin outbreak (Hunter, 2014).

Figure 21 – The Albufera de Valencia Lagoon, Spain. Carlos Oltra

Technologies

Nutrients can be recovered by a variety of technologies and from various wastewater treatment processes.

Options include recovery from biosolids incineration ash using conventional mining technologies, extraction from sludge, or processing solids recycle streams by precipitation for struvite or calcium phosphate. Struvite is a high-quality, slow release fertilizer, and calcium phosphate is similar to phosphate ore. Ammonia-nitrogen can be stripped from these streams and adsorbed into sulfuric acid to form ammonium sulfate, which can be used as a fertilizer.

Milwaukee, Wisconsin, in the USA has been producing a fertilizer (Milorganite) at their central plant for close to 100 years. In addition, Edmonton, Alberta, is constructing what will become Canada's largest nutrient recovery facility (10,000kg/day) (Knapschaefer, 2015).

The promotion of decentralized wastewater systems with source separation has led to the emergence of technologies for concentrating and recovering phosphorous from human urine, such as hybrid anion exchange or adsorption via polymers and nanomaterials. Integrated algal biofuel cultivation with wastewater treatment presents another alternative for recovering nutrients from wastewater.

Research

Research continues on techniques to cost effectively remove and recover nutrients from wastewater via new and enhanced treatment processes before discharge to receiving waters. One example is the Aby treatment plant in Aarhus, Denmark's second largest city. Sponsored by the Danish Ministry for the Environment, the project will test technologies to extract phosphorus from wastewater.

Figure 22 - Aby Treatment Plant in Aarhus, Denmark. Straton Childers 2014

The economics of nutrient recovery and energy generation are not always favorable, although fertilizer costs have recently been increasing faster than construction costs, so this part of the picture is changing. The economics plus the quantity of biosolids actually reused along with their nutrient content are all driving the need for more research.

Nutrients enter waterways from point sources (e.g., discharges from wastewater resource recovery facilities) and non-point sources (e.g., runoff containing natural and synthetic fertilizers).

Non-point sources are often the major contributor of nutrients entering a particular water body. Since removing nutrients from these sources is desirable, but often challenging, research is being conducted on in-stream mitigation techniques. In this connection, a recent study by the USGS and NOAA on the Chesapeake Bay in the United States has demonstrated that shellfish, especially oysters, are effective for in situ nutrient removal (Stratton Childers, 2014).

Another emerging area of research concerned with recovering valuable constituents from wastewater is being conducted at Arizona State University where some valuable metals including gold, copper and silver have been found in biosolids from a number of treatment facilities in sufficient concentrations to warrant additional research (Straton Childers, 2015).

Infrastructure

Total Water Infrastructure Needs

Global infrastructure investment is woefully inadequate and devastating consequences are expected if this matter is not addressed. Global expenditures in the trillions of dollars will be required just to maintain the status quo.

Consistent with their obligation to protect public health and safety, professional engineers must inform the global community about the world's water challenges and advocate for increased infrastructure investment in the world's water infrastructure. Professional engineering organizations have been taking action in this regard. In the United States, the American Society of Civil Engineers (ASCE) produces a report card on the nation's infrastructure. The latest report card gave drinking water, wastewater and dams a "D." The U.S.-based American Water Works Association (AWWA), Water Environment Federation (WEF), USEPA, American Public Works Association (APWA) and others have, in a variety of ways, stated the need for more investment to address water issues.

Aviation	D
Bridges	C+
Dams	D
Drinking Water	D
Energy	D+
Parks and Recreation	C-
Ports	C
Rail	C+
Roads	D
Schools	D
Solid Waste	B-
Levees	D-
Transit	D
Wastewater	D
Inland Waterways	D-
Hazardous Waste	D

Figure 23 - 2013 ASCE Report Card ASCE

On a global scale, the IWA, the United Nations, Engineers Without Borders (EWB), the IWMI, Water Supply and Sanitation Collaborative Council (WSSCC), Water for People (WFP), the Global Water Partnership, the Pacific Institute and other organizations have addressed global water challenges. FIDIC has consistently stated that the global investment in the world's infrastructure including water is insufficient. FIDIC often uses as a benchmark the ratio of infrastructure investment to GDP. The 2009 FIDIC State of the World Report on Infrastructure contains more information on country total infrastructure spending. A major finding in that report remains true today - while infrastucture spending as a percentage of GDP varies from country to country, it is not enough to meet the global community's needs.

Estimates

The actual annual amount of required expenditure is difficult to accurately estimate due to the variety of variables that need to be considered. These include the actual extent of population growth, emerging middle classes, sea level rise, innovative and cost-saving developments, effective public-private partnerships, regulatory agency actions related to streamlining, permitting and fit-for-purpose guidelines, intergovernmental cooperation, public acceptance of reuse, currency swings, smarter integrated projects that address multiple needs, and climate change. Many of these variables affect all new as well as aging infrastructure needs not just water.

Despite the difficulty of producing investment estimates, some have been made. The numbers are alarming. McKinsey recently estimated that US $57 trillion would need to be expended by 2030 to address global transportation, energy and water needs (Matthews, 2013). The Organization for Economic Cooperation and Development (OECD) has estimated that the global community needs to invest $17.5 trillion by 2030 to address the world's new and aging water infrastructure needs.(Wyman, 2012). While this is a large number, when annualized, it equates to only about 1.5% of the World's GDP. Barrie Stevens (Stevens, 2010) estimated the annual water and wastewater investment requirements for selected OECD countries in 2025 shown in Table 7.

Countries	Estimated Water and Wastewater Annual Expenditure Requirement $B/yr
USA	$170
France	$30
Germany	$40
Japan	$60
China	$245
India	$110

Table 7 – Estimated Annual Water and Wastewater Expenditure Requirements for Selected OECD Countries. Barrie Stevens, "Global Infrastructure Needs and Financing into the Future."

In the article "Engaging the Private Sector in Water Infrastructure Investment," OECD estimated that a $72 billion expenditure would halve the number of people without access to safe drinking water and adequate sanitation. The same article also included water infrastructure repair and replace requirements for Russia at $459 billion and Egypt at $13 billion.

The USEPA has estimated that $775 billion will be required for the U.S. water and wastewater system over 20 years (Lafferty, 2014). A breakdown of the estimate for drinking water is shown in Figure 24. The AWWA estimated a need for $1 trillion for U.S. water mains over the next 25 years (Lafferty, 2014).

A similar estimate for Latin America is $60 to $70 billion (Anderson, 2006).

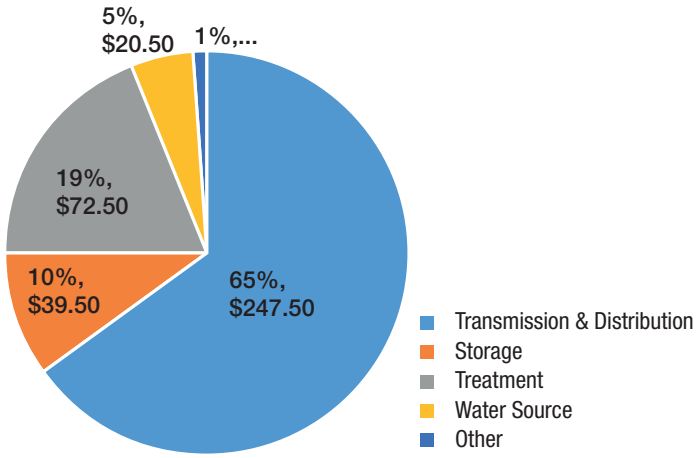

Figure 24 - Estimated Needed Investment in USA Drinking Water for 2011-2030. (Values are in Billions of Dollars) USEPA

While the magnitude of the various available cost estimates vary, considering the condition of the world's water infrastructure and the many issues mentioned previously, the message is clear. The global community needs to do more to address water infrastructure needs. Required actions include investing more money and ensuring that the right projects are done right. Engineers, as trusted advisors, are best suited to lead the latter action.

The rest of this section presents some thoughts on the unique challenges related to each major element of the world's aging water, wastewater and stormwater infrastructure (treatment plants, pumping stations, dams, pipelines and associated facilities).

Aging Infrastructure

Treatment plants

Treatment plants often represent the largest individual investment a utility faces. Accordingly, when they are close to serving their useful life and a rehabilitation program is in order, utilities are well advised to work with their engineer to develop a comprehensive rehabilitation program that should consider:

- The appropriate, sustainable and cost-effective processes to meet current and expected regulatory needs.
- The potential for onsite renewable power generation (e.g., solar, hydraulic, bio fuels for wastewater plants).
- The location and condition of the existing structures.
- The maximum hydraulic and structural capacity of existing facilities, using sophisticated modeling techniques, to minimize the requirement for new facilities.
- The correct balance between capital and operation and maintenance (O&M) expenditures.
- Fit-for-purpose treatment opportunities for wastewater plants (e.g., reuse).
- More hybrid or decentralization of facilities.
- The potential for resource recovery (e.g., nutrients, pharmaceuticals, process chemicals) especially for wastewater plants.
- Demand/flow reduction strategies.
- The potential for multiuse of facilities (e.g., laboratories, maintenance shops for the entire community etc.).
- Appropriate odor control (primarily for wastewater).
- Impacts of climate change including sea level rise, if appropriate.

Pump Stations

With the exception of process and resource recovery opportunities, the same above considerations apply to pump stations. In addition, pump station rehabilitation projects should include consideration of:

- Options to improve or reduce energy usage via more efficient pumps. This is particularly critical for water utilities since most energy consumed by water utilities is used for pumping. The average wire to water efficiency of pumping systems is currently around 55% in the USA. New installations are targeting 76% to 82% (Bigelow 2014).
- Effective operation of tanks for peak demand dampening.
- Variable frequency drives.
- Pressure reduction for drinking water systems and onsite power generation.
- For wastewater pump stations, the need for special devices to properly handle non dispersible contaminants such as flushable wipes and similar potential obstructions.
- For wastewater and stormwater pumping stations, the maximum capacity of existing wet wells using, if appropriate, computational fluid dynamics (CFD) modelling and the incorporation of appropriate hydraulic standards to prevent problems such as vortexing.

Dams

The main challenges related to dams (Spanish Committee on Large Dams, 2013) are:

- Structural condition (i.e., more than half the world's dams are more than 50 years old).
- Function vs original design intent.
- Increased environmental requirements.
- Ability to respond to important climate change challenges, such as more severe and frequent droughts and floods.
- Challenges associated operation of some existing structures beyond their originally planned life.
- Social demand for higher safety levels and risk reduction.

Most well-designed and well-built dams with good foundations can be heightened (Giron et al., 2010) to provide greater regulating capacity, improve hydroelectric power production, increase downstream safety and flood protection, and offer better protection against wave action or dam body settlement. In Spain, the height of Yesa dam was increased 38% from 78m to 108m, doubling the surface area of the reservoir and tripling its capacity. See Figure 25.

Figure 25 - Heightening of Yesa Dam, Spain. TYPSA

However, the primary reason for improving the world's dams is safety. Analyzing the condition of aging dams using state of the art analytical tools (e.g., structural, hydrological and geological techniques have all improved dramatically) and investing in effective maintenance to maximize functional life is essential. Risk assessment can provide valuable information on structural and non-structural risk reduction options (Bowles et al., 1999) to address both natural and anthropic threats.

Aging Pipelines

The developed world's distribution and collection system pipelines are feeling their age. Potable water pipeline systems are experiencing capacity reductions and the energy costs to deliver water have been increasing due to diameter reductions from tuberculation or sediment build up. These older pipelines are also exhibiting signs of increased leakage, and service interruptions due to main breaks.

The deterioration of wastewater collection systems are also leading to serious issues, such as SSOs that threaten the environment, public health and safety. Structural failures result in approximately 75% of the U.S. piping system functioning at 50% or less of capacity (ASCE, 1994). SSOs and exfiltration occur when there is a high level of Infiltration and Inflow (I/I) that enter the sewer systems via direct connections (e.g., roof leaders, drains) or underground passages (e.g., pipe joints, defective pipes, manhole walls). A deteriorating sewer network can exacerbate I/I problems by surging downstream piping and wastewater treatment plants and pumping stations. This may lead to sewer overflows in residential neighborhoods which, in turn, can pollute the groundwater and surface water supplies.

Stormwater collection systems have similar issues. Leakage and pipe failures cause pollution, albeit to a lesser degree than wastewater. Stormwater piping failures may cause streets to collapse, thus forcing road closures for repairs and creating traffic problems. And, of course, increased flooding is a major potential problem.

Regardless of what a pipeline is carrying, rehabilitation is significantly more complicated than the original installation due to the communities and roads that have been built over them. This makes replacement much more expensive and complex. Fortunately, trenchless technologies are available as an alternative to expensive pipeline replacement programs. Some of the most common methods are cleaning and cement mortar lining of unlined cast or ductile iron pipes, pipe bursting, pipe splitting, slip lining and cured-in-place lining and cleaning lines with poly pigs. All have proven effective in extending the life of existing pipelines, minimizing structural problems and reducing infiltration and leakage. Trenchless technologies generally score high from a sustainability standpoint, as well. Carbon output can be as much as 90% lower than pipe replacement (Corum, 2014).

In some instances, pipeline rehabilitation projects offer the opportunity to generate electricity via in line turbines (Landers, March 2015).

New technologies are also emerging for collection system maintenance, deterioration detection and rehabilitation, including sewer scanner and evaluation technology (SSET), sonar, seismic resurgence testing (SRT), acoustic testing; infrared thermographic investigations and electrochemical impedance or polarization decay for monitoring corrosion. Robots capable of locating and unsealing house and other connections have been developed and are being used more frequently resulting in a further reduction in excavation requirements.

Like any technology, it is important for owners to obtain quality advice from their engineer regarding the option or technique that best meets their needs. In providing this advice, engineers need to consider hydraulic factors, especially with slip lining that reduces pipe diameters, but also provides smoother pipe walls; the layout of the pipe to be rehabilitated; the need for bypass piping; and traffic disruptions.

Total System Approach.

Given the magnitude and complexity of addressing the aging infrastructure problems, all levels of government and the private sector must work together to develop sustainable effective, efficient and economic solutions. More advanced and cost-effective methods and technologies are needed to properly rehabilitate aging systems. Programs must also focus on improvements in management and O&M practice as well as system asset evaluation on a life-cycle cost basis.

Asset Management

Many utilities are implementing infrastructure asset management (IAM) programs to address the complexities of their infrastructure challenges. IAM includes a set of processes that utilities establish to ensure their infrastructure performance meets expectations, that risks are adequately managed, and that corresponding life-cycle costs are as low as possible.

Sustainable management of these systems should be geared to extending the service life of existing assets instead of more expensive new facilities when feasible.

Sustainability

Guidelines

Whether one is dealing with new or aging facilities, sustainability must be considered if we are to provide the public with clean and safe water and sanitation now and in the future. An increasing number of planning and regulatory agencies provide guidelines and roadmaps to help water and wastewater utilities sustainably plan and manage their water infrastructure and adopt innovative practices following green infrastructure or eco-city concepts. For example, in the United States, the USEPA has worked with states, industry and other stakeholders to release the "Clean Water and Safe Drinking Water Infrastructure Sustainability Policy" and "Planning for Sustainability: A Handbook for Water and Wastewater Utilities," which describes USEPA's overall vision and priorities for ensuring the long-term sustainability of water infrastructure and communities. The handbook describes a number of steps utilities can undertake to enhance their existing planning processes and ensure that water infrastructure lifecycle investments are cost-effective, resource efficient and support other relevant community goals (USEPA, 2010).

Assessment Tools and Methods

To be sustainable, a system must be socially acceptable, economically affordable and use environmental resources at rates that do not exceed their regeneration or replacement frequency. These principals are often referred to as the triple bottom line. Sustainability concepts do add complexity to the task of evaluating alternatives. The common approach of using Present Worth (PW) to evaluate options is no longer sufficient because it is a financial tool that does not consider sustainability and other factors. Tools that consider both the capital and life-cycle O&M costs of options on an equivalent basis with non-monetary factors are needed to help decision makers select the most sustainable option.

Fortunately, such tools are being developed. FIDIC's 2012 State of the World Report on Sustainable Infrastructure includes discussion of decision support and rating/certification tools and guidelines. Others have developed sophisticated computer models for helping decision makers evaluate alternatives in sustainable ways.

CDM Smith has developed an Urban Systems Model to simulate the performance of a city's water, energy, transportation, solid waste, urban form and other sectors; the relationships between these sectors; and the impacts related to land resources, greenhouse gas emissions and financial analyses. The urban systems model provides analytical capabilities for decision makers to consider a wide array of factors when evaluating alternatives.

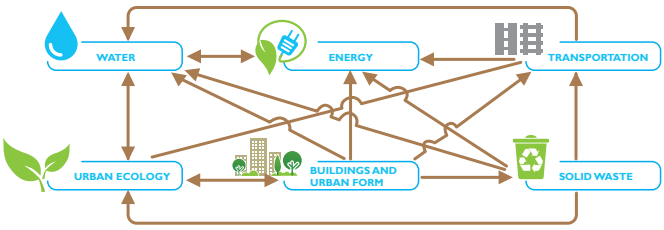

Figure 26 - Urban Systems Model Relationship Diagram. CDM Smith

The Envision Rating System by the Institute for Sustainable Infrastructure, is another tool that provides planning and design guidance, performance evaluation and award recognition to infrastructure projects that contribute to a sustainable future. The Envision Rating System is rapidly gaining acceptance throughout the water industry in North America and around the world (Nelson, 2014).

Risk and Opportunity Analysis

These tools can be effective when used in evaluating risk and opportunities associated with innovative technologies. They allow the inherent uncertainties in less developed technologies and approaches to be rationally addressed, thereby overcoming the bias that often prevents their selection. With the key risks and opportunities identified, an implementation approach can be developed incorporating the identified mitigation measures.

Identification of risks and opportunities also provides a rational basis for assigning them to the party best able to manage them (e.g. the owner, technology provider, contractor, engineer), thereby maximizing the likelihood of successful implementation. It is especially important for all stakeholders to be aware of the inherent risks involved with any new technology or approach. The engineer, operating as trusted advisor, can play a crucial role in this important aspect of alternative analysis.

Integrated Water Resource Management

The recognition of water, wastewater and stormwater as a resource; sustainability considerations; and cost pressures have created significant changes in water management and project planning. Consistent with this change is the concept of Integrated water resource management (IWRM), which scores quite high on sustainability scales due to its potential to address multiple issues simultaneously, which, in turn, dramatically increases the probability of the development of cost effective programs.

According to the Global Water Partnership, "Countries are experiencing water-related problems that are proving intractable to conventional, single-sector approaches. Some possible examples include drought, flooding, groundwater overdraft, water-borne diseases, land and water degradation, on-going damage to ecosystems, chronic poverty in rural areas, and escalating conflicts over water. The solutions to such problems may fall outside of the normal purview of the agencies tasked with addressing them, and usually require cooperation from multiple sectors. In such cases, an IWRM approach makes identifying and implementing effective solutions much easier. It also avoids the all too common situation where solving one problem creates another." Ideally, such integrated systems would be river basin-wide and possibly include multiple political jurisdictions or nations. Without IWRM at a broad enough scale, the risk of poorly conceived projects that do not address the big picture increases.

Even when executed at the local level, IWRM can reduce cost by addressing multiple issues under one project. For example, the Netherlands have integrated power generation and flood control in many of their projects.

Figure 27 - Netherlands-Flood Control and Wind Power Generation. https://www.google.com/?gws_rd=ssl#q=netherlands+flood+control

The Marina Barrage Project in Singapore is also good example, as it addresses flooding, water supply, recreation, aesthetic and education needs. Every year, thousands of people from all over the world visit the site to exercise, socialize and, most importantly, to learn a bit about water at the education center.

Figure 28 - Marina Barrage in Singapore. CDM Smith

Resilience

Overview

Climate change, the associated impacts of sea level rise, decreasing reliability of historical precipitation records and more intensive storms, along with threats due to accidents, vandalism and terrorism, have all added significant challenges to water resource engineers. This has resulted in the addition of "resilience" and more risk management into projects. "…Risks (of climate change) to infrastructure from extreme weather events, degradation of water quality and water supply and adaptation and mitigation of future impact…" are three of the 12 key findings of the US Global Change Research Program on National Climate Assessment (Wilcox, 2014).

Historically, water resource engineers used simulations of precipitation events based on past records as one of their tools in designing flood protection facilities. Climate change has seriously reduced the value of these simulations because of the probability of more severe and perhaps more frequent weather events in the future.

Since historical records are becoming less reliable for prediction of future storm frequencies, water resource engineers are being challenged to establish reasonable design criteria in a more uncertain environment. This is making scenario based planning, risk management and sustainability considerations even more important. Just one example of the challenges associated with establishing design criteria for flood control is London, England. Considering its 1.25 million population and property values of about $300 billion, London's flood control systems are using a 1 in 5,000-year event. However, sea level rise could increase this frequency to 1 in 100 years (Landers, March 2015, pg.21).

Planning Tools

To help utilities become better prepared for climate change related events and other threats, the USEPA has been developing tools and programs to assist utilities. Two of these include the CREAT (Climate Resilience Evaluation and Awareness Tool) and the Water Contaminant Information Tool (WCIT) tools. CREAT was developed under USEPA's Climate Ready Water Utilities initiative that assists drinking water, wastewater, and stormwater utility owners and operators in assessing risks to their assets and operations. Extreme weather events, sea-level rise, shifting precipitation patterns, and temperature changes will affect water quality and availability. CREAT provides access to the most current scientific understanding of climate change and guides users through a process of identifying threats, vulnerable assets, and adaptation options to help reduce risk, while comparing the performance of adaptation in mulitiple time periods across climate scenarios.

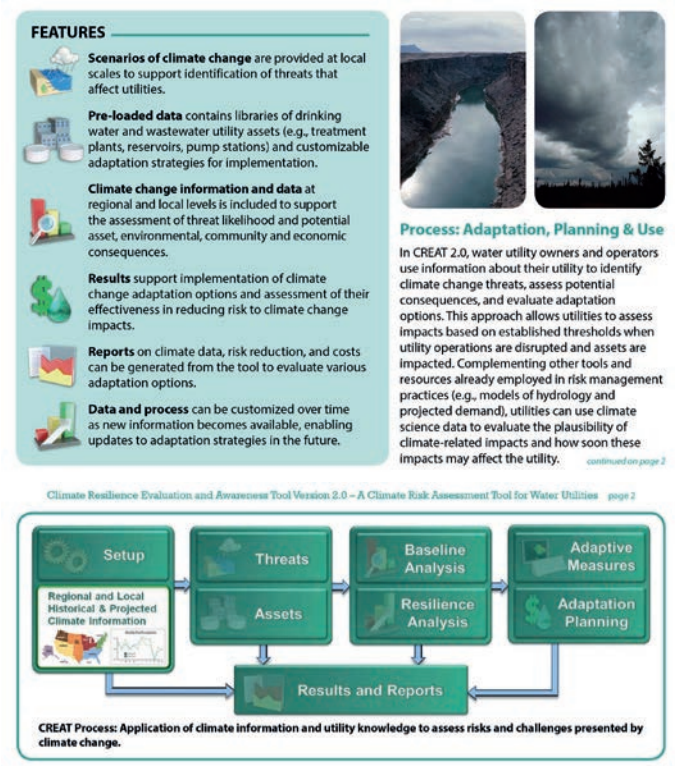

Figure 29 - Climate Resilience Evaluation and Awareness Tool (CREAT). http://water.epa.gov/infrastructure/watersecurity, Nov 2010

The WCIT tool is designed to help utilities plan for potential contamination incidents, whether man-made or natural. It includes information on governmental and regulatory officials to contact as well as emergency responders. It is a secure online database with comprehensive information about chemical, biological and radiochemical contaminants of concern for the water sector. This tool compiles drinking water and wastewater-specific data in a one-stop, easy to use manner. WCIT's functionality and content were shaped and validated by water utility professionals, scientists and public health experts. Summaries of these tools are shown in Figures 29 and 30.

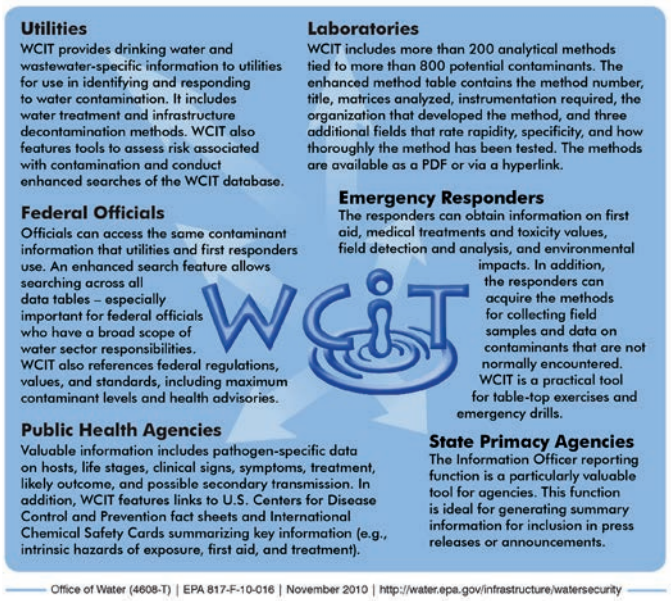

Figure 30 - Water Contaminant Information Tool (WCIT). http://water.epa.gov/infrastructure/watersecurity, Nov 2010

Dams and Other Resiliency Installations

Dams are critical in the flood control and mitigation element of resilience.

To address sea level rise and flooding due to more severe storms, coastal communities have been constructing levees, dikes, seawalls, massive tide gates and other similar low-elevation dams throughout the world. This trend will likely accelerate as the threat from sea level rise and climate change intensifies. London, Rotterdam, St. Petersburg, New Orleans and Shanghai have all built levees and stormwater barriers in the past few decades (Folger, 2013).

St. Petersburg, Russia, has constructed a multi-purpose flood control system to provide protection from flooding from the Baltic Sea up to 5.4 meters above sea level. See Figures 31 and 32.

Figure 31: St. Petersburg, Russia (Satellite View) http:\\water technology.net/projects/stpetersburgwater/

The multi-billion dollar project, which comprises flood gates, sluices, embankments and appurtenances, includes a portion of the city's ring road and some pollution control facilities.

Figure 32 - St. Petersburg, Russia Flood Control System http://www.transmost.ru/en/projects/integratedprojects/ artificial_structures_of_the_stpetersburg_floodprotection_barrier

With its highest land elevation about 3 meters above sea level and with 80 % of its land below one meter, the Maldives are particularly vulnerable to sea level rise. In addition to constructing resilient structures (a sea wall surrounds its capital, Malé), the government is considering population migration to another location as a mitigation strategy.

For New York City and environs, nearly US$1 billion has been allocated for six resiliency projects including a sustainable "living breakwater" project near Staten Island. The breakwater will have pore spaces for fish, accessibility for divers, and the project will include constructed tide pools and habitats for aquatic life (Cardno, 2014).

Figure 33 - Rotterdam, Netherlands – "Water Plazas" http://nationalmallunderground.org/examples-precedents/

Other strategies that are evolving include "floating architecture" as mentioned previously, and multi-use facilities such as underground garages that also serve as reservoirs for flood waters. In the Netherlands, the City of Rotterdam is taking what it considers a "holistic" approach to combating the challenges of flooding by developing dual-purpose stormwater collection facilities, including neighborhood, "water plazas" which are able to retain stormwater and reduce flooding, and green roofs that can absorb rain water and reduce runoff. The innovative dual-purpose Rotterdam Museum-park is both a parking garage for the city's museum district and a stormwater reservoir, which is capable of storing 10 million liters of stormwater in times of heavy rainfall, while providing 1,150 parking spaces for use during normal times.

See Figures 33 and 34.

Figure 34 - Rotterdam, Netherlands – "Green Roof" http://nationalmallunderground.org/examples-precedents/

Larger and higher dams will also have an even more important flood control resiliency role in the future. The analysis of 50 actual cases in Europe (European Working Group on Dams and Floods, 2010) concluded that the impact of dams on reducing peak flood flow values range from 12% to 100%, the average being 54%.

This analysis showed that, in general, dams and reservoirs benefit flood mitigation when they are well designed, properly maintained and operated. Of course, all dams are designed for a particular flood level and, therefore, may not provide total protection in the case of very extreme floods.

However, their effectiveness can be greatly improved via structural and non-structural measures, such as elevation increases and improved forecasting and alert systems.

A flood control plan for the Guadalentin River, a Tributary of Segura River in Spain, which has experienced severe flooding since the Middle Ages is particularly efficient. On September 29, 2012, torrential rain fell in the basin headwaters at a maximum rate of 179 l/m^2 in about 8 hours. As a result, the Valdelinfierno dam (one of the 13 dams in the watershed) recorded a peak flow of 4,570 m3/s, which the dam successfully retained.

Subsequent studies (Berga, 2013) showed that without the plan, downstream flow rates would have been approximately 3,000 m^3/s. The works of the plan reduced this to about 125 m^3/s.

Figure 35 - The Guadalentin River, A Tributary of the Segura River, Spain, September 29, 2012 – Diario Información

Government Role

Governmental entities have been involved with water issues throughout history, since water ways often form political boundaries between countries as well as states and communities within them. Governments also have primary regulatory and security roles for their citizens.

Transboundary Waters

As population and associated water demands increase, the pressure on governments to provide their citizens with adequate supplies will intensify, as will the pressure from adjacent jurisdictions to provide environmental flows to transboundary waterways. This could lead to more disputes over ownership of water resources. In the worst case scenario, wars could be fought at least in part over water supply. According to the United Nations, there are 276 transboundary river basins in the world – 64 in Africa, 46 in North America, 60 in Asia, 68 in Europe and 38 in South America (UN Water.org). Approximately 40% of the world's population relies on water from international river basins (Gleik, 2014).

> "POTENTIALLY EXPLOSIVE INTERNATIONAL GROUNDWATER SITUATIONS ARE ESCALATING FROM PLACES AS DIVERSE AS INDIA AND BANGLADESH, THROUGHOUT THE MIDDLE EAST, MEXICO AND THE UNITED STATES, AND LIBYA AND EGYPT" (HAYTON AND UTTON, 1989).

The existing 276 transboundary basins cover nearly one half of the Earth's land surface and account for an estimated 60% of global freshwater flow (Journal AWWA January 2014 pg.84). There are just as many if not more transboundary subsurface aquifers (Brooks, 2013).

As awareness increases about how local decisions have global impact, perhaps there will be increased support for global organizations, such as the United Nations, International Financial Institutions (IFI), and the World Health Organizations (WHO), to have more involvement in that local decision making. In fact, the United Nations General Assembly declared 2013 as the United Nations International Year of Water Cooperation (Resolution A/RES/65/154) (http://www.unwater.org/water-cooperation-2013/water-cooperation/en/). All of these organizations will be well served by obtaining quality advice from the engineering community.

Inter-Governmental Agreements

About 450 international agreements have been established for transboundary waters since 1820 (http://www.unwater.org/statistics/en/?page=98), but there is still work to be done. Sixty percent of the surface transboundary basins do not have agreements. One hundred and forty eight countries share at least a river basin with neighbors (http://www.unwater.org/statistics/statistics-detail/en/c/211758/) and, in general, transboundary sub-surface aquifer agreements are lagging those for surface water. Considering the groundwater overuse problems mentioned previously, more focus is needed on this element.

While there is still work to be done, there have been many effective transboundary agreements reached, a few of which are mentioned herein.

In Africa, the agreement between Lesotho, Botswana and South Africa (the Lesotho Highlands project) addresses the water and energy needs of these countries. Also in Africa, the Nile Basin Initiative (NBI) promotes dialogue and action plans for cost-effective sustainable uses of water by the 10 countries in the basin. The Nile River is the longest in the world (about 6,700 kilometers). Of special interest is the diversity of the member countries: in general the downstream countries have more developed water infrastructure and more technical capacity than the upstream members. An NBI goal is to develop projects with "win-win" scenarios among these diverse countries.

The European Water Framework Directive of 2000 involves even more countries and numerous watersheds. This directive promotes sustainability as well as the full recovery of costs, including opportunity costs from those that directly benefit from a use or service.

The United Nations has been addressing transboundary water issues in a variety of ways, including the UN Watercourses Convention. The convention encourages the reasonable, equitable and sustainable use of transboundary waters and dedicates resources to identify challenges associated with transboundary water management (www.unwatercoursesconvention.org).

The water resource engineering community must support these intergovernmental discussions and encourage countries to look beyond their borders and think globally about water issues.

Leadership

Leadership is a critical component of any successful government initiative. Providing basic sanitation to those in need is no exception. India's "Toilet for Every Home Initiative," led by Prime Minister Narenda Modi, is a good example of the personal leadership from a head of government, which the world needs. He has set this goal for his country by 2019—the 150th anniversary of Mahatma Ghandi's birth.

Achieving this will take financial investment and education to change cultural views regarding public health. But most of all it will take visible leadership. To symbolize the importance of this initiative, Mr. Modi took a broom and started sweeping a street in New Delhi. In so doing he demonstrated his commitment to "sweep away" India's reputation for poor public hygiene and rudimentary sanitation (www.dawn.com/news/1135755).

Another example of leadership is Ho Chi Minh City's commitment to work with the World Bank to address their polluted canals, control flooding and improve the living environment for its citizens. One of the program's initial successes has been the cleanup of the Nhieu Loc-Thi Nghe (NLTN) Canal, which was a highly polluted waterway traversing businesses and residential districts. Untreated wastewater from a combined sewer system; overflows from an aged and undersized drainage system; waste from residences, businesses and factories; and a build-up of solid waste, sludge, debris and sediments had turned the canal into a public health and environmental hazard. Today, the canal has been transformed into a clean waterway with landscaped banks and waterside parks. The World Bank recently recognized the NLTN project as one of its top three featured projects worldwide.

Big Picture View

Governments, especially their regulatory agencies, must have a big picture focus, and encourage integrated planning by the full spectrum of agricultural, energy and water stakeholders.

They should proactively engage water utilities in addressing performance expectations and other critical issues. Through such dialogue planning efficiency would be improved. Regulatory agencies can support innovation through research and development programs and by judiciously establishing guidelines for direct and indirect reuse. In this connection, governments and their regulatory agencies can lead initiatives to clean up polluted water by treating wastewater to the degree necessary–and not more—by incorporating a fit-for-purpose philosophy to treatment requirements for all projects.

In China, the Ministry of Water Resources has selected 45 cities across 28 provinces to pilot "water ecological civilization" principles, which emphasize the balance between the environment and economic development. The first "ecological civilization" master plan has been completed by the firm GHD for Yangzhou, a city of 4 million people. As part of the planning, the principle of water sensitive urban design (WSUD) was introduced, which is widely used in Australia, but is a somewhat new concept in China. According to Xiaoming Shi, GHD's project director, "Depending on the circumstances of each city, there are opportunities to use stormwater to reduce environmental degradation, improve the appearance of urban areas and provide recreation space." The Yangzhou Master Plan has been commended by experts from the China Academy of Engineering, Yangzhou municipal government and Ministry of Water Resources.

An additional example of a big picture focus and fit-for-purpose philosophy is the city of Los Angeles (California, USA) "Blue Green City" initiative. The initiative is taking an organized "one water" approach to reduce the need for imported water and meet an array of sustainability objectives, ranging from flood reduction, groundwater recharge and pollution control, to education, efficient irrigation, and the revitalization of urban areas (Hagekhalil et al., 2014).

Innovative Financing and Procurement

Government should explore ways to stretch available funds through innovative financing, such as public-private partnerships, to fund more water related projects and close the "need vs. revenue" gap.

Public agencies and other funding institutions should also work with the engineering community to streamline permitting and procurement programs while maintaining integrity and transparency. Permitting needs to be done properly, as well as expeditiously. It should not be used as a mechanism to delay or cancel necessary projects. Procurement of engineering services for some assignments can last more than 1 year, which is time consuming and wasteful for all involved. All stakeholders need to find ways to streamline procurement while maintaining transparency and integrity.

Human Rights of the Poor

Government and regulatory agencies must play a supportive role in addressing the special needs of the poor. As the economic and social contexts vary significantly between those living above and below the poverty line, we may expect different sustainable

solutions for each group. While many of those living above the poverty line are already enjoying relatively healthier water supplies and a relatively clean, albeit significantly threatened, environment, a great portion of world's population has limited access to even basic drinking water.

The development of sustainable water supply and wastewater management systems for this segment of the population should, at a minimum, maintain and, when possible, enhance their living standards.

There are two concepts that may be useful when thinking about government's role in serving the poor. The first involves developing improved water and wastewater approaches that they can implement themselves. This would allow poorer communities to enjoy greater health and improved productivity and economic development faster. It is very important that governments provide the resources necessary to allow for proper operation and maintenance of whatever facilities or approaches are incorporated locally. This has been a problem in the past with a number of projects which have failed due to lack of O&M, which, in turn, can cause frustration for all stakeholders. Second, when the water supply to maintain basic life becomes limited by economics and resources, human rights come into play. If we can reach a basic level of public health protection for all, then the challenge will be to increase the level of service as the standard of living for these individuals improves. We need to recognize that not all segments of society are able to afford the same level of service, but all deserve the same degree of public health protection.

GOVERNMENTS, WHO HAVE NOT DONE SO ALREADY, NEED TO CLEARLY ESTABLISH THE RIGHT OF ALL OF THEIR CITIZENS TO CLEAN WATER AND BASIC SANITATION.

Providing clean water and basic sanitation to those who do not have it now is our most important challenge. Sanjay Wijesekra, global head of UNICEF's water, sanitation and hygiene program, stated, "This is an emergency no less horrifying than a massive earthquake or tsunami. Every day hundreds of children are dying. We can and must act in the face of this colossal daily human tragedy" (Landers May, 2014).

Engineers need to work with governmental organizations to ensure that proper actions are taken. This will create special challenges for engineers and require them to work differently in the future.

Role Of The Engineer, Students And Other Professionals

Leadership and Communication

Engineers need to take a leadership role in helping the world community address global water challenges. They must have a clear and influential voice as trusted advisors, especially with policy makers. If the engineering community does not do this well, others will or may try–possibly without the unique technical expertise engineers bring to water sector issues.

A few years ago, the ASCE produced a Vision 2025 Report: "Civil Engineers: Trusted Leaders for a Modern World." In a 2009 document, titled "Achieving the Vision for Civil Engineers in 2025," ASCE envisioned that civil engineers will be "Entrusted by society to create a sustainable world and enhance the global quality of life, civil engineers (will) serve competently, collaboratively and ethically as master:

- Planners, designers, constructors and operators of society's economic and social engine – the built environment,
- Stewards of the natural environment and its resources,
- Innovators and integrators of ideas and technology across the public, private and academic sectors,
- Managers of risk and uncertainty caused by natural events, accidents, and other threats,
- Leaders in discussions and decisions shaping public environmental and infrastructure policy.''

Education of younger engineers will be one of the keys to achieving this vision.

> THE COMPLEX CHALLENGES FACING 21ST CENTURY SOCIETY WILL REQUIRE PROFESSIONAL ENGINEERS (PEs) TO ADVANCE THEIR TECHNICAL EXCELLENCE AND PROFESSIONAL LEADERSHIP.

The "Raise the Bar Initiative" in the United States aimed at requiring more education beyond the bachelor's degree for engineering licensure is consistent with encouraging engineers to assume more influential roles with policy and decision makers.

The U.S. National Academy of Engineering has made a number of suggestions about engineering education, including:

- Strongly encourage engineers to earn advanced degrees beyond a bachelor's degree.
- University engineering education should produce engineers who can both define and solve problems.
- Institutions must teach students to be lifelong learners.
- Engineering undergraduate programs should introduce interdisciplinary learning and use case studies of both engineering successes and failures as a learning tool.

The most successful water engineers of the future will be those who influence policy makers and clients in their efforts to address the myriad global water challenges they will face. Thus, all engineers are well advised to hone their leadership skills and broaden their education. Firms are encouraged to offer leadership training to their best and brightest. Likewise, engineering universities need to include leadership and experiential education (e.g., internships, cooperative education programs) in their curriculums.

The Engineers Without Borders program has been effective in helping communities in developing countries implement sustainable water and sanitation facilities, while providing young people–not just engineers–with opportunities to explore parts of the world and gain hands-on experience at an early stage of their careers. For example, in 2013 members of the Northeastern University Chapter travelled 212 kilometers and spent 52 days in other countries.

To lead, one must communicate effectively. As a profession, engineers are generally highly respected and trusted. However, they also are sometimes criticized for communicating primarily amongst themselves. More professional engineers need to go beyond their comfort zone and seek forums to communicate outside of the profession to create a more acute global awareness about our water challenges.

Professional organizations can play a role in training younger engineers to be better leaders, communicators and networkers. FIDIC's Young Professionals Program is an excellent example of what professional organizations can do to help meet this challenge.

Trusted Advisors

In representing the communities they serve, clients make many decisions related to their particular water issues. In doing so, they need to conceive the right projects and they need to ensure that these projects are done right. The right projects do not always need to involve capital intensive construction. While advising clients, engineers need to ensure that nonstructural measures are considered. These include, among other items, environmental conservation, integrated resource planning, sustainability, innovation, and effective O&M.

Consideration of non-structural measures is important. If the engineering community is to effectively address the global water challenges the world is facing, they need to demonstrate that proper engineering is much more than building something. The best engineering should, and often does take place in the planning stage where problems are framed, alternatives considered and solutions developed.

Including the need for conservation and efficiency improvements in the infrastructure message helps with the credibility of advocating for more concrete and steel, when large capital investments are needed. When done right, investment in concrete and steel projects will support performance of the non-structural approaches.

Clients require experienced assistance to develop the right projects in the planning stage and execute them correctly. Professional engineers skilled in leadership and communication can provide it. While, legal, finance, purchasing and other entities have extremely important roles in infrastructure projects, it is the professional engineer who has the proper technical training to advise clients.

With such a key role as trusted advisor, it is important for clients to choose the best engineer they can. Accordingly, clients are well advised to select engineers based on their qualifications and approach, and not on price. When price is considered, the engineer is forced to develop the least costly engineering approach to meet a client's needs, while potentially driving up the cost for the client in the long run, or for society at large.

When engineers compete for assignments based on qualifications and approach, the clients benefit by getting the best thinking from the best engineers about what is best for them. This dramatically increases the chances of getting the right project done right. Engineering reflects only 1 to 2% of the life-cycle cost of a project, but it has enormous influence on the remaining 98 to 99%. It has been said that some of the most "expensive" engineering is the engineering that was not done during the planning phase. The cost of corrective engineering and construction can be hundreds of times greater than money "saved" during the planning phase via price based competition for engineering services.

Design

As design tools improve and as pressure to do more with less mounts, the tolerance for design errors and omissions will decline. As such, there is an ongoing trend toward improving the quality of engineering design tools. Computer aided design (CAD), 3D design and BIM is the norm for many clients. Adding other pertinent items, such as cost, schedule and equipment, is advancing these tools to 4D and beyond. Successful engineers of the future in the design field will be those that not only practice within their area of expertise and deliver what they promise in accordance with FIDIC's Integrity Management System (FIMS) guidelines, but also stay current with evolving design tools.

Today's complex designs require quality engineering and multidisciplinary teams to address them. Beyond sustainability, other issues that must be addressed are safety, analysis of construction phases, detailed risk assessment, lifecycle cost optimization and maintainability. As technology changes, so do the ways in which design teams interact. BIM has been evolving in parallel with the increasing need to collaborate and share project information, while focusing on infrastructure lifecycle cost optimization. The challenge of BIM implementation has more to do with rethinking processes than about learning how to use new software. The technological challenge is to provide the tools that allow engineers around the world to work together as if they were in the same room.

Encourage Careers in Engineering

The water challenges the world is facing are diverse, severe and daunting. The world will need more engineers to help the global community address them.

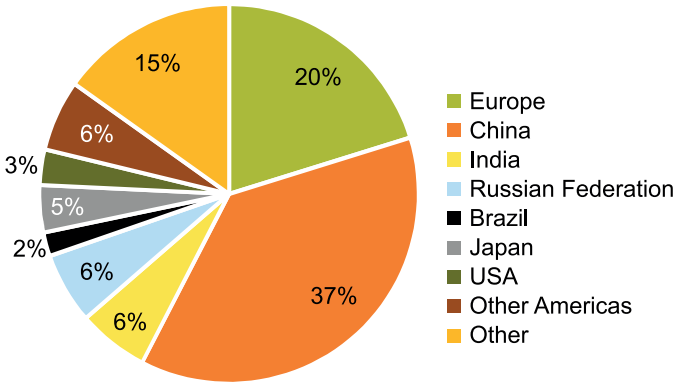

Figure 36 - Graduates with Engineering as Their First Degree. US National Science Foundation Science and Engineering Indicators 2014 Digest

Some countries are doing better than others in attracting their best and brightest to science and engineering. See Figure 36.

In addition to encouraging more students to earn engineering degrees, we need to find ways to keep more of them in the profession. Continuous education opportunities, recognition programs and clear paths to economic and professional advancement are all appropriate strategies to meet this need.

While efforts to encourage more young people to pursue STEM careers are important, there is an equal need to open up dialogue between STEM professionals and the rest of the global population.

Role of Today's Student and Other Professionals

Improving Diversity

With the global population ballooning to nearly 9 billion in the next several decades, it is more important than ever that young people with diverse skills be encouraged to pursue careers in the water sector. The United Nation's Educational, Scientific and Cultural Organization (UNESCO's) statement that "Solutions to water problems require the consideration of cultural, educational, communication and scientific aspects," speaks to the magnitude of the global challenge in this area, which will only increase with the higher stresses of a larger, more affluent population.

There is a great opportunity to develop the upcoming generation of STEM professionals as the most diversely trained, widely engaged group yet. The ability to mainstream newly proven ideas is key to the ultimate success of water innovations, hence the popular trend of "interdisciplinary learning" at the university level. Here are three ways this can be achieved.

Cross-Sectoral Engagement

In an increasingly transparent and interconnected world, engineers and scientists cannot implement meaningful change unassisted. There is much that can also be accomplished outside of the immediate STEM family, particularly addressing the needs for organizing, financing, researching, coordinating projects and stakeholder outreach. In these areas, there exists a critical shortcoming in the water resources sector. Namely, that the industry primarily self-selects only from the pool of engineers, chemists, biologists and other STEM professionals. This imposes severe limitations not only on other students and young professionals interested in furthering sustainable development, but on the water industry itself, which could benefit immensely from greater inclusion.

It is vital that those working in the water field understand and tap every potential resource available. The first move to that end is to generate open dialogue between STEM professionals in this sector and policymakers, stakeholders, businesses, educators and writers—the holders of soft power who will influence or determine where future resources are committed. Only through such a dialogue can we hope to not only brainstorm the most effective technical solutions, but to engage entire cultures and populations in their own long-term survival. Public awareness, funding and forward-thinking policies can generate progress towards securing significant water-use reductions and help us bridge the gap between a culture of waste and dependency to one where the human right to safe water is realized through established innovations.

Outreach and Advocacy

No matter what part of the world or socio-economic background one hails from, water management needs to be a common concern for every living human. Understandably though, we are far more inclined to embrace changes of any kind, particularly those requiring massive investments, when we have a greater understanding of what's at stake. This is a critical gap in our current system, and it separates those with the technological solutions, from those with the resources for implementation or the power to ensure these solutions are executed. The often large costs of funding and implementing solutions serves as a deterrent for action, but the more difficult to calculate costs of inaction may far outweigh investment needs today. Engaging policymakers, educators and business people in water/energy decisions will open up vast opportunities for the STEM community to see their designs made reality and create lasting, sustainable, solutions that improve the quality of life and the environment within which humanity must operate.

Embracing Multiple Participants

The water challenges the world faces presents a textbook opportunity to engage experts in numerous fields, applying the lessons of the lab to real-world situations where stakeholders and policymakers can easily relate. Even with the rise of the most highly-educated generation to date, it is unrealistic to expect engineers and other scientists to be experts in all areas. Likewise, it would be shortsighted to neglect the abundant resources of writers, policy experts, community engagement professionals and educators who are likely better-positioned to catalyze effective cross-sector collaboration, which can enable engineers to more knowledgeably and ethically serve greater populations in need.

In the larger picture, STEM professionals are more likely to influence modern socio-economic development and sustainability with the public's understanding and even participation on their side. The scientist of the modern era must be comfortable engaging experts in every field who can respond to questions, negotiate regulatory

boundaries, reconcile conflicting interests, leverage financial commitments, and clearly see the big-picture socio-economic implications of any given resource project. In short, they must have an awareness of the broader world beyond their area of expertise.

Students and young people are the natural heirs to this task. Millennials comprise a generation more adept at communication across diverse fields. They are a huge segment of society that has been enabled by their general comfort with information technologies to interact constantly and with candor. And, as a well-traveled group with more diverse demographics than any generation heretofore, they possess the most personal, prescient understanding of the transnational implications of even isolated water resource mismanagement.

The Future

While our water issues are extraordinarily challenging, there is reason for optimism. Awareness is growing and we are educating a larger population with perhaps the highest potential to be the most inclusive generation in history. As a result, more of those in the engineering community will develop broader approaches by looking "beyond the technical" and recognize the benefit of involving all stakeholders regardless of their background in developing solutions to problems.

A few years ago, in responding to a question about civil engineers, the author David McCullough said he would like to see more "civil" civil engineers. He went on to describe John A. Roebling, the designer of the Brooklyn (and many other) bridges. Mr. Roebling also was an accomplished musician and wrote about science and philosophy. His skills and interests went well beyond engineering.

The engineering community would be well served by taking David's advice: develop great technical engineers who are also broad thinkers and who realize the importance of including the entire global community in addressing our water problems. After all, everyone on Earth has a stake in the outcome.

Conclusions

The state of the world's water is not good. People are suffering from preventable diseases and are dying at alarming rates due to lack of basic sanitation or clean water. Sea levels are rising and our oceans are getting warmer, more acidic and more polluted. Marshes, wetlands, coral reefs and other aquatic life are being damaged or unbalanced. Flooding due to storms of increasing severity are putting more coastal properties at risk. Extraordinary economic loss and population shifts could well be in our future because of these trends.

Fresh water continues to be deleteriously affected by pollution from untreated or inadequately treated wastewater and nutrients from a variety of sources, including agricultural runoff, CECs, and overuse. More than half of the world's groundwater aquifers are being over pumped—an especially disturbing problem for some "fossil" aquifers that are essentially being mined.

Compounding these issues is the global community's lack of investment in our water infrastructure. This is reflected in the ongoing tragedy faced by those without access to basic sanitation and clean water; continuing discharge of inadequately or untreated wastewater entering our receiving waters; and deteriorating or outright failure of aging infrastructure in developed countries.

The global population is projected to grow to more than 9 billion people and more of them will be demanding "middle class level" goods and services, such as adequate water supply and wastewater disposal, electricity, and more protein-enhanced diets that demand higher water footprints. The world's demand for fresh water is expected to increase creating demand versus availability gaps in the trillions of cubic meters. This will compound the problems we have with water scarcity now.

Despite numerous advances in alternative and renewable energy generation, it is likely that fossil fuels, a major CO_2 emission generator, will be used to generate the majority of the world's electricity for the foreseeable future. This will further add to our water challenges especially those related to global warming.

Due to these and other factors, it is not hard to see that the world has a water problem—now. We need to do a lot more than what we are currently doing and attack it from all directions to avoid a water crisis. Infrastructure to provide basic sanitation and clean water to those currently without them need to be provided with a sense of extreme urgency. We must do all we can do to stop the deaths and debilitating diseases caused by poor sanitation and lack of clean water. Facilities to treat wastewater to reasonable limits before discharge to receiving waters must be provided in all locations requiring them. We need to reduce fresh water demand by addressing agricultural requirements (which makes up about 70% of fresh water usage), lowering potable use and reusing water as much as possible. Better decisions need to be made on what to grow, where to grow it and how to grow it.

All elements of water should be considered a resource to be used and reused. Discharging fresh water in any form to oceans should be avoided when reasonably feasible. Wastewater contains potential energy that should be tapped and nutrients should be captured.

Stormwater should be used to recharge groundwater aquifers, wherever desirable and feasible. Decentralized or hybrid distribution and collection systems should be considered wherever possible. Flood protection, including floating structures, early warning systems, dams of all sizes, and perhaps even population shifts need to be considered. We must also obtain a better understanding of the impact of CECs on all elements of our environment. And, we need to seriously address our aging infrastructure.

However, the good news is that society has most, if not all, of what it will take to address these and other water challenges. What is needed more than anything is the will to act. For this to happen, the global community needs to insist on action. There is good news here as well. More people are becoming aware of our water challenges. Hopefully, what will follow will be a willingness to invest more financial and other resources in addressing the problems. Government, engineers, students and other professionals have the ability to create much of this willingness.

That willingness will produce much needed solutions to our water challenges. These include transboundary agreements focusing on what's best for the watershed, not the countries themselves; fit-for-purpose treatment

as a tool to stretch limited funds; integrated resource management geared toward ensuring that the right projects are identified, and that solving one problem does not result in causing another; and sustainability considerations that take into account future as well as present needs.

Engineers have the technical skills to solve our water issues, but they must not attempt this by themselves. They need to proactively include other professionals, especially younger professionals and students who will inherit the results, to use their special skills to implement the technical solutions. This global inclusivity has the potential to help society understand and support the urgent needs. In turn, this will hopefully result in more funds available for the right projects through smarter planning; more effective use of resources, such as innovative financing; and streamlined permitting and procurement. All of this will take leadership and communication among the entire global community, not just technical skills.

While the tasks at hand are difficult, the skills and tools are available to succeed. With proper willingness and understanding, there hopefully will come a day when every world citizen has clean water and basic sanitation, where we have enough water for everyone's needs, where climate change is addressed, and where our infrastructure requirements are met. With confidence, trust and teamwork, the world can get there.

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