The Water Security Challenge

Building a Framework

THE CENTER FOR WATER SECURITY & COOPERATION

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Introduction

Water Security remains an ambiguous concept with an uncharted path to achievement. Water is an essential resource for our survival and for the pursuit of our livelihoods. However, countries lack a clear strategy for how to protect and manage water. To get to that strategy, we need a clearer understanding of what water security means, how our needs depend on water, and how existing law reflects and directs those relationships. We need a framework that is responsive to our multifaceted dependence on water and that lays out a strategy for how to preserve and protect water availability for the future. Creating a water security framework will provide communities the tools to nimbly manage their water resources to guarantee that our current and future needs can be met.

To create this Framework we must break down the concept of water security before we can build it up. We must understand and detail our complex relationship with water to understand how and where we need water and how those uses impact each other as well as overall water quality and water quantity. These relationships and impacts must be reflected in any framework that will advance water security.

Getting to a Water Security Framework

To advance water security and inform the development of a responsive, actionable water security framework, The Center for Water Security and Cooperation has launched the *Water Security Challenge*. The first phase of the *Challenge* is to prepare a series of white papers illustrating and analyzing the critical water nexuses that form the basis of water security. This white paper introduces the Water Security Series by identifying the nexuses which shape the contours of water security and must be reflected in the Water Security Framework. This paper introduces the relationships with and dependencies on water that form the foundation of this discussion.

The *Series* will continue with a series of white papers focused on each of ten nexuses the The Center for Water Security and Cooperation has identified. Each white paper will delve deeper into the scope of these relationships, seeking to draw out each and every way water is needed, depended on and connected to each aspect of our lives. Based on these interrelationships, we will identify and analyze how the law governs and influences these relationships. Each white paper will illustrate how law directs or shapes water in each area, analyze the mosaic of existing laws governing or influencing water in that area, evaluate challenges and opportunities to achieving water security, and make initial recommendations for how to create a legal framework that is responsive to that area's needs. A final white paper will examine holistically the legal and physical interrelationships to define the contours of a complete Water Security Framework that considers and connects all of these areas. This research will allow stakeholders to have a clear picture of the influence of law on water management across all uses and impacts.

Facing the complexities of these relationships is daunting. The complexity of water is immense. *There is nothing that touches on more of what matters to us than water.* Yet, the ubiquity of water has allowed for it to be marginalized as an environmental protection issue. The approach to water management has taken the same form of environmental management and protection, a siloed approach that deals with each relationship independently from the multi-faceted, interdependent reality in which water exists. That approach is manageable and digestible because it keeps the focus narrow on specific relationships. However, water cannot be properly addressed as a tangential concern or as a need of other interests. To most effectively support life and livelihood, our legal frameworks and institutional approaches to water must strategically address our complex relationship with water.

Addressing the complexity of water is no small or simple task. Water security is a standalone priority whose achievement will safeguard the myriad of interests dependent on water.

The Water Security Series

The CWSC defines water security as the ability to safeguard an availability of water sufficient to sustain lives and livelihoods and protect against threats to and from water. Water security presents water management and protection as an access and availability issue focused on guaranteeing that *our* needs as humans are met.

Humans need water to meet our basic needs. We need water to drink and water to grow our food just to survive. However, our relationship with and dependency on water has grown more complex as society has developed and advanced. Many of our developments and advancements rely on water, from energy production and space exploration to the manufacturing of computers and life-saving hospital equipment. Each water use and dependency has consequences for other needs and uses. These new needs and demands for water and their impacts on one another have complicated our simple relationship with water. Any framework expected to guide our management and protection of water resources to meet these needs long-term must reflect this new, complex matrix of human dependency on water.

We have selected ten nexuses that most effectively and comprehensively capture our complex relationship with and dependency on water in the Twenty-First Century.

National Security	**Sanitation, Health and Hygiene**
Energy Production and Use	**Global Markets**
Natural and Manmade Disasters	**Natural Resources and Services**
Agriculture	**Infrastructure**
Peace and Conflict	**Governance and Institutions**

These nexuses reflect the fundamental dependencies on water and where impacts of changes in water are most felt. Each nexus is further broken down by the relationships that depend on or impact water. A discussion of each nexus follows below.

Energy Production & Use

Water and energy are inextricably linked. We use energy for heating our homes, for transportation, for manufacturing goods, for lighting and heating our businesses and hospitals, and for withdrawing, treating and conveying drinking water and wastewater.[1] On average, an American uses 148.6 million BTU or 15,370 lbs of coal.[2] The world per capita energy consumption is 75 million BTU. Not only is energy generation dependent on water, but the treatment and movement of water requires energy.

Water for Energy

Without water, today's rapidly growing energy needs could not be met. Energy's need for water is not isolated to one part of the industry. Energy's use of water is spread across the industry, from the generation of electricity and the mining of the fuels used to generate the electricity to the disposal of wastes produced during the energy generation process. The Water for Energy nexus can be broken down into the following relationships, each with its own unique need for and impact on water.

Electricity generation

The electricity industry is second only to agriculture as the largest user of water. Globally, the energy sector is responsible for 10% of total water withdrawals.[3] In the United States in 2010, thermoelectric power production required 161,000 billion gallons of water per day (Bgal/day). This equates to 45% of total water withdrawals, 38% of total freshwater withdrawals and 51% of total fresh surface-water withdrawals, for all water uses.[4] Approximately 89% of electricity in the US is produced using steam turbines in thermoelectric power generating stations.[5] While the energy industry withdraws a significant volume of water, the industry only consumes 2.5% of the water it withdraws, meaning that the remainder becomes available in return flows to the river basin.[6] This presents a stark comparison to agriculture where irrigation accounted for 29% of total fresh surface-water withdrawals, but 90% or more is consumed by the crops or evaporation.[7]

Energy is generated in different ways using different fuels. Each method of generation and each type of fuel used require different amounts of water and can have different direct and indirect impacts on water quality.

Thermoelectric power

Thermoelectric power plants vary based on generation type and cooling technology which determine the amount of water needed for energy generation. There are four types of thermoelectric generation: (1) fossil-fuels (i.e. coal, natural gas, oil and biomass), (2) nuclear, (3) geothermal, and (4) concentrated solar power (CSP). There are three types of cooling technologies associated with thermoelectric production: (1) once-through, (2) closed-loop, and (3) dry. Thermoelectric power plants convert heat into electricity by turning water into steam that turns electricity-generating turbines.

Fossil fuels are used in conventional power plants, also known as separate heat and power plants ("SHP"), combined heat and power ("CHP") plants, also known as cogeneration or combined-cycle plants, and integrated gasification combined cycle ("IGGC"). A conventional power plant burns fuel to create high-pressure steam. The steam drives a turbine that causes the generator to spin and produce electricity.[8] Using a gas turbine generator with waste heat recovery and a steam turbine generator, CHP plants recover heat that is normally wasted in conventional power generation as useful energy. SHP plants have a combined efficiency of 45%, depending on if they are fueled by coal or nuclear, while CHP plants have an efficiency of 80%.[9] This kind of heat recovery maximizes the water use by maximizing the energy output.

Geothermal, nuclear and concentrated solar power all offer lower- to no-carbon-emissions alternatives to fossil-fuels, but still require almost the same, and sometimes more, water. Geothermal plants use the hot water and steam found in subsurface reservoirs to produce electricity.[10] Water consumption by geothermal ranges from 0 to 4784 gallons of water per megawatt (gal/MWh) of energy generated depending on the type of geothermal technology and cooling system used.[11] Nuclear plants use uranium fuel to produce electricity through fission.[12] Nuclear power generation ranges in water consumption depending on the cooling technology, from 269 gal/MWh for once-through cooling to 672 gal/MWh for tower cooling.[13] Concentrated Solar Power technologies "use mirrors to reflect and concentrate sunlight onto a single point where it is collected and converted into heat. This thermal energy can then be used to produce electricity."[14] Depending on the type of CSP technology deployed – linear concentrator, dish/engine, power tower and thermal storage system – water consumption ranges from 5 to 1000 gal/MWh.[15] While geothermal, nuclear, and solar all present low-carbon options, they are not necessarily low-water.

Each of these generation types and cooling technologies present different benefits and drawbacks to water. For example, nuclear power plants require the mining of uranium using an open pit or underground mine, which, like mining for coal or fracking for natural gas, may present threats to water quality. Nuclear power plants create radioactive waste, from the spent reactor fuel and uranium mill tailings to the water used to initiate the nuclear reaction and later cool the spent fuel reactors.[16] While nuclear power generation creates radioactive wastes that take hundreds of years to decay and must be specially stored underground, nuclear plants do not directly generate carbon dioxide emissions.[17] As renewable options are explored as alternatives to traditional energy, it will be important to define "renewable" in terms of water use, impact and efficiency in addition to the volume of carbon emissions.

Hydroelectric plants

Hydropower accounts for about 7% of total energy production in the United States and depends 100% on flowing water.[18] Globally, 16.4% of total energy production comes from hydropower.[19] Hydropower also supplies 71% of all renewable electricity generated. There are three types of hydropower. Run-of-river hydropower directs flowing water through a canal to spin a turbine that generates electricity.[20] Storage or impoundment hydropower uses a dam to store water in a reservoir and later releases the flow through a turbine to activate a generator that produces electricity.[21] Pumped-storage hydropower pumps water to a reservoir at a higher elevation from a reservoir at a lower elevation and releases water at periods of high demands to spin the turbines.[22] Hydropower is fueled by water instead of fossil-fuels or uranium; reducing ancillary impacts of energy production (i.e. fuel extraction and processing impacts) on water resources. However, being fueled by water means that hydropower is vulnerable to shifts in rates of precipitation and periods of drought. Reservoirs whose levels decline risk the ability of the dam to effectively operate and generate depended-upon power. This would have the greatest impact in developing countries where there are fewer energy

alternatives to hydropower.

While more carbon-neutral than other energy options, hydropower presents a variety of concerns to water management. Hydropower is not a consumptive use of water; however, the storage of water in above-ground reservoirs often results in evaporation.[23] Depending on the climate where the dam is located, more or less water may be consumed through evaporation. Furthermore, dams create a divide in the river which can change the water quality by reducing dissolved oxygen levels in the water, necessary for plant and animal life. Dams can also change the geomorphology of the river as sediments from upstream collect behind the dam. Dams also modify river flow and create a barrier to fish passage.[24]

Wind-powered electric plants

Wind power is a renewable energy that neither emits greenhouse gases nor requires water for energy generation.[25] In the United States in 2015, there was a net savings of 73 billion gallons of water from the 191 million megawatt hours generated by wind that displaced fossil fuel-based energy.[26] Wind energy saved California 2.5 billion gallons and Texas 14.7 billion gallons of water.[27] In the European Union, wind energy avoided the use of more than 102 billion gallons of water.[28] Once the component parts of the wind turbine are created, water is only used for periodic cleaning of the blades. Therefore, wind energy presents an opportunity to *reduce* water use by displacing other types of energy generation that use or consume more water.

Solar Photovoltaic (PV)

Solar Photovoltaic or solar panels convert sunlight to electricity directly. Because the solar energy is converted directly into electricity, no water is needed. Water is only necessary for periodic cleaning of the solar panels.

There are significant risks to water quality posed by PV manufacturing and end-of-life. However, the manufacturing of solar panels requires the use of caustic chemicals like sodium hydroxide and hydrofluoric acid and the mining of rare earth metals like tellurium and copper.[29] The use of these chemicals and the mining of these metals present potential threats to water quality. Furthermore, the life span of PVs averages 20-30 years. With limited options and economic incentives to recycle PVs, the end-of-life of PVs raises a potential concern for water quality.[30]

Fuel extraction and production

Without fuel, whether it is the sun or fossil-fuels, there is no energy. Fuel extraction includes crude oil production, natural gas production, coal mining, uranium mining, and growing biomass which is converted into biofuels. Each extractive process requires water, some more than others.

Coal mining implicates water in a variety of ways. In the United States in 2010, 5.32 Bgal/d of water were withdrawn for mining, 73% of which was groundwater and 57.7% of which was saline water.[31] Water is used for quarrying, milling of mined materials, and injecting water for unconventional oil and gas recovery (e.g. hydraulic fracturing).[32] Underground mining often hits the water table which results in the mine being flooded and the water needing to be pumped out. While this water can be used for mining purposes, mining can expose groundwater to contaminants. This kind of exposure can permanently contaminate groundwater, thereby increasing the costs and energy use associated with treating it prior to use. Mining also results in "produced water" or industrial wastewater that is returned to the surface through a well borehole. In the U.S., produced water must be treated subject to §404 of the Clean Water Act prior to discharge.[33] These waters are laced with minerals and chemicals and without proper treatment will contaminate groundwater or surface waters. While the processes are somewhat different, drilling for conventional and unconventional oil as well as mining for uranium present similar water quantity and water quality concerns.[34]

Biomass is organic matter that can be converted into energy.[35] In other words, feedstocks such as corn, soybeans, switchgrass, perennial grass, wood waste and byproducts, and animal manure can be converted into biofuels. This includes any cultivation of crops specifically for energy production—primarily corn, soybeans and switchgrass—and the use of crop byproducts such as corn stover, the leaves and stalks left over from corn. Water consumption for corn production ranges from 83 gal/MMBtu in USDA Region 5 (Indiana, Illinois, Missouri, Ohio and Iowa) to 3805 gal/MMBtu in USDA Region 7 (Nebraska, Kansas and The Dakotas).[36] The more than 3500 gallon/MMBtu difference is attributable to differences in climate, differences in soils, and differences in irrigation efficiencies.

Cultivating corn and collecting corn stover present water quality concerns. Fertilizers are used to improve crop yields; however some of these fertilizers, depending on irrigation practices, run off into nearby watercourses. Agricultural run-off introduces nutrients such as nitrates and phosphates to waterbodies, often in large quantities. The use of buffers and the adoption of certain best practices can reduce the concentration of fertilizers in runoff. Collecting corn stover, the leaves and stalks of the corn plant that remain after the harvest, can increase the presence of fertilizers in waterways. Collecting corn stover maximizes the use of the crop and can be turned into cellulosic ethanol, a fuel for energy generation. However, using the stover for fuel prevents these nutrients from returning to the soil. This increases the need for fertilizers to replace the nutrients. The law will need to balance the tradeoffs in pursuing different forms of renewable energy.

Fuel refining, processing and transportation

Coal, natural gas, uranium, oil and biofuels are all fuels that require the use of water in refining, processing and transportation before use in generating energy. Extracted natural gas is much closer to its useable end product than other fuels and therefore requires the least amount of water for processing.[37] Without refining and processing, these fuels are unusable for the purposes for which they are extracted. The water needed to refine and process these fuels range from 0 gal/MMBtu to 130 gal/MMBtu depending on the fuel type and refinement process.

Fuel type	Water use for refining and processing (gal/MMBtu)[38]	Method of transportation[39]
Coal	1-2	Rail and barge
Coal gasification	11-26	
Natural gas	0-2	Pipeline
Liquefied natural gas	50	
Gas-to-Liquids	19-86	
Oil	7.2-32	Rail, truck, tanker and pipeline
Biofuels: Corn Ethanol, wet mills	62	Truck
Biofuels: Corn Ethanol, dry mills	40	
Biofuels: Cellulosic Ethanol, biochemical conversion	78-130	
Biofuels: Cellulosic Ethanol, thermochemical conversion	25-30	
Biofuels: Biodiesel	4.2	
Uranium: Diffusion	12-13	Truck, barge
Uranium: Centrifugation	10-11	

Municipal solid waste

Municipal solid waste ("MSW")–more commonly known as trash–can be converted into a second-generation biofuel. As the size of landfills has grown, robust recycling efforts have been undertaken to convert waste into valuable energy.[40] Americans generated 254 million tons of trash in 2013.[41] 87 million tons were diverted from the landfill through recycling and composting. The remaining waste can be converted into biofuels. Organic materials can be converted into biogas via anaerobic digestion, while the materials that cannot be recycled (e.g. wood, paper, plastics) can be combusted and converted to syngas through gasification.[42] Increasing the conversion of MSW into biofuels will decrease the volume of landfill waste, therein decreasing the threat landfills pose to groundwater.

Energy for Water

Meeting our water needs requires energy. Energy is needed to capture water and bring it to treatment facilities, to treat water and wastewater to comply with drinking water standards or discharge requirements, to heat and cool water, and to convey water to other river basins. Globally, water and wastewater extraction, distribution and treatment account for 4% of electricity consumption.[43] This percentage varies dramatically across countries. The IEA estimates that by 2040, 16% of electricity consumption in the Middle East will be related to water supply.[44] The questions is, how do we use energy for water, what opportunities exist to reduce energy use, how might energy needs change in response to outside factors, and how does the law influence these interactions?

Water Extraction

Water extraction is energy intensive. 22 billion gallons of surface freshwater, 13 billion gallons of surface seawater and 85 billion gallons of groundwater are withdrawn daily in the United States. While energy for surface water or seawater extraction are usually considered part of conveyancing, it takes 30,000 to 50,000 gigawatt-hours (GWh) annually to extract groundwater to meet demands.[45] These realities necessitate the exploration of alternative sources like recycled water.

Water purification and distribution

Water that is withdrawn from rivers and oceans must be purified before it can be used for drinking or other purposes. In the United States, drinking water quality standards are set by the Safe Drinking Water Act ("SDWA") and implementing regulations.[46] To meet the maximum contaminant levels set forth in these regulations, withdrawn water undergoes coagulation and flocculation, sedimentation, filtration, and disinfection.[47] On average it takes 1422 kW per million gallons per day (MG) to treat our water supply.[48] As more treatment requirements are adopted, more energy will be necessary to meet those standards.[49]

It takes almost the same amount of energy to distribute water as it takes to purify. Based on case studies, it is estimated that public water systems in the United States use 1200 kWh/MG to deliver water to end users.[50] On average, public water systems lose 16% of treated water to leaky pipes.[51] A recent study found that pipes distributing treated drinking water to homes and business in New Jersey leak 130 million gallons of treated water a day. That is enough water to fill the Empire State Building every two days.[52]

Household leaks amount to more than 1 trillion gallons annually.[53] These non-revenue leakages amount to lost energy (i.e. the energy used to purify water for drinking water purposes that is instead lost to seepage), increased energy usage as treatment facilities have to treat more water to make up the difference, and reduced return flows. In line with recommendations by the American Water Works Association, some states are adopting policies requiring utilities to report losses and set targets for water loss reduction.[54] These losses represent energy losses and water inefficiencies that put additional strain on water resources.

Similar water losses may also be experienced during large-scale water transfers. Depending on how water is conveyed, water may be lost in evapotranspiration (if the transfer is conveyed in canals) or through leakage (if the transfer is conveyed through pipes). However, the movement of water presents opportunities to generate energy. Using conduit hydroelectricity, power can be generated from water flowing through a canal, aqueduct or pipeline.[55] The energy generation potential for conduit hydropower ranges from 1 or 2 kW to about 1 MW.[56] These types of technology help to capture and use kinetic energy that would otherwise be lost.

In-home Water Use

13% of total residential energy use is used to heat water.[57] After space heating, water heating is the second largest energy user in the home. In terms of in-home appliances, showers are the third largest water user in the home, after toilets and washing machines. Reducing shower-times and increasing showerhead efficiencies would both reduce the amount of water used as well as the amount of energy used to heat that water.[58]

Wastewater collection, treatment and discharge

Wastewater treatment uses approximately 30.2 billion kWh annually, or 0.8% of total electricity use in the United States.[59] "According to the most recent Clean Water Needs Survey ("CWNS"), the municipal wastewater treatment industry is composed of about 14,780 publicly owned treatment works (POTWs) that handle a total flow of about 32,345 MGD and serve a population of 226 million, or about 74% of the U.S. population."[60] Discharges from wastewater treatment plants ("WWTPs") are subject to the Clean Water Act ("CWA") and implementing regulations.[61] Under the CWA no pollutants can be discharged without a permit that set forth certain technology-based effluent limitations. WWTP discharges undergo primary, secondary and often tertiary treatment (e.g. denitrification, chlorination or filtration). Because WWTPs are only equipped to treat for certain pollutants, certain industrial and commercial dischargers are subject to pretreatment requirements as prescribed by regulation before discharging to WWTPs.

Wastewater presents opportunities to offset the energy needs for WWTPs. Anaerobic digesters can recover biogas (i.e. methane) from organic materials from the biosolids found in wastewater. EPA estimates that the theoretical energy potential that could be recovered from WWTPs that process more than one MGD exceeds 400 MW of electricity or 38,000 MMBtu/day.[62] Not only does this energy recovery reduce WWTPs' draw on the grid, but also reduces waste that would otherwise be transported to a landfill, another energy expense.

Water reuse and recycled water

Recycling wastewater offers energy and water savings. In the United States, WWTPs discharge 32 billion gallons per day of treated effluent, 38% of which is discharged to an ocean or estuary.[63] Treated wastewater discharged to rivers and lakes serve as return flows which both provide for downstream needs and maintain the flow of watercourses. Water reclamation for potable and non-potable uses requires advanced treatment following primary and secondary treatment. Recycled water can be used to replace water conveyances, recharge aquifers, or for agricultural or golf course irrigation instead of being discharged into surface water for recapture. EPA estimates that the annual net energy savings of conveying recycled water directly to the end users that want it ranges from 3000-5000 kWh/MG and could reach 1TWh/year.[64] In the United States, regulations concerning wastewater reuse have been adopted by 30 states to ensure safe water quality and address water rights concerns, facilitating this type of water recycling.

Pollution created by energy production that presents a threat to water resources

Power generation creates two types of pollution that can impact water quality: air pollution and thermal pollution. Electric power generated 69% of the sulfur dioxide (SO_2) and 20% of the nitrogen oxides (NO_x) responsible for acid rain.[65] Acid rain reduces the pH levels of waterways, making the water too acidic to support certain plant and animal life. While the use of renewable energies might reduce the emission of air pollutants, most forms of electric generation generate a thermal pollution that can harm the receiving waterbody. Large volumes of water are used during generation to provide cooling. The intake water that cycles through the cooling system and then is discharged back into the waterway is typically 8 to 12°C warmer than its original temperature when extracted.[66] Warmer waters can create uninhabitable conditions for certain fish and aquatic organisms.

Natural & Manmade Disasters

Disasters disrupt communities and cause significant damage to ecosystems and habitats. Too much, too little and too dirty water often create long-term challenges for communities and ecosystems. Natural and manmade disasters cause property damage, loss-of-life, famine, water supply contamination and the disruption of water supply and wastewater treatment services.

Floods and droughts

Too much and too little water hurt communities.[67] Annually, flooding impacts 250 million people and results in $40 billion of losses globally.[68] In the U.S. alone floods cost Americans $6 billion in damage and kill 140 people annually.[69] Droughts also have expensive and deadly consequences. Droughts have killed 11 million people since 1900.[70] The drought in California cost $2.7 billion and 21,000 jobs in 2015.[71] In March 2017, a drought in Somalia killed 100 people in just 48 hours.[72] While floods and droughts may not be preventable, the impacts can be limited by improving resiliency. Inadequate preparedness increases the costs incurred and the lives lost. The effects of droughts and floods are amplified by poor water management, including groundwater exploitation, cheap water, and deteriorating water infrastructure.

Natural disasters with water-related impacts

Earthquakes, hurricanes, tsunamis and tornadoes all have dramatic effects on access to a freshwater supply and water and wastewater management. Natural disasters cause pipeline fissures and water infrastructure damage, from the collapse of dams to the cracking of wells and irrigation aqueducts. Cracked pipes may lead to the leakage of wastewater, fuels or chemicals that are transferred by pipes, causing the contamination of groundwater and soil. Damaged pipes also result in water service disruption and may expose clean drinking water to contaminants which presents health risks to communities. Treated water that leaks from pipe fissures also represents a loss in energy and resources. The collapse of dams and levees can cause flooding and the pollution of surface waters. Damage to wastewater treatment plants threatens surface water quality in the event that raw sewage is discharged. Natural disasters present real threats to water, especially given that climate change increases the likelihood and intensity of these events.

Manmade disasters

Human activity can cause disasters. Manmade disasters are those disasters that are caused by human activities, such as fracking, aquifer mining and resource extraction, and oil and chemical spills. The U.S. Geological Survey found that there is a connection between the injection of fracking wastewater into the subsurface and an increase in earthquakes.[73] Researchers at the University of Calgary also found that fracking itself causes earthquakes in western Canada by adding pressure to tectonic faults.[74]

Groundwater overdraft is the single largest cause of subsidence, when water or mineral resources are extracted and the surrounding rocks and sediments compact.[75] The land subsides when the rate of groundwater withdrawals are higher than the rate of recharge. Basic physics demands that empty space be filled when under pressure. Sometimes this empty space collapses on itself, causing sinkholes at the surface.

More commonly, subsidence causes underground aquifers to lose critical capacity. Not only does land subsidence represent the consequences of a larger problem (i.e. groundwater mining), but it also further frustrates water management and availability by permanently reducing the capacity of the aquifer. Once the land sinks, the aquifer looses the ability to hold the same volume of water it once held. NASA's mapping of the California Aqueduct shows that the Aqueduct has a carrying capacity of 20% less than its design capacity due to subsidence.[76] In Tehran, the exploitation of groundwater has led to a 36 centimeters per year rate of land subsidence.[77] Continuing groundwater mining will have serious consequences for aquifer capacity in the years to come.

Resource extraction and transport can result in disastrous spills and chemical releases. While fuel extraction and transport are essential to meeting our current energy needs, the consequences of spills can be felt for decades after the spill. Two of the largest oil spills in U.S. history–the 1989 Exxon-Valdez oil spill and 2010 BP Deepwater Horizon spill–released more than 15 million gallons of oil into the Gulf and Prince William Sound.[78] Recent spills include a 2011 1000-gallon spill into the Yellowstone River in Montana,[79] a 2016 530,000-gallon spill into the Little Missouri River tributary in North Dakota,[80] and a 2016 spill in Nigeria's Akwa Ibom state.[81] Oil spills have long-lasting impacts on the effected watercourse, surrounding environment and communities. The ability to manage these impacts is frustrated by differing degrees of regulatory oversight of extraction and transportation processes across different fossil-fuel producing countries.

Sea level rise

Norfolk, Fort Lauderdale, Charleston and Miami are just some of the cities around the United States experiencing the impacts of sea level rise.[82] Sea level rise is also threatening the survival of island nations, like the Maldives, Seychelles and Solomon Islands, where sea level rise can submerge their entire country.[83] Sea level is rising at about a

rate of one-eighth of an inch per year. There are two major causes of global sea rise: thermal expansion (or a warming of the ocean) and glacier melt.[84] Sea level rise causes flooding and shoreline erosion, which threatens infrastructure and communities on and near the coast line. A study published by scientists in 2016 revealed that the melting of Antarctica alone could cause the ocean to rise at least 1 meter.[85] With approximately one in ten people in the World living in low elevation coastal zones, sea level rise will have an increasing impact on communities and national security.[86] Sea level rise compromises inland freshwater resources needed to survive, leaving no source of freshwater for local populations. For island nations that do not have access to aquifers or other sources of water, this threat is existential.

Saltwater intrusion

Saltwater intrusion is the movement of saline water into freshwater aquifers which can lead to the contamination of drinking water sources. Saltwater intrusion occurs naturally in coastal aquifers as well as a result of groundwater withdrawal. By preventing excessive groundwater extraction, aquifers can be protected from saltwater intrusion. Once saltwater intrusion occurs, those aquifers are no long available for freshwater purposes. To be used for freshwater purposes, those contaminated waters would require desalination, a costly and energy intensive removal of salt.

Agriculture

Agriculture[87] is essential to sustaining life and building a strong economy. Every dollar of agricultural exports stimulates another $1.27 in business activity.[88] 2015 agricultural exports generated $169.4 billion in economic activity and supported 1,067,000 full-time civilian jobs, 751,000 of which were in the nonfarm sector.[89] Agriculture is both dependent on water and presents challenging hazards to water quality through fertilizer-laced runoff.

Water for food crops and livestock

Without water, crops do not grow, livestock die, and communities succumb to famine. In the United States, 115 Bgal/day of water in 2010 was withdrawn for irrigation, 2.00 Bgal/d for livestock and 9.42 Bgal/d for aquaculture.[90] This means, 356.3 gal/d are withdrawn per person for agriculture, and that is in addition to the 80-100 gal/d an average American uses for domestic purposes.[91] Irrigation withdrawals accounted for 38% of total freshwater withdrawals. 58% of irrigated lands are irrigated with sprinkler or microirrigation systems.[92] Globally, 70% of total water withdrawals are used for irrigation with an efficiency of 56%.[93] 80% of cultivated land world-wide is rainfed and produces 60% of global food production.[94] The remaining 20% of cultivated land provides 40% of food globally.[95] We need a lot of water for food production.

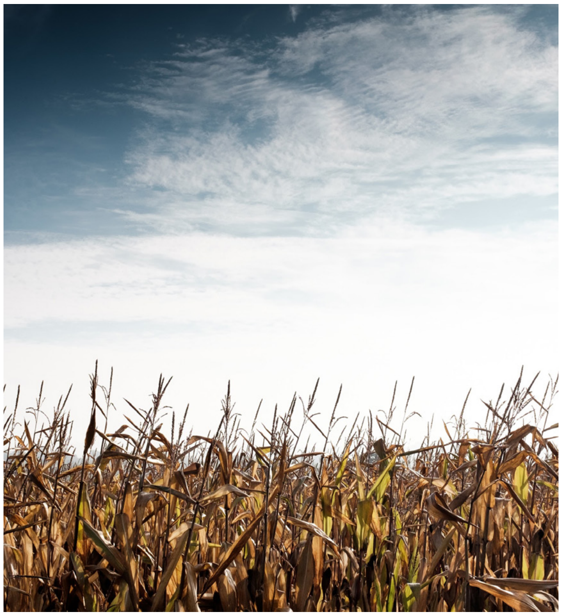
As the population continues to grow and changes in precipitation patterns shift the location, frequency and volume of rainfall, the need for the adoption of irrigation practices which promote water efficiency will be essential to meeting growing needs in water. Water scarcity and drought cause famine, resulting in thousands of deaths annually.[96] Drought in Somalia has caused widespread famine, at one point leading to the death of more than 100 Somalis in 48 hours.[97] The consequences of poor water management on human life and livelihoods are severe.

The deployment of better technology and adoption of more efficient practices, including the exploration of GMOs and drought resistant crops, will improve the resiliency of agriculture to water scarcity. We need to examine how our laws are incentivizing greater water use efficiency, encouraging regional crop planning to ensure crops are grown in areas best suited for those crops given soil types and water needs, building regional and global stakeholder engagement and reducing the impact of agriculture on water quality. As greater strain is put on our water resources it will be necessary to think more strategically about our food production and water use.

Water for non-food crops[98]

Part of our agriculture production consists of industrial crops such as tobacco, rubber, cotton, and hemp which are grown as a commodity or as the raw material for manufactured goods rather than for direct human consumption. Agricultural production also includes forestry. These crops provide jobs and generate important revenues.

However, growing these crops may have repercussions for water resources and the surrounding environment. For example, tobacco requires the multiple-application of pesticides throughout its growing cycle, often replaces food crops because of its commercial profitability and promotes deforestation as farmers seek to dedicate more acreage to tobacco, creates post-consumption waste that pollutes lands and rivers and cigarette butts that present a toxic threat to fish, generates carbon dioxide emissions, and requires energy for sowing, irrigation, weeding, harvest, transport and tillage.[99] Many of these risks are not unlike the risks presented by food production.



Agriculture as an energy supplier

Agricultural crops and waste products are one type of biomass that are burned directly to generate electricity or are converted into biofuels.[100] Farms may grow crops for the creation of biofuels or may lease out land for on-farm fossil fuel development or renewable energy generation. 2.7% of U.S. farms produced renewable energy in 2012.[101] Sugarcane and corn are grown to produce ethanol; soy, rapeseed and oil palm are converted into biodiesel. In 2005, 14.3% of the U.S. corn harvest produced 1.72% of U.S. gasoline usage while 1.5% of U.S. soybean harvest produced .09% of U.S. diesel usage.[102] Laws in the United States and the European Union have encouraged the use of biofuels.[103] While biofuels present a renewable alternative to fossil-fuel based sources of energy, dedicating more corn crops to ethanol production has consequences for food production or may increase the acreage of cropland, both increasing water consumption and fertilizer use.

Energy for agriculture

Agriculture consumes energy directly as well as indirectly by using energy-intensive inputs such as fertilizer and pesticides. Direct energy inputs include the use of electricity, diesel, gasoline, natural gas, propane and renewables.[104] In 2014, the agricultural sector used 1,714 BTU or 1.74% of total US energy consumption.[105] Energy is needed for land preparation, cultivation, irrigation, harvesting, post-harvest processing, food production and storage, transport of agricultural outputs and inputs, and water withdrawal.[106] Energy consumption differs across farms and depends on the commodity being grown. For example, rice producers spend $250/acre for energy-based expenses whereas wheat producers spent $60/acre.[107]

When it comes to water, agriculture uses groundwater which may require considerable energy to withdraw depending on the depth to water from the surface. Agriculture uses 55.3 billion gallons of groundwater per day. If it takes 2.7 kWh of electricity to lift 100,000 gallons of water to the surface then it takes 1.493 million kWh/day to withdraw groundwater for agricultural purposes.[108] In the United States it costs $54.75/acre to pump water from wells for irrigation. Reducing water use and increasing water efficiency reduces the need for groundwater and therefore the demand for energy. Furthermore, the very irrigation systems which promote water-efficiency also require energy. The costs of operation, degree of water-efficiency achieved and level of carbon emissions of these systems depend on whether the sprinklers are high, medium or low pressure and on the type of fuel powering the pump.[109] Agricultural production is water and energy intensive.

Sanitation, Health & Hygiene

Improved sanitation and access to safe drinking water set developed countries apart from emerging economies. Clean, safe drinking water and proper sanitation keeps people from getting sick and allows them to be healthy, productive members of society. The World Health Organization estimates that inadequate water supply and sanitation costs the world 260 billion USD yearly.[110] These costs result from premature deaths, healthcare costs, losses in productivity, and time lost through the practice of open defecation. Investing in access to improved sanitation and improved water supply has a rate of return of more than 4 times for every 1 USD invested.[111] More than 2 million people die every year from diarrhea, with 90% of those deaths caused by poor hygiene and unsafe water.[112] At least 1.8 billion people drink fecally contaminated water.[113] Adequate water supply and sanitation underpin socio-economic development and ensure healthy people.

Improved Sanitation

Improved sanitation reduces human exposure to contaminated water that causes disease and death. Improved sanitation is defined as a flush or pour-flush toilet linked to a piped sewer system, septic tank or pit latrine, a ventilated improved pit, a pit latrine with a slab, or a composting toilet.[114] Two significant gains result from access to improved sanitation. The first is time. Access to improved sanitation saves people 30 minutes per day or 7.6 days per year.[115] Otherwise that time is spent finding a safe place to defecate. This time can be spent attending school, earning an income, or spending time with family and friends.

The second benefit is a reduced number of cases of water-borne and water-washed diseases caused by pathogenic microorganisms. Human waste contains pathogens that cause infectious diarrhea, *E. coli*, cholera, and other diseases. Left untreated, raw sewage flows into surface waters that are drinking water sources. These waters may then be withdrawn as drinking water, without being treated, therefore exposing people to these life-threatening and potentially permanently disabling diseases. Other bacterial and viral infections use water as a vector or as an incubator for disease-spreading insects or animals, leading to malaria, guinea worm disease, typhoid and trachoma, among others. Exposure to these diseases results in lost income, lost productivity, increased medical and health care expenditures and permanent disabilities, including impaired cognitive ability in children.[116] Improved sanitation reduces diarrhea morbidity by 37.5%.[117]

Though considerable advancements have been made since the adoption of the Millennium Development Goals (and subsequent adoption of the Sustainable Development Goals), 2.4 billion people worldwide still do not use an improved sanitation facility.[118] More than 75% of those people are located in Southern Asia, Eastern Asia and Sub-Saharan Africa.[119] By 2015 only 95 countries met their Millennium Development Goal sanitation target. Less than 50% of the population uses an improved sanitation facility in 47 countries.[120] While the greatest challenges for guaranteeing improved sanitation exist in the least developed countries, in countries where advanced infrastructure provides these important services it is equally important to invest in ongoing operation and maintenance of wastewater infrastructure as well as future capital improvement projects that rehabilitate and enhance operations. Without these investments and periodic rehabilitation, developed countries' water infrastructure will be unable to protect citizens from untreated sewage or guarantee the provision of safe drinking water.[121]

Water Supply

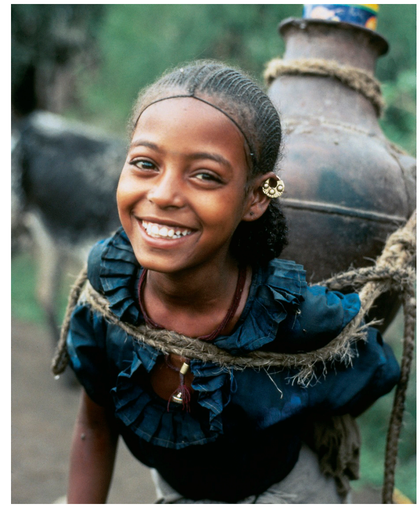
Access to safe drinking water is essential for healthy people. Improved sources of drinking water include piped water into a dwelling (i.e. a household connection), piped water to a tap in a yard or plot (i.e. a yard connection), a public tap, a protected dug well, a protected spring, harvested rainwater, or a borehole.[122] These constructions are designed to prevent contamination of water from fecal matter, but may not necessarily provide treatment of water. There are a variety of concerns to be addressed with respect to water supply including, the water quality of drinking water and source waters, access and affordability, and reliable, sufficient availability. The benefits derived from providing safe, accessible drinking water include: time to attend school and complete assignments, to earn an income, or to relax in down time; better health and fewer health-related expenses; greater surface water protection; and more tourism.

Access to drinking water presents one of the largest water supply challenges. These supply challenges are felt the most in developing countries and by women, girls and the rural population. Only 84% of the rural population uses improved drinking water sources, compared to 96% of the urban population.[123] 147 countries have met the Millennium Development Goal. However, 99% of the population in developed regions use improved drinking water sources compared to 69% of the population in the least developed countries.[124] Just under half of the remaining population that remains without access to improved drinking water sources is located in Sub-Saharan Africa.[125] Globally, women and girls spend 200 million hours per day collecting water, which exposes them to unsafe circumstances and prevents them from attending school or getting jobs that could provide economic freedom.[126] The benefits of increasing access to improved water supply are significant. These benefits include:

- More hand-washing and consequently better hygiene
- Greater menstrual hygiene
- More girls with time to attend school and play with other children
- Fewer women and girls exposed to dangerous circumstances as they walk to retrieve water
- More women with time to earn an income, socialize, spend time with family, and pursue interests
- Fewer visits to health care facilities
- Fewer lost work days due to water-borne diseases
- Greater likelihood that healthcare facilities will have access to water
- Improved ability to prevent infection and reduce patients' exposure
- Greater likelihood that schools will have access to water, increasing school attendance[127]

These benefits have cascading effects which improve the overall health and livelihood of communities and countries as a whole.

As more advanced water infrastructure is built to transport and treat drinking water, there are increased costs with providing these services that will have to be accounted for in order to maintain a safe quality of service. Plans for long-term operation and maintenance plans will be needed in addition to the construction of wells, piping, and treatment facilities to ensure that initial investments are maintained. Providing these services costs money. To ensure the poorest communities, whether in developed or developing countries, will continue to receive water, questions of affordability should be addressed in operation and maintenance plans. As the population grows and demands for water increases—especially as developing countries are able to take great advantage of available water use—communities may look to explore alternative water sources such as reclaimed wastewater and desalination.



To guarantee that advancements made under the MDGs and Sustainable Development Goal (“SDGs”) endure, communities must remain attentive to the challenges associated with water quality of surface water, drinking water, groundwater and discharges; sourcing, reliability and vulnerable populations; costs and affordability; and accessibility and distribution. Guaranteeing a secure water supply also requires more active management of surface waters and groundwaters. Overuse can threaten the long-term availability of water resources by mining aquifers to a point that they cannot recover or there is salt-water intrusion which permanently removes that aquifer as a source of drinkable freshwater. As the volume of withdrawals and diversity of types of water uses increase and changes in precipitation patterns and climate alter the volume and frequency with which certain regions receive water, communities will need to work harder to maintain gains in reliability of access and minimize vulnerability to changes.

Arts and Culture

Water also plays an important role in art and culture, providing the imaginative basis for works of art, performance, music and writing. Huckleberry Finn’s trip down the river, Coleridge’s “The Rime of the Ancient Mariner”, Monet’s water lilies and impressions of the Thames River, fountains in gardens, and many other water images rely on clean, sufficient water to feed the imagination.

Indigenous peoples are also reliant on water as an integral part of many customs. Fishing in traditional waters, irrigation for crops and other uses are central to the history and longevity of these communities.[128] Water also plays an important cultural role in religion. Baptisms and other religious ceremonies rely on water and use water as a symbol.

Water is also a part of recreation. Water is necessary for swimming in pools, rivers and lakes, and for events that include swimming like triathlons, diving, and water polo. Water is a prerequisite for canoeing, kayaking, surfing, sailing, tubing, whitewater rafting, playing in fountains or fire hydrants, water-balloon and squirt-gun fights, and other water-based activities. Fishing and hunting are also reliant on sufficient water to support animal habitats. Water is also necessary for golf to provide green grass and water hazards; though fertilizers and watering can pose issues to water quality and quantity.

All of these aspects of life are dependent on water, and are integral to the mental health, physical health and creativity of humanity.

The Global Economy

Water is essential to global economic growth. The World Bank estimates that water scarcity will result in growth rate declines by as much as 6% of GDP by 2050.[129] Without the adoption of better water management practices to ensure there is water to support our trade and economy, millions of people may be driven back into poverty or never escape poverty.[130]

Water-dependent jobs and revenue

In the United States, "half of the global workforce is employed in eight water and natural resource-dependent industries: agriculture, forestry, fisheries, energy, resource-intensive manufacturing, recycling, building and transport."[131] Water jobs include jobs directly related to water resources management, infrastructure, water supply and wastewater treatment while water-dependent jobs refer to jobs in other economic sectors that are heavily or moderately water-dependent.[132] These jobs can be found in a wide-range of sectors including agriculture, industry, forestry, inland fisheries and aquaculture, mining and resource extraction, power generation, healthcare, tourism, ecosystem management, recreation, construction, and transportation.[133] 78% of jobs comprising the global workforce are dependent on water.[134] Changes in the availability of water would have widespread impacts on the global economy given the centrality of water to so many critical sectors.

Water generates revenue and supports jobs and income.

Sector (in the United States)	Revenue Generated (2007, USD)
Public water supply systems	$53 billion
Agricultural production	$297 billion
Livestock	$154 billion
Mining and energy resource extraction	$418 billion
Manufacturing	$2.4 trillion
Sale of electricity	$197 billion
Commercial fishing	$4.5 billion
Travel and tourism	$379 billion
TOTAL	$3.9025 trillion[135]

Just eight of the water-dependent sectors in the United States generated almost $4 trillion in revenue in 2007. Given their dependence on water, these revenues are vulnerable to water-related risks, like floods and droughts. Economic losses from natural disasters range from $250-$300 billion a year.[136] Certain industries are particularly vulnerable to natural disasters. For instance, more than 84% of the damage and losses caused by drought is to agriculture.[137] Agricultural losses result in lost revenue and employment as well as lost national per capita dietary energy supply which can lead to food insecurity and lost calorie intake.[138] These impacts tend to be felt more and for longer by developing countries where agriculture remains a primary employer and economic driver.[139]

RIVER BASIN	REVENUE GENERATED	JOBS GENERATED
Mississippi River[140]	$400 billion	1.3 million
Chesapeake Bay[141]	$107.2 billion	600,000 (tourism); 41,000 (commercial seafood industry)
Nile River[142]	$304 billion	Unavailable
Ganges River	$690 billion	Unavailable
Danube River	$1305 billion	Unavailable

Revenue and Jobs Generated for 5 Transboundary River Basins

Global trade in water

Every day we trade in water itself and in embedded water. When you buy a bottle of water, you are participating in the trade in water. Depending on which type you buy–for example, if it is Fiji or VOSS–you are more directly participating in the global trade in water.[143] States may also transfer water from one part of the state to another or out of state to meet growing urban or agricultural needs.[144] These large-scale transfers are just one of the types of water transfers made through water markets.[145] Water markets allow water rights holders to sell or lease water where the need for water is the greatest. Markets are intended to maximize the efficiency of water use by encouraging rights holders to use only what they need in order to be able to sell the remaining amounts.

The trade in embedded water–also known as virtual or invisible water–is the most intensive trade in water. Invisible water is the water embedded in food and manufactured products.[146] For food, the embedded water is measured by green water (i.e. precipitation) and blue water (i.e. irrigated water withdrawn from surface water and groundwater sources) used to grow crops. The amount of water necessary to grow crops varies across countries and regions because of differences in climate, precipitation patterns, soil types and water use efficiency.

Crop	United States	China	Mexico	Australia	World (average)
Rice (paddy)	1275	1321	2182	1022	2291
Wheat	849	690	1066	1588	1334
Maize	489	801	1744	744	909
Soybeans	1869	2617	3177	2106	1789
Sugar cane	103	117	171	141	175
Cotton seed	2535	1419	2127	4268	3644
Sorghum	782	863	1212	1081	2853
Coffee (roasted)	5790	7488	33475	N/A	20682
Beef	13193	12560	37762	17112	15497
Pork	3946	2211	6559	5909	4856
Chicken	2389	3652	5013	2914	3918
Eggs	1510	3550	4277	1844	3340
Milk	695	1000	2382	915	990

Table: Average virtual water content (m^3/ton) (adapted from Chapagain/Hoekstra)[147]

The global volume of virtual water flows related to the international trade in manufactured products is 1625 Gm^3/year, 80% of which is held in agricultural products.[148] The remaining 20% is held in manufactured products.

Country	Average industrial water withdrawal ($10^5 m^3$/year)	Virtual water export of exported industrial products (average)	Virtual water import of imported industrial products (average)
Brazil	10293	2211	3694
Cambodia	14	N/A	89
Denmark	324	38658	2693
Germany	31926	25416	29757
Mexico	4128	3790	9710
Morocco	261	123	599
Nigeria	678	531	542
Saudi Arabia	195	136	1703
South Africa	1527	912	1924
Spain	7298	3753	8520
Thailand	1789	1655	3596
United States	215495	59195	69763
World	716764	361838	361838

Table: Industrial water withdrawals, virtual water exports and virtual water imports (1997-2001)[149]

The world economy is based on a globalized market where goods can be produced in one country and sent all around the world.[150] The export of goods externalizes the environmental impacts of water use and increases dependency on foreign water resources. The global nature of trade does not necessarily correct the inefficiencies in production or the mismatch of crop-type to the climate, soil type, and rate of precipitation of the exporting country. Greater dependency on foreign water resources increases countries' vulnerability to exporting countries' mismanagement of water resources.

As the available water per capita shrinks, countries may seek ways to restrict other countries' access to water resources located within their political borders. These efforts may give rise to formal restrictions on exports of water via transfers or bottled water outside of the country. However, international treaties may prohibit such restrictions.[151]

Circular economy and industry standards

Because of, and sometimes in spite of, government leadership on sustainability and resource efficiency, businesses are actively developing industry standards to encourage more sustainable and efficient practices.[152] The circular economy approach encourages greater resource productivity throughout the supply chain.[153] Industry standards and supply-chain reporting generate greater transparency and accountability in water use and impact by businesses by creating minimum standards that are expected to be met across the industry. Businesses will play an increasingly more important role in resource management.

Natural Resources & Services

The natural environment and ecosystem is a complex matrix of interactions between air, water, land, flora, and fauna. It is these interactions and relationships which provide a rich diversity of services that support the human population. A water security framework will have to navigate the relationships between these natural resources and account for the management and protection of one natural resource and its impacts on other natural resources.

Air

Poor air quality causes poor water quality. Air pollutants–such as nitrogen oxide (NO_x), ammonia (NH_3), chromium, and lead–can be deposited onto solid surfaces and washed into watercourses by rain and runoff through dry deposition, or be deposited directly into watercourses through wet deposition, also known as acid rain.[154] These contaminants can cause eutrophication or toxicity in organisms that drink or live in the water. The Maryland Department of Natural Resources estimates that 27% of the nitrogen delivered to the Chesapeake Bay comes from the atmosphere.[155] While some of these depositions can be prevented with the use of buffer strips and retentions ponds, the greatest reduction of depositions will be achieved by fewer emissions from point sources regulated by the Clean Air Act in the United States or similar laws. In fact, researchers have found that the NO_x emission controls established through the 1990 Amendments to the Clean Air Act have resulted in reduced nitrogen yields across the Upper Potomac River Basin.[156] Reducing air pollutants improves water quality.

Water

Today we drink the same water that the dinosaurs drank more than 200 million years ago.[157] The water cycle is the circulation of water from the ocean, to evaporation, to condensation, to precipitation and to accumulation as snowpack, ice caps and glaciers, to surface runoff that accumulates as rivers and lakes and infiltrates into the ground and replenishes aquifers, and back to the oceans. Water fills inland surface waters, aquifers and oceans.

Inland surface waters

Rivers, lakes, streams, and wetlands make up inland surface waters. These waters serve an essential role in the maintenance of the ecosystem, as a source of water for humans and organisms, and as a highway for commerce and recreation.

Aquifers

Groundwater is locked in underground aquifers. In the United States, about 130 million people rely on groundwater for drinking water. Differences in geology, hydrology, geochemistry, hydrogeology, climate, and possible sources of contaminants explain the differences in water quality and vulnerability to contaminants that can be found across aquifers.[158]

Oceans

Oceans hold 96.5% of Earth's water. Globally, oceans support 350 million jobs, fish to feed 1 billion people, coral reefs that reduce 97% of a wave's energy and protect coastal communities, oysters that filter 190 liters of water/day, and plant life that creates half of the oxygen we breathe.[159] Oceans also play a critical role in absorbing carbon dioxide from the atmosphere.

Land-use

Land use patterns and practices impact water quality and watershed health. The impact of land use on water depends on the type of land use: residential, commercial, industrial, or agricultural. Each type presents their own unique impacts on water quality.

As we build and develop urban centers, we turn green spaces into buildings and paved surfaces. In building our communities, we change the natural flow of water either by building on green spaces or by engineering the watercourses themselves through dams and reservoirs. Harnessing the power of rivers to generate hydroelectricity contributes to sources of renewable energy and creates life-supporting reservoirs. At the same time, dams slow the flow of the river which causes suspended sediment to deposit in the reservoir.

Cities are centers of innovation and community. The impact of the built environment weakens the long-term sustainability of our communities. Impervious surfaces collect different pollutants, like gasoline from cars, that are washed into nearby watercourses by rain events. These impervious surfaces can also create or exacerbate flooding issues. Water cannot percolate through impervious surfaces which means that during rain events, water will rapidly flow across the pavement, picking up pollutants, and dump those pollutants into the stormwater system. This high rate of flow not only taxes stormwater systems but may lead to flooding. In cities like Washington D.C. where there are combined sewer systems–or sewers which combine wastewater and stormwater before treatment–these heavy flows can overwhelm the infrastructure and lead to overflows that contain raw sewage.

As cities have become more crowded and the cost of living has increased, people are leaving the cities to build communities in the suburbs. As the population spreads across greater acreage, more land is converted into homes and businesses, more time is spent in cars commuting to work, and the cost of providing public services increases. The challenges of urban development are not only felt by developed countries. As emerging economies build more advanced infrastructure and move away from agrarian economies, more land will be converted to urban centers, placing new pressures on water resources. More concrete infrastructure, from roads and gray water infrastructure to buildings, facilitates the movement of people and the operations of a modern nation, but impedes the natural movement of water.

Agriculture feeds our communities and generates jobs and revenue for Americans. Besides being one of the greatest water users, agriculture uses fertilizers and pesticides to improve crop yields and maximize profits. Fields are leveled to efficiently drain off excess water which make it easier for excess fertilizer to drain off into nearby watercourses. These impacts can be alleviated by the use of buffers and adoption of irrigation and fertilizer application practices that reduce the chance of water quality degradation.

Land ownership can also determine water rights. The riparian doctrine grants land owners whose property is adjacent to standing or flowing water a right to reasonable use of the adjacent waters. Riparianism originated from the English common law doctrine of natural flow. A riparian rights holder also has the right to wharf out and erect docks and piers as long as they do not obstruct navigation. Riparians also have exclusive right to use adjacent non-navigable watercourses.

Flora and Fauna

Water supports a broad array of life from trees and insects to larger animals like bison and alligators. This biodiversity sustains a vibrant ecology and a healthy environment. A clean environment supports human health and livelihoods. To protect minimum flows of water necessary to quench these needs, instream flow protections are typically set by state governments. These instream flows reduce the available water for allocation, but provide essential environmental services.

Forests provide invaluable water services. More than half of drinking water in the United States originates in forests.[160] Forested watersheds supply 75% of the world's access to freshwater.[161] Forests serve as natural water filters by reducing soil erosion, minimizing sedimentation and filtering water pollution. At the same time, forests demand tremendous amounts of water to sustain the trees and soils. Forests also provide a source of wood and pulp necessary for goods like paper, furniture and wood for constructing homes. Deforestation–natural or manmade–threatens water quality, exacerbates the impact of floods and droughts, and decreases the capture of greenhouse gases.

Infrastructure

Water infrastructure provides invaluable services to communities. Infrastructure purifies and distributes safe drinking water, treats wastewater that otherwise would present a significant danger to public health, generates renewable energy, creates reservoirs that satisfy our thirst, and manages water flows to protect our community from flooding and extreme weather events. There are two types of infrastructure. Gray infrastructure is "hard" or concrete infrastructure such as wastewater treatment plants, tunnels, water mains, pumps, dams, and levees. Green infrastructure aims to maintain or increase green space and vegetation in order to reduce floods and minimize erosion.

Gray infrastructure

Our concrete infrastructure provides essential public health services. Dams collect water in reservoirs that provide reliable sources of water to meet communities' drinking water needs. Wastewater treatment plants collect and treat wastewater to prevent the discharge of raw sewage to our waterways. Drinking water treatment facilities bring safe drinking water to our homes free from life-threatening contaminants. Dams and levees help manage higher-than-normal volume flows to prevent the flooding of communities. These infrastructures carry out essential services.

The construction, maintenance, operation and rehabilitation of gray infrastructure are costly. Today, the American Society of Civil Engineers estimates that more than $1 trillion is needed to meet current and future wastewater and drinking water demands. These costs are associated with daily operation and maintenance and periodic capital improvement and guarantee compliance with regulatory standards.

Infrastructure	Investments Needed	Average Age of Components
Drinking Water	$1 trillion	75-100 years
Dams	$45 billion	56 years
Levees	$80 billion	50 years
Wastewater	$271 billion	75-100 years
Total	$1.396 trillion	

Wastewater

Wastewater treatment plants ("WWTP") are critical to the protection of public health and the environment. Wastewater treatment plants treat municipal and industrial wastewater, removing contaminants that would be harmful to human health and degrade the environment. 14,748 treatment plants provide 76% of Americans wastewater treatment.[162] The remaining population is served by private septic systems. There are over 1.3 miles of public sewers and private lateral sewers conveying wastewater to the WWTP. EPA estimates that there are between 23,000 and 75,000 sanitary sewer overflows annually which dump raw human waste into rivers and streams.

Over the next 25 years, $271 billion is needed to update and rehabilitate wastewater infrastructure. The federal government provides an average of $1.4 billion annually to states for capital improvement projects. Other expenses are paid by ratepayers and financed through tax-exempt municipal bonds. Some communities turn to Public-Private Partnerships (P3s) to finance new construction or rehabilitation.

Drinking water

90% of Americans receive their drinking water from a public water system.[163] The lifespan of the one million miles of pipes delivering drinking water throughout the United States is 75-100 years. Based on utilities' 0.5% average rate of replacement, it will take 200 years to replace drinking water systems.[164] In the meantime, 6 billion gallons of treated water is lost every day through leaky pipes and water main breaks.

EPA sets minimum contaminant levels for more than 90 contaminants, including lead, arsenic, *giardia lamblia*, *E. coli*, and polychlorinated biphenyls (PCBs). Minimum contaminant levels are mandatory standards that must be met by all drinking water providers. EPA also establishes voluntary secondary standards for 15 contaminants, including fluoride, corrosivity, color, iron and pH. These primary and secondary contaminants are called "regulated contaminants". Every five years EPA is responsible for identifying no more than 30 contaminants which are not currently regulated.[165] Public water systems are then required to monitor those contaminants. Similar water standards are adopted worldwide and are essential to protecting human health.

Public water systems and WWTPs are not equipped to treat certain types of contaminants, including unregulated and emerging contaminants. Emerging contaminants are chemicals or microorganisms that are not currently monitored but have been found to have the potential to contaminate watercourses. Pharmaceuticals and Personal Care Products ("PPCPs"), Endocrine-disrupting chemicals ("EDCs"), and Perfluorooctanoic acids ("PFOAs") are three emerging contaminants. EDCs, such as birth control pills, have been found to elevate the estrogen levels of

fish. EDCs are introduced to surface waters through human waste. PPCP may include Advil, sunscreen, or antidepressants. PFOA is a type of chemical used in the process of creating Teflon® and can contaminate drinking water. Nanotechnologies used in various products also have an undetermined effect on water quality and health.[166] Without the necessary technology, WWTPs do not have the capability of treating for these contaminants. Therefore, these contaminants are discharged into surface waters which then serve as the source waters for public water systems. Public water systems also lack the technology to remove these contaminants, which then remain in the treated drinking water that is distributed. Communities then consume small traces of these contaminants over many years. The health effects of this type of exposure are unknown.

Stormwater

Stormwater, runoff from rain and snow, is collected and treated through storm drains. Most cities have separate systems to handle sanitary waste and stormwater runoff. 772 communities have combined sewer systems where stormwater and sewage are collected into the same system and then treated before discharge into nearby surface waters.[167] These systems are susceptible to overflow, especially during storm events. A growing population and rising number of impervious surfaces increase the chances that these overflows will occur by increasing the volume of water flowing into the system. In 2014, there were more than 1400 combined sewer overflows that dumped 22 billion gallons of untreated wastewater into the Great Lakes Basin. In the majority of communities, stormwater is collected independently from sewage, treated and discharged.

Dams and levees

Dams provide water storage capacity for meeting community needs, flood protection, and energy generation. Levees–embankments or walls–are designed to prevent flooding. While dams provide a number of beneficial services, this type of intervention changes the natural flow of water which has cascading impacts on the surrounding ecosystem. Properly-maintained dams and levees are essential to reducing property damage resulting from floods, though extreme weather or poor maintenance can lead to dam failure and flooding.[168] Dams are also important in creating reservoirs that provide reliable sources of drinking water for municipalities. Communities in arid and semi-arid climates are beginning to explore options for storing water underground to reduce the amount of water lost from reservoirs to evaporation.

Green infrastructure

Green infrastructure is an alternative approach to managing water flows.[169] By increasing the acreage of natural cover, green infrastructure aims to restore natural processes that have been eliminated or diminished by the built environment. Green infrastructure improves water quality by allowing water to filter through land before entering watercourses as well as by reducing urban runoff laced with oil and other contaminants from reaching waterways without treatment. Green infrastructure is one type of Low Impact Development, land-use practices intended to reduce the impact of land-use decisions and construction on water and the environment. As climate change increases the severity and frequency of storm events, green infrastructure serves as an important tool for reducing the impact on communities.

Governance & Institutions

Effective governance and empowered, stakeholder-driven institutions will advance water security. The level of government that has authority, the individual decision-makers, and the nature of government's obligation (e.g. voluntary or mandated) matter for determining the effectiveness of any governance structure.

The role of government

Depending on the country, water can managed at the local, state, provincial, national, regional, and international levels or at a combination of these levels. For the most part, countries govern waters according to their internal political boundaries. There are exceptions, as in the European Union, where Member States are required under the Water Framework Directive to govern their waters according to river basins instead of political boundaries.[170] The

division of authorities and responsibilities across different levels varies from country to country.

In the United States, under the Clean Water Act the U.S. government ("USG") is responsible for managing discharges of pollutants from point sources into waters of the United States and regulating quality standards for surface waters. Under the Safe Drinking Water Act, the USG is responsible for declaring Minimum Contaminant Levels ("MCLs") for identifying contaminants in drinking water.

Power to regulate allocation and most water rights have been reserved to the states. While this has resulted in different approaches to water allocation, approaches are broadly based on riparianism or prior appropriation. Under a riparian system water rights are based on land ownership whereas appropriative rights are granted based on first in time, first in right. In unpacking different approaches to governance and institution building, we will examine the following key questions:

- At what level of government are decisions made? What decisions are made by those levels? From where are they granted their authority? What are the goals and objectives informing those divisions of responsibilities? What are the related institutions involved in decision-making?
- How are mandatory and voluntary measures used?
- How and when should the public be engaged in decision-making?
- Should the government mandate a human right to water, and what does that right entail?

Understanding these questions across different jurisdictions will help to understanding existing approaches and identify alternatives.

Market-based solutions

Water quality and water quantity markets are often established to help encourage water efficiency and to more efficiently distribute the costs of meeting water quality protections. Water quality markets allow for dischargers who are able to more cost-effectively reduce the percentage of contaminants in their discharges to sell those credits for profit to other dischargers whose cost of reducing contamination is greater.[171] Water quality markets are also helpful in managing pollution that is not otherwise overseen by the government. Establishing these types of markets creates an economic incentive to find ways to reduce pollution.

Water quantity markets incentivize maximizing water use efficiency by providing a benefit for having "extra" water. That saved water can be sold to other users willing to pay. Most markets create a system where certain rights are removed from the available market. This ensures there is an actual reduction in water being used, not just an increase in efficiency.

National Security

Every nation's security is dependent on water. Water is a necessity to preserve the health and human security of citizens of all states, and water scarcity has the capacity to upend a delicate balance.[172] Inadequate water supplies also serve as a driver of internal and international conflict, particularly in areas of critical strategic interest for the world. Lack of water also has the potential to induce migration and other large-scale movements of people. In addition to these threats, without sufficient water military bases may also be unable to serve their strategic purpose properly. In short, without sufficient water, countries face existential threats.

Considering water from the national security perspective requires a holistic view of threats. This includes internal and external threats to national security. External threats include threats against water that come from any external source, ranging from terrorist groups to transboundary pollution of waterways. These external threats include attacks against extraterritorial interests that are of strategic importance to the stability of the nation or which affect the ability of a nation to defend itself. Internal threats range from water shortages that affect the availability of clean water for human and economic consumption. For both sets of threats, the effects on water can lead to health catastrophes, food insecurity and famine, economic collapse, and political upheaval.

Because of the numerous demands on water, the definition of national security is, and must be, exceptionally broad. To fully encapsulate the linkages that bind water and national security, national security will be defined as the capacity of a state to maintain: (1) immediate political and economic stability; (2) the life, health and liberty of its denizens; (3) essential, if not complete, political independence from external forces or powers at both the domestic and international level; and, (4) the integrity of its borders and territorial independence.

Different threats to water implicate different combinations of these factors and illustrate the complex interdependence between water and national security.

National Security v. Water Security

The national security of water is not as much about the current flow or availability of water, but about the future flow. Does the nation have sufficient water to ensure that these four basic needs will continue to be met? In this way, national security, like water security, must consider water in a holistic manner. But unlike water security, national security is more about immediate results instead of a long-term vision. There is greater room for trade-offs and replacements if the national security of water is threatened. If there is insufficient water to allow for manufacturing, threatening economic stability, a national security approach will maintain economic stability by providing monetary relief to affected workers or creating jobs through spending. If there is insufficient water for agriculture and food security is threatened, a national security approach will ensure that there is a strategic food reserve ready to meet that need.

Water security approaches these needs in a different way by making sure that we never get to that point, that we never run out of water for manufacturing or agriculture in the first place. This negates, at least in part, the need for fungibility, for trade-offs, and for the development of so many other redundancies—at least when it comes to water.[173]

Internal instability

Water is necessary for life. The disruption of water supplies internally can have a significant effect on the ability of a country to ensure political and economic stability and the life, health and liberty of those who live within its borders. Drinking water shortages can lead to significant health effects,[174] and water shortages in key agricultural areas can lead to food insecurity for an entire country or region.[175]

Water also serves as an important input in economic development and stability. In addition to the impact that unclean water has on the health of the workforce and the output of the agricultural sector, unclean water may be unfit for manufacturing or other purposes.[176] While cleaning this water for human purposes may be possible, it may be prohibitively cost-inefficient overall. Water shortages may also impact agricultural and manufacturing sectors that rely on water to create products ranging from tomatoes to cars to silicon chips.[177] The agricultural and manufacturing sectors need sufficient clean water to exist. It is a necessary input, and without it, these sectors will fail. Even in the service economy, the health of workers in service industries will also be affected. In other words, every sector of the economy is tied to water, and water threats create economic instability.

Water is also necessary for hygiene and proper health, including the provision of medical care. Hospitals rely on the availability of water to provide for proper sanitation; schools require water for hygiene and sanitation. Without water these fundamental governmental services may be compromised, undercutting human health, increasing infection and mortality, increasing the spread of disease, and decreasing the possibility to learn and achieve a better life.

Water also serves as a vector for some serious diseases and health conditions if it is not properly managed and treated. Introduction of wastewater into water used for drinking water or other purposes can be a serious threat to drinking water. Cholera and dysentery threats in Haiti,[178] Burundi,[179] Iraq and Syria,[180] and Israel,[181] E. coli outbreaks in Canada,[182] and lead poisoning in Flint, Michigan all indicate that water contamination is a persistent threat to water security.[183]

The threats to economic and political stability posed by water are durable. Without proper access to food, water, and hygiene, children may not be able to be healthy enough to attend school or fully engage in the classroom. Other students may suffer from water contamination-related developmental issues. These impacts in education disproportionately affect girls, just as water scarcity more broadly tends to affect women and children disproportionately. These effects can have a deep impact on the mobility and economic future of a country, meaning that water insecurity can have lasting impacts on the economic and political futures of a country.

Most countries have not experienced systemic internal violence resulting directly from water. Economic hardship, including a lack of opportunities for all citizens, has been tied to violent uprisings.[184] Shortages of water have been at the root of recent political violence, including the Arab Spring uprisings and the Syrian conflict.[185] While the outbreak of violence is often a result of many factors, the linkages of water to economic success, human health, and societal equality put water at the center of all of these stress points. As a result, water security helps to deescalate pressures placed on countries and water insecurity ignites these pressures.

Internal instability poses a threat to the strategic interests of other states. In addition to the destabilization caused by internal conflicts that flow over borders, water-driven conflict can interfere with other strategic priorities like trade, access to fossil fuels or other goods, access to food and water,[186] and movement of capital and availability of markets. While these threats and the strategic importance of these goods are more broadly understood inside of the national security apparatus and frameworks, their links to water have not been fully explored. In short, it is better to address the causes of instability and extremism proactively instead of reactively after the threats have crystallized.

Massive migrations destabilize regions

With internal upheaval and violence comes internal displacement and migration. Water-related violence displaces millions of people around the globe. In water-scarce regions situated in conflict areas, water stress in neighboring countries may be compounded by large scale refugee movement. These migrations have the potential to destabilize fragile states and to create water and sanitation issues, including transboundary wastewater issues, though these stressors are often mitigated by international organization cooperation.

Without sufficient water resources to provide for all persons and without the water necessary to support economic growth, water scarcity drives large scale migrations around the world. Syria is a recent example, where water shortages for farmers led to economic collapse of the agricultural sector and widespread migration to urban areas. These urban areas were unable to provide economic opportunities for the migrated farmers, leaving them destitute and hopeless, factors which contributed to the insurrection in Syria.[187] While some joined the insurrection in Syria, others took refuge in neighboring countries, like Jordan, Lebanon and Turkey. In Jordan, existing water scarcity has been heightened by the needs of the growing refugee population, causing greater instability in Jordan as it tries to meet these new needs.[188] This situation shows the destabilizing potential for large-scale migration, first to urban areas and then to neighboring countries.

The indirect effects of water scarcity on migrants and refugees can set these populations back by a generation. Migrants are constantly under threat as unwelcome visitors; they risk their lives on ships to cross oceans; their personal safety is compromised, particularly for women and girls; and, the availability of education and proper nutrition for children is almost nil, unless they reach a welcoming country or are protected by aid organizations. But resources are sometimes insufficient even there, meaning that water insecurity becomes the norm for another generation.[189]

Water scarcity is both a driver of migration and a result of migration. With water security, countries will be better able to prevent mass migration to cities or across borders. By removing one of the fundamental threats to human health, countries will be better positioned to manage humanitarian crises caused by disasters and to have sufficient water to provide to refugees in times of crisis or war.

Threats to military operations

The ability to project military power is also implicated by water issues. Issues of scarcity or abundance can affect the ability of littoral or other naval vessels to operate out of existing bases or ports. The same issues can affect military troops that rely on *in situ* natural resources like water for the success of their mission. Salt water intrusion caused by overuse can also impact the availability or mission cost. Without these water resources at hand, states may find it more difficult or more costly to project power abroad and to protect their national interests.

The impacts of military operations on local communities—even those in allied nations—can become a liability and a diplomatic issue as they relate to water. Use of resources for sustenance or contamination of water by waste or toxins have the potential to undermine military operations, including public diplomacy missions, and to create significant diplomatic issues that can lead to forced withdrawal of troops. States may also seek to change liability rules, which in turn makes missions abroad more costly overall. Finally, these ancillary impacts caused by military deployments can shift political fervor against troops abroad, turning military forces into targets of civilian unrest.

Without forward operating bases or bases that can maximize their advantage, the military will have to expend more energy and cost on procuring new land and supplies for bases. This will infringe upon the ability of the military to exercise their soft power in the region where they operate, to respond as efficiently, and to be as effective as they otherwise might be.

Threats to strategic interests

It is in every country's strategic interest to protect water quality and quantity around the world. If water is not managed properly, the threats are clear: internal instability, instability in partner countries, threats to availability of food and manufactured goods, threats to human health and hygiene because of communicable diseases, inability to project power through the military effectively and mass migration. These threats can strike any country, ally or enemy alike.

Because of the interdependence and globalization of our economies and lives, water insecurity's effects can be felt around the globe. Countries need markets for goods, economic support, raw natural resources and other imports, a healthy population, an international workforce and other economic requirements. Water crises may curtail mining of minerals needed for international manufacturing. When countries suffer from economic stress due to water, they cannot serve as a market for imports. When a pandemic seizes a country, international travel can increase global infections and complicate the response. When political destabilization strikes an ally in the war on terror that ally may withdraw from attacks; when destabilization strikes a country that is taking in refugees, it may not be able to continue to house and protect refugees. Water stability helps keep these critical strategic interests stable.

To respond to these national security threats, many countries have used foreign aid and other funding to manage and address water issues in neighboring countries or in countries of strategic interest. This has included Israel providing Jordan with increased water withdrawals from the Jordan River to build Jordan's capacity to respond to influxes of refugees. This example, and others around the world, illustrate that countries help their neighbors cope both in their own national security interest and in the interests of broader regional stability.

Cyber, psychological, or kinetic attacks on water

National security strategies must also consider attacks against water infrastructure that can undermine the availability or quality of water. These attacks fall into three major categories: cyberattacks, psychological operations and kinetic actions.

Kinetic actions represent the low-tech attacks on water. Poisoning of water supplies, attacking dams with explosives or otherwise compromising the water systems all represent kinetic attacks. These attacks require physical action, and their effects can be devastating. If dams are destroyed, areas may be flooded, causing widespread damage and casualties. If dams are otherwise rendered inoperable, the availability of water and the integrity of the surrounding ecosystem might be threatened. If water is poisoned with a biological or toxic agent,[190] the resultant health catastrophe would be immense, particularly if the attack was directed against a major city. Even other actions that interfere with the provision of water, like the destruction of major pipes or underground transfer points for stormwater, drinking water and wastewater or sewage, could have potentially outsized effects on health and hygiene.

Cyberattacks can also have a significant effect on water infrastructure, albeit with a lesser range of options available to attackers. Cyberattacks target computer systems that manage dams, pumps, and water systems, leading to attacks that are similar in effect to kinetic attacks.[191] Though it is difficult to introduce a toxic agent into water via cyberattack, cyberattacks can potentially destroy computer systems, can be used to change the flow of water from dams, and to prevent the procurement or delivery of water through pipes and pumps systems. Denial of water through a cyberattack has the same effect on health and economy as a kinetic attack; the opening of a dam's gates also can have the same effect as destroying the dam completely: as the water flows, areas can become flooded and destroyed, and people may be killed.

Psychological operations against water can also have significant deleterious effects on the public's trust in water resources. These operations can create situations that amount to a denial of water. Using social media, fake accounts, false news reports, and other mechanisms, state actors and non-state actors can create and spread information that calls the safety of water into question. Fear and panic sown through these reports will keep people from using water until they are confident that it is safe. However, the echo chamber of news reporting and distrust of government may undermine the effectiveness of government response. As a result, psychological operations can have as severe an effect on water as a kinetic or cyber-attack.

Peace & Conflict

When water stress becomes too great, water can become a driver of conflict. Equally, when water stress is minimized or when countries cooperate on water, water becomes a tool of peace.

Upstream v. Downstream

Geography plays a major role in geopolitics. In water, this role is maximized. Upstream states typically have greater physical control over the waters in a shared basin, which creates an inherent power differential that affects peace and conflict. How these states manage their water resources and how well they cooperate on water has a significant effect on the maintenance of peace and security.

When conflict does break out, water can become both a weapon of war and an innocent casualty. The flow of water through dams can be shut off, choking downstream states of irrigation water; water can also be contaminated for downstream users, causing vast human suffering. While either of these actions would violate international law, not least because of their effect on citizens, and incur the opprobrium of the international community, even short-term effects of this kind of coercion can be significant. This weaponization of water can have profound, lasting effects on the economic viability, human security and stability of these regions.

So much of water's effect on peace and conflict is tied into a notion of coercion and control. Downstream states are reluctant to allow new construction on rivers upstream because of the potential for—at best—mismanagement or—at worst—manipulation of water resources. The fear of coercion of State sovereignty and the loss of control is a real factor in whether countries cooperate. Water is irreplaceable, particularly in an emergency, and water shortages have a cascading effect on energy, food, manufacturing and other critical areas. Without cooperation, this coercion and control becomes part of the day-to-day considerations of diplomacy and relations with neighbors. These relations can be peaceful and constructive when water is managed collaboratively and comprehensively.

Armed Conflict v. Transboundary Cooperation

International armed conflict over water is atypical nowadays, but conflict that threatens to boil over because of water shortages is becoming more frequent. The Arab Spring, the Syrian Civil War, Ethiopia and Egypt, disputes between Bolivia and Chile, China and India, Afghanistan and Iran, Yemen and a host of other conflicts—violent and political—have been tied to present or feared water shortages or other misuse. India and Pakistan are engaged in legal disputes over the application of the Indus Waters Treaty, which could have potentially severe ramifications for the future of the compact. The cost of war is high, even to protect water. But if the amount of water becomes stretched too thin, these regions are dry tinder.

There is room for cooperation as a means of mitigating these conflicts. At the first official meeting on Water, Peace and Security at the U.N. Security Council, one of the speakers noted that countries that when countries cooperate on water, they do not go to war for any reason.[192] It is unclear if water cooperation signals an interdependence and reliance that removes full-scale conflict as a means of dispute resolution. The other option is that when countries cooperate on water, those inroads and that trust creates stronger relationships that extend to other arenas.

Either way, cooperation on transboundary waters is linked to less armed conflict.

It's What's on the Inside that Counts, too!

In addition to surface waters like shared rivers and lakes, groundwater overuse also poses a significant threat to international peace and security. As surface waters have become over-allocated, many farmers and communities have turned to underground aquifers to fulfill their water needs. However, some of these aquifers cross international boundaries, and overexploitation by one side can essentially empty the aquifers for all users. Groundwater exploitation is often separated from international agreements on water management, leaving the aquifer use unregulated and unmonitored. Water aquifers often serve as an essential reserve for times of significant drought. However, current use appears to be outpacing supply greatly.[193]

With overexploitation comes other concerns. As groundwater is exploited in wells, it can become more and more affected by rising salinity through intrusion among the coastline, through contamination as many more people drill wells, and through other naturally occurring impacts. Cities that rely on underground aquifers as their sole source of drinking water can be deeply affected by this type of contamination or by overexploitation. Empty aquifers also pose additional risks of geological collapse, which can affect millions. In short, groundwater exploitation can have significant transboundary effects.

The transboundary nature of these water sources creates the potential for conflict, particularly if one country is overexploiting the resource to the detriment of the other. Exploitation on this level has the potential to destabilize multiple countries and encourage a race to drain the aquifer first, leading to a tragedy of the commons and a complete depletion of the resource. Even with all of these concerns, groundwater exploitation still remains generally unregulated on a transboundary level.

Water as a Weapon

Water's potential as a weapon is also multi-faceted. Water can be contaminated at the source or along the supply lines, preventing any use by down-system users. Water flows can be impeded, by dams or other mechanisms, preventing water from reaching down-system users. Alternatively, water flows can be intensified leading to floods and destruction. Pumps and other infrastructure can be attacked, preventing water from reaching citizens. In conflict, humanitarian aid can also be attacked, leaving civilians without water.[194]

Inadvertent contamination is also a concern in conflict. Environmental degradation of water resources can be an outcome of attacks on infrastructure or the use of chemical weapons. Attacks on certain infrastructure may cause significant damage to water resources and aquifers that will last after the conflict ends and prevent economic and other rehabilitation.

Direct, indirect and inadvertent attacks on water are all addressed by the law of international armed conflict, which prevents direct attacks on civilians and civilian infrastructure. However, urban guerilla warfare and terrorist control of oil infrastructure in recent conflicts has made it more difficult to make necessary targeting decisions that also completely protect civilian water infrastructure. By using civilian infrastructure to finance terror and war, groups are blurring the lines between military and civilian targets and creating a greater risk that water supplies will become legitimate targets in conflict.

Water Mismanagement Creates Crises

Water scarcity, drought and other shortages create dire situations that threaten a country's existence. As noted earlier, water shortages are tied to many conflicts in the past five years. But more than creating struggles for water between countries, water shortages create internal strife, are a driver of migration to cities and other countries, and a cause of disaffection with government that leads, in the long term, to violence.

Two examples prove this link between water and violence. In Syria, as an example, this progression is very evident. Water shortages in rural agrarian areas of the country due in part to water mismanagement destroyed farmer's economic future and output. These farmers moved to cities to find opportunity, straining the food security of the country. These farmers struggled to find additional opportunities in cities, became disaffected with the regime, and began to militate for political change. This political movement eventually became a violent insurrection that caused massive displacement of persons, including a refugee crisis that continues to impact Europe and the Middle East. In countries like Jordan, the additional stress on water threatens Jordan's ability to provide water for refugee camps and their own citizens. As long as a political solution remains elusive, this regional destabilization continues. Migration to Europe from Northern Africa is also tied to the same pressures. Agrarian economies are desiccated and failing as water shortages constrict farmers. These farmers in turn try to escape to cities, to other countries, or to Europe.

In addition to being at the heart of migration and internal insurrection, water issues create crises in health, food and safety that threaten internal stability and can lead to political upheaval. Loss of agrarian and subsistence farming creates the potential for food shortages and malnutrition. Water overexploitation can also threaten the ability of a country to provide energy, to build its economy, or to ensure that its ecology can weather natural disasters. While some of the water shortages could be weathered through more effective water management, others require a consideration of greater systemic issues. This is true of both internal and transboundary waters.

Conclusions

Water touches upon every area of our lives, and this first paper attempts to outline the many ways that water intersects with areas like energy, agriculture, health, national security and many others. The examples in this paper are designed to show the sheer interconnectedness of water and to help initiate a conversation about our path forward. Each choice we make on water influences the quality and quantity of water for every other person and every other use. By understanding these relationships and recognizing how our water decisions in one area affects water use in other areas, we can make better choices.

The Water Complex

The complexity of our relationship with water is not reflected in our laws; in most countries, the law is used as a blunt instrument, lacking nuance and thoughtfulness. We treat water differently in each sector, acting as though the water that is pulled in and used by factories is not the same water that we drink later. We often refuse to break down the barriers between the way that the law regulates water and the way that water regulates itself. Through our framework, we hope to create enduring solutions built on smart law and policy that can help every country reconsider and reenvigorate its relationship with water.

But what this paper series will do is break down the artificial distinctions and divides that have colored these areas. The Center for Water Security and Cooperation is going to break down water into its minutiae and then build a framework that considers water and its impacts on all levels. As this paper indicates, water's relationships are exceptionally broad, touching upon every area of life. In order to create an effective framework, we must consider these nexuses fully.

In other words, this challenge will break down the complexity of water and its nexuses in an attempt to create a framework that addresses our constant undervaluation of water.

Water is...

As we move forward, our future papers will address these complexities in greater detail, investigate these relationships in greater detail, and look more closely at the legal components of these relationships. The law has developed steadily over decades and centuries, and its role in creating these relationships and managing these relationships will be a major focus going forward. So much of our relationship with water is governed by law, and understanding how water relates to these disparate areas requires a deep and thoughtful analysis and evaluation of the existing legal infrastructure. By understanding what has worked and what has not worked, we can work to build a stronger, more effective, more practical policy and legal framework for water going forward.

For these reasons, as much as water is life, water is law. This unique and special relationship will be a major component of our future research on this topic.

The work does not stop here.

As we move forward, we encourage you to reach out with your examples of waters relationships. The richer the work that we create, the more that it will be able to provide for all of the complexities and criticisms that are raised. As the world changes, our relationship with water changes. As our relationship with water changes, our relationship with law must change as well. These areas are inseparable.

Appendix I: Definitions of Water Security

Water security has been defined in a variety of ways. While different, each definition seeks to capture the complexity of water use and impact.

- The working definition of water security for **The Center for Water Security and Cooperation** is: "the ability to safeguard an availability of water sufficient to sustain lives and livelihoods and protect against threats to and from water." The definition attempts to capture that water security is an access and availability issue.

- The **UN** defines water security as: "The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability."[1]

- **UNESCO-IHP** defines water security as: "For our purpose, water security is defined as the capacity of a population to safeguard access to adequate quantities of water of acceptable quality for sustaining human and ecosystem health on a watershed basis, and to ensure efficient protection of life and property against water related hazards -- floods, landslides, land subsidence,) and droughts."[2]

- **GTZ** bases its definition of water security on the UNDP's Human Security concept which refers to the *security of the peoples'*. Therefore, water security is defined as: "freedom from direct or indirect impacts of lacking provision of sufficient and clean water. At the international level, it is determined by the dependency on transboundary water flows, the relationship to riparian countries, and the ratio of food security based on secure supply or own production."[3]

- **Grey and Sadoff** define water security as: "the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies."[4]

- The **Global Water Partnership** states that "Water security, at any level from the household to the global, means that every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, while ensuring that the natural environment is protected and enhanced."[5]

- The **OECD** takes a risk-based approach to water security. Achieving water security means maintain acceptable risk levels for: risk of shortage (including droughts), risk of inadequate quality, risk of excess (including floods) and the risk of undermining the resilience of freshwater systems.[6]

- **USAID** defines water security as "reliable access to water of sufficient quantity 'and quality for basic human needs, small-scale 'livelihoods and local ecosystem services, coupled 'with a well-managed risk of water-related disasters."[7]

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1 UN Water, "What is Water Security?", http://www.unwater.org/fileadmin/user_upload/unwater_new/docs/water_security_poster_Oct2013.pdf.

2 International Hydrological Programme (IHP) Eighth Phase "Water Security: Responses To Local, Regional, And Global Challenges" Strategic Plan IHP-VIII (2014-2021), http://unesdoc.unesco.org/images/0021/002180/218061e.pdf.

3 Dr. Annabelle Houdret, Annika Kramer, Alexander Carius, GTZ *The Water Security Nexus: Challenges and Opportunities for Development Cooperation*, p. 5, http://ccsl.iccip.net/gtz2010-0546en-water-security-nexus.pdf.

4 David Grey and Claudia W. Sadoff, *Sink or Swim? Water Security for Growth and Development*, 9 Water Pol'y 545, 569 (2007).

5 Global Water Partnership, Integrated Water Resources Management. TEC Background Paper No. 4., (2000).

6 OECD (2013), *Water Security for Better Lives*, OECD Studies on Water, OECD Publishing, available at http://dx.doi.org/10.1787/978926402405-en.

7 WaterAid (2012) *Water security framework*. WaterAid, London.

Notes

1 National Academies of Sciences, *What You Need To Know About Energy* available at http://needtoknow.nas.edu/energy/interactive/our-energy-system/.

2 Department of Energy, *How much energy do you use?* available at https://energy.gov/articles/how-much-do-you-consume.

3 International Energy Agency, *World Energy Outlook 2016*.

4 USGS, *Estimated Use of Water in the United States in 2010*, Circular 1405 (2014). All uses include public supply, domestic, irrigation, livestock, aquaculture, industrial, mining and thermoelectric power.

5 National Renewable Energy Laboratory, *Consumptive Water Use for U.S. Power Production* (December 2003).

6 *Id*.

7 USGS, *Total Water Use in the United States 2010* available at https://water.usgs.gov/edu/wateruse-total.html

8 USGS, *A Coal-Fired Thermoelectric Power Plant* available at https://water.usgs.gov/edu/wupt-coalplant-diagram.html.

9 C2ES Cogeneration/Combined Heat and Power (CHP) Fact Sheet (March 2011).

10 Department of Energy, *How a geothermal power plant works (simple)* available at https://energy.gov/eere/geothermal/how-geothermal-power-plant-works-simple. There are three types of geothermal plants: dry steam plants, flash steam plants and binary cycle power plants. EIA, *Geothermal Explained*, available at https://www.eia.gov/Energyexplained/index.cfm?page=geothermal_power_plants.

11 NREL, *A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies*, Technical Report NREL/TP-6A20-50900 (March 2011).

12 https://www.nei.org/Knowledge-Center/How-Nuclear-Reactors-Work

13 NREL, *A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies*, Technical Report NREL/TP-6A20-50900 (March 2011).

14 DOE, *Concentrating Solar Power Basics* available at https://energy.gov/eere/energybasics/articles/concentrating-solar-power-basics.

15 NREL, *A Review of Operational Water Consumption and Withdrawal Factors for Electricity Generating Technologies*, Technical Report NREL/TP-6A20-50900 (March 2011).

16 EIA, *Nuclear Explained: The Nuclear Fuel Cycle* available at https://www.eia.gov/energyexplained/index.cfm?page=nuclear_fuel_cycle.

17 EIA, *Nuclear Explained: Nuclear Power and the Environment* available at https://www.eia.gov/energyexplained/index.cfm?page=nuclear_environment.

18 USGS, *Hydroelectric power water use* available at https://water.usgs.gov/edu/wuhy.html.

19 World Energy Council, *Hydropower* available at https://www.worldenergy.org/data/resources/resource/hydropower/.

20 International Hydropower Association, *Types of hydropower* available at https://www.hydropower.org/types-of-hydropower.

21 Department of Energy, *Types of Hydropower Plants* available at https://energy.gov/eere/water/types-hydropower-plants.

22 *Id*.

23 IAE, *Technology Roadmap: Hydropower*, 28 (2012).

24 IAE, *Technology Roadmap: Hydropower*, 29 (2012).

25 Water is necessary in the production and manufacturing of the equipment for wind energy. Seanica Otterby, *How does wind energy's water consumption compare to other energy technologies?* (December 19, 2013) available at http://apps2.eere.energy.gov/wind/windexchange/filter_detail.asp?itemid=4083.

26 AWEA U.S. Wind Industry Annual Market Report 2015 published April 12, 2016.

27 Michael Goggin, *Wind energy saves 2.5 billion gallons of water annually in drought-parched California*, AWEA Blog (April 2, 2015) available at http://www.aweablog.org/wind-energy-saves-2-5-billion-gallons-of-water-annually-in-drought-parched-california/.

28 European Wind Energy Association, *Saving water with wind energy* (June 2014).

29 National Geographic, *How Green Are Those Solar Panels, Really?* (November 11, 2014) available at http://news.nationalgeographic.com/news/energy/2014/11/141111-solar-panel-manufacturing-sustainability-ranking/.

30 Vasilis M. Fthenakis, *End-of-life- management and recycling of PV modules*, Energy Policy, Vol. 28 pp. 1051-1058, Elsevier (2000).

31 USGS, *Estimated Use of Water in the United States in 2010*, Circular 1405 (2014).

32 *Id.*

33 USGS, *Estimated Use of Water in the United States in 2010*, 37 Circular 1405 (2014).

34 Stanford, *Water and Energy Nexus: A Literature Review* (August 2013).

35 CRS, *Biomass: Comparison of Definitions in Legislation* (January 6, 2015).

36 Harvard Kennedy School, Belfer Center for Science and International Affairs, *Water Consumption of Energy Resource Extraction, Processing and Conversion* (October 2010), http://www.belfercenter.org/sites/default/files/legacy/files/ETIP-DP-2010-15-final-4.pdf.

37 Stanford, *Water and Energy Nexus: A Literature Review*, 77 (August 2013).

38 Stanford, Water and Energy Nexus: A Literature Review, 65 (coal), 77 (natural gas), 112 (crude oil), 1*18 (biofuels), 84 (uranium) (August 2013).*

39 Stanford, Water and Energy Nexus: A Literature Review, 78 (oil, coal, n*atural gas), 119 (biofuels) (August 2013).*

40 EPA, *Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figures for 2012* available at https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/msw99.html.

41 EPA, *Municipal Solid Waste* available at https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/.

42 Blanca Antizar-Ladislao and Juan L. Turrion-Gomez, *Second-generation biofuels and local bioenergy systems* (Biofpr 2008).

43 International Energy Agency, *World Energy Outlook 2016*.

44 *Id.*

45 Stanford, *Water and Energy Nexus: A Literature Review*, 13 (August 2013).

46 42 U.S.C. §300(f) et seq. (1974).

47 EPRI and WRF, *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries*, 2-12 (November 2013).

48 Stanford, *Water and Energy Nexus: A Literature Review*, 32-33 (August 2013).

49 EPRI and WRF, *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries* (November 2013).

50 Stanford, *Water and Energy Nexus: A Literature Review*, 36 (August 2013).

51 EPA, *Water Audits and Water Loss Control for Public Water Systems* (July 2013).

52 James M. O'Neill, *Aging and leaky water mains cost N.J. million* (January 17, 2017) available at http://www.northjersey.com/story/news/environment/2017/01/27/aging-and-leaky-water-mains-cost-nj-millions/96988100/.

53 EPA WaterSense available at https://www3.epa.gov/watersense/our_water/fix_a_leak.html.

54 NRDC, *Cutting our Losses* (March 8, 2017) available at https://www.nrdc.org/resources/cutting-our-losses.

55 Stanford, *Water and Energy Nexus: A Literature Review*, 27 (August 2013).

56 CEC (Klein, G., M. Krebs, V. Hall, T. O'Brien and B. Blevins). "California's Water–Energy Relationship." California Energy Commission (2005).

57 EIA, *Annual Energy Outlook 2015, Table: Residential Sector Key Indicators and Consumption* available at https://www.eia.gov/outlooks/aeo/data/browser/#/?id=4-AEO2015&sourcekey=0.

58 Chris Mooney, *Your shower is wasting huge amounts of energy and water. Here's what you can do about it.* (Washington Post March 4, 2015) available at https://www.washingtonpost.com/news/energy-environment/wp/2015/03/04/your-shower-is-wasting-huge-amounts-of-energy-and-water-heres-what-to-do-about-it/?utm_term=.bdf6b0e45cf0.

59 EPRI and WRF, *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries*, 3-1 (November 2013).

60 EPRI and WRF, *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries*, ix (November 2013).

61 33 U.S.C. §1251 et seq. (1972). 40 CFR 122 et seq.

62 EPRI and WRF, *Electricity Use and Management in the Municipal Water Supply and Wastewater Industries*, 5-2 (November 2013).

63 Stanford, *Water and Energy Nexus: A Literature Review*, 48 (August 2013).

64 Stanford, *Water and Energy Nexus: A Literature Review*, 54 (August 2013).

65 EPA, *Acid Rain Program: 2005 Progress Report* (October 2006).

66 N. Madden, A. Lewis and M. Davis, Thermal effluent from the power sector: an analysis of once-through cooling system impacts

on surface water temperature, (IOPScience, 2013 Environ. Res. Lett. 8 035006, published July 3, 2013).

67 OECD, *Mitigating Droughts and Floods in Agriculture: Policy Lessons and Approaches* (2016).

68 OECD, *Financial Management of Flood Risk* (2016).

69 National Geographic, *Floods* available at http://www.nationalgeographic.com/environment/natural-disasters/floods/.

70 UN Water, *Water and Disasters: Thematic Factsheet* available at http://www.unwater.org/statistics/thematic-factsheets/ar/.

71 TIME, *The Cost and Consequences of the U.S. Drought* (October 26, 2012) available at http://business.time.com/2012/10/26/the-cost-and-consequences-of-the-u-s-drought/.

72 Amanda Erickson, *In Somalia, a drought killed 100 people in just 48 hours*, Washington Post (March 4, 2017) available at https://www.washingtonpost.com/news/worldviews/wp/2017/03/04/in-somalia-a-drought-killed-110-people-in-just-48-hours/.

73 James Conca, *Thanks To Fracking, Earthquake Hazards In Parts Of Oklahoma Now Comparable To California*, Forbes (September 7, 2016) available at https://www.forbes.com/sites/jamesconca/2016/09/07/the-connection-between-earthquakes-and-fracking/#79a7a38f6d68.

74 Henry Fountain, *In Canada, a Direct Link Between Fracking and Earthquakes*, NY Times (November 17, 2016) available at https://www.nytimes.com/2016/11/18/science/fracking-earthquakes-alberta-canada.html . Kristin Hugo, Earthquakes triggered by fracking, not just wastewater disposal, study finds, PBS (November 18, 2016) available at http://www.pbs.org/newshour/rundown/earthquakes-triggered-by-fracking/.

75 USGS, *Land Subsidence* available at https://water.usgs.gov/edu/earthgwlandsubside.html.

76 Todd Fitchette, *How land subsidence could reduce surface water deliveries in California*, Western Farm Press (February 9, 2017) available at http://www.westernfarmpress.com/water/how-land-subsidence-could-reduce-surface-water-deliveries-california.

77 Financial Tribune, *Tehran Land Subsidence a Serious Threat* (February 2, 2017) available at https://financialtribune.com/articles/environment/58706/tehran-land-subsidence-a-serious-threat.

78 Alan Taylor, The Exxon Valdez Oil Spill: 25 Years Ago Today (The Atlantic March 24, 2014). Drew Griffin, *5 years after the Gulf oil spill: What we do (and don't) know* (CNN April 20, 2015) available at http://www.cnn.com/2015/04/14/us/gulf-oil-spill-unknowns/.

79 Scientific American, *Oil Spills in Yellowstone River after Pipeline Leak* (January 19, 2011) available at https://www.scientificamerican.com/article/oil-spills-in-yellowstone-river-after-pipeline-leak1/.

80 Derek Hawkins*, Pipeline 150 miles from Dakota Access protests leaks 176,000 gallons of oil* (December 13, 2016) available at https://www.washingtonpost.com/news/morning-mix/wp/2016/12/13/pipeline-150-miles-from-dakota-access-protests-leaks-176000-gallons-of-oil/?utm_term=.4bce8e2f7627.

81 Anamesere Igboeroteonwu, *Exxon Mobil oil spill hits communities in southeast Nigeria: local leader* (Reuters December 21, 2016) available at http://www.businessinsider.com/r-exxon-mobil-oil-spill-hits-communities-in-southeast-nigeria-local-leader-2016-12. John Vidal, *Nigeria's agony dwarfs the Gulf oil spill. The US and Europe ignore it* (The Guardian May 29, 2010) available at https://www.theguardian.com/world/2010/may/30/oil-spills-nigeria-niger-delta-shell.

82 Justin Gillis, *Flood of Coast, Caused by Global Warming, Has Already Begun*, NY Times (September 3, 2016).

83 Randy Astaiza, *11 Islands That Will Vanish When Sea Levels Rise* (Business Insider October 12, 2012) available at http://www.businessinsider.com/islands-threatened-by-climate-change-2012-10/#tegua-5.

84 National Oceanic and Atmospheric Administration, *Is sea level rising?* available at http://oceanservice.noaa.gov/facts/sealevel.html.

85 Robert M. DeConto and David Pollard, *Contribution of Antarctica to past and future sea-level rise* (Nature Vol. 531 March 31, 2016). Chris Mooney, *The alarming science driving much higher sea level projections for this century* (Washington Post March 30, 2016).

86 Nell Greenfieldboyce, *Study: 634 Million People at Risk from Rising Seas* (NPR March 28, 2007) available at http://www.npr.org/templates/story/story.php?storyId=9162438.

87 Agriculture includes all activities associated with cultivating, harvesting and processing all types of crops (including crops grown to produce goods for manufacturing), raising livestock, forestry and aquaculture.

88 ERS, *Effects of Trade on the U.S. Economy – 2014*, available at https://www.ers.usda.gov/data-products/agricultural-trade-multipliers/2014-data-overview/.

89 ERS, *Interactive Charts: Effects of U.S. Agricultural Exports on the Economy in 2015*, available at https://www.ers.usda.gov/data-products/agricultural-trade-multipliers/interactive-chart-and-highlights-effects-of-agricultural-exports-on-the-us-economy/.

90 65.9 Bgal/day or 57% were surface water withdrawals and 49.5 Bgal/day were groundwater withdrawals. USGS, *Estimated Use of Water in the United States in 2010*, Circular 1405 (2014).

91 This calculation is based on an end-of-year estimated population of 322,762,018 by the U.S. Census Bureau. USGS, *Home much water does the average person use per day?* available at https://water.usgs.gov/edu/qa-home-percapita.html.

92 *Id.*

93 FAO, *Irrigated Crops Infographic* (2014) available at http://www.fao.org/nr/water/aquastat/infographics/Irrigated_eng.pdf.

94 GWP, *Water and food security – Experiences in India and China*, Technical Focus Paper (2013).

95 *Id.*

96 Ken Sofer, *The California Drought's Lessons for Food Security*, Slate (June 22, 2016) available at http://www.slate.com/blogs/future_tense/2016/06/22/the_california_drought_s_lessons_for_food_security.html. Kevin Corriveau, Food security crisis in southern Africa after drought, Aljazeera (January 5, 2017) available at *http://www.aljazeera.com/news/2017/01/food-security-crisis-southern-africa-drought-170105094830319.html*.

97 Colin Dwyer, Drought Threatens To Drive Famine In Somalia As Hunger Kills More Than 100, NPR (March 5, 2017*)* available at http://www.npr.org/sections/thetwo-way/2017/03/05/518624610/drought-threatens-to-drive-famine-in-somalia-as-hunger-kills-more-than-100. *Marilia Brocchetto, Somalia drought: At least 110 die as fears of famine grow*, CNN (March 7, 2017) available at http://www.cnn.com/2017/03/04/africa/somalia-drought-deaths/.

98 B.P. Singh, *Industrial Crops and Uses* (2010)

99 WHO, The environmental and health impacts of tobacco agriculture, cigarette manufacture and consumption (2015) available at http://www.who.int/bulletin/volumes/93/12/15-152744/en/. Portland State University, *Fact Sheet: Environmental Impact of Tobacco* (March 2013) available at https://www.pdx.edu/healthycampus/sites/www.pdx.edu.healthycampus/files/Environmental_Impacts.3.7.13.pdf. UNESCO-IHE, *The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products: Volume 1* (December 2010).

100 Biomass is defined as organic material that comes from plants and animals and contained stored energy from the sun. Plants absorb the sun's energy through photosynthesis, which when burned releases heat. Biomass can be burned directly or converted into biofuels or biogas. EIA, *Biomass-renewable energy from plants and animals* available at https://www.eia.gov/energyexplained/index.cfm/data/index.cfm?page=biomass_home.

101 USDA ERS, *Trends in U.S. Agriculture's Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass*, Economic Information Bulletin Number 159 (August 2016).

102 PNAS, *Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels* (June 2, 2006).

103 EU Renewable Energy Directive 2009/28/EC; Energy Independence and Security Act of 2007, Pub.L. 110-140 (2007).

104 USDA ERS, *Trends in U.S. Agriculture's Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass*, Economic Information Bulletin Number 159 (August 2016).

105 USDA ERS, *Trends in U.S. Agriculture's Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass*, Economic Information Bulletin Number 159 (August 2016).

106 FAO, *The Energy and Agriculture Nexus* (Rome 2000).

107 USDA ERS, *Trends in U.S. Agriculture's Consumption and Production of Energy: Renewable Power, Shale Energy, and Cellulosic Biomass*, Economic Information Bulletin Number 159 (August 2016).

108 NGWA, *Groundwater and Energy*, Information Brief (November 2016).

109 USDA Natural Resources Conservation Service, *Conservation Practices that Save : Irrigation Water Management* available at https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/energy/conservation/?cid=nrcs143_023638. USDA Census of Agriculture, *2013 Farm and Range Irrigation Survey* available at https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/.

110 WHO, *Global costs and benefits of drinking-water supply and sanitation interventions to reach the MDG target and universal coverage* (2012).

111 *Id.*

112 UN, *Clean Water and Sanitation: Why it Matters* available at http://www.un.org/sustainabledevelopment/water-and-sanitation/.

113 UN, *Clean Water and Sanitation: Why it Matters* available at http://www.un.org/sustainabledevelopment/water-and-sanitation/.

114 WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, *Improved and unimproved water sources and sanitation facilities* available at https://www.wssinfo.org/definitions-methods/watsan-categories/.

115 WHO, Guy Hutton and Laurence Haller, *Evaluation of the Costs and Benefits of Water and Sanitation Improvements at the Global Level* (Geneva 2004).

116 World Bank, *Effects of Early-Life Exposure to Sanitation on Childhood Cognitive Ability: Evidence from India's Total Sanitation*

Campaign (October 2013).

117 http://www.unmilleniumproject.org/documents/WaterComplete-lowres.pdf;

118 UNICEF/WHO, *25 Years Progress on Sanitation and Drinking Water: 2015 Update and MDG Assessment*, 21 (2015).

119 *Id.*

120 *Id.*

121 American Society for Civil Engineers (ASCE) 2017 Infrastructure Report Card available at http://www.infrastructurereportcard.org/.

122 WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, *Improved and unimproved water sources and sanitation facilities* available at https://www.wssinfo.org/definitions-methods/watsan-categories/.

123 UNICEF/WHO, *25 Years Progress on Sanitation and Drinking Water: 2015 Update and MDG Assessment*, 12 (2015).

124 *Id.*

125 UNICEF/WHO, *25 Years Progress on Sanitation and Drinking Water: 2015 Update and MDG Assessment*, 16 (2015). 319 million people in Sub-Saharan Africa remain without access to improved drinking water or 48% of the total population of people without access. 39% of the population remaining without access is located in Asia.

126 WaterAid, *Water for Women* (2015).

127 UNICEF/WHO, *25 Years Progress on Sanitation and Drinking Water: 2015 Update and MDG Assessment*, 16 (2015).

128 UNESCO, 2006, *Water and Indigenous Peoples*. Edited by R. Boelens, M. Chiba and D. Nakashima. *Knowledges of Nature 2*, UNESCO: Paris, 177 pp.

129 World Bank Group, *High and Dry: Climate Change, Water and the Economy*, vi (2016).

130 *Id.* at 15.

131 UN Water, *The United Nations World Water Development Report 2016: Water and Jobs*, 23 (2016).

132 *Id.* at 50.

133 *Id.* at 15-16.

134 *Id.* at 51.

135 EPA, The Importance of Water to the U.S. Economy: Synthesis Report, 10-11 (November 2013). Information regarding c*ommercial navigation, recreation and tourism comes from EPA, The Importance of Water to the U.S. Economy, Part 1:Backgound Report (September 2012).*

136 FAO, *The impact of disasters on agriculture and food security* (November 2015).

137 *Id.*

138 *Id.*

139 World Bank, *High and Dry: Climate Change, Water and the Economy* (2016).

140 Data reported by the Mississippi River Mayors, available at http://www.kfvs12.com/story/30048682/mississippi-river-economic-impact-exceeds-400-billion.

141 Chesapeake Bay Foundation, The Economic Bene*fits of Cleaning up the Chesapeake (October 2014).*

142 Frontier Economics, Exploring the links between water and econo*mic growth, A Report Prepared for HSBC (June 2012).*

143 Fiji water is withdrawn from an artesian spring in Fiji and VOSS water is withdrawn from an artesian spring in southern Norway.

144 Western Governors Associations, *Water Transfers in the West: Projects, Trends and Leading Practices in Voluntary Water Trading* (December 2012).

145 William Easter and Quiqiong Huang, *Water Markets for the 21st Century: What have we learned?* (Springer 2014).

146 A.Y. Hoekstra and A. K. Chapagain, *Water footprints of nations: Water use by people as a function of their consumption pattern* (Springer 2005). A.K. Chapagain and A.Y. Hoekstra, *Water Footprint of Nations, Volume 1: Main Report* (UNESCO-IHE November 2004).

147 A.Y. Hoekstra and A. K. Chapagain, *Water footprints of nations: Water use by people as a function of their consumption pattern*, 41(Springer 2005). See also World Water Council, *Virtual Water Trade – Conscious Choices* (March 2004).

148 A.Y. Hoekstra and A. K. Chapagain, *Water footprints of nations: Water use by people as a function of their consumption pattern*, 11(Springer 2005).

149 A.K. Chapagain and A.Y. Hoekstra, *Water Footprint of Nations, Volume 2: Appendices*, 203 (UNESCO-IHE November 2004).

150 UN World Water Assessment Programme, *Water in a Changing World: The United Nations World Water Development Report 3* (UNESCO 2009) available at http://unesdoc.unesco.org/images/0018/001819/181993e.pdf.

151 *See* General Agreement on Tariffs and Trade, Article XX, https://www.wto.org/english/docs_e/legal_e/gatt47_e.pdf

152 Michael P. Vandenbergh, *Private Environmental Governance*, 99 Cornell L. Rev. 129 (2013) available at http://scholarship.law.cornell.edu/clr/vol99/iss1/3.

153 *See*, *generally*, *Circular Economy*, European Commission, http://ec.europa.eu/environment/circular-economy/index_en.htm.

154 Chesapeake Bay Program, *Cleaner Air, Cleaner Bay Interactive Story Map*, available at http://gis.chesapeakebay.net/air/.

155 Maryland Department of Natural Resources, *Atmospheric Deposition* available at http://dnr.maryland.gov/streams/Pages/atmosphericdeposition.aspx.

156 Keith Eshleman and Robert Sabo, Declining nitrate-N yields in the Upper Potomac River Basin: What is really driving progress under the Chesapeake Bay restoration? (Atmospheric Volume 146, December 2016, Pages 280–289).

157 James Salzman, Drinking Water (2012

158 USGS, *The Quality of Our Nation's Waters: Water Quality in Principal Aquifers of the United States, 1991-2010* (Published January 21, 2015) available at https://pubs.usgs.gov/circ/1360/.

159 The Nature Conservancy, *An Ocean of Benefits* available at https://www.nature.org/ourinitiatives/habitats/oceanscoasts/howwework/an-ocean-of-benefits.xml?redirect=https-301.

160 https://www.americanforests.org/blog/the-important-relationship-between-forests-and-water/

161 FAO, Forest and Water Programme available at http://www.fao.org/in-action/forest-and-water-programme/en/.

162 American Society of Civil Engineers, *2017 Infrastructure Report Card: Wastewater* available at http://www.infrastructurereportcard.org/wp-content/uploads/2017/01/Wastewater-Final.pdf.

163 American Society of Civil Engineers, *2017 Infrastructure Report Card: Drinking Water* available at http://www.infrastructurereportcard.org/cat-item/drinking-water/.

164 American Society of Civil Engineers, *2017 Infrastructure Report Card: Drinking Water* available at http://www.infrastructurereportcard.org/cat-item/drinking-water/.

165 EPA, *Fourth Unregulated Contaminant Monitoring Rule* (published December 20, 2016) available at https://www.epa.gov/dwucmr/fourth-unregulated-contaminant-monitoring-rule.

166 Kellogg J. Schwab, *Are nanoparticles a threat to our drinking water?* (Johns Hopkins Water Magazine, March 7, 2012), http://water.jhu.edu/index.php/magazine/are-nanoparticles-a-threat-to-our-drinking-water.

167 American Society of Civil Engineers, *2017 Infrastructure Report Card: Wastewater* available at http://www.infrastructurereportcard.org/wp-content/uploads/2017/01/Wastewater-Final.pdf.

168 Stephanie Koons, *Oroville Dam crisis spurs debate on California's aging water infrastructure*, Accuweather (March 24, 2017), http://www.accuweather.com/en/weather-news/oroville-dam-crisis-spurs-debate-on-californias-aging-water-infrastructure/70001200.

169 EPA, *Green Infrastructure Cost-Benefit Resources* available at https://www.epa.gov/green-infrastructure/green-infrastructure-cost-benefit-resources.

170 Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, 2000 O.J. (L 327), Article 3.

171 USDA, *Water Quality Markets* available at https://www.usda.gov/oce/environmental_markets/water.htm.

172 Global Water Security, Intelligence Community Assessment, https://www.dni.gov/files/documents/Special%20Report_ICA%20Global%20Water%20Security.pdf.

173 This may not eliminate other threats—like pestilence, locusts, changes in markets—that might also have similar effects on economic or food security. But by taking water scarcity off of the table, it does remove a key variable from the national security equation.

174 See, generally, *Water & Nutrition*, The Centers for Disease Control and Prevention, https://www.cdc.gov/healthywater/drinking/nutrition; Barry M. Popkin, Kristen E. D'Anci, and Irwin H. Rosenberg, *Water, hydration, and health*, 68 Nutrition Rev. 439 (2014).

175 UN-Water Decade Programme on Advocacy and Communication, Water and Food Security Reader (2012), http://www.un.org/waterforlifedecade/pdf/03_2012_water_and_food_security_eng.pdf

176 World Health Organization and the Stockholm International Water Institute, Making Water a Part of Economic Development: The Economic Benefits of Improved Water Management and Services (2005).

177 Id.

178 Rick Gladstone, “Poor Sanitation Persisted at U.N. Missions Long After Haiti Cholera Crisis,” N.Y. Times (Aug. 20, 2016), at A4.

179 Azad Essa, “UN says Burundi refugees cholera epidemic worsening,” Al Jazeera (May 22, 2015), http://www.aljazeera.com/news/2015/05/burundi-refugees-cholera-epidemic-worsening-150522110614073.html.

180 Dan Barel, “Cholera Epidemic Could Be Biggest Danger to Middle East,” Haaretz (Dec. 4, 2015), http://www.haaretz.com/middle-east-news/1.689866.

181 Michelle Malka Grossman, “Gaza Sewage Crisis is a Ticking Timebomb for Israel,” Jerusalem Post (March 17, 2016), http://www.jpost.com/Arab-Israeli-Conflict/Gaza-sewage-crisis-is-a-ticking-timebomb-for-Israel-448335.

182 “Inside Walkerton: Canada’s Worst-ever E.coli Contamination,” CBC News (May 10, 2010), http://www.cbc.ca/news/canada/inside-walkerton-canada-s-worst-ever-e-coli-contamination-1.887200.

183 Waterborne Disease & Outbreak Surveillance Reporting, Surveillance Reports for Drinking Water-associated Disease & Outbreaks, https://www.cdc.gov/healthywater/surveillance/drinking-surveillance-reports.html (2015)

184 See, generally, Alberto Alesina, et al., *Political instability and economic growth*, 1 J. of Econ. Growth 189 (1996); David E. Bloom and David Canning, The World Bank Center for Growth and Development, Population Health and Economic Growth (2008).

185 Peter H. Gleick, “Water, Drought, Climate Change, and Conflict in Syria,” Weather, Climate and Society (July 2014), p. 335. Caitlin E. Werrell and Francesco Femia, eds., The Center for American Progress: Arab Spring and Climate Change (2013), https://www.americanprogress.org/issues/security/reports/2013/02/28/54579/the-arab-spring-and-climate-change.

186 Because the flows of virtual water are not completely understood, the impact of conflict on the flows of virtual water, and the issues that this would create, are also not

187 Peter H. Gleick, “Water, Drought, Climate Change, and Conflict in Syria,” Weather, Climate and Society (July 2014).

188 Alexandra Francis, “Jordan’s Refugee Crisis” (September 21, 2015), http://carnegieendowment.org/2015/09/21/jordan-s-refugee-crisis-pub-61338. http://carnegieendowment.org/2015/09/21/jordan-s-refugee-crisis-pub-61338http://carnegieendowment.org/2015/09/21/jordan-s-refugee-crisis-pub-61338

189 That said, many of migrants and refugees are exceptionally resourceful when it comes to water. As was reported by the UNHCR, refugee camp denizens sometimes collect rainwater to get water for their families. Ruth Schoeffl, ed. Leo R. Dobbs, “Liquid treasure: The challenge of providing drinking water in a new refugee camp”, U.N. High Commissioner for Refugees (Jul. 4, 2013), http://www.unhcr.org/en-us/news/latest/2013/7/51d5443f9/liquid-treasure-challenge-providing-drinking-water-new-refugee-camp.html.

190 In Syria, the Wadi Barada Spring was tainted with diesel gasoline, making it dangerous to drink.

191 Mark Thompson, “Iranian Cyber Attack on New York Dam Shows Future of War”, Time (March 24, 2016), http://time.com/4270728/iran-cyber-attack-dam-fbi.

192 U.N. SCOR, 71st Sess., 7818th mtg., U.N.Doc. S/PV.7818 (Nov. 22, 2016)

193 World Resources Institute, India Water Tools, http://www.indiawatertool.in.

194 Marcus DuBois King, “The Weaponization of Water in Syria and Iraq,” The Washington Quarterly (Winter 2016), pp. 157-159.

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