Positive Water Sector Disruptions by 2030

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Overview:

Water security has emerged as a global concern over the last two decades. This creates the impetus for a broad range of innovations that should disrupt water and wastewater services. The most significant disruption I expect to see is that a much greater role will emerge for the private sector, which will in turn modify processes in use by this public sector dominated area. This will come through:

(1) the provision of water and wastewater services, from the bottom up – highly decentralized yet networked solutions;
(2) the use of financial instruments to securitize water, climate and environmental risks;
(3) management services that try to leverage the value of water for other sectors, such as mining, energy and agriculture; and
(4) pressure for reforms in regulatory processes that lead to adaptive environmental and resource management that is informed by data, active trend mapping and attribution.
(5) Increasing concern with climate variability and change, as climate extremes coupled with existing stresses lead to an increasing demand for adaptation and risk mitigation for supply chains, cities and populations.

Absent the role of the private sector, NGOs and finance/development organizations, given the conservative nature of the water sector it is not likely that tremendous changes will emerge by 2030. In the sections that follow, potential disruptive strategies (ones that would significantly change the way things are done now, and translate into higher water system effectiveness and resilience) are sketched for 3 areas:

1) *Water and Wastewater systems*: revolutionary decentralized networks with remote sensing and control of water quantity and quality parameters, ability to use rainwater, surface, ground water or wastewater as source water, and assure safe, affordable drinking water at the point of use.
2) *Flood & Drought Risk*: The use of parametric financial instruments such as index insurance to address preparation, as well as rapid response to climate extremes to help leverage probabilistic seasonal and longer climate forecasts for risk prediction, water allocation and system operation.
3) *Environmental Management and Regulation*: The intersection of the engagement of Environmental NGOs with watershed stakeholders, and Green Bonds issuers to devise participatory, adaptive approaches for monitoring and investment in watershed services that address the cumulative effects of human use on water quantity and quality in a changing world. A significant departure from the current resource allocation and environmental permitting and regulation model may emerge.

Water and Wastewater systems:

Large, centralized infrastructure systems were developed in the 20th century for storage, treatment and distribution of piped water, and for the collection, treatment and disposal of wastewater in urban areas. Economies of scale, and the need for specialized technicians to operate such systems led to the development of such systems. Typically, projections of future population growth and demand 10-30 years into the future are made when such systems are being planned, leading to designs that are oversized relative to the demand when implemented. The capital costs of these systems are consequently high and require financing for most communities. Since these are upfront costs, they determine the financial viability of the projects.

Several challenges are now seen with such infrastructure. The maintenance and operation of the systems is usually expensive, especially when they are oversized. Concerns as to raising water and wastewater rates lead to financial constraint. As a result, maintenance and upgrades are deferred and the systems degrade over time, in developed as well as developing countries. The USA currently faces a challenge of finding nearly $1 trillion to replace aging water and wastewater infrastructure. Water and wastewater leaks are common, and given the low price charged for water, often addressing leakage is more expensive than the value of water loss in the system.

Further, as has been illustrated by the serious issues with lead in drinking water in Flint, Newark, Pittsburgh, Chicago, Philadelphia and elsewhere, even in first world settings there is no assurance that water delivered to the consumer will meet safe drinking water standards even if the water produced at the treatment plant does. In developing countries, such as India, piped water supplies from the public system are intermittent – an hour or two in the morning and a similar duration in the evening. Affluent consumers use PVC storage units augmented by pumps in their houses, and RO systems for water purification in the kitchen to adapt to this situation. This translates into a private expense in a personal water system for some and lack of service for others. Even so, there is no testing or verification of the drinking water quality.

Israel, Australia and parts of India now mandate that property owners capture rain water and store or recharge it. Many countries practice rainwater harvesting or capture in urban areas and wetlands to recharge aquifers or even to alleviate floods. However, examples of systems that allow the integration of piped, centralized systems and rain water systems are few. Typically, rivers, lakes and aquifers are primary water sources.

Wastewater treatment systems discharge treated effluent into rivers or lakes, and in the process many chemicals whose effects on aquatic species may or may not be known are discharged (Oakley, Gold, & Oczkowski, 2010). Biological systems used for wastewater treatment can be energy intensive and also require relatively large land areas. The current thinking is that wastewater should be seen as a resource and purified water as well as energy and other products should be recovered from it, in the spirit of a circular economy.

Decentralized wastewater treatment systems have also been promoted in many areas. Their potential advantage is that they can be added as needed, and do not require the potentially large investment in sewer systems and pumping. A traditional example is the use of septic tanks with or without additional treatment. The success of such systems has been quite mixed (Naik & Stenstrom, 2016). They require periodic renewal at an expense comparable to the original cost. They can lead to high nutrient loadings to groundwater, unless the density is rather low. Nitrogen control for septic systems has also been explored and several solutions have been identified, but have met with a variety of reliability challenges in real world applications (Oakley et al., 2010)(Iribarnegaray, Rodriguez-Alvarez, Moraña, Tejerina, & Seghezzo, 2018). Newer decentralized systems consider constructed wetlands (Machado, Beretta, Fragoso, & Duarte, 2017) as well as membrane bioreactors and miniaturized versions of centralized wastewater systems. The membrane based and miniature systems can also include thermal exchange and energy recovery.

Wastewater treatment and reuse occurs indirectly nearly everywhere where the drinking water source is downstream of another town's wastewater (treated or not) discharge (Rice & Westerhoff, 2015). Direct treatment and re-use directly from the wastewater has largely been for agricultural or non-potable water use. Exceptions include Singapore, Texas, California, Namibia, Jordan, India, Australia, and the Philippines, where the treated wastewater may be used directly, or used to recharge an aquifer for subsequent withdrawal. Drinking water is typically a very small fraction of even household water use, and consequently, even if energy intensive technologies such as nanofiltration are used to finally purify treated wastewater, the total expense for treatment will be significantly lower than the cost of bottled water.

To summarize, centralized systems have high capital costs, and face maintenance challenges to preserve the integrity of the network. Decentralized systems, enabled by digital technologies (e.g., real time monitoring) can be added as needed, and locally maintained, but posed high transaction and reliability challenges for the operators in the past. In both cases, at present the quality of the water provided at the point of use is not pervasively tested or assured. Wastewater reuse is feasible, and the level of treatment needed may depend on the intended (re-)use.

Potential Disruption:

Smart Decentralized Networks:

In a utopian world, one would be able to use any local water source – rain water, surface water, ground water or "wastewater", assure its storage, including during droughts, treat it and supply it locally at an affordable cost with high reliability as to quantity and quality at the point of use. In this paper, the argument is that such a utopia may soon be technically and economically achievable, in much the same way that solar electricity has emerged as a decentralized, renewable energy source with widespread application at different scales, with an accompanying growth of the private sector and service industry.

Examples of pioneering companies who are leading the way for such a disruption include Natural Systems Utilities (NSU), based in New Jersey, and Ketos, based in California. NSU has developed and operated onsite water and wastewater treatment and reuse systems in a variety of settings including dense urban infill buildings, and resorts for more than the past 20 years. The systems installed in several high rise buildings in New York City are fully automated, and remotely monitored and treat wastewater to near drinking water quality at a unit cost that is competitive with centralized wastewater systems. Ketos focuses on real time, automated and smart-connected monitoring of water quantity and quality. Research in this area is getting to the point that many of the key contaminants of interest can be sensed in real time and in-pipe, and the information can be transmitted to central servers for processing and response (Besmer et al., 2016; Cogan et al., 2015; Lambrou, Anastasiou, Panayiotou, & Polycarpou, 2014; Lin, Li, & Burns, 2017; Maity et al., 2017; Shahat et al., 2015; J. P R Sorensen et al., 2015; James P.R. Sorensen et al., 2018; Verma & Gupta, 2015; Zamyadi, Choo, Newcombe, Stuetz, &

Henderson, 2016; Zhou et al., 2018). Ketos is developing such an ecosystem. These are just two of many companies that are developing similar products, including units of major corporations such as Fluence, Xylem, Veolia and Suez. Others of note are Aqwise,and Organica Water.

A large number of vendors including Suez, Veolia, Waterfleet , Applied Membranes, Aquamove, Culligan Matrix Solutions, and Envent have mobile water treatment operations that brings the treatment plant to the site. This is a rapidly growing area that serves the hydraulic fracking industry, military operations, and emergency relief for plant failure or after natural disasters. A range of technologies ranging from filtration membranes to reverse osmosis to ion exchange to electrocoagulation are in use, with scales that could serve a small cluster of houses all the way to neighborhoods (Griffith, Shumakov, Akbayev, & Fejervary, 2015; Moro, 2018; Park, An, Park, & Oh, 2015; Ramli & Bolong, 2016; Yu, Choi, Choi, Choi, & Maeng, 2018). Quotations for water and wastewater treatment from several of the mobile operators translate into numbers that are very competitive with current water charges.

(Ennenbach, Concha Larrauri, & Lall, 2018) show that residential water demand could be met with greater than 90% reliability over much of the USA from rainwater collected from the typical roof area. Rainwater was used to serve the typical home demand in each county in the USA, considering over 60 years of daily climate data, and a 70% reuse of the wastewater generated domestically. In related, unpublished work, the technical and economic feasibility of rainwater collection and use at large buildings in Mexico City was demonstrated, even factoring in the current subsidies for water costs. Where, the subsidies are not considered, rainwater harvesting and local potable and non-potable use becomes competitive. Given the grave water, flooding and wastewater situation in Mexico City, a strategy that embodied decentralized networks, at neighborhood and/or building scales, and leveraged rain water collection, storm water collection and wastewater collection locally could be very effective. Parking structures and roofs installed with solar panels could also double as water collection systems, and local storage could be created using existing domestic and public tanks as well as subsurface tanks in areas with parks.

The convergence of the following elements translates into a strategy for the disruption of the water and wastewater systems:

1) The high cost structure and performance of existing centralized systems, and their operation largely in the public sector or by private companies.
2) The need for infrastructure renewal, and new infrastructure globally, that comes with a high financing need, and questions as to affordability.
3) The availability of real time water quality, system integrity monitoring and remote control to assure point of use performance.
4) The availability of a range of advanced, yet affordable water and wastewater treatment systems that cover different scales and contaminants, and could be operated remotely and semi-automatically.
5) The potential to develop and add decentralized networks of systems as needed instead of developing a large, oversized system at the outset. This translates into an economic

advantage, that is further enhanced by the reduction in hard infrastructure needed for piping and pumping, and by the ability to rapidly deploy replacement systems with lower operating costs, and economies of scale derived through mass manufacturing. This economic efficiency translates into faster return on investment and efficiency in capital deployment, leading to easier financing.

6) The large number of small and large companies and innovators entering this space
7) Successful examples of business models for decentralized treatment systems at some scales. Pilots to assess best scales and network designs are still needed.
8) The willingness of middle and higher income consumers and corporations to embrace alternatives to traditional water utilities by installing their own treatment and storage systems that are serviced by third parties.
9) Much higher sustainability and resilience given the ability to develop effective water reuse strategies, including thermal energy exchange, thus reducing outflows and pollution to water bodies, as well as intake of water from natural water bodies. This translates into higher ecological performance and eligibility for impact investing.
10) Substantially lower and more efficient utilization of real estate by smaller systems that can be installed in building basements or below grade in parks and green space.

The obstacles to the disruption are similar to what was experienced in the electricity industry. Large scale centralized electric system operators, initially did not respond to the opportunity of solar and other renewable sources, and were primarily concerned with revenue loss. Subsequently, as the prices for delivered solar and wind systems dropped, operators started considering these alternatives, but in many cases still want control so that they can assure grid reliability. The water situation is more complex, since there are rarely national or regional water utilities, and local utilities have little interaction with each other, or innovation potential and hence tend to be insular and resistant to change. They have used health concerns as an issue to block on site wastewater treatment and use as drinking water, and have generally resisted decentralized systems as well as pervasive real time monitoring. They have embraced digital metering and smart metering for leak detection, as these show promise for revenue enhancement. It would be quite reasonable to integrate remote water quality sensing at the point of use directly into emerging smart meters. This may start happening at utilities where significant drinking water quality concerns emerge. (Allaire, Wu, & Lall, 2018) find significant increases in safe drinking water violations in the USA, especially in rural and smaller communities, where the financial health of the utilities is also a concern.

Companies such as Rotoplas in Mexico are well primed to develop such a convergent strategy for decentralized water and wastewater and apply it in Mexico. A key obstacle they face is that as a private water and wastewater services provider they are unable to compete with the subsidized prices of water services available to the public, even if they can deliver a higher quality and more sustainable product. A direct benefit-cost analysis for Mexico City, and potentially for other cities would likely show that a transition to high technology water and wastewater networks could rapidly become cost effective and transformative, if a apples to apples comparison of the full capital and operating costs of the systems was done. This means that either the public utilities or large system operators need to rethink their strategy, or the same subsidy has to be made available to the private water and wastewater service developer, especially to serve areas that are economically disadvantaged. This is a challenging problem in most locations, that could be solved by public-private partnerships financed by Green Bonds. Some initial experiments need to be done to understand the types of public-private business models that could be successful in terms of governance and economics, to deliver an unprecedented quality and range of service to meet the growing need of communities worldwide.

Flood and Drought Risk:

Floods/storms and Droughts lead to significant annual average losses globally, and are projected to increase in frequency and impact. In the 20th century, the primary water sector responses to these stresses were:

1) Flood control infrastructure, zoning and reservoir/dam construction
2) Traditional insurance programs and catastrophe bonds.
3) Drought and flood planning, early warning and response strategies.

These were typically pursued by different actors, with little integration, and the basis for risk analysis was typically the use of relatively short at site climate records to develop a statistical rating of the annual risk or probability of exceedance of a “design” event. With growing populations, changing social preferences, increasing economic activity, and changing land use and climate, the inefficiency of this traditional approach has become increasingly apparent, as impacts increase and are not effectively managed. Further, as (Bonnafous, Lall, & Siegel, 2017a, 2017b) show, a consequence of globalization is that supply chains or even a single company may experience significant flood and drought risk across their portfolio of global assets in the same year, due to the space-time clustering of climate extremes. This clustering emerges from the nature of the underlying climate variability – a combination of nearly cyclical climate patterns at global scales with preferred time scales of recurrence every 3-7 years (El Nino), 8-12 years (North Atlantic Oscillation), 16-20 years (Pacific Decadal Oscillations), 40-80 years (Atlantic Meridional Oscillation) in addition to the trends imposed by anthropogenic climate change. Thus, a company’s exposure may be 3 to 10 times more than what may be expected by the traditional risk estimation process. This is very different from the random extreme event assumption made in traditional risk analyses, designs and insurance pricing. To an extent, periodic climate regimes and their impacts are predictable, and a large body of academic literature has emerged around this topic. This is getting translated into the consulting and insurance industry, as well as into water system operation (N. E. Brazil, Philippines, USA, (Asefa, Adams, & Wanakule, 2015; Clayton, Asefa, Adams, & Anderson, 2010; Sankarasubramanian, Lall, Devineni, & Espinueva, 2009; Sankarasubramanian, Lall, Souza Filho, & Sharma, 2009; Souza Filho & Lall, 2003).

Potential Disruption:

Financial Instruments:

Gaining impetus from the dramatically increased awareness of climate induced risks, and the growing perception of climate impacts on cities (e.g., the Day zero analyses following Capetown), and the limitations of existing insurance-like instruments, a dramatic increase in creative financial instruments to address climate risks is likely. Take floods for example. Insurance companies are developing global flood risk models and integrating climate change aspects. However, most of this work does not address the potential prediction of flood risk changing cyclically over the next few years or decades, or of the local or global spatial correlation of risk. It is primarily designed to serve traditional insurance contracts (that require financial loss verification), or local zoning rules that work off a point estimate of a 100-year event (or similar). Such estimates continue to have significant uncertainty and potential for mispricing risk in the near and long term.

An alternative that has been emerging and could see widespread application is the use of parametric instruments, e.g., index insurance, or catastrophe bonds. A key aspect of such an instrument is the definition of a parameter or an index associated with the event of concern. If such an index is triggered the instrument pays off without the need for actual loss verification. The premium is priced based on the probability of event occurrence, rather than on loss. The transaction costs are consequently substantially lower, with improved pricing. Further, information on the changing/predicted risk of event occurrence can be used to update premium pricing thus sending a risk signal that could help users and markets prepare for the potential loss. An example of one of the early applications of such an idea was in Peru where the central banks were insured from floods, through a parametric index linked to the El Nino conditions (Khalil, Kwon, Lall, Miranda, & Skees, 2007; Skees, Hartell, & Murphy, 2007). Similar products have been developed and applied for drought and also to securitize water market option contracts and utility finances, including their use as ex ante or forecast insurance, that pays out potentially even before an event occurs in many different settings and countries (Brown & Carriquiry, 2007; Carriquiry & Osgood, 2012; Chantarat, Barrett, Mude, & Turvey, 2007; Goes & Skees, 2003; Zeff & Characklis, 2013)(Bjerge & Trifkovic, 2018; Maestro, Bielza, & Garrido, 2016). The Caribbean Risk Facility developed by the World Bank provides an example of a regional risk pooling and indexing approach.
Such instruments are emerging as disruptive tools for water/climate risk management for the following reasons:

1) They can be offered to farmers, individuals, corporations, or nations (i.e., easily customize to scale). Donor countries/organizations, and relief programs can use such instruments to provide a mechanism for rapid emergency response in affected countries or areas, without waiting to mobilize resources to effect a response.
2) They offer the opportunity to deal with financial needs when a catastrophic risk is manifest. This addresses a key bottleneck for a rapid emergency response.
3) They can be designed to cover multiple types of hazards and potential losses through an appropriate choice of indices in the same contract, and hence a buyer can much more clearly evaluate what their risk exposure pathways may be and seek an instrument that provides an appropriate coverage at a lower cost. This is especially important for water markets or water futures contracts. A product like this could have allowed Capetown, Sao Paulo or Santa Barbara to have the financial resources to rapidly acquire alternate water sources or invest in technologies when their supply became constrained, if the underlying reason had been diagnosed, indexed and priced. The risk covered in this way

need not just be of climatic origin. It only needs to be indexed to a risk-related parameter for which data is collected by a third party.

4) Water utilities and managers are often reluctant to act on probabilistic climate forecasts, and their conservatism can lead to a loss of opportunity to mitigate risk. If the risk of using such forecasts were also indexed, then managers would be able to take such opportunities recognizing that the potentially adverse consequences are financially covered. This can stimulate demand for the product, and also provide resilience to water operations.
5) A variety of organizations, not just insurance companies, could start offering such products, if basic data on climate parameters of interest were publicly available and forecast. This has now become possible due to the interest in climate change with both public and private sector providers.

There are no apparent barriers to the development of such products, other than the ability to collect the data related to the index of interest, by a neutral third party and link it to a payment mechanism as well as a risk analysis.

Resource/Environmental Management/Regulation

A well-developed set of principles for water resource management and regulation of its quantity and quality are now in place in most countries. However, their effectiveness is continually questioned. Let's take environmental regulation as an example. Companies and cities are asked to file environmental impact statements (often expensive), prior to new development. Using sparse information on baseline conditions as well as potential impacts, a discharge permit may be granted. Subsequently, there is compliance reporting, and fines if there is a violation of the permit. Separately, the regulator, or more often, a science agency may collect data on ambient water quality at a few places on the water body. Over time, the cumulative effects of pollution from multiple dischargers, and the climate induced cycles of sediment production and deposition, accompanied by contaminant attachment, resolution, and deposition may occur, threatening the ecological function of the water body that was protected. Rarely is the monitoring and emissions data brought together to assess the reason the problems emerged and to re-allocate permits. One can visualize a corresponding example for water rights allocation based on a few years of data, and subsequent severe, sustained drought. These situations emerge as serious concerns, with media attention, and little ability to address when they are manifest. Many of the conflicts related to mining and water in S. America and elsewhere can be traced to such regulatory and allocation failures. How should one address the changing conditions in such settings?

Some of the innovations that emerged around anthropogenic climate change provide an interesting example of a potential for disruption in environmental regulation and resource allocation. First, there has been a movement towards assessment and voluntary disclosure of carbon emissions and footprints by public and private entities. Second, intensive analyses of trends in emissions, greenhouse gas concentrations, and climate impacts across many sectors emerged. Third, attribution of climate events and impacts to potential causes using causal and statistical modeling emerged. The resulting awareness of the causal chain and its impacts has started shaping the behavior of the actors responsible as well as public policy. While this process is far from complete or successful, it provides an interesting paradigm for local and regional action on water quantity and quality regulation. While climate change impacts projected for the mid to late 21st century are a significant concern, the associated uncertainties and the long time horizon contribute to the political stalemate. On the other hand, water quantity and quality are a current and emerging concern over most of the world, and this provides impetus for immediate action.

Potential Disruption:

Data driven adaptive, participatory regulation and investment:

Environmental NGOs (e.g. The Nature Conservancy, The World Wildlife Fund), their innovation partners (e.g. Techstars) and citizen scientists are increasingly active in creating data portals and analyses related to water conditions in many ecosystems, as well as in developing stakeholder participation processes to implement ecosystem or watershed services. Corporations and governments are drawn into these processes, thus influencing the overall environmental regulatory process and water allocation decisions. So far these activities have been restricted to actions in specific locations, and to specific local issues.

Given the interest in Green Bonds (Dupont, School, Levitt, & Bilmes, 2015; Shishlov & Morel, 2016), the NGO activity promoting their use, and the interest of governments in using these instruments, there is an opportunity for a radical transition in the way environmental regulation is financed and implemented. Green Bond issuers would require mechanisms and data to verify that the environmental investment objectives were met. From a watershed management perspective, this would require monitoring of emissions, mitigation actions and outcomes, followed by analyses of attribution to the instruments used. This could change the paradigm from passive regulation to active investment and management driven by environmental goals with both short and long term objectives. Modern data collection and sensing tools could significantly reduce the cost of monitoring, and also the changes in the system could potentially reduce the burden, the cost and the time and effort involved in initial permitting actions.

Since a significant convergence of players and actions is needed to enable this transition, I expect that by 2030 only a few examples may develop in areas where there is an obvious and critical need. These would be in places where there is a push by both the financial and the NGO communities, and the government is receptive. However, in the long run, enabled by data and interest, and the continuing pressure on license to operate for major global companies, and their competition for water and land, disruption of the water sector in this direction will take place.

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