DIGITAL TECHNOLOGY OPPORTUNITIES FOR THE COLORADO RIVER BASIN

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The Environmental Law Institute (ELI) works to shape the fields of environmental law, policy, and management, domestically and abroad. ELI celebrates 50 years as an internationally recognized, nonpartisan research and education center working to strengthen environmental protection by seeking new and innovative approaches to improve the governance of all resources.

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1. BACKGROUND

The American West, including the cities of Las Vegas, Nevada; Los Angeles, California; Phoenix, Arizona; and Denver, Colorado, falling under the reaches of the greater Colorado River Basin (CRB), is now among the world's water stressed regions facing the environmental, economic, and social challenges of increased water scarcity.

The region formed and flourished with the pulse of seasonal floods providing ecosystems with nutrients and nursery habitat, the rush of spring runoff bringing new waters to downstream wetlands, and the corrosive power of heavy flows carving out immense landscapes.[1] The terrestrial and aquatic of the region all evolved with a dependency on the Colorado River, yet with the river's waters now dammed, stored, and allocated for human use, many species are finding their homes and populations threatened.[2] Birds are losing migratory habitat,[3] native fish are facing increased predation and pressures from invasive species,[4] and many species (e.g., macroinvertebrates,[5] birds, fishes) are losing breeding grounds due to altered river dynamics.

In addition to its environmental role, the economic importance of the CRB cannot be overstated: the Colorado River supports $1.4 trillion in annual economic activity and 16 million jobs in California, Arizona, Nevada, Utah, Colorado, New Mexico, and Wyoming which is equivalent to about 1/12 of the total gross domestic product in the U.S.[6] It is estimated that if 10 percent of the river's water were unavailable (a decline quite possible under projected climate change scenarios of 10 to 30 percent flow reductions by 2050[7]) there would be a loss of $143 billion in economic activity and 1.6 million jobs, in just one year.

The CRB supplies more than 1 in 10 Americans with some, if not all, of their water for municipal use, including drinking water.[8] The Basin provides irrigation to more than 5.5 million acres of land and is essential as a physical, economic and cultural resource to at least 22 federally recognized tribes. In addition, dams across the Colorado River Basin support 4,200 megawatts of electrical generating capacity, providing power to millions of people and some of the U.S.'s largest cities. It has become clear, however, that under current and projected conditions, the Colorado River is no longer able to meet the demands of its many users. Challenges are emerging that will require the acceptance of a new reality among stakeholders in the CRB.

For this reason, the CRB is seen as a strategic "testbed" to determine the feasibility of emerging and novel digital technological solutions for the water sector. This report is intended to profile the potential opportunities of emerging digital technologies to address the water quality and quantity challenges faced by public and private entities in the Basin. In conjunction with this report, a workshop on Digital Technology Applications for the CRB was held in October 2019 with the objective of identifying and defining two (2) digital pilot projects to address high priority issues in the CRB. Prior to the workshop, three digital technologies in particular were identified as having the greatest potential to manage increasing water demand, ensure water quality, and to build resilience to climate change; these are

[1] (Environment and Ecology of the Colorado River Basin 2012)
[2] (Building a New Future for the Colorado River 2016)
[3] (Water and Birds in the Arid West: Habitats in Decline 2017)
[4] (Increasing Drought Favors Nonnative Fishes in Dryland River: evidence from a Multispecies Demographic Model 2019)
[5] (Flow Management for Hydropower Extirpates Aquatic Insects, Undermining River Food Webs 2016)
[6] (Economic Importance of the Colorado River 2019)
[7] (Colorado River 2017)
[8] (Drought in the Colorado River Basin n.d.)

Artificial Intelligence (AI), blockchain and sensor networks, alone or in combination.[9] This report is not intended to provide an exhaustive list of water challenges or digital technology solutions for the CRB, but will serve as a point of departure for the potential to adopt, scale and commercialize digital technology as a part of the solution to address water scarcity in this region and others. Highlights and outcomes of the workshop are reflected in this report.

2. COLORADO RIVER BASIN

(USGS 2019)

The CRB is one of the most productive and influential, economically and environmentally, yet conflicted regions of the United States. Known as the "river of the west," the Basin spans about 8 percent of the continental U.S. and encompasses seven states, with its northernmost borders stretching into Wyoming, across Colorado and Utah, and down into Nevada, southern California, Arizona and New Mexico. From there, the basin expands into northern Mexico where the Colorado River reaches toward the Gulf of California.[10] Water in the Basin originates as snowmelt high in the Rocky and Wasatch Mountains and as it flows along the Colorado River's over 1400 miles, the landscape and climate varies from high alpine forests to barren desert, with everything from rural farms to massive metropolitan areas found in between.

The Colorado River is the lifeblood of ecosystems across the west, home to numerous endangered species and the carving force behind ancient canyons. In the last century, however, the river has come to support more than just ecosystems and now includes communities and industries that have grown and flourished across the Basin as well. Water from the Colorado River has enabled agriculture, utilities, industry and recreation to thrive, yet that water, famous for the rafting, hydropower and irrigation opportunities it provides, has become infamous in its scarcity. Heavily managed, over-allocated, and threatened by ongoing climate change, the Colorado River has become an icon of controversy. Exploring the Basin's many water management policies and governing bodies provides a foundation for understanding the challenges now faced across the region and the opportunities for action that those challenges provide.

2.1 River Governance

Most western states maintain that all waters are owned by the state, and allow water rights to be allocated in association with a given property and beneficial use. For the most part, western states follow the Law of Prior Appropriation (the first in time, first in right principle), wherein those who first

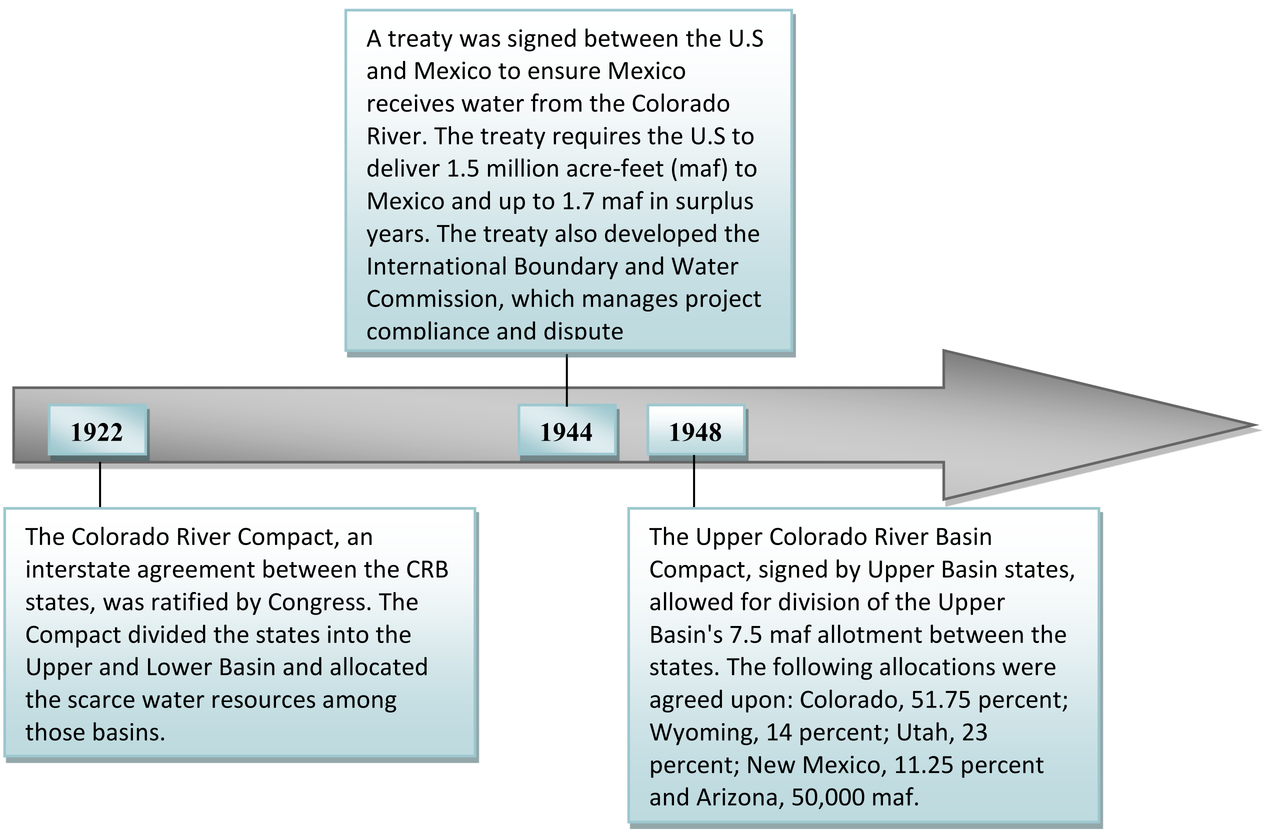
9 (Harnessing the Fourth Industrial Revolution for Water 2018)
10 (Colorado River 2017)

established a claim to and beneficial use of water had a right to use such water. Any entity or individual obtaining a permit thereafter is then only able to utilize their water right after senior water rights holders' allocations are fulfilled.

Despite internal processes for each state's management of water resources, as the West continued to develop in the early 1900s, a collection of statutes, court decisions and decrees, interstate agreements, and international treaties emerged from disputes over the allocation of the Colorado River's water.[11] Loosely described as the "Law of the River," a collection of the primary basin-wide agreements governing the CRB are described below along with the organizations developed to aid in the Basin's management.

2.1.1 Basin-wide Agreements

Although far from a complete list of laws governing the CRB, the primary agreements governing water usage across the Basin include the following.



[11] (Liquid Assets: Investing for Impact in the Colorado River Basin 2015)

2.1.2 Basin-wide Organizations

Working with the foundations laid by the Law of the River, several associations and other groups have emerged to facilitate discussions, share information, uphold group interests, pursue conservation efforts, and generally aid in managing the waters of the CRB. These organizations are developing unique partnerships to address the challenges experienced in the CRB. Table 1 below summarizes the mission and efforts of such organizations.

Table 1: Organizations involved in overseeing the CRB

Organization	Mission
Western Governors' Association (WGA)	The WGA is made up of governors from the 19 Western states and 3 U.S. territories. Established in 1984, the WGA is an instrument for bipartisan policy, information exchange and collective action among western states. In addition to other interests, the WGA aids governors and their states in addressing water quality, water supply and drought management issues.[12] In 2014, the WGA launched the Western Governors' Drought Forum to foster regional dialogue and sharing of best practices on drought policy, preparedness and management.[13]
Western States Water Council (WSWC)	The WSWC, although created in 1965, now operates under and is held accountable to the Western Governors' Association. The WSWC consists of representatives appointed by governors of 18 western states and with a purpose similar to that of the WGA: to establish interstate cooperation and information exchange, maintain state interests and accommodate federal prerogatives, and provide analysis and evaluation of federal and state developments as it pertains to the management of water resources.
Ten Tribes Partnership	The Ten Tribes Partnership was developed in 1992 when ten of the CRB tribes came together to participate in discussions regarding CRB water. The tribes' goal was to attain an equal seat at the table for bargaining over CRB water, to assist member tribes in establishing and developing their water right, and to ensure other river uses do not interfere with their ability to utilize each tribe's respective water rights.[14] The Partnership has been active in advocating for accurate representation of tribal water rights and has expressed interest in voluntary water transfers via water banking or leasing and other market opportunities in the CRB.
Bureau of Reclamation	The Bureau of Reclamation was established in 1902 by President Theodore Roosevelt to design, install, and manage water projects to store and transport water in the arid western United States. Regions 3 and 4 of the Bureau of Reclamation manage the Lower and Upper CRB respectively, ensuring the Law of the River is observed. The Secretary of the Interior acts as Watermaster of the Lower Colorado Region, managing the delivery of all water below the Hoover Dam.[15]

In addition to carrying out the "Law of the River," some basin-wide organizations have been instrumental in developing pilot projects to address the region's water challenges. From 2014-2018, the Bureau of Reclamation, in partnership with the Basin's four largest municipal water providers – the Central Arizona Water Conservation District, the Southern Nevada Water Authority, the Metropolitan Water District of Southern California, and Denver Water – held a pilot project to gage the interest of farmers and ranchers in fallowing portions of their land, leaving water in the system, in exchange for monetary compensation.[16]

12 (Western Governors' Association 2012)
13 (What is the Western States Water Council? 2015)
14 (Ten Tribes 2018)
15 (Bureau of Reclamation 2018)
16 (Will Climate Change Mean Less Farming in the West 2019)

2.1.3 Current and Emerging Partnerships

Many unique partnerships are also at play in the CRB, using the expertise, networks and resources of NGOs, foundations, corporations and other environmental organizations to initiate change and address a variety of problems across the CRB. Below, a few organizations developing key partnerships in the CRB are described in Table 2.

Table 2: Organizations developing key partnerships in the CRB

Organization	Partnership
The Nature Conservancy (TNC)	TNC has been instrumental in deploying water conservation projects on the ground, working with federal agencies, local farmers, and community leaders alike. TNC's partnership with the Grand Valley Water Users Association in Colorado has led to a pilot project testing a large scale approach to a water bank. Project participants are reducing irrigation, generating one billion gallons of water savings to improve river flows in the region. In another TNC effort, the NGO is working with federal funding and local partners to develop a network of projects, including groundwater recharge, to protect Arizona's San Pedro River – the region's longest undammed river and a hotspot for migratory birds and wildlife. TNC also works with a wetlands preserve near Moab, Utah to develop and manage critical nursery habitat for the endangered razorback sucker, as well as elected officials and community leaders across Arizona to manage the Salt and Verde Rivers (both a part of the CRB) which are significant water supplies to the state's people, including the Phoenix area.[17]
Bonneville Environmental Foundation (BEF)	The BEF works with its partners, bringing together the public, corporations and conservation organizations to raise awareness on and restore flows to vital freshwater ecosystems through their Change the Course initiative. Beginning in 2014, the Change the Course pilot project in the CRB saw 130,000 individuals over the course of three years pledge to conserve water, resulting in four billion gallons of water being restored to the Basin's depleted river systems.

Additional organizations such as the Gates Family Foundation, Encourage Capital, and the Walton Family Foundation have specific interest in the CRB and are funding projects and developing partnerships related to water conservation and market based solutions across the region (see Section 4.3). Likewise, the Audubon Society, recognizing the importance of the CRB for bird migration and habitat, works with water users, farmers, and other stakeholders to protect critical habitat and develop long-term water-management solutions in the Basin. Other such partnerships continue to emerge across the Basin as stakeholders begin to realize the scale, severity, and urgency of challenges within the CRB.

Several private sector companies are also promoting water stewardship through new partnerships in the CRB. For example, Intel has partnered with NGOs, agencies, and local communities in the CRB to promote the use of low water use crops, install advanced irrigation systems, capture snowmelt and runoff, and improve water quality. In addition, some food and beverage companies such as MillerCoors and ABInBev are encouraging water stewardship in their supply chains, working with local farmers in the CRB to support the use of water conserving practices and technologies.

2.2 Challenges

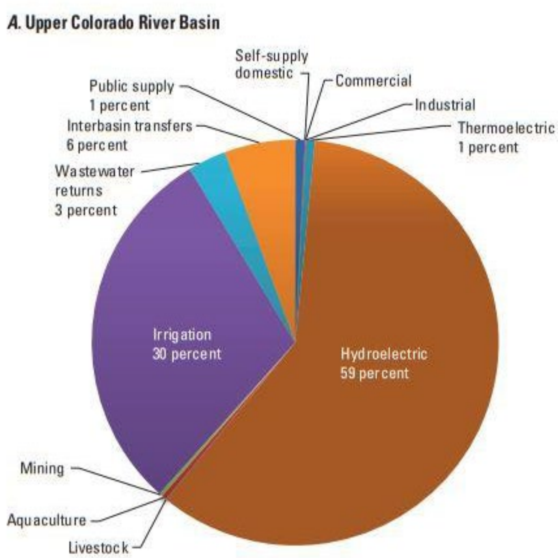
Despite (yet partially as a result of) the elaborate water management policies agreed upon and implemented across the CRB, numerous challenges have emerged that now pose a threat to the

[17] (Colorado River Basin 2019)

complex arrangement of water supply and demand (and quality) in the Basin. The many uses of and high demand for the Colorado River's water are only increasing, adding stress to an already limited resource. Exacerbated by climate change, this stress will only continue – becoming the new norm in coming decades. In addition, new data provided by modern science have highlighted errors in the quantification of the average annual flow which was based on a small sample size during a particularly wet period that ultimately led to incorrect water allocations in the CRB. Understanding these challenges and the impacts they have on stakeholders in the region is a necessary first step for exploring the implementation of digital technologies and their implications for addressing water management issues in the CRB.

2.2.1 Water Demand

Water from the CRB has historically been used to meet the needs of western society across a variety of sectors. Agriculture, industry, municipalities, etc. all tap into the CRB's most valuable resource at different levels but with a shared voracity. According to the U.S. Geological Survey, as shown in Figure 1, 59 and 69 percent of water in the Upper and Lower Colorado River Basins, respectively, is used for hydrologic power generation.[18] In total, over 11,000 GWh of hydroelectric power was generated from dams in the CRB and more than 170,000 GWh were produced using water withdrawn for thermoelectric power generation in the CRB in 2010. Water from the CRB provides the electricity to power metropolises across the west as well as rural areas and Native American reservations.



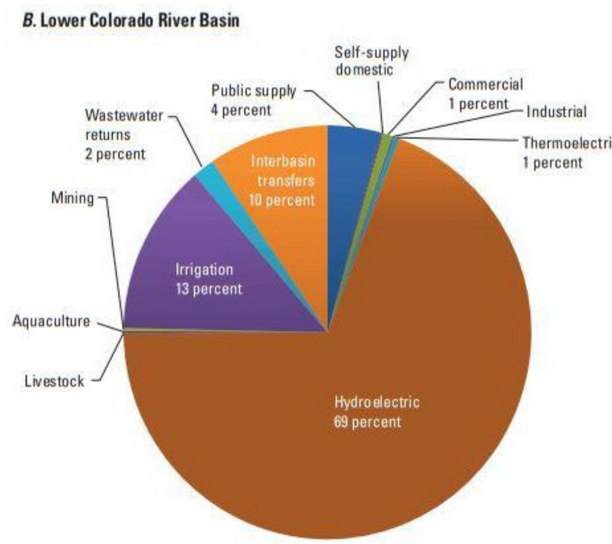


Figure 1: Percentage of total estimated water withdrawals for the upper (A) and lower (B) CRB (U.S.G.S.)[19]

Of water withdrawn or diverted from the Basin, however, the agricultural sector is by far the largest consumer, making up over 70 percent of all CRB consumptive uses.[20] Water is primarily used to irrigate pasture and forage crops for horses and cattle, yet the Colorado River's waters also support alfalfa, vegetable, wheat, and cotton crops among others.[21] Following agriculture on the list of heavy CRB water uses are interbasin transfers (Some Colorado River water is exported from the Basin into Southern

[18] (Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985-2010 2018)
[19] Ibid
[20] (Municipal Deliveries of Colorado River Basin Water 2011)
[21] (Water to Supply the Land: Irrigated Agriculture in the Colorado River Basin 2013)

California, the eastern Colorado Front, and west of the Wasatch Range in Utah.[22]) and municipal deliveries – deliveries to the residential, commercial, industrial, and institutional sectors. The Colorado River and its tributaries are the primary source of water for some of the largest cities in the west including Phoenix and Tucson, Arizona and Las Vegas, Nevada, and also contribute to the water supply of Los Angeles, San Diego, Denver, and Tijuana, enabling major metropolises to grow on what in many cases would be otherwise uninhabitable land.

Water from the CRB, however, is used in more ways than direct consumption and power production. The CRB also supports a thriving tourism and recreation industry. People both from within the basin and around the world come to the CRB to engage in fishing, hiking, boating, rafting, swimming, or simply relaxing along its river banks and reservoirs. A 2012 study determined such recreational activity along the river generates $17.0 billion in retail sales (recreational equipment and travel expenses) and that the value of spending resulting from recreational activities associated with the CRB totaled $25.6 billion.[23]

Between recreation, agriculture, energy production, and municipal and industrial supply, water use and demand in the CRB have been steadily increasing since the establishment of the Colorado River Compact in the early 1900's. It has become clear, however, that under current and projected conditions, the Colorado River is no longer able to meet the demands of its many users (Figure 2). Challenges are emerging that will require the acceptance of a new reality amongst CRB stakeholders.

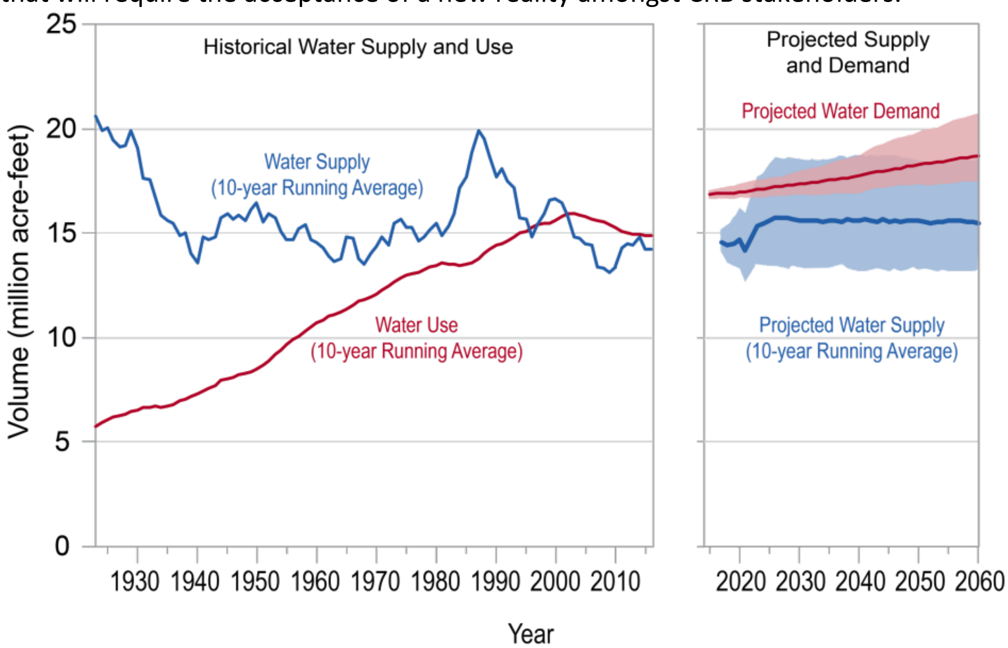


Figure 2: Historical and projected water supply in the Colorado River Basin shown in comparison to water demand[23]

2.2.2 Water Supply

For the last 19 years, the CRB has been in an extended period of drought – a prolonged period of abnormally low rainfall, leading to a shortage of water. Or so we thought. Complications from the overallocation of its waters in tandem with the escalating effects of climate change have instead replicated drought conditions, creating a new normal of water stress and scarcity. In the CRB, climate

22 (Drought in the Colorado River Basin n.d.)

23 (Economic Contributions of Outdoor Recreation on the Colorado River & Its Tributaries 2012)

change is expected to increase the risk for prolonged, multi-decadal droughts. Higher temperatures leading to increased evaporation in combination with decreased snowfall are also projected to decrease flows and reservoir levels in the CRB.[24] Ultimately, the effects of climate change will exacerbate water shortages already felt in the region and will further complicate requirements under the Law of the River.

Obligated to fulfill the requirements of the Colorado River Compact and the Treaty of 1944, the Upper Basin has been forced to release water from Lake Mead and Lake Powell (the reservoirs behind Hoover and Glen Canyon Dams). When full, the Lakes hold 80 percent of the storage potential in the CRB. However, in recent decades water levels have dropped to near-critical lows. As of July 2019, their reservoirs are respectively only at 39 and 57 percent capacity.[25] The declining water levels have already impacted hydropower production and recreation and have drastic implications for both the water and energy supply of millions of people, not to mention the impacts on a trillion dollar economy and the environment.

In 2007 and again in early 2019, the CRB states came together to address the water shortages and develop plans (the 2007 Shortage Guidelines and 2019 Drought Contingency Plans) for temporarily managing water resources under drought conditions. The agreements created guidelines for reservoir management and incentives for decreased use of water rights during the drought conditions.[26] However, what these new agreements don't recognize is that the water shortages are not in fact, the result of a drought. The conditions are normal, and they are here to stay.

At the time the Colorado River Compact was signed in 1922, annual water flow at Lee's Ferry, based on the previous sixteen years of data, was estimated to be 18.0 maf. Later, when the U.S.-Mexico Treaty was executed in 1944, the average annual flow was 16.3 maf.[27] Actual flow, based on new data from the last several centuries, places the annual average closer to 13.5 maf.[28] Tree ring studies have since shown that the 20-year time period used to estimate historic flows prior to the signing of the Colorado River Compact were among the wettest of the last several thousand years.[29] To put it bluntly, the volumes of water promised by law to the respective Basin countries and states (7.5 maf to both the Upper and Lower Basin plus 1.5 maf promised to Mexico) do not actually (or at least normally) exist. The water scarcity experienced across the west is not the result of drought, it was written into the Colorado River Compact itself.

Until the turn of the century, the over-allocation of the CRB was not immediately evident as the Upper Basin, several tribes, and the state of Arizona were not using their full allocations. Since 2003, however, human use of water in the CRB has exceeded natural supply, with shortfalls in availability falling on the Upper Basin (the Upper Basin remains legally obligated to provide its downstream counterparts with their allotted water supply despite scarcity conditions).[30] Now throw climate change in the mix and the situation gets a lot more complicated. Climate change is already contributing to the variability in annual flows, increases the potential for drought and flood events, and will add to the overall decline in water availability. Nevertheless, the requirements set forth by the Law of the River remain and any challenges

[24] (The 21st Century Colorado River Hot Drought and Implications for the Future 2016)
[25] (Lower Colorado Water Supply Report 2019)
[26] Ibid at 7
[27] Ibid at 21
[28] (Sharing the Colorado River Water: History, Public Policy and the Colorado River 1997)
[29] Ibid at 7
[30] Ibid

or risks that ensue (e.g., increasing costs of water, mandatory cutbacks in water usage, etc.) will fall on water users.

2.2.3 Water Quality

Water scarcity and over-allocation are not the only challenges facing the Colorado River Basin. The water quality of the region has also been of rising concern. Mining and irrigation in the west have led to the leaching of heavy metals, primarily selenium and mercury, from tailings piles and soil into the Basin's rivers. Herbicide and pesticide runoff from agriculture and storm water runoff from urban areas are another continued threat Basin-wide. Although a majority of salt runoff (47 percent) is from natural sources in the CRB, water used for irrigation dissolves additional salts in underlying soils which then crystallize due to evapotranspiration and are later washed into bodies of water in runoff.[31] Irrigation therefore accounts for 37 percent of salt runoff into the CRB and is becoming a source of concern due to the potential for increased salinity to damage water infrastructure and impact crop success, ecosystem health, and drinking water quality.[32]

Understanding these different challenges, their impacts on the CRB and how they will continue to manifest in the coming decades is critical for stakeholders to maintain business continuity and growth. Continued private and public collaboration will be necessary to address the water scarcity and over-allocation issues in a timely, effective manner while ensuring the interests of stakeholders and the health of the Colorado River system remain at the center of all projects and partnerships.

2.3 Defining the Problems

Although water remains the focal point of challenges in the CRB, addressing these challenges requires recognizing that the problems extend beyond issues of water demand, supply, and quality. Inadequate data, poor demand management, the lack of an ecosystem perspective, and degrading and insufficient infrastructure broadly define additional challenges faced by the region in relation to water management. Prior to the Digital Technology Applications Workshop, these challenges were built out by participants into a series of problem statements which further outline issues specific to the CRB.

2.3.1 Inadequate Data and Information Management

- Are there applications to collect information on seasonal and geographic use patterns? How do you address the cyber security risks resulting from increased connectivity?
- How can we incorporate and translate water quality data, data from pipe monitoring, data from hydraulic models, AMI, etc. for informed decisions?
- Is there a way to analyze satellite imagery to identify parcel boundaries, type of crop grown, and distinguish between irrigated and non-irrigated parcels?

2.3.2 Poor Demand Management

- Are there digital technologies that can provide data needed by different audiences (e.g., service users, service providers, policy actors) to help reduce peak demand, thereby saving money (infrastructure costs) and water?

[31] (Salinity in the Colorado River Basin 2016)
[32] (Salinity 2019)

- Is there a technology that would give agricultural producers the data they need about their own water use and ways to conserve and enable them to enter the conversation?
- Is there a technology that would help inform estate planning and water management for agricultural lands that may change hands or be converted to different land uses?
- Are there technological tools that could help provide financial incentives for ranchers to conserve water? How can these tools be financed to enable use by both profitable and struggling enterprises?
- Is there an application to both educate and incentivize consumer conservation?
- Could blockchain help track water transactions and support water markets? What would such an application look like and how would it function?

2.3.3 Lack of Consideration for Ecosystem Services

- Can AI help contribute to restoration of environmental flows? How would such an application function?
- Is there a way to apply the Las Vegas Valley Water District's successful turf removal program to other states in the CRB? Can it be applied to smaller towns and rural areas in addition to large cities?
- Are there ways to measure stream flows other than expensive USFS stream gauges?
- Can we use AI and /or remote sensing to calculate baseline volume of aquifers and quantify changes?

2.3.4 Outdated Infrastructure

- Are there methods/approaches/data analytics to reduce consumptive use associated with cooling towers?
- Are there additional technologies to pinpoint leaks and quantify losses in water distribution networks?
- Can technology (e.g., sensor networks) help with monitoring snowpack, especially on tribal lands with few monitoring sites?
- Is there a way to incentivize investment and open access to new markets?

These statements represent just some of the problems specific to the CRB and many, if not all of these questions will need to be answered in order to solve water in the American west. The following sections review the technologies identified for best addressing some of the above challenges, current water use cases in the US and abroad.

3. DIGITAL TECHNOLOGICAL SOLUTIONS

Society is currently undergoing a digital revolution through which digital technologies are already transforming the transportation, energy, and retail sectors among others. Similarly, there are numerous possibilities for digital technologies to transform the way water is managed. Several papers have been produced on this topic, including *Harnessing the Fourth Industrial Revolution for Water*, published by the World Economic Forum in 2018 and *Digital Water: Industry Leaders Chart the Transformation Journey*, published by the International Water Association and Xylem in June 2019. As water infrastructure ages, demand grows, and the various stressors from climate change continue, embracing the digital revolution will be critical to ensuring adequate water quality and supplies throughout the region. Utilizing digital technologies such as AI, blockchain, and sensor networks may be particularly beneficial for addressing the unique challenges in the CRB. An overview of each digital technology is provided below with an array of case studies on their applications in the water sector.

3.1 Artificial Intelligence

In contrast to early software decision support system, AI technology is dynamic. Systems programmed with AI use pattern recognition mechanisms to “learn” as they receive new data inputs, replicating some of the sophistication of human learning. In this way, AI technologies offer numerous potential benefits for sustainable water management including forecasting the availability of water resources under changing hydrologic and climatic conditions, improved asset management, planning for future water consumption needs by extrapolating from current usage patterns and more efficiently operating distribution networks.

AI-enabled platforms can also offer customers real-time information on water consumption and quality in addition to expediting bill-pay. These platforms can educate consumers on the environmental and social impetus for conservation in addition to the personal financial benefits of careful usage. Utilizing AI technologies to their full potential will require comprehensive, quality data sets, meaning as AI technologies are adopted, secure data management platforms must also be developed.

3.2 Blockchain

Blockchain is a digital ledger that decentralizes, encrypts, and divides data into parcels. Blocks of data are added together, forming a chain of information. Blockchain differs from traditional ledgers or databases in that the chain of blocks is not stored centrally, but copied and distributed in a computer network. By eliminating the intermediaries that are traditionally required to validate transactions among parties, blockchain technologies add a layer of security to transactions and optimize processes that require storing, sending, accessing, or verifying information.[33]

The distributed, secure and transparent nature of blockchain technology lends itself to a variety of novel applications within the water sector including peer-to-peer water rights trading, creative and democratic financing for water projects, the establishment of cryptocurrency-enabled smart meters, the aggregation and distribution of water data the deployment of smart-contracts and more.

3.3 Sensor Networks

Sensor networks – wireless and infrastructure-less configurations of sensors – offer enormous potential to precisely monitor physical and environmental conditions, passing data through their network in real-time. Wireless sensors can be deployed to monitor variables including pressure, temperature, pH, pollution, flow rate, equipment performance and more.[34] A network of sensors may contain hundreds or thousands of sensor nodes, allowing the data retrieved from such networks to provide a more comprehensive and nuanced characterization of the studied landscape than traditional monitoring techniques. Moreover, this infrastructure allows for the study of an area (e.g., infrastructure, water source, etc.) over time and at close intervals.

[33] (GEF Novel Entities, 2018)

[34] (Harnessing the Fourth Industrial Revolution for Water 2018)

Sensor networks can be utilized in the application of digital twin technologies wherein real-time data is paired with virtual reality technologies to generate a working replica of physical systems. The digital twin simulates infrastructure functions to help visualize and monitor current conditions and predict real-world scenarios.[35]

Within the CRB, deploying a network or networks of wireless sensors could enable water professionals and the public alike to achieve a better understanding of the availability, demand and use of hydrologic resources. This information is invaluable to devising conservation and distribution strategies. Wireless sensors could also be deployed at the tap to collect more accurate and near real-time data on water usage. This information, if illustrated appropriately, can then be used as an educational tool to encourage consumers to adopt conservation-conscious behavior. Sensor data can also be used to monitor and better plan around peak usage times, as well as to quickly detect and remedy problems with water quality or delivery infrastructure.[36]

3.4 Technology Use Cases

AI, blockchain and sensor network technologies have already been applied in water resource management to varying degrees. In the following case studies, we identify innovative projects employing these digital technologies to alleviate stress on water resources and infrastructure and to increase data-driven, efficient, and sustainable stewardship of available resources.

Use Case 1: Blockchain and Wireless Sensing to Facilitate Trading of Groundwater Shares in California's Sacramento-San Joaquin River Basin

Technologies: **Blockchain Platform, SweetSense Sensors**

In 2014, California signed into law the Sustainable Groundwater Management Act (SGMA), which required planning for and implementation of local sustainable groundwater management. In response to this, IBM Research, The Freshwater Trust, a non-profit working to protect and restore freshwater ecosystems, and SweetSense Inc., a provider of low-cost satellite-connected sensors, partnered to develop pilot technologies to monitor groundwater use in one of the largest and most at-risk aquifers in North America: northern California's Sacramento-San Joaquin River Basin. The partners are funded jointly by the Water Foundation and the Gordon and Betty Moore Foundation.

Still in development, the collaboration endeavors to demonstrate how remote Internet of Things (IoT) sensors and blockchain-enabled applications can provide an accurate measure of groundwater usage and, further, allow water consumers to trade usage rights in furtherance of water conservation goals.

The project will be piloted in a portion of the River Basin that provides water to the San Francisco Bay Area, as well as coastal and southern California. The area, situated in the Sacramento-San Joaquin River Delta, supports numerous protected plant, fish, and animal species and is used heavily for agriculture. Sensors provided by SweetSense will transmit water extraction data to the IBM Blockchain Platform hosted in the IBM Cloud. The blockchain uses "smart contracts," through which transactions are automatically executed when certain conditions are matched.[37]

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[35] (Digital Water: Industry Leaders Chart the Transformation Journey 2019)
[36] (One Day For a Digital Water Future 2016)
[37](IBM Newsroom 2019)

The project will launch a web-based "dashboard," through which water consumers, like farmers, as well as investors and regulators, will be able to monitor and track groundwater usage. When individual users require water in excess of their designated share, they can purchase groundwater shares at a market-regulated rate from other users who opt not to maximize their own usage. The hopeful output of the project is a data-driven, transparent, and scalable platform through which water usage shares can be traded in a way that helps meet both stewardship goals and usage needs.[38]

Use Case 2: Wireless Sensing to Measure Snowpack in the Sierra Nevada Mountains

Technologies: **Smartmesh IP**

Mountains have been called natural 'water towers' because of their ability to effectively store fresh water in the snowpack that accumulates over the winter at higher altitudes. It is estimated that meltwater accounts for 50 percent of the world's fresh water and 75 percent of the water in the American West. For decades estimating snowpack was an arduous and dangerous process which often involved sending people into the mountains with poles to measure snowpack depth.[39]

Since 2011, a network of sensor stations have been operating in the Sierra Nevada mountains, which provide approximately 2/3 of California's water through the snowmelt process. This hydrological observatory now consists of almost 1,000 sensors, which measure snow depth, temperature, solar radiation, and relative humidity, interconnected in 14 low-power, mesh networks. These sensor nodes are strategically placed at different elevations, slopes, and canopies over a 2,000 km^2 area, representing one of the largest, river-basin wide, hydrological monitoring networks in the world. Over the course of one year, the sensors provide well over 40 million unique measurements, which are analyzed by a machine learning algorithm to continually improve data quality. Outputs from predictive models are being used by the California Energy Commission to improve the prediction of hydropower availability based on snowpack meltwater. [40]

Use Case 3: Deploying a Network of Adaptive Sensor Platforms to Monitor the Water Quality Of Lake George in New York

Technologies: **IoT Smart Sensor Network**

In 1791, Thomas Jefferson visited Lake George and declared it, "the most beautiful water I ever saw." Today a wide variety of stressors, including road salt, nutrient run-off, and invasive species (including Zebra mussels and Asian clams) threaten the lake's water quality. Launched in 2013, the Jefferson Project is a partnership between Rensselaer Polytechnic Institute (RPI), IBM, and a local NGO, the FUND for Lake George. The project involves more than 30 RPI faculty and senior researchers and 18 IBM scientists.

The project takes an integrated approach by combining traditional sampling, advanced sensor sampling, experimenting, and computer modeling. Data on the lake and its tributaries are gathered by traditional sampling of the chemistry and food web as well as a network of 52 sensor platforms comprised of more than 500 sensors. These sensors collect nine terabytes of physical and chemical data annually as part of an IoT Smart Sensor Network. Some of these sensor platforms are designed and built "in-house." Machine learning algorithms support

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[38] (WIRED 2019)
[39] (Technical Report: The design and evaluation of a basin-scale wireless sensor network for mountain hydrology 2017)
[40] (A Machine Learning Based Connectivity Model for Complex Terrain Large-Scale Low-Power Wireless Deployments 2017)

'adaptive sampling' to optimize when and where the sampling takes place. The data feed models of the weather, lake circulation, hydrology, and food webs. Every morning, IBM's supercomputers deliver high-resolution forecasts every 10 minutes for a 36-hour period. Experimental venues range from highly controlled lab experiment to large in-lake mesocosm experiments that examine the separate and combined effects of different anthropogenic stressors. New work includes the development of low-cost phosphate sensors and a new 'Scenario Engine' that will enable policy makers to better understand feedback loops and future conditions of the lake under different potential policy scenarios. The project also emphasizes moving from science to real-world solutions, producing insights into the need to reduce road salt pollution, the impacts of excess nutrients, and the consequences of invasive species[41].

Use Case 4: Water Drones to Measure Water Pollution in the Volga River, Russia

***Technologies:* Libelium IoT Smart Water platform, Blockchain and Sensors**

Airalab Rus, Libelium and the Tolyatti State University co-developed the "Drone on the Volga" project. They each brought a unique set of skills and technology to build a solar-and battery powered water drone with built in sensors to measure water quality parameters and an onboard computer which allows for communication with an open source platform and network (Robonomics)[42]. Robonomics uses blockchain technology that allows citizens/public users to request, negotiate and pay for a service from the drone. Water temperature, pH, dissolved oxygen, water conductivity, ions of NH4+ and NO3- are just a few measurements recorded in a public blockchain, using the Ethereum blockchain platform, ensuring data transparency. The technologies combined in the project aimed to demonstrate how decentralized environmental monitoring could occur with limited oversight.

Use Case 5 & 6: Artificial Intelligence to Optimize Utility Processes

***Technologies:* CSIRO's FLECK™ Sensors**

Use Case 5 - Australia's Lake Wivenhoe Catchment Area

In 2009, the Commonwealth Scientific and Industrial Research Organization (CSIRO), an independent Australian federal government agency responsible for scientific research, and a Queensland local water authority, SEQWater, partnered to pilot one the first applications of sensor network technology to monitor water quality and quantity. They developed a monitoring program in the Lake Wivenhoe catchment area, which supplied water to the region's then more than 1.5 million residents. [43]

The partnership of agencies deployed approximately 120 sensor nodes – CSIRO's FLECK™ smart wireless sensor technology – on Lake Wivenhoe and in the surrounding catchment to monitor environmental conditions, including water quality, supply and flows. Among these, 40 nodes were set afloat on the lake to monitor water temperature profiles at different depths. Temperatures detectable from these floating nodes correlated with pollution levels in the lake, thus illuminating to authorities when and where to treat water downstream. Land-based nodes in the

[41] (The Jefferson Project at Lake George, Advancing Science and technology for Freshwater Ecosystem Protection, ND)
[42] (Drones, Sensors and Blockchain for Water Quality Control in the Volga River to Promote Trustworthy Data and Transparency 2018)

[43] (Wireless Sensor Networks for Water Management that supports Differentiated Services 2013)

network provided comprehensive data on the behaviors of livestock and other animals in the catchment region that might contribute to the pollution of its waterways.[44]

Use Case 6 – Singapore's Smart Water Grid

In 2016, Singapore implemented a Smart Water Grid system to support its Public Utilities Board (PUB)'s goals of providing quality water to customers while simultaneously encouraging water-saving behavior.

PUB, which delivers more than 430 million gallons of water to customers each day, called upon SUEZ Environment, a French utility company specialized in waste management and water treatment, for its expertise in smart water technologies. The parties agreed to jointly develop technologies targeted at protecting water resources by harnessing data and effective decision support mechanisms. In conjunction with this commitment, Suez opened a Singapore-based Innovation Center, composed of 15 research scientists and engineers to support project development.[45]

One of the primary products of this collaboration has been the deployment of a network of wireless sensors across the island to gather real-time monitoring data from throughout the water distribution system. This network of wireless sensors gathers information on usage rates, pressure and water quality within the delivery infrastructure and can identify emerging leaks.[46] The data gathered via the network of sensors allows authorities to more effectively model for future demand on water resources, reduce non-revenue water due to infrastructure failures, optimize energy usage, and provide quality water with fewer disruptions to service.[47] The data unlocked via the new sensor network is helping the PUB more efficiently use and conserve water resources. The data can also be translated into educational tools to encourage water-saving behavior among customers.[48]

Use Case 7 & 8: Artificial Intelligence to Optimize Utility Processes

Technologies: Artificial Intelligence Platform

Use Case 7 – United Utilities in England

EMAGIN, a Canadian tech company out of the Toronto-Waterloo Region corridor, merges expertise in process engineering and digital technology to provide process optimization tools to businesses.[49] Specifically, the company harnesses the power of AI to predict and optimize utility operations.[50]

EMAGIN's signature product is a Hybrid Adaptive Real-Time Virtual Intelligence system (HARVI). The HARVI platform employs AI to streamline activities to be as efficient, effective, and smooth as possible. HARVI can also generate real-time predictions of asset performance, helping to predict events that might disrupt service.[51] In the water sector, this platform can allow a utility to predict and quickly remedy infrastructure degradation or failures, thereby reducing non revenue water and ensuring safe, reliable water supplies to consumers. The technology can also be used to assist a utility in planning for high demand or loading events.

In 2018, United Utilities in England partnered with EMAGIN, implementing the company's HARVI technology to optimize its services. Initial implementation of the AI-enabled optimization technology resulted in a 22% energy

[44] (CSIRO Wivenhoe Water Quality Monitoring 2016)
[45] (Suez environment opens a new regional business hub in Singapore pursuing its development in the smart water market 2015
[46] (Managing the water distribution network with a smart water grid 2016)
[47] (Singapores smart water grid nd)
[48] (Singapore and Suez partner on smart water grid project 2015)
[49] (EMAGIN website nd)
[50] **(**How Digital Technology Can Be the Fundamental Agent of Change in the Modernization of Global Water Infrastructure 2018)
[51] (EMAGIN website nd)

savings. HARVI is scheduled to be fully implemented throughout the water utility's operations by the end of 2019.[52]

Use Case 8 – JEA: Water, Sewer and Electric Provider for Jacksonville, Florida

JEA is a community-owned utility serving an estimated 478,000 electric, 357,000 water, 279,000 sewer customers and 15,000 reclaimed water customers[53]. JEA is considered one of the early adopters of artificial intelligence to operate a production well field. JEA changed its standard operating procedures once it became clear that there aquifer withdrawals in the St. Johns River Water Management District were unsustainable.

With the help of Idea Integration, JEA installed a new system, Optimized System Controls of Aquifer Resources (OSCAR). The system monitors and regulates the water pumped from the aquifer by evaluating data in real time, providing water for immediate use as opposed to storing water for later use. OSCAR regulates the pumping of water from the aquifer by integrating data from a variety of sources, including weather related data[54].

This system, supported by supplementary software allows operations staff to develop daily forecasting schedules, allowing for efficient pumping across all wells within the grid. This means that wells located nearest to where the demand is, will be pumped first and supplemented with water from wells further away. In addition, the system also allows for flow adjustments from wells, ensuring that wells are not depleted. There have been significant benefits of the system, optimized well production, reservoir storage, pump and energy efficiency and lower operational costs.

Use Case 9: Aqaix Employs Artificial Intelligence and Blockchain Technology to Develop Financing for Water Projects

Technologies: Artificial Intelligence, Blockchain

Aqaix, a Silicon Valley startup, seeks to transform how projects within the water space are financed, with the ultimate goal of bringing more capital to projects advancing conservation, groundwater recharge and storm water retention, among others.[55] The "Software as a Service" company seeks to integrate data and the power of digital technologies like AI and blockchain to facilitate de-risked investment in projects.[56]

In February 2019, Aqaix announced a partnership with QStone Capital, an emerging water investment advisory boutique focused on wastewater treatment and technology. QStone has specialized in bringing capital to novel water treatment endeavors, primarily in India and the Middle East. The partnership of Aqaix and QStone Capital seeks to blend the companies' expertise, respectively, in applying smart software to facilitate water investment and executing innovative water project finance and development. The two companies share a vision of mobilizing private capital to the under-funded water sector, supporting water conservation, and sustainable development.[57]

These case studies highlight a few ways in which digital technologies are being utilized around the world to address water quality and quantity challenges. As shown above, transformative water management often requires new partnerships and the combined use of several innovative technologies. Although many digital water projects are still in proof-of-concept stages, the following section illuminates the

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52 (United Utilities Becomes the First Water Utility to Adopt AI 2018)
53 (JEA website, nd)
54 (Artificial Intelligence helps JEA Optimize Water Resources 2006)
55 (Aquaix and QStone Capital to Develop Software and Source Opportunities in Water Finance 2019)
56 (Water Action Hub 2019)
57 Ibid at 21

continued growth of the digital water market as well as the funding sources available to accelerate projects around water conservation and quality.

4 EMERGING DIGITAL TECHNOLOGY OPPORTUNITIES

Several emerging opportunities in the areas of digital technology and financing are providing hope for water resource management in the CRB. As the market for digital solutions expands, new digital technologies are developing with the potential for addressing some of the many water challenges faced by Basin states. Uptake of such digital technologies is already occurring across the CRB, laying the foundation for future pilot projects and a scaling of digital water technologies. By utilizing financing opportunities available for water sustainability projects and pursuing innovative financing strategies, water sustainability may soon be a reality in the CRB.

4.1 Market Expansion

The CRB is not unique in its thirst for limited water resources. As the benefits and necessity of water conservation have become clearer, the digital technology market has been expanding to provide new solutions. Digital technologies are now emerging to fill niches across the water sector with not only new innovations, but innovative ways of using established technologies as well. Many such digital technologies have implications for water conservation and sustainable management and are already being deployed by utilities, industries, and in agriculture alike. Below (Table 3) are examples of technology and solutions providers highlighted in the press for their emerging potential as the market expands.

Table 3: Platforms and applications emerging as the market expands for digital water technologies

Platform	Application
Apana: uses meters and sensors connected through the Internet of Things to monitor water infrastructure in real time. The technology is paired with artificial intelligence that analyzes the data generated for anomalies, identifying leaks, breaks, and other malfunctioning equipment and sending notifications to managers.	*Acoustic Sensing Technologies*: uses sonar to detect and asses leaks or pipe breaks deep underground; combines hardware, software and data analytics to survey pipelines.
Gybe: uses satellite imagery and proprietary ground-based hardware to aid in the management, conservation, and restoration of aquatic ecosystems. Gybe products provide insights on water quality (e.g., nutrient and sediment pollution, the onset and severity of harmful algal blooms, land use, and more) by processing broad ranges of data from multiple sensors and satellites.	*Arable Labs*: has developed an irrigation management tool that combines precipitation, radiation, evapotranspiration, humidity, temperature, soil moisture, water stress, and other variables to help farmers prioritize irrigation efforts by sharing data from solar powered remote sensors directly to a smart phone or tablet application.
Hydromodel Host: groundwater management tool for planners, water managers, and aquifer users that utilizes cloud services to automatically upload field data and run simulations of scenarios under complex conditions to assess the impact of future demand, calculate maximum extraction volumes to ensure sustainability, understand the impacts of climate change, assess the impact of land use, and more	*Crop Metrics*: uses field probes to collect data on soil moisture which is then paired with crop models and weather data and used to drive irrigation scheduling. Data and recommendations are stored in the cloud and shared to users via a mobile app. Coming in 2020, machine learning will also be used to adjust pivot application rates based on real-time crop and weather conditions.

WaterChain: uses blockchain and distributed ledger technologies to open funding for developing smarter water treatment facilities. WaterChain utilizes smart contracts and cryptocurrencies to accelerate water projects in order to better address the global drinking water crisis.	Flo: in-home sensor that continuously checks for leaks, alerting home-owners to issues through an app; allows users to set conservation goals, monitor consumption, and remotely shut off water in the event of a leak or pipe burst.
Water Ledger: developed by Civic Ledger using the public blockchain Ethereum. Water Ledger has been used by the Australian government to verify water trades, update records of trades in the state registry, and identify the location of water trades.	Fracta: uses artificial intelligence and machine learning to assess the condition and risk associated with utility drinking water distribution mains. The Fracta software performs Likelihood of Failure, Consequence of Failure, and Business Risk Exposure assessments for utilities through a SaaS system and cloud applications.
	Plutoshift: algorithms designed to analyze existing data from SCADA systems, sensors, and meters in order to provide insights regarding excess resources consumption (e.g., chemicals for treatment of wastewater – industrial or municipal), process optimization for energy efficiency or water conservation, and equipment maintenance.
	Utilis: uses sensors on satellites with a signal that can penetrate the first few meters the Earth to collect data which is then analyzed to pinpoint leaks in utilities' underground infrastructure.

With the emergence of new digital technologies and market expansion in the digital water realm, there are a plethora of opportunities for adopting and scaling digital solutions. As the following section elaborates, many of these digital technologies are already being adopted across the CRB to address some of the many water challenges the region faces.

4.2 Regional Potential for Digital Technology

The adoption of digital technologies in the water sector has been slower than in other sectors (e.g., energy and transportation); nonetheless, a scaling of digital solutions is critical for addressing the water scarcity challenges faced by the CRB both now and in the future. Albeit far from widespread, digital technologies have begun to be adopted in the pursuit of water conservation in the CRB. As discussed in Section 3, pilot projects are currently underway in California.

Similar to drought stricken California, the desert metropolis of Las Vegas faces the challenges of water scarcity paired with a high demand for water from residents as well as the city's infamous resorts and casinos. Leaks and major water losses can be disastrous for utilities and ratepayers alike, thus the Las Vegas Valley Water District has worked with solutions providers to deploy sensors and IoT infrastructure across their service lines to aid in leak detection. [58] In addition, some of the city's casinos are taking conservation into their own hands. Atlantis Casino Resort Spa has adopted smart water-metering and AI to detect leaks, preventing damage and reducing water loss.[59] Smart meters from WINT Water Intelligence are installed throughout the resort's facilities and are linked to a cloud-computing service. The system tracks water flows, identifying anomalies and alerting resort managers to any issues.

[58] (Las Vegas Utility Refuses to Gamble with Water Mains 2017)
[59] (Nevada Casino Resort Uses AI to Manage Water Consumption 2019)

Meanwhile, in Arizona, sensors are used at the ASU Smart Devil football stadium to monitor sinks and automatically shut off water that is left running.[60] Whereas custodial staff previously required several days to perform maintenance on all the stadium's bathrooms, water loss can now be addressed within minutes, aiding campus conservation efforts.

In addition to initiatives taken by the private sector, digital technologies have been explored by state legislatures in the region as viable tools for addressing water challenges. In early 2019, Coloradan state legislators proposed a bill that would task the Colorado Water Institute with exploring the use of blockchain technology in water rights management, citing potential benefits such as database management and data tracking for more informed decision making.[61] The bill also explored the potential for developing and operating a water market with the use of blockchain. Although the bill did not advance, it shows that conversations around digital water are widespread and occurring at a high level in CRB states.

4.3 Funding Opportunities

Many financing opportunities exist for funding digital water projects in the CRB and a combination of such opportunities will need to be pursued by project developers to implement and scale solutions to the Basin's water challenges. Opportunities range from strategic partnerships with foundations and corporations (as discussed previously in Section 2.1.3) to grants and green bonds. Although the following section is not a comprehensive list of financing opportunities, it provides a foundation from which interested parties can begin exploring sources of funding for digital water projects.

Whereas many corporations are taking sustainability initiatives into their own hands within their operations and supply chains, corporations are also taking a new approach to investing in digital water solutions. According to a recent article in Forbes magazine, corporations are beginning to invest directly in water technology start-ups, eventually becoming acquirers once the start-up is established.[62] The corporation can then help to accelerate the development of the young company through their more established marketing and distribution networks. Veolia, SUEZ, GE, and others have played a role as strategic investors in start-ups, and in this way are helping to finance and scale digital water solutions.

In addition to investing in start-ups, digital water projects can more directly be financed by one of several foundations with missions focused on water, conservation, sustainability, climate change and more. A list of foundations with interests in water and/or the CRB are provided below:

- Walton Family Foundation: has a focus on conserving oceans, coasts and rivers all while promoting healthy economies and communities. The WFF is committed to finding solutions that benefit nature and people and supports efforts specific to the CRB, including developing a water bank, securing funding for agriculture and urban water conservation and restoring river flows in targeted areas throughout the CRB.

- The Gates Family Foundation: has specific ties to Colorado and seeks to advance new tools, processes and ideas to realize a long-term, sustainable balance between water demands. Prioritizes projects that promote cross-sector cooperation and market-based tools, connect land

[60] (Arizona State University Embed Sensors Deep into Student Life 2017)
[61] (Colorado Senator Wants to Study Blockchain for Water Rights Management 2019)
[62] (Capital Flowing to Water Technology Startups From Big Corporations 2019)

use and water conservation, support instream flows and healthy rivers and develop better water data and analysis.

- Encourage Capital: has built a community of investors, foundations, market-leading companies, and non-profits to deploy private capital into solutions for world challenges. Encourage Capital recognizes the opportunity for investments in the CRB and is developing strategies for conserving water through infrastructure and land management projects.

- The Rockefeller Foundation: promotes the well-being of humanity through projects pertaining to sustainable agriculture and climate change resilience among others.

- Pisces Foundation: supports smart water management in cities, using technology to protect water, increasing peer-to-peer sharing, smart water management on farms, and developing modern water policies.

- The Ford Foundation: seeks to improve natural resource governance, challenge irresponsible natural resource extraction, and support climate change policies and investments that benefit rural and indigenous communities.

Several financing opportunities also exist through the US federal government. For example, the US Bureau of Reclamation offers WaterSMART Water and Energy Efficiency Grants through which it provides 50/50 cost share funding to irrigation and water districts, tribes, states, and other entities' water or power delivery authority. Grants are used to conserve and use water more efficiently, mitigate conflict risk, increase hydropower production, and otherwise promote water supply reliability in the western United States. The selection process focuses on projects that can be completed in 2 to 3 years.

Other federal grants are available through the EPA, US Department of Agriculture, and US Department of Housing and Urban Development including the Clean Water State Revolving Fund, Drinking Water State Revolving Fund, USDA Rural Development Water and Environmental Program, and more. An extensive list of government funding sources and other resources can be found at: https://www.epa.gov/waterfinancecenter/effective-funding-frameworks-water-infrastructure.

In addition to federal grants, green bonds are another means to finance digital water and sustainability initiatives. A green bond is a bond whose proceeds are used to fund environmental projects, often issued by the government or private companies. The World Resources Institute is one organization working to build the frameworks for issuing green bonds to pilot source water protection projects; support conservation, restoration and enhanced water stewardship; and to finance green-gray infrastructure projects.

Other innovative financing methods are emerging as well such as the WaterWorks Fund which has designed a platform for entities to fundraise and individuals to invest in sustainable water solutions. The platform was developed to support the UN Sustainability Goal #6 regarding clean water and sanitation and to promote healthy waters, watersheds and communities. Likewise, the Water Funder Initiative has initiated a campaign to accelerate progress toward a sustainable water future in the CRB and is leveraging funding from private and public partners to improve water distribution in the West, drive data-informed decision making, improve water governance, and accelerate innovation.

No single financing opportunity will provide the funding necessary to address the water quality and quantity challenges in the CRB. Rather, meeting the shortfalls in regional infrastructure and technology investments will require corporations and private entities to invest more in water conservation and efficiency initiatives, increased private investment, new partnerships, grants, and green bonds among other financing strategies. By leveraging new technologies, seeking innovative partnerships, and developing broad financing portfolios it is possible to achieve sustainable water management in the CRB, ensuring water quality and quantity needs are met for nature and society alike.

5 CRB DIGITAL PILOT PROJECTS AND NEXT STEPS

The objectives of the workshop held in October 2019 were to prioritize feasible technological solutions for the basin and to define two digital technology pilot projects for the CRB. To achieve these objectives, participants were initially asked to prioritize a set of pre-defined challenges or problems (Section 2.3) that could be addressed through digital technologies. The criteria considered during this prioritization exercise were: high impact, economic feasibility and short term implementation. The three following problem areas emerged as key priorities for the CRB. The first two are considered to be priorities for the short term, while the third problem area is considered a priority for the long-term.

- **Lack of data integration for informed decisions**. There is a need for a platform to gather data from different sources and translates that into actionable information for all stakeholders.

- **Demand management** solutions at scale may solve the compounding water supply challenge in the CRB. There is a need for financial incentives for water conservation in the agriculture sector and other sectors that rewards stakeholders for their conservation choices/behavior.

- **Barriers to investment and new markets.** There is a need for structured opportunities that leverage investment based on stages of development and risk and types of investor.

Groups of attendees participated in a design charrette at the end of the workshop, during which conceptual ideas were formed for each of the priorities identified above. These groups are presently working on further defining the problem as well as designing a digital technology solution that integrates AI, sensor networks and/or blockchain technology to address a defined challenge affecting the CRB.

Technologies to address the region's water challenges exist – it will now require innovative funding portfolios for investing in, piloting, and scaling technologies across the CRB. Through this initiative, it is our hope to establish a collaboration to drive these digital technology pilot projects forward as a part of the long-term strategy for CRB system conservation.

Digital Technology Solutions for the Colorado River Basin

Location: 1601 Wewatta Street, Suite 400
Denver, CO

Date 23 October 2019

Workshop Objectives

- ✓ Highlight the challenges of the Colorado River Basin that could be addressed through digital solutions.
- ✓ Map and prioritize feasible technological solutions for the basin.
- ✓ Identify and define two digital technology pilot projects to implement in the Colorado River Basin.
- ✓ Establish a long-term collaboration for the pilot projects.

Agenda

9:00 – 9:30	**Welcome and Meeting Goals** Brief welcome by Sponsors (Microsoft, Intel and Blue AB) and Conveners (Water Foundry and Environmental Law Institute). Attendees are invited to share supplementary goals.	Water Foundry & ELI
9:30 – 9:45	**Introductions and Guidance for Participants** Jennifer Pratt Miles, the workshop facilitator will provide guidance and brief introductions of participants will follow.	Meridian Institute
9:45 – 10:45	**Colorado River Basin Challenges** Brief presentation (20 minutes) on the current water use and supply challenges and the dynamics of water management in the Colorado River Basin. A facilitated discussion will follow, to identify strategic focus areas of improvement in the Colorado River Basin.	James Eklund Brad Udall

10:45 – 11:00	**Break**	
11:00 – 12:30	**Lightning Talks** Each participant will be given 5 minutes to discuss their area of expertise and experience in the application of digital technology. Participants are encouraged to also provide brief thoughts on the barriers to and potential solutions for commercialization and scaling of these technologies.	All Participants
12:30 – 1:15	**Lunch Break**	
1:15 – 2:15	**Mapping Technological Solutions onto Challenges** Based on earlier sessions and discussions, the group will collectively create a matrix to plot the digital technologies discussed against the identified challenges in the Colorado River Basin. The technological solutions for each problem area will be ranked, based on specific criteria, including economic feasibility.	Group Work
2:15 – 4:15	**Pilot Project Design Charrette** Following the prioritization of technological solutions for the Colorado River Basin, the group will be divided into sub-groups (2-3) to design a pilot project for implementation.	Group Work
4:15 – 4:45	**Next Steps** The workshop will come to a close with the group identifying: ✓ Immediate steps to move the pilot projects forward and person(s) responsible ✓ Individuals and/or organizations who would need to be involved to plan and implement the projects ✓ Potential funding sources	Meridian Institute
5:00	**Final Thoughts and Adjourn**	