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America’s Water: Developing a Road Map for our Nation’s Infrastructure

Executive Summary

Water security in the U.S. is increasingly threatened. Many utilities are facing major supply issues (water quantity and/or water quality), aging infrastructure, and major funding shortfalls. In the last decade, prolonged droughts and floods from Texas to California to Colorado to the Mississippi to the North-East have stressed our water storage and flood control infrastructure, and led to considerable environmental, social and economic impacts. Groundwater depletion continues unabated in much of the country. The pollution of water bodies and their ecosystem impacts are increasing costs for the treatment and supply of urban water. Aging pipes and urban water infrastructure lead to increasing rates of main breaks and the potential for contamination of treated water supplies. On top of all this, water revenues have been declining due to decreasing per capita demands and political pressure in many areas. Historically, the federal government was a major investor in public works and water infrastructure, securing the health of the citizenry. Today, local communities and states struggle with the increasing costs of providing water, and the maintenance of these aging systems. The tragedy of Flint, Michigan reflects the confluence of these economic and physical factors. Yet, threats to water supply and quality violations may be set to repeat in different ways across the nation. A fragmentation of responsibility for addressing floods, droughts, reservoir operation, ecosystem demand, water allocation, and water and wastewater provision, across a myriad local, state and federal agencies, whose mandate relates to water, contributes to the challenge of developing water solutions locally or nationally. Water is seen as a local issue, until it is a regional, national, or global concern.

It is a matter of pride that our urban water supplies came to be considered some of the best in the world, and the mortality rate associated with water borne diseases such as typhoid and cholera have been eliminated. The contributions of large water infrastructure in the last century were equally noteworthy for the country’s economic development and integration. The Clean Water Act and the Safe Drinking Water Act signaled our recognition of the interdependence between ecological and human health and well-being. In each case, standards were set for how things are done in much of the world. It is this history of accomplishment across these diverse areas that gives us hope that the collective water challenges we face in America, and in the world today, are setting the stage for a new golden age for innovation in the technology, infrastructure design, financing and governance of our water systems.

An integrated, national approach to regional and urban water infrastructure development is critical to address the challenges posed by changing demographics, financial and water governance constraints, climate change and to capitalize on rapid innovation in emerging technologies. A trusted, transparent, fact based national conversation on water is needed to engage academics, and the water industry including technology developers, utilities, and public infrastructure managers to propose a road map of how regional and urban water infrastructure for the 21st century can be developed, financed and managed. This document represents initial reflections as to regional and urban water infrastructure development and management that could deliver significant gains in efficiency, resilience, risk management, and costs, while providing a high level of economic, human and ecosystem health
services. We envision a collaborative process to identify opportunities, set performance standards, and develop and test implementation mechanisms for a transformation in the water sector that provides global leadership in the area.

**Background**

*Water infrastructure* involves what is constructed to pump, divert, transport, treat, store, and deliver water, as well as to collect, treat and discharge storm and wastewater. In regions without adequate supply sources to meet current and projected demand (e.g., some western U.S. states), water is transported over great distances, and/or across geographic barriers using vast amounts of power. Infrastructure design entails anticipating uncertain future water supply and demand and making decisions to provide a socially acceptable level of system reliability without over-design.²

Renewable water supplies, correspond to precipitation, streamflow and shallow aquifers, are subject to climate variability. The United States has been subjected to significant droughts and floods over the last 5 centuries as inferred from paleo-climate data. Many of these droughts were of national scale and lasted for multiple decades. In most cases, our planning and design processes have not addressed this range of climate variability. Considerations of future climate variability may add further uncertainty as to what a planner or designer may expect. Reservoir storage provision was seen as a solution to addressing climate variability in the 20th century. However, very few reservoirs have been built in the USA since the 1970s, while many older dams have been decommissioned. Consequently, many areas of the country, ranging from California to the mid-West to the Mississippi to counties across the country that have large urban and industrial use, now report increasing groundwater depletion. In addition, there is also growing interest in conservation, urban water reuse and desalination to improve

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**WATER RISK**

Normalized Deficit Cumulated (NDC) is the maximum cumulative water deficit between supply and demand in each US County, as a ratio to its average annual precipitation.

Analysis² using the last 62 years of daily climate data and daily water use estimated from the 2010 USGS Water Census at each county. Note the large areas and also cities with exposure to multi-year drought, shown in red.
water supply reliability.

VANISHING GROUNDWATER

Groundwater extraction is increasing and levels are falling in the same regions where we find high multi-year drought stress.

All data used here are from the USGS, and the analyses were performed at a county level across the USA. The lower figure is based on data from all wells in deep aquifers (>30 m depth below surface) where recharge is limited.

WATER USE

USGS Estimates of water use by different sectors for US Counties based on the 2010 Water Census.

Irrigation dominates the arid West and parts of the South where groundwater depletion is noted.

Municipal & Industrial use leads in the East with local groundwater depletion

Thermoelectric plants have high local diversions. More renewable energy could limit the growth in these demands.
Nationally, current diversions for energy production and consumptive use of water for irrigation account for over 90 percent of the water use. Future thermal electric power plants and hydraulic fracturing for natural gas face regional water constraints as opposed to lower water footprint renewable energy options. Agricultural water use efficiency is highly variable, depending on the economics of the particular crop grown, the source of water, and the water rights or permit structure. Urban and industrial use can account for a high fraction of the local water use, especially in the North-eastern United States. However, urban and industrial use is often considered “high value use”, since the price such users are willing to pay for water is often higher than what most agricultural users pay or are willing to pay. Consequently, cities, in regions where agricultural water use is governed by the same water rights systems, may look at investments in improving agricultural water use efficiency as a way to acquire supply at a lower cost than other alternatives.

Municipal water-supply systems have to meet federal safe drinking-water standards established by the U.S. Environmental Protection Agency (EPA). Stormwater and wastewater also have to undergo appropriate treatment prior to disposal under the Clean Water Act. The result has been a fragmented governance system and separate infrastructure for each purpose. As water reuse is being considered as a potential water supply, the opportunity emerges to take a fresh look at how we regulate and manage the water system at the urban scale. “Green Infrastructure” elements are being explored in many cities to reduce peak stormwater generation and to reduce some of the associated pollutant load. However, there are very few efforts still to examine what could be new infrastructure models that treat both storm and wastewater flows as a resource, and how best they can be captured, stored, treated and used. Is the traditional, centralized model for each infrastructure, with pumping water in both directions, treating, and disposing or distributing it, the optimal strategy considering public health, energy demand and economics, or could one conceive a newer, linked local networks that can manage these resources integrally?

Non-point source pollution of surface and ground water sources by fertilizer and pesticide applications by farmers, un-metabolized pharmaceuticals and by stormwater runoff from cities is translating into high treatment costs for urban water supplies, leading to a collective interest in solving such problems to improve the water supply outcomes. Perhaps, the greatest complexity associated with managing water resources as opposed to other natural resources is exactly this–the actions of one water user have impacts on other water users in a number of ways. These impacts depend on geography, soils, climate and other physical and chemical factors. While there has been much discussion of Integrated Water Resources Management to address such challenges, they persist.

As technology for identifying potential biological and chemical threats from a contaminated water supply has improved, regulations are being developed for drinking water standards that would require the treatment of additional contaminants. The costs to utilities for implementing such systems are expected to be high, at least at the outset. The majority of the water supplied at these standards would likely not be used for drinking, cooking or bathing – the primary pathways of human exposure. Consequently, rethinking the stage at which this level of treatment is done and the associated cost of the likely distributed treatment system relative to treating all the water to this standard at a central location needs to be examined.
America’s water infrastructure, although regarded as one of the best in the world, is showing its age and deterioration. While most of the nation’s estimated 53,000 community water systems do provide safe drinking water, the reports that have emerged since the Flint, Michigan incident, suggest that we have reasons to be concerned about the safety of our water, especially as we look forward into the next few decades. While the most poignant stories coming out of Flint are about decisions that were being made, and the failure of the governance system to ensure a safe supply, the underlying thread is economic distress. This economic distress lead to poor decisions which highlight the problem of aging infrastructure coupled with revenue shortfalls. Across the US, communities face the challenge of long overdue maintenance and replacement as well as growing debt and higher water rates. The larger issue is that there are many such communities like Flint that are not getting as much attention. Lead exposure in many places in America may be even worse than in Flint. Lead exposure is prevalent in Pennsylvania, Illinois, and New York. Elevated lead concentrations were discovered in large parts of Washington, D.C., a little over 10 years ago. Since Flint, there have been news stories of similar lead violations in Ohio. Lead contamination is an issue that is currently getting a lot of attention, but the broader problem also includes deteriorating water supplies (e.g., harmful algal blooms on Lake Erie) PFOA contamination in Hoosick Falls, and major infrastructure failures like LA and elsewhere that result

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**Municipal Water**

Based on the Bi-annual Water Utility Surveys conducted by the American Water Works Association (AWWA), the rate of increase of debt across the utilities with data from 2002 to 2010 is approximately twice the rate of increase in water rates. Water rates have also been increasing at a rate much higher than inflation.

The median rate for 1500 cubic feet for groundwater only utilities is $30 vs $37, $44 and $42 for surface water only, surface/groundwater utilities and those that use other sources, respectively.

Deeper groundwater, leads to source switching and higher costs.
Thoughts for a Road Map for America’s Water

**Goal:** Assure high water security for all uses for the foreseeable future, through innovation in technology, governance, policy and financing mechanisms, thus providing global leadership to address our collective water challenges.

The long term economic development of every country, and the health of its people and ecosystem depends on its ability to manage its natural resources – water. Today, there is much talk of the water-climate-energy-food-urban nexus of challenges and of water risk. These observations provide the context for the *America’s Water initiative*.

The goal, as stated above, embodies considerations of supply reliability, efficiency of use and quality of service, of the economics, affordability, equity and mechanisms of delivery, the legal and governance structures, opportunities for public and private enterprise, of risk management and resilience, and addressing natural (e.g., floods and droughts) and man-made (e.g., pollution) hazards while considering the total water resource, covering the geographic and temporal variability of all components of the water cycle – atmospheric, surface runoff and river flow, shallow and deep ground water, and “return flows” from each point of use.

**Challenges or opportunities for innovation:** Selected challenges or constraints that provide an opportunity for innovation are listed below.

1. **Fragmentation and Scale:** The energy industry is dominated by large private sector players, as well as large, regulated electric utilities. Consequently, when disruptive technologies such as solar and wind energy are introduced, focused research and implementation strategies eventually emerge, providing a pathway for innovation in policy, financing and adoption. By contrast, the water sector is highly fragmented. With a few exceptions, urban water utilities are local. Most are small and have limited financial and technical capacity. Water supply and wastewater treatment and disposal functions are often with different organizations. Large volumes of water used in agriculture are either privately developed by the user, or managed through irrigation districts, with dams and canals managed by state and federal agencies. Industrial users, may rely on urban utilities, or develop their own sources for high quality water at higher costs than other users. Energy users, typically develop their own water sources under permits. The volumes and quality of water needed for different purposes, and the price paid varies significantly across different sectors of use, and so do the return flows that are generated. A large number of federal, state and local agencies have regulatory, management and financing roles, which are not always coherent. *Collectively, the above factors translate into a limited*
ability to conjunctively manage and develop regional water resources. **Opportunities for innovation could be provided by:**

- **Promoting consortia of urban utilities, and for water users in other sectors:** Address financial, governance and technical capacity issues induced by utility or enterprise scale, through explicit sector based consortia. Increase transparency through standardized and collective data collection, reporting, and implementation of sensors and emerging technologies and measures for risk management.

- **Promoting cross sectoral water transactions:** Introduce mechanisms that allow water and financial transactions across sectors of use. These could be instruments like water markets, or opportunities for co-investment in water efficiency or water quality or aquifer recharge, e.g., building on past efforts in water quality trading, one could develop water markets where cities or industry or an energy enterprise could invest in water efficiency improvements and facilities for managed aquifer recharge in rural areas, in exchange for access to water. Other examples include, an industry developing a facility for high quality treated water and providing it to a local utility; and insurable, and tradable option contracts for reservoir water that allow water re-allocation across use sectors recognizing water quality, ecosystem needs and climate uncertainty.

- **Regional and national water information systems:** Multi-resolution (in situ sensors, remote sensing, paleo-climate proxies, archival sources, economic and commodity markets, billing and financials) data platforms to enable access to water supply, quality and use parameters, including but not limited to historical data on surface and groundwater availability, water rights, regulatory requirements & permits, costs, transactions, climate forecasts/risk analyses and their application to supply chains related to water. Such information systems would provide the backbone to support large scale market based transactions, investments and regulatory structures that promote a more systems thinking and solution scaling approach.

- **National and state water agency integration:** An Office of Water that would break the fragmentation of responsibility for data collection, regulation and enforcement, infrastructure planning, development, management and financing, and work with similarly configured state agencies, and with the private sector to support the transition to a new platform for integrated, cross-scale and cross-sector water innovation. Ideally, this would not be a new agency, but a consolidation of the offices that exist across many agencies. The result would support each of the opportunities listed above, and enable regional and local stakeholders to play a greater and more informed role in determining their water investment strategies.

2. **Climate Uncertainty and Managing Water Supply-Demand Imbalances:** The marginal, economic value of water is low in wet periods and high in dry periods, reflecting the imbalance between renewable supply and demand at local as well as regional scales. Significant impacts on ecosystems also occur during wet and dry extremes. Given the constraints on developing new surface storage, one needs to look at innovations in alternate storage mechanisms, and managing demand for water as well as for flood protection and water quality maintenance. Conjunctive use of surface and groundwater resources has often been preached but the opportunities have been limited given resource ownership constraints. **Opportunities for innovation include:**
• **Financial Instruments for Risk Management**: Direct human use, which is a critical concern during drought, is actually a small fraction of the overall use. In most cases, economic and ecosystem impacts can be the dominant concerns for infrastructure managers and regulators. In addition to demand management, and securing alternate sources, the use of financial instruments, such as reserve funds, index insurance, and weather derivatives, by water utilities, ecosystem managers, energy companies, and industries is an underused opportunity today. Parametric products that are regionally indexed could be attractive to a regional multi-sectoral or single sector consortia, which may or may not be focused in a single region. Regions that have climate patterns that are negatively correlated with each other may do well by pooling their risks and subscribing to a common financial instrument. A similar consideration applies to addressing flood risk using a combination of non-structural measures (e.g., zoning) and financial instruments, as an alternative to additional physical infrastructure. The energy and agriculture sectors, as well as some urban water utilities in the USA, and other countries have implemented strategies in this direction. Climate informed water information systems would facilitate innovations in this direction.

• **Reducing Supply-Demand Imbalances**: Storage infrastructure seeks to reduce the probability and severity of an imbalance between supply and demand. Managing peak imbalances by appropriate demand adjustment and alternate source development strategies are an alternative. The US Army Corps of Engineers manages floods on the Mississippi River using both physical infrastructure (e.g., levees) and also through payments to farmers for the right to flood their fields with compensation under extreme conditions that cannot be managed through the dikes. This idea has broader applicability for both floods and droughts. Given warnings of drought, or drought conditions, targeted programs to provide investment in demand reduction, through increases in water use efficiency (e.g., improved irrigation systems, alternate cooling strategies for thermoelectric generation or increase in renewable energy that is less water intensive), water treatment and reuse, and changes in crops planted could be developed. Such programs could come from market processes with private sector participation, or from a national or state water agency acting on behalf of other uses, including ecosystem functions. Resilience to the imbalances could be developed through ongoing programs that target multiple scales of investment in demand adjustment, investments in development of surface and groundwater storage as well as alternate sources (e.g., reuse and desalination) as well as demand management from a systems perspective.

3. **Urban and Industrial Water Infrastructure**: Our 20th century highly centralized urban water infrastructure, typically has separate elements for clean water supply, and waste/stormwater treatment and disposal. Considering the high capital investment needed, economies of scale, and technical expertise needed to operate and maintain, a large centralized system model, has dominated the design of such systems. This also represents a high sunk cost, which limits innovation towards new models of operation at the system scale. Today, as we are faced with the high costs of replacing the aging infrastructure, one needs to think of options so that the large investment does not lock us into an old paradigm. As competition for water has increased, and costs have gone up, we have seen users reduce consumption, and utilities have
seen revenue reductions, even as debt and water rates have increased, in some cases dramatically. Given that fixed costs for debt service, employees and facilities maintenance, comprise a large part of the utility’s annual expense, the reduced revenue induced by water conservation poses a challenge. In places facing drought or scarcity, there has been a resurgence of interest in wastewater treatment and water reuse, since this is a potentially less expensive source to develop than desalination. In recent surveys, both utilities and consumers also appear to be overcoming the issues with acceptability of reused water. Recognizing the scarcity challenges, as well as the regulatory burden of wastewater treatment and discharge, many industrial users have also opted to move to innovative reuse systems. As such systems emerge, the question is whether the traditional centralized system model or a newer model with distributed and decentralized systems, yet networked facilities for water storage, treatment, distribution and reuse may characterize 21st century water infrastructure. A related question is whether all urban water needs to be treated to the same standard. Current safe drinking water regulations limit the opportunity in this regard, especially for point of use systems. This limits the ability of closed loop systems, such as those at the Solaire building in Manhattan to serve the treated wastewater through this U.S. Green Building Council, a leading driver in water innovation, LEED platinum rated building. However, even utilities that produce very high quality water at the treatment plant face challenges in ensuring that what is delivered to the consumer at the tap is contaminant free, as demonstrated by the media reports recently. Finally, the regulatory structure leads to a disjunctive model for most water utilities, where different subgroups deal with water supply, wastewater and combined sewer overflow problems.

**Opportunities for innovation include:**

- **System Design Research & Implementation:** The agriculture sector has benefited from research through the USDA, land grant universities and state extension programs. The objective of many of these programs was crop yield maximization and has been moving to yield sustenance and environmental goals. These programs have been instrumental in delivering targeted innovations in technology and practices, recognizing geographical, climatic, soil and social attributes. Similarly, the energy sector has seen sustained advances through the engagement of EPRI, NREL, and several DOE national labs. Many of the programs in these sectors have been translational and have explored system design and operation as well as technologies and policy framework. A comparable effort on urban water systems has been absent. There are two NSF Engineering Research Centers that have recently been established that focus on specific technological aspects of these issues, but this is still not comparable to the industry, university and government efforts in the other areas. As we consider stimulating significant advances in the sensing and treatment technologies, a comparable effort in understanding how urban water systems could be designed for the future and evolve is critical, not just for America, but globally. Singapore has demonstrated, how at the scale of that country, such a center of excellence can be developed and can transform the urban water landscape in the country. In the broader context, one would consider the evaluation of designs for different geographical and socio-economic settings and climates across a country as vast as the USA; focusing on the scale of centralized vs distributed systems; levels of treatment by intended use; isolation of systems by water quality and use; the integration of sensors to assure water quality and system performance; financing and
governance mechanisms; risk analysis and other design factors; energy use, and capital and operational costs. The goal would be to evolve system designs considering available and tested technologies, as well as coming up with prescriptions or design criteria for needed technologies. The type of questions that could be addressed include:

- What are the optimal scales of storage, distribution, treatment and reuse in a sustainable, urban water infrastructure that considers all water streams as resources, and a reduced impact on traditional water sources? What are the opportunities for cities to participate in regional water infrastructure development and use? How best does one forecast distributed demand (as a function of price, climate, billing mechanism/rate structure etc.) for different uses under different system scales and settings, and what are the opportunities for adaptively managing such demands with feedback as to the status of the supply? For resilience and risk management, what degree of redundancy is needed, and where in the system, and what types of sensors and controls are needed to effectively manage the system performance?

- **Technologies:** As one considers water reuse, the evolution towards direct potable reuse systems, and point of use treatment systems, existing and emerging micro and nano filtration technologies as well as biological treatment technologies may have significant applications. Desalination and grey-water treatment technologies that rely on renewable energy sources and support the integration of distributed water-energy grids could be of interest. The December 2015 White House Water Resources Challenges and Opportunities for Water Technology Innovation document sets an ambitious target of lowering the cost of seawater desalination from $2 to $0.5/m³ by targeting improvements across the value/supply chain. As water from different sources is mixed and treated to different levels, the importance of biological and chemical sensing increases. In-line water quality sensors, and systems that can rapidly detect a change in performance and can communicate with a central data system become important. If source separation and isolation by targeted use emerge as solutions, the importance of last mile multi-barrier filtration and disinfection systems will increase, and innovation in these areas will be valuable. Opportunities for the implementation of all these technologies into an integrated hardware-software platform has to be anticipated, necessitating a parallel effort on software development (including near real time information on metering and quality communicated to the end user). Innovations in rain water harvesting systems at different scales (e.g., rooftop, parks/landscape) and their integration to a sub-network of the utility will also be of interest, especially as part of a Green Infrastructure intended to address water supply and stormwater reduction goals. Still, this has to be in the context of innovation in the system design, since pipes and pumps, and raw water development will still be expected to dominate capital and operating costs faced by a utility.

- **Governance and Financing:** Water utilities are usually regulated by government entities, and may be structured in different ways, whether they are in the public or private sector. Depending on their structure, they may or may not have access to low cost financing through municipal bonds. Private activity bonds, as envisaged in the pending
Water Infrastructure bills in Congress may be an avenue. The degree of transparency as to finances and governance, and future financial risk induced by either physical factors or governance factors also varies greatly, and impacts their creditworthiness and access to capital. Efforts to provide increased transparency through better data, projections and risk information would help. Some utilities have access to property tax revenues, but the primary revenue source is water rates. Increases in rates are usually regulated, with concerns for affordability. As the physical structure of water/wastewater systems changes, the governance, financing and management/operational structures of a utility may need to change. The example provided by the deregulation of the electricity industry is not quite appropriate given the significant differences in the nature of the systems. However, it is one that needs to be assessed, to understand some of the possibilities and limitations of disruptive technical innovation from a governance and financing perspective. In the near term, addressing the fragmentation and scale issues from a governance perspective provides an opportunity for innovation. In the long run, disaggregating the raw water, treatment and services models may emerge as an innovation from both a governance and a revenue stream perspective. Finally, innovations are needed towards a full cost recovery model, which is mindful of affordability considerations as well as the costs of operation and ecosystem services.

Developing the Road Map
The opportunities discussed in the last section provide a multi-scale view of selected challenges and opportunities presented for integrating water conservation, use efficiency improvement, technological innovation, risk management, governance, financing and systems research to facilitate thinking about how a road map for America’s Water could be developed in the context of the water-climate-agriculture-energy-urban nexus of issues. At the meeting on March 25, 2016 we hope that the participants and the America’s Water Initiative Steering Committee will engage in evaluating and prioritizing possible directions to take for a time bound process with specific goals that define a road map for research and implementation.

References