April 2021

THE AGRICULTURE AND MS4 SECTORS:

A DIGITAL REVOLUTION

National Municipal Stormwater Alliance

ABOUT NMSA

The National Municipal Stormwater Alliance or NMSA is a 501(c)(3) devoted to supporting Municipal Separate Storm Sewer System (MS4) permittees. We are the only national stormwater organization comprised of, operating on behalf of, and for the benefit of, MS4 permittees. NMSA is an alliance of 24 state and regional groups focused on MS4 permittees and our vision is to help communities tackle stormwater challenges to provide clean water for the nation. For more information, please visit www.nationalstarmwateralliance.org.

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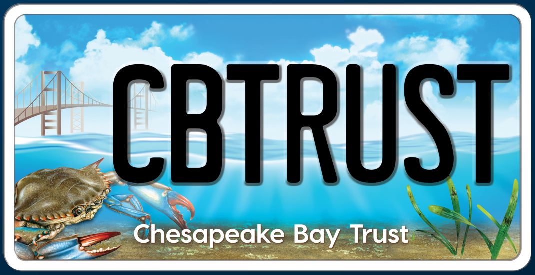

NMSA would also like to recognize and thank CO_2EFFICIENT LLC for its significant contribution to the development of this report. CO_2EFFICIENT is a mission-based strategic consultancy focused on advancing public policy and market solutions in the energy and environmental sectors. Located in Washington, D.C., CO_2EFFICIENT is a leader in developing transformational 21st century climate policies that integrate environmental sustainability and corporate governance with digital technology solutions.

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EXECUTIVE SUMMARY

Management of urban stormwater systems, in the context of water pollution and climate uncertainty, is a growing challenge for the water sector. Water quality, already under threat by agricultural runoff, is worsened by pollutant loads from urban areas. The power of digital technologies and data analytics has enabled a suite of new solutions to concurrently address these complex challenges within the shared agriculture-water dimension. This report aims to demonstrate the co-optimized benefits derived from digitalization vis-à-vis an overview of digital applications that have delivered smart and sustainable solutions to both sectors.

A widespread digital transformation of the water sector is imperative for its efficiency, sustainability, and long-term financial and operational resiliency. The municipal separate storm sewer systems or "MS4" sector is particularly well-positioned to benefit from advancements in digitalization. Deployment of "big data" and digital technology solutions can enable real-time insight into the quality and performance of a utility's assets, enhance overall performance through predictiveness and adaptive management, increase efficiency in reporting and compliance, and promote more effective customer engagement, education, and communications.

Agriculture, an early adopter of the digital revolution, harnessed the power of data and integrated market-driven approaches to leverage successful economic and environmental outcomes. Given the nexus of ag-water challenges and solutions, these innovative outcomes in ag can be informative to new approaches and applications in the stormwater sector. The report assimilates a portfolio of case studies that summarizes real-world insights to inform the MS4 sector of the environmental, financial, and business risk-management opportunities of digitalization. It also outlines the impact of digital technologies, some specific applications of interest, and the forward-looking trends for the MS4 sector in the future.

Against the backdrop of current market and non-market signals, a move towards investment in digital solutions becomes increasingly imperative for both the ag and MS4 sectors. This report describes five major drivers of change – policy and regulation; consumer and public awareness; corporate risk and responsibility; investor influence and climate resilience; and asset management and aging infrastructure – that are reshaping markets towards innovative, sustainable systems. The demand for data and environmental transparency will continue to shape factors for both the ag and MS4 sectors to diverge from the status quo, modify their actions, and adopt new technologies, practices, and mechanisms to conform with changing standards and consumer preferences.

Investment in digital innovation and adoption of creative market-driven thinking is key to unlock and accelerate digital sustainability solutions for the MS4 sector. Advanced technologies will lead the transition of the sector from ‘business as usual’ to a ‘digital water’ utility. Lessons learned from digital ag can help propel digital water forward and act synergistically to address nexus issues related to water pollution, water quality, and climate change resiliency.

INTRODUCTION

The Clean Water Act has been deemed a success…

A new wave of "big data" and digital technology solutions are at the forefront of environmental innovation.

NMSA presents this report to identify emerging opportunities that harness the power of data using digital technologies and market-driven approaches in the agricultural sector, an early adopter of digital innovation, to educate and inform potential applications in the stormwater sector. Specifically, technologies and approaches that minimize costs and external environmental impacts, provide market signals tied to performance, increase data security, transparency, and credibility, and enable the full value chain to drive optimal sustainability outcomes can be utilized within the context of agriculture for the benefit of stormwater programs. Another potential is for these digital strategies to be transferred into the urban stormwater context considering the close technical similarities associated with runoff from agriculture and urban areas.

This report highlights initiatives and provides case studies from the agricultural and regulated stormwater sectors (i.e., municipal separate storm sewer system or "MS4") that present how agricultural operations and MS4 communities can benefit from data-driven technologies, tools, and frameworks in watershed- and place-based applications, ultimately improving water quality and environmental outcomes using digital solutions and forward-looking technologies. This report is divided into four sections.

- **Section 1** provides essential background information explaining digital technology today. It provides insights on how the ag sector has harnessed data and digital solutions to increase efficiencies, performance, and sustainability, and offers explanations of terms and technologies used within the tech world and now being adopted by a multitude of sectors including agriculture, water, and energy. Technologies that are shaping the MS4 sector are also included to illustrate that the role of digitalization in this sector is developing as well. Moreover, it highlights the ag-water nexus through the lens of digital innovation.

- **Section 2** delves into the driving market forces behind the high-performing, sustainable ag transition. Forces such as consumer demand, corporate responsibility, investor influence, and climate change, as well as the policy and regulatory landscape, have and will continue to materially enhance the digital transition and innovation in the ag and MS4 sectors. Some drivers, such as asset management, aging infrastructure, and project delivery challenges, that are unique to the MS4 sector are also included.

- **Section 3** delivers case studies about notable digital technology companies and partnerships capable of delivering innovative, market-driven, and scalable sustainable performance outcomes. It showcases the real-world application of these digital technologies and innovative markets within the ag and MS4 sectors, and how these examples coincide with a more sustainable future.

- **Section 4** envisions a path forward by first considering how the digital solutions introduced in this report in the ag and MS4 sectors can benefit water quality and long-term sustainability in the country today and in the future. A pathway forward is discussed that leverages the cutting-edge digital solutions of today and how some of these will become commonplace in the future.

SECTION 1: DIGITAL INNOVATION TODAY

Twenty-first-century problems demand twenty-first-century solutions. Today that means *digital innovation.*

Digital technology has permeated every sector of the economy. It is estimated that current data production is 44 times greater than it was in 2009, and by 2022, there will be over 50 billion smart connected devices in the world, fully enabled to collect, analyze, and share data.[1]

The power of data analytics has enabled new solutions to complex challenges, particularly within natural resource sectors, such as agriculture, water, and energy. In 2017, the global market for artificial intelligence (AI) in agriculture alone was valued at approximately $545 million; it is predicted to reach nearly $2.1 billion by 2024.[2] PwC has estimated that using AI for environmental applications in ag, water, energy, and transportation could contribute up to $5.2 trillion to the global economy, 38.2 million net new jobs, and a 4.0% reduction to greenhouse gas emissions – equivalent to the annual emissions of Australia, Canada and Japan combined – by 2030.[3]

The agriculture (ag) industry, which is extremely vulnerable to climate change impacts, is harnessing the benefits of digital technologies to evolve farm operations and business models and build a more resilient and sustainable future. Similarly, the Municipal Separate Storm Sewer System (MS4) sector has seen a recent evolution in technology-based management practices and modeling platforms to enhance the performance of urban stormwater infrastructure as well as drive more effective asset inventorying and management programs. Both sectors play a critical role in the water quality conditions and health of watersheds and receiving waters across the country.

The Chesapeake Bay watershed is impacted by significant pollutant loadings from the ag and MS4 sectors. Figure 1 shows the loadings of nitrogen and phosphorus from a variety of sources, including ag, wastewater and combined sewer overflows (CSOs) and MS4 (urban runoff), in 1985 and in 2015. The percentage of loading from the ag sector for nitrogen remained unchanged, but the portion of phosphorus loading increased from 43% to 55% - so now over half of all phosphorus comes from one source – the ag sector. The contribution from the MS4 sector has increased for both nitrogen and phosphorus has increase from 11% for both pollutants to 17% and 18%, respectively. The increasing portion of nutrient loading from MS4s in the Chesapeake Bay is a cause for concern and for action; however, it is the loading from agriculture that is most significant.

The sector in the Chesapeake Bay that offsets the increases in both the ag and MS4 sectors is the wastewater sector, which decreased from 28% and 39% for nitrogen and phosphorus, respectively, to 16% by 2015 for both pollutants. What drove the drastic decreases in wastewater contributions to nutrient loadings in the Chesapeake Bay watershed? Some of these decreases came from source control, such as phosphorus detergent bans, while other reductions can be attributed to general wastewater treatment upgrades (EPA, 2016). However, the most significant factor for the wastewater sector meeting Chesapeake Bay TMDL load reductions ten years ahead of schedule and for making such drastic nutrients reductions overall can be most squarely attributed to technological advancements in wastewater treatment processes. The adoption of biological nutrient removal (BNR) and enhanced nutrient removal (ENR) technologies pushed load reductions to levels not previously envisioned.

The take-away here is that technology adopted and implemented in strategic ways can propel advancements in an industry in a way that other factors cannot. Accelerated innovation and adoption of digitally enabled solutions will be needed to cost-effectively counter the very real environmental, financial, and business risk-management realities that lay ahead. Other vital industries to the public interest, such as the water and infrastructure sectors, can gain valuable insights from the experience and lessons learned from early digital adopters.

The upstream/downstream dynamics of agriculture/urban pollutant loadings is commonly characterized as upstream areas generating excessive pollutant loads that are delivered to downstream waterbodies in suburban and urban areas. The lack of regulatory drivers in the ag sector creates a challenge for motivation by farmers to adopt water quality improvement measures and until solutions are developed that can encourage ag sector actors to implement such measure, it is likely that these upstream/downstream dynamics will continue.

The ag and MS4 sectors have been lagging in the ability to successfully reduce key pollutants, such as nutrients and sediment, but new digital-based technologies are being developed and deployed that are anticipated to change that. Investments in digital solutions in the ag sector are improving farm output production and efficiency and enabling sustainability solutions that reduce downstream impacts on water quality as well as leverages previously untapped value from farming activities. Similarly, technologies in the MS4 sector are improving performance and encouraging better asset management. In some instances, the technological growth in these two sectors act synergistically. This report focuses on these technologies, some specific applications of interest, and the direction of growth in the future for digital solutions.

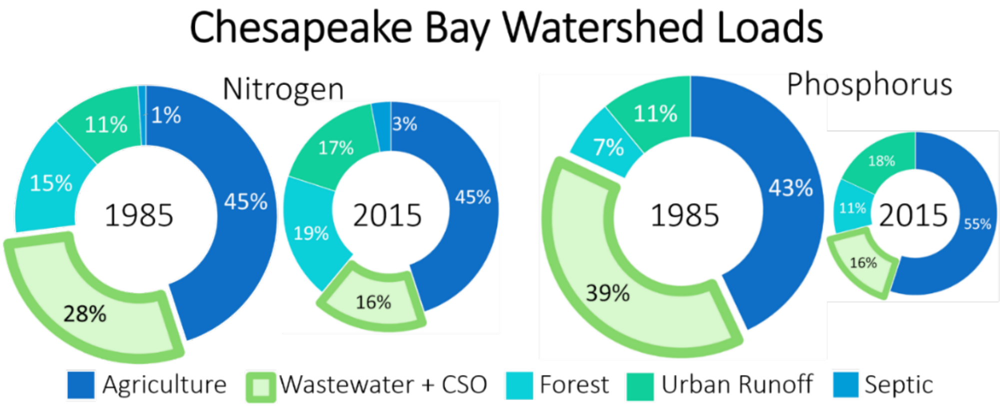


Figure 1 - Decrease in Wastewater Contrtibution to Bay Watershed Loads, 1985-2015 (from EPA, 2016)

DIGITAL TERMINOLOGY EXPLAINED

Engaging with digital technology requires a new vocabulary. The following is a list of commonly referred to terms and technologies used to describe digital innovation across sectors like agriculture, water, and energy in this new era of digitalization.

- **Internet of Things (IoT):** Simply stated, IoT is machines "talking" to other machines – the concept of connecting any device to a network of appliances, electronics, mobile devices, smart meters, sensors, drones, and satellites that can generate, collect, communicate, and exchange data and information.[4] Any internet-connected, stand-alone device that can be monitored or controlled from a remote location is an IoT device.[5]

- **Big Data:** Big data is the aggregation of numerous individual sets of data, pooled together and analyzed to unearth patterns and trends, especially relating to human interaction with the environment. The process of converting big data into useable information that can ultimately influence future decisions is called data analytics.[6] A relatable example includes cell phone apps that pool user data to geolocate traffic congestion and predict efficient commutes home for each individual user.[7]

- **Digital Twin:** A digital representation of a real-world, physical asset, reflecting the aggregation of multiple data sources, that enables an organization to understand, forecast, and optimize performance of its assets and processes, as well as differentiate its goods and services. A digital twin enables users to synthesize sensor data to reduce asset downtime and maintenance costs, improved process efficiency, and increased market responsiveness.[8] It also enables product differentiation based upon verifiable characteristics (e.g., sustainability attributes) captured through the underlying data. As applied to water distribution and treatment networks, the digital twin would be the computer-based digital depiction of the water piping system, equipment assets, and operator control systems, strengthened and enhanced using data (e.g., flow, pressure, water composition) collected from the sensor network in real-time to inform efficient decision-making.[9] In the context of agriculture, the digital twin represents multiple sources of production-level data combined to create a digital representation of a farm's operation and goods produced. This provides data-driven transparency to further enable commodity or product differentiation.

- **Artificial Intelligence (AI):** AI combines large amounts of data with intelligent algorithms to allow machines to learn from experience, adapt to new inputs and outputs, and perform human-like tasks. AI is often used to analyze patterns or hidden insights within big data and allows software applications to become more accurate without being explicitly programmed by a person, resulting in increased automation. With the help of AI, farmers can bolster yield through better informed seed selection, monitor crop health in real-time, and address environmental challenges and shifting conditions by powering smarter resource management.[10]

- **Blockchain Technologies:** Blockchain (and distributed ledger technology) is a digital ledger or database in which transactions and entries are recorded chronologically, creating a permanent record that is transparent to anyone connected to the network.[11] For instance, farm data is notoriously disjointed. By connecting various sensor data to a distributed ledger, all data entry and human manipulation can be tracked to better ensure data quality.[12] Blockchain is also being deployed in agriculture predominately for product traceability. This enables heightened supply chain transparency and cost efficiency, faster and more accurate handling of food safety issues, and product differentiation to meet new consumer demands for greater information about where their food comes from.[13]

- **Digital MRV:** Markets are based on the ability of consumers to value different attributes of products and services. Traditionally, markets identify such attributes through the process of Measurement, Reporting, and Verification (MRV). Existing MRV mechanisms collect and authenticate data for policy and regulatory compliance (e.g., identify and report GHG emissions data, gather and report stormwater permit obligations). Emerging Digital MRV tools, leveraging an ecosystem of digital technologies (e.g., IoT, data analytics, blockchain, AI), with the capability to quantify, communicate, and authenticate outcomes in real-time, has the potential to improve speed and accuracy of reporting, lower reporting, verification, and transaction costs, and more effectively capture a range of performance attributes including resiliency and sustainability.[14] Such Digital MRV platforms are facilitating more automated, efficient carbon trading markets and other results-based finance systems, as well as corporate supply chains and sustainability reporting.[15] In the context of agricultural water quality improvements, Digital MRV offers the potential to vastly improve the accuracy and economics of water quality (i.e., nutrient credit) trading and other environmental asset markets. Moreover, it will enable further differentiation of agricultural goods produced based on sustainability impact attributes, such as soils management, water conservation, and source water protection.

AG SECTOR OVERVIEW

Digitalization of Ag

The agricultural sector has witnessed a revolution of digital technologies that are driving a new wave of environmental innovation set to tackle today's most pressing risks, including climate change, soil health degradation, and water quality impairments. This revolution has introduced new ideas, economic benefits, market innovation, and scalable improvements in how we incentivize environmental performance. Companies focused on precision agriculture and farm data management are at the forefront of the digital ag transformation.

Precision ag is a management strategy that gathers, processes, and analyzes complex data to support management decisions for improved resource-use efficiency, profitability, and sustainability of agricultural production.[16] Precision ag employs innovative digital technology and equipment to radically improve farm management.[17] Data-driven insights help guide farmers on both immediate and future decisions, such as what seed to plant in what field, how much water irrigation is sufficient, or where exactly a precise amount of fertilizer is needed.[18]

Following data collection and analysis, precision ag equipment is utilized to inform and complete operational tasks. For example, analyzed data can direct innovative guidance systems and variable-rate application technology to precisely maneuver a fleet of ag equipment (e.g., combines, tractors, sprayers, irrigation systems) while applying the optimal amount of seed, fertilizer, chemicals, and water, resulting in cost savings, environmental performance, and higher yields through more precise management of inputs.[19] The power of data is unlocking speed, accuracy, and accountability for next generation farm management.

Furthermore, farm data management has become a significant area of investment and enabler creative partnerships.[20] In 2018, agribusiness and food company Land O'Lakes Inc. launched Truterra Insights Engine, an on-farm digital platform that aims to advance farmers' stewardship goals and their acre-by-acre return-on-investment, while helping food companies quantify progress on sustainability in real-time. The Truterra platform seeks "to enable conservation at scale across a variety of crops, commodities, and commitments … by providing data-driven insights from farm-to-fork."[21] Campbell's is deploying the Truterra platform and partnering with its growers, which include a number of farmers located in the Chesapeake Bay region – a watershed challenged by runoff of excess nutrients from farms. Campbell's goal is to obtain 70,000 acres of crops under a fertilizer optimization program by 2020; digital tools like Truterra will help the company meet this commitment by enhancing supply chain engagement and easing barriers with sustainability measurement, reporting, and verification.[22]

Role of Farm-Level Sustainability Data

Digitalization of ag has strengthened our ability to harness farm-level sustainability data in order to measure, assess, and inform farming practices and performances on conservation, resiliency, and eco-consciousness while maximizing yield. IoT devices generate and collect real-time data for farm-level operations, such as machine and fleet efficiency, fertilizer and water usage, soil composition and health, weather inputs, conservation practices (e.g., tillage and cover cropping), seeding and yield data, and other data related to measuring sustainability performance. This data can then be standardized for benchmarking farm performance against peers to create verified sustainability datasets.[23] These systems are enabling a market that properly values conservation and prices-in externalities.[24]

Once sustainability data is understood, farmers are seeking outside help to optimize operations and environmental performance. Field-to-Market: The Alliance for Sustainable Agriculture, is a Washington, DC-based public-private collaborative that has created a digital FieldPrint Calculator.[25] The calculator harnesses data from individual farm profiles and analyzes its performance against peer-reviewed environmental indicators and national metrics and benchmarks, digitally illustrating the sustainability performance of a farmer's unique operation. FieldPrint results provide farmers with data-rich information to better manage risks, differentiate products, and advance conservation, while helping standardize sustainability performance reporting. The digital tool has also provided the fulcrum for a wide array of innovative partnership projects.

In 2018, ADM, General Mills, and Agrible received Field to Market's Collaboration of the Year Award for partnering on the Southern Plains Wheat Fieldprint Project. The project has engaged farmers across Kansas, Oklahoma, Texas, and Nebraska and evaluated the sustainability performance of more than 176,000 acres of hard winter wheat. Through Agrible's data-driven platform, which fully integrates the Fieldprint sustainability metrics, participating farmers have leveraged farm-level data to quantify their sustainability performance and identify specific opportunities for further improvement through benchmarking performance against their peers.[26]

The quest for increased transparency in ag supply chains helps incentivize and facilitate collaboration and decision-making among farmers, suppliers, retailers, and precision ag companies to further advance sustainability. However, data solutions and digital platforms do not come without challenges and limitations.

The Sustainability Consortium (TSC), a global non-profit advocating for transparent supply chains, launched a multiyear initiative to assess how ag data flows through supply chains and identify ways to reduce the burden of data access and reporting. This is particularly relevant for food companies seeking consistent access to quality farm-level data in order to measure progress against their own sustainability commitments and identify collaborative opportunities for improving on-farm sustainability performance.[27]

TSC's 2019 study "Data Landscape Mapping in Agricultural Supply Chains" revealed that among more than 20,500 product suppliers surveyed specific to the food, beverage, and ag sectors, 49% responded they were "unable to determine at this time" impacts of farm-level performance indicators. The study results indicated that "food companies face a barrier when attempting to collect, analyze, and communicate farm-level information to retail[ers]." It further concluded that "the lack of systems connectivity across ag supply chains is likely the most influential barrier to data flow." Advancing systems connectivity, interoperability, and data alignment across digital platforms was identified as a priority solution. Meanwhile, many of the farm data management platforms are not currently equipped with sustainability analytics and reporting services. As such, interconnection activity is occurring between data management platforms and digital farm-level sustainability tools (e.g., through Application Program Interface (API) to the FieldPrint Calculator), which should further reduce the data management and sustainability reporting burden for growers.[28]

Furthermore, data generation on farm sustainability attributes like soil carbon storage, water quality, and nutrient control monitoring face existing technical and feasibility challenges from a real-time data collection standpoint.[29] Effective, low-cost remote sensors and widespread rural broadband internet expansion will help, but more progress is necessary to ensure a full suite of quantitative farm-level sustainability data. Moreover, the adoption and acceleration of data-driven technologies has been constrained by legitimate concerns regarding data privacy, ownership, and access, in addition to the lack of data standardization, interoperability, and sharing across digital platforms. A recent American Farm Bureau Federation study found that 77% of farmers were concerned about which platforms and entities had access to their data.[30] These challenges are long from settled, but the emerging architecture (i.e., data policies, standards, certifications, market mechanisms) is becoming more robustly investigated and better understood to address these issues.

MS4 SECTOR OVERVIEW

Monitoring Aspects

Within the overall water sector, the MS4 sector is particularly well-positioned to benefit from advancements in digital solutions. This is due to this sector being relatively nascent in maturation compared with other infrastructure sectors, it's spatially-defined nature, the passive and static performance of traditional stormwater infrastructure, and the dependence upon climate-driven inputs that are inherently chaotic, unpredictable, and increasingly problematic and impactful.

Traditional efforts to study watersheds and the dynamics of water quality or quantity in an area or waterbody require measurement of parameters, storage of data, and later analytical work. An example would be the establishment of an artificial weir in a stream and an algorithm that relates stage of water with a discharge, and a float or other type of instrument is used to track flow depth over time during a storm event. In the past, this data associated with the stream water depth would be saved to device that would store the information for a period of time. If a local power source is not available, usually a battery would be used. Using this monitoring approach requires regular efforts by staff to go to the site and download the data and replace the battery. If a problem occurs between site visits, this is not identified until a site visit occurs (with visible damage apparent) or a review and analysis of the data illustrates inconsistencies in monitoring data results. Costs for these types of monitoring efforts were significant in previous decades, which limited the broad application of such set ups.

To contrast, a real-time data monitoring effort leverages cell-based or other remote data links to store collected data in the cloud. Solar power provides an energy source and the ability to transmit, and store collected data remotely eliminates the staff time needed to collect data by hand. With the costs of stormwater sensor technology decreasing and data storage capacity increasing, the cost-effectiveness of measuring stormwater system performance/dynamics and managing large data sets of monitoring data is becoming more and more evident. This type of "smart sensor" framework is being used in greater frequency in the MS4 sector to provide critical performance information. In growing instances, remotely sensed data is fed to a data dashboard, which is a web-based interface that shows real-time data in a variety of contexts. This type of tool not only provides the utility of data-sharing with virtually no delay, but it also enables transparency in infrastructure performance as well as opens up the possibility of more efficient maintenance of stormwater practices – in other words, a stormwater O&M manager does not have to wait until data is collected and analyzed to know that there is a problem with data collection set up or the performance of a stormwater feature.

Real-Time Controls

It is one thing to monitor infrastructure performance using a "smart" framework, but it is another to enhance this performance using data collected in a "smart" context. The ability to manipulate the performance of a stormwater practice, or a series of practices, moves the conversation from real-time data monitoring to "real-time controls" (RTC). As Branko et al (2016) notes[31], stormwater infrastructure performance is often regarding as static in the context of an inability to adapt to changing watershed characteristics (land use, hydraulic connectivity, etc.) as well as shifting inputs, primarily climate-driven precipitation patterns. Several new technological advancements leading to varied applications based upon the transition from a static to a dynamic-based operational profile for stormwater infrastructure. This approach builds upon the Internet of Things (IoT) movement that is based upon the interconnections of assets and information nodes – from smart buildings to cars to appliances.

One example is the use of low-cost, reliable and secure valves, gates and pumps in existing stormwater ponds that are controlled by algorithms driven by real-time precipitation forecasts that inform the dynamic infrastructure to maximize storage capacity for incoming storm events to provide enhanced water quality and quantity treatment and protection.[32] This type of system was used during Hurricane Irma in a location particularly hard-hit in Florida. The technology, real time control (RTC), was employed across multiple stormwater ponds in this area with the result being no localized flooding in a location that would have certainly seen inundated roads and properties.[33] Research examples show that RTC systems that increase hydraulic retention time can have significant benefits for water quality treatment as well. Examples include a 57% reduction in sediment loading for an RTC-controlled stormwater pond in one case and a 90% increase in both sediment and ammonia-nitrate removal in a similar system.[34, 35]

System-Wide Applications

Beyond single or multiple stormwater practices retrofitted or designed to have dynamic performance is the ability to act in concerted and coordinated fashion for larger beneficial impacts. Branko (2016) notes that stormwater practices are normally designed and implemented on a site-by-site basis with no or little regard for the impacts of local performance impacts on the broader, collective outputs.[36] Figure 2 illustrates a system-level stormwater network that includes multiple practices, locations, and sensor technologies.

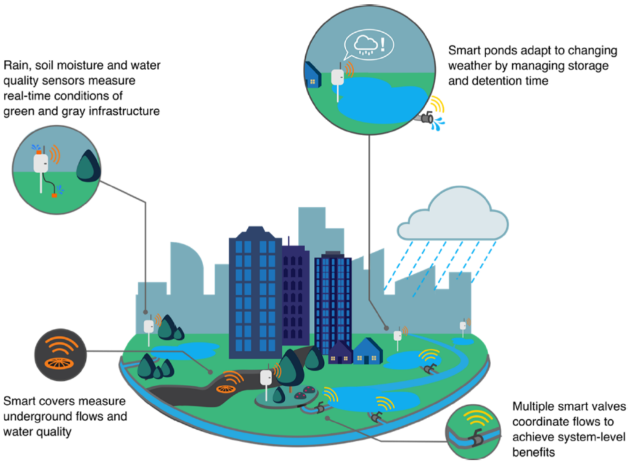


Figure 2 - System-level stormwater measurement and control (Branko et al, 2016).

The capacity to consider system-wide adoption is made possible due to the reduced costs of flow-based sensors, especially in the area of flood control.[37] However, the ability to control all aspects of a larger stormwater system is currently an unrealistic endeavor, which drives the need for the development of smart stormwater systems that are a mix of passive and dynamic practices. This type of partially controlled, system-wide framework was established and studied in a catchment located in Ann Arbor, Michigan.[38] The system includes two controlled stormwater ponds and a third pond that is uncontrolled, all of which drain to a constructed wetland that is also uncontrolled. Figure 3 provides a generic watershed with hubs that are static and dynamic along with locations for sensor placement as well as a schematic of the Ann Arbor system. By controlling only two of the four stormwater practices in the catchment and considering the performance of the passive practices as well, a nearly 50% reduction in cumulative nitrogen loads was measured in the system overall. This type of mixed-RTC approach suggests that the effectiveness of stormwater systems can be enhanced in a cost-effective manner.

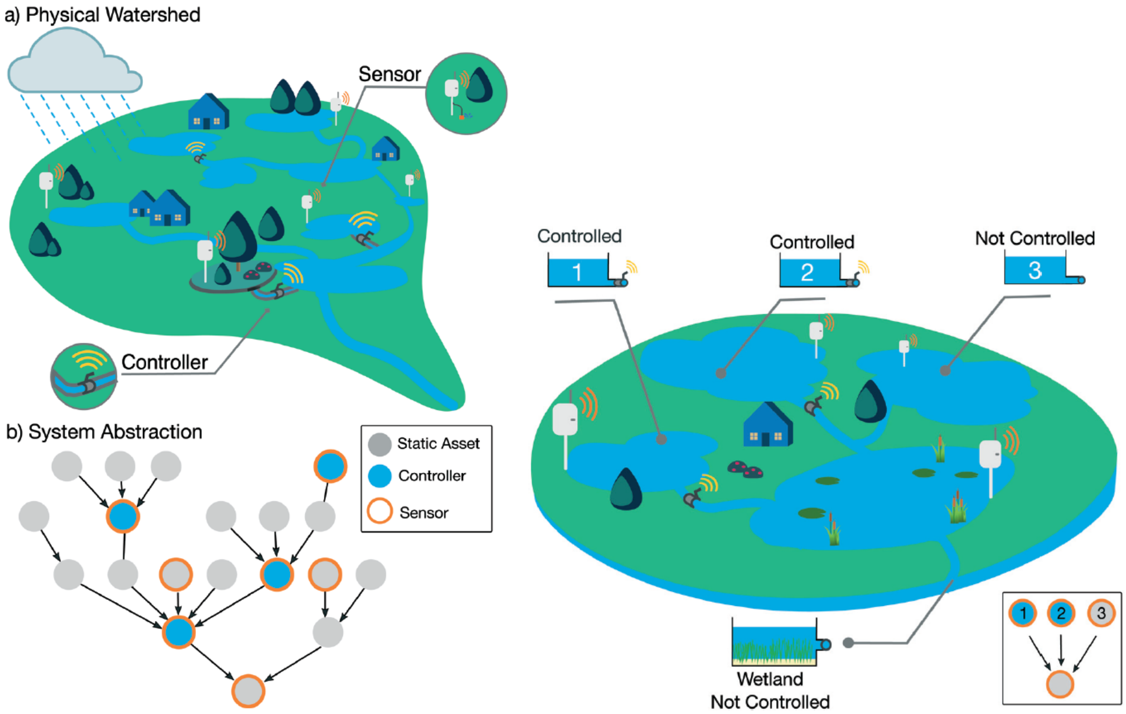


Figure 3 - Physical and Abstract Views (a and b) of a Mixed-Controlled Smart Stormwater System along with Schematic of Partially Controlled Smart Stormwater System at Ann Arbor, MI location (Mullapdi et al, 2016).

Stormwater systems that are monitored as well as controlled in real-time is a revolution in the management of urban stormwater runoff; however, adoption of RTC has been limited. Several factors have been attributed to limited uptake of stormwater RTC, which includes institutional barriers, such as cybersecurity and data management, as well as legal barriers, such as liability due to negligence or nuisance and increased data collection raising awareness of issues overall. An even more advanced development is occurring in the stormwater sector that builds upon RTC applications through the use of AI control systems and includes attribute that may help to overcome the barriers to adoption.

A standard RTC approach uses algorithms that factor in precipitation inputs and stormwater practice information (stage-volume relationship, for instance) to control outflow actuators (valves, etc.). These algorithms are predetermined and applied consistently until or unless changed by the operator of the system. Applications have been developed that employ machine learning, which is a form of an AI application that utilizes algorithms that allow computer programs to automatically improve through experience.[39]

Applications in Guam and Southern China in 2019 and 2017, respectively, employ a sophisticated framework of sensors that tie a supervisory control and data acquisition (SCADA) network to monitor and control a series of stormwater and green infrastructure practices that exist in an urban stormwater system. This framework is referred as an AI Urban Stormwater System that collects data through an "Internet of Water" (IoW), which employs a blockchain water platform (BWP) to secure and verify data collected, and feeds information on inputs (precipitation) and responses via sensors to a modeling platform that employs machine learning algorithms to adjust actuators within the system based upon the system input-response dynamics to meet the objectives as defined within the programming. As noted by the lead researchers, "the entire system functions like a human, (with the) IoW functions as the eyes, ears and nerve system to gather environment data…and the model works as a human brain, doing the logic process (analysis, calculation, decision)." Though these AI applications have been employed for only a brief period, the system in southern China has seen a reduction in Chemical Oxygen Demand (COD) with no incidents of flooding while the Guam system has led to a 20% reduction in potable water use through input via stormwater and rainwater capture and use targeting domestic and irrigation services.[40]

DIGITAL AG-WATER NEXUS

Current trends in the water sector are also shifting towards digitalization. Deployment of big data and digital solutions are enabling more cost effective and smarter management of water supplies and aging infrastructure. A widespread digital transformation of the water sector ("digital water") is imperative to its efficiency, sustainability, and ultimately, long-term financial and operational resilience.

Digital water can be viewed as the convergence of information across various systems of a water utility (e.g., drinking water, wastewater, and stormwater) to create real-time, deeper intelligence. This involves accessing and connecting data across disparate and siloed sources. Digital water enables enhanced asset management, increased efficiency gains in operations, and advanced monitoring and diagnostics.[41]

Of the various solutions digital water can unlock for a utility, one of the most critical is *predictiveness*. Through holistic, real-time insight into the quality and performance of a water system's assets, utilities and communities can harness data to reveal when to invest in infrastructure and extend the life of a water asset based on how the asset is performing, not just the age of the asset itself. Diagnostics and predictive maintenance drive out unexpected costs and prevent service disruptions.[42]

Data can also enable more effective customer engagement, education, and communications. Robust and transparent communication with consumers not only helps justify utility actions (e.g., new investment, rate increases, system failure responses), but also promotes customer engagement related to their own actions. For instance, digital water creates instantaneous information on water usage, such as notifying customers of running toilets, unusually excessive usage, and tailored ways for a household to conserve. As a society, we are accustomed to instantaneous information; however, the water sector has not yet realized the full potential digital water presents to harness the power of real-time information.[43]

Adoption of big data and digital technologies in the water sector have been slow relative to other sectors, such as agriculture. Communities and water utilities are inherently risk-adverse and many lack organizational capacity.[44] However, lessons learned from digital ag can help propel digital water forward. Advanced, data-driven asset management has been a recommended starting point for water utilities to focus their digital engagement strategy. Taking a watershed and regional perspective, the *digital ag-water nexus* presents a major opportunity to activate and scale system-level innovation across these two sectors. Digital systems present new opportunities for cross-sector engagement, real-time data sharing, and market-based solutions to drive toward resilience at the ag-water nexus.

SECTION 2: DRIVERS OF CHANGE

Change in any capitalistic society is driven primarily by financial opportunity, with the understanding that the needs and wants of society will be expressed as demand and will push the invisible hand of the market to develop the supplies needed to meet society's demands. In a recent listing of the top ten industries in which to start a new business – based upon expected opportunities – technology is listed as the top industry of potential, with the best sub-sectors being cloud computing, machine learning/AI, and big data[45]. But there are drivers that exist beyond those implied by market-based signals, such as environmental and social changes.

Consider the growth in interest on organic food, as an example. Sales of organic produce rose over 14% in 2020 while conventional product sales rose 10.7%.[46] This type of growth reflecting an increasing demand in organic foods drove organic food sales from $13B to $35B between 2005 and 2014.[47] For a market sector to increase its growth during a global pandemic reflects a deeper driver, which in this case is public awareness of health issues. Another non-market driver includes public concerns regarding climate change impacts, which reflects that two in three Americans are at least "somewhat worried" about global warming and 26% are "very worried" with 45% who think that the U.S. is being harmed by global warming "right now" based upon a 2020 survey[48]. In this same survey, it was found that a record-level amount (73%) of Americans believe that global warming is occurring with the vast majority attributing it to man-made activities. FEMA polling shows that between 30-40% of Americans believe their own community is at risk of flooding[49]. Similar to the growth in organic food sales, the awareness and impacts of global warming, especially in the context of flooding, is increasing, which reflects a non-market driver to address flood resilience. Considering that a recent survey of Americans found greater than 60% support for investments in flood protection and infrastructure across Republicans, Democrats, and Independents suggests that political barriers are declining as well.[50]

But how are these identified drivers tied to technological and digital solutions? The answer is that these types of solutions are ubiquitous, which makes the technology sector (and noted sub-sectors) such a lucrative investment in the future. Blockchain can enable food traceability in the organic food sector, for instance[51]. Technological applications are growing so much in the water resources sector that the Journal of Water Resources Research dedicated an entire series of publications under the heading of "Big Data and Machine Learning in Water Sciences: Recent Progress and Their Use in Advancing Science".[52] Clearly, there are both market and non-market drivers in the ag and MS4 sectors for digitally-based solutions. This section will explore these drivers and consider common areas of synergies that connect these two sectors.

POLICY AND REGULATIONS

Ag Sector

The U.S. government has recently adopted a number of administrative and legislative policies that will have lasting impact on data strategies, digital technologies, and market-centric solutions for agricultural and water systems. These recent policies (detailed in Appendix) address distinct yet complementary goals: (1) ensuring the Federal government is harnessing the power of data and digital technologies in a responsible manner, (2) engaging with technological partners in search of the next digital breakthrough, and (3) promoting and incentivizing market-based solutions within the agricultural and conservation sphere to improve water quality outcomes.

For example, a U.S. Federal Data Strategy has been launched to coordinate and deliver a consistent and cohesive approach for Federal data stewardship, use, and access.[53] This initiative represents an enormous opportunity for both public and private sectors to leverage environmental data as a tool to digitally streamline measurement, reporting, and verification (MRV), design and accelerate innovative applications for resource and policy management, and optimize both regulatory and market-driven objectives to drive desired environmental outcomes.

Moreover, digital precision ag solutions require reliable internet connectivity to enable high-quality data collection, real-time analysis, and full use of IoT solutions. The Federal Communication Commission (FCC) launched a new task force initiative in July 2019 to "promote rapid, expanded deployment of broadband internet service on unserved agricultural land, with the goal of achieving reliable capabilities on 95% of agricultural land in the U.S. by 2025." The Precision Agriculture Connectivity Act of 2018, which was ultimately incorporated into the 2018 Farm Bill to become law, addressed head-on the broadband infrastructure gap in rural communities.[54] The Biden Administration's proposed American Jobs Plan is looking to address the fact that more than 35% of rural America lacks reliable high-speed internet by proposing that broadband be available to ALL Americans via the $2T investment in infrastructure proposed in this package.[55, 56]

MS4 Sector

Regulations governing the MS4 sector have been evolving, and continue to evolve, in ways that motivate communities to adopt a digital approach to stormwater management. The most significant effort that is currently driving this sector in this way is the EPA Electronic Reporting (E-Reporting) rule, which was initially established in 2015 and targeted the wastewater sector. The E-Reporting rule is now focused on the MS4 sector and requires that all 7,500 MS4 communities submit permit compliance documentation via a standardized data element format by 2025.[57] The benefit of this rule includes saving time for permittees, states, tribes, territories and federal regulators, enhancing transparency, and providing EPA and the states the ability to strategically address the most serious water pollution problems. Regarding digital aspects, E-reporting benefits are increasing data accuracy and taking advantage of advances in information technology.[58]

The E-reporting rule provides an opportunity for MS4s to migrate their information into a more standardized digital format. Geographic Information System (GIS) platforms are commonly used in stormwater programs to locate and store information on stormwater infrastructure. Currently, ESRI, a global leader in GIS, had developed and is sharing a standardized data schema for stormwater infrastructure assets.[59] Even prior to the E-reporting rule focusing on MS4 was public, some efforts were already underway to standardize GIS stormwater infrastructure data, such as the Stormwater Geodata Transfer Standard developed by the Metro Stormwater Geodata Project in the Minneapolis/St. Paul area[60]. A consistently used data standard for regulatory compliance driving a GIS stormwater asset infrastructure data standard can enable a more comprehensive understanding of macro-scale stormwater assets that currently does not exist. There is no single resource today that provides the number of miles of MS4 conveyance systems or the number of stormwater control management practices (i.e., BMPs); however, a more unified data standard could enable a greater understanding of these assets at a regional or national level. This understanding of assets would enhance advocacy for the stormwater sector greatly at the national level.

CONSUMER AND PUBLIC AWARNESS

Ag Sector

New consumer demand is helping to launch sustainability and eco-conscious enterprises into the mainstream. No longer a niche industry, sustainability is now a primary driver of consumer choice that extends from resource management to product packaging and beyond. In a recent survey, roughly 73% of global respondents said they would definitely or probably change their behavior to reduce their impact on the planet. Further, 30% of consumers said they would be to pay higher-than-average prices for products that deliver on social responsibility claims.[61] Moreover, 59% of American consumers say they care about whether their food is grown sustainably.[62]

In response, industry must compete with sustainable business models, products, and services. This point has been recognized by Business Roundtable, an association of nearly 200 chief executive officers (CEOs) of America's leading corporations and a principal voice for the business case of sustainability. The group has promoted that "environmental sustainability and economic growth in the U.S. can be achieved together."[63] Moreover, a recent Stanford University publication found that "more than 90% of CEOs state that sustainability is important to their company's success" and "88% of business school students think that learning about social and environmental issues in business is a priority, and 67% want to incorporate environmental sustainability into their future jobs."[64]

These evolving consumer preferences have the ag industry's attention, and emerging partnerships and digital strategies are being leveraged to achieve desired sustainability outcomes. For instance, Tyson Foods partnered with the Environmental Defense Fund (EDF) in an effort to accelerate conservation by focusing on land stewardship. Tyson credits the new collaboration as an effort to "*meet consumer demands for more sustainably grown food[s].*" Together, they launched a pilot program to gauge agriculture practices on 500,000 acres of corn to reduce greenhouse gas emissions, improve water quality, and maximize farmer profitability, while helping Tyson accomplish its own sustainability commitments.[65]

Moreover, the partnership has enlisted the help of digital cloud-based ag technology companies, MyFarms and Farmers Business Network, both of which collect and analyze farm-level data on ag production to better inform and scale sustainability practices and supply-chain transparency. As part of this initiative, farmers can deploy MyFarms' innovative nitrogen loss calculator, a data-driven tool for preventing excessive nitrogen application – a primary contributor to water quality impairments and ag emissions and a source of lost farmer income.[66]

MS4 Sector

Market drivers are not as significant in the stormwater sector; however, there are ways that consumer awareness and interest could benefit the MS4 sector through digital solutions. An example of a public awareness driver from the ag sector is the use of certification programs for farming operations that protect and enhance water resources. The Minnesota Agricultural Water Quality Certification Program has certified over 1,030 farming operations covering 730,000 acres of land based upon a review of practices on-farm that address water and soil protection, such as controlling gully erosion, nutrient management, and the use of cover drops.[67] For certified ag producers, the benefits include regulatory certainty in questions of compliance for new water quality rules or laws, recognition for public and consumer audiences, and priority for technical assistance from other state programs related to environmental improvements.[68] In a state with the greatest number of freshwater lakes in the continental U.S., there is a strong water ethic and support for protecting water resources, so a certification program such as the Water Quality Certification program in Minnesota has value to the public.

Another type of recognition-based approach that is more consumer-based in nature is a certification based upon water quality practices that can be conspicuously branded on retail packaging for products from farming operations that hold this type of certification. This certification could be built upon organic certification and require a higher level of water quality protection than traditional organic certification requirements, or it could be independent. Regardless, the value of this certification is premium pricing, and the use of digital solutions, such as blockchain, could provide a low-cost and high-credibility pathway for data storage and supply chain product traceability related to information on certified farms.

A last example of public awareness and support in the MS4 sector is the Adopt-a-Drain program launched by Hamline University in St. Paul, Minnesota and used by MS4s in the state. This program enables volunteers to identify storm drains near their place of residence or employment and “adopt” them by keeping them clear of leaves, trash and other debris to reduce water pollution. The innovation of this program is the web-based platform that is used to aggregate the data collected by volunteers via an online GIS platform. This crowdsourced digital solution has been used by nearly 8,000 residents to address over 14,000 storm drains resulting in over 340,000 pounds of debris collected and removed[69]. These results translate to gross solids reduced for the communities in which these storm drains are located based upon a methodology developed by the Minnesota Pollution Control Agency (MPCA).[70]

CORPORATE RISK AND RESPONSIBILITY

Ag Sector

Beyond consumer demand, corporations are further recognizing the financial dangers associated with the failure to adapt to emerging trends in sustainability and impacts from climate-related physical risks and transition risks to a low-carbon economy. In August 2019, Business Roundtable caught the attention of financial markets when it redefined the purpose of a corporation to promote "an economy that serves all Americans." 181 CEOs signed a new statement "to lead their companies for the benefit of all stakeholders – customers, employees, suppliers, communities and shareholders …. a modern standard for corporate responsibility."[71]

USDA estimates that foodborne illnesses, a concern linked to climate-induced changes that create unfavorable environments for bacteria, have cost the U.S. $15.6 billion annually in recent years.[72] Recognizing the dangers and risks of foodborne illnesses, Walmart sought to vastly improve food traceability in its supply chains when an outbreak occurs.[73] Partnering with IBM, Walmart created a blockchain-enabled, end-to-end food traceability system. This digital food supply network, powered by blockchain technology, creates full transparency across the food chain and enables enhanced recall response efficiency, helping to improve food safety and reduce the economic and environmental implications of food waste.[74]

Demonstrating the effectiveness of the platform, Walmart and IBM traced mangos sold within the U.S. The food safety team were tasked to identify the originating farm of a packet of sliced mangoes. Through traditional efforts of calling and emailing suppliers and distributors, the team received an answer in 7 days. The blockchain food-traceability system identified the originating farm of the mangoes in 2.2 *seconds*. The success of the program resulted in the creation of IBM Food Trust that allows additional industry players like Nestle and Unilever to join the digital network.[75]

The potential for digital technologies like blockchain is continuously evolving. For instance, studies suggest widespread implementation of digital supply chain tools could reduce food loss and waste by up to $120 billion annually.[76] But to fulfil their potential, digital technologies face fundamental adoption barriers such as lack of access, technical knowledge, and capacity. Public-private partnerships and proof of concept projects can help address these challenges head-on.[77] With widespread implementation of traceability systems, improved transparency and efficiency will open the doors for innovative market-driven opportunities for sustainability across all sectors.

MS4 Sector

The risk to corporations goes beyond food-centric issues, especially considering that water is used through supply chains consistently. In 2014, the prospect of a global water crises rose to a top-three business risk for impact and likelihood, and 70% of companies surveyed identify water as a substantive business risk.[78] Of US-based Fortune 500 companies, 95% face potential physical challenges due to water-related issues while 80% say water will affect their decisions on where they will locate facilities and 60% indicate that water will likely affect business growth and profitability within a 5-year window[79]. More recently, Larry Fink, the CEO of Black Rock, stated that, "the risks that climate change poses to the world of finance can no longer be ignored."[80]

With a corporate culture that is more concerned and aware of climate change and water-related issues, MS4s have an opportunity work with the private sector to identify ways to mitigate flooding risks in communities to reduce potential impacts to corporate holdings as well as develop partnerships to become more efficient stewards of water resources. The National Municipal Stormwater Alliance (NMSA) is a partner with EPA in an effort to explore the potential to reuse/recycle water resources. While a significant amount of focus on water reuse is on wastewater and produced water issues, NMSA signaled the need to consider rainwater and stormwater capture/use as a significant part of the overall water reuse discussion in the context of EPA's Water Reuse Action Plan (WRAP).

A webinar hosted in February 2021 by NMSA and supported by EPA explored the barriers and solutions for stormwater capture and use.[81] It is evident from this event that stormwater capture and use (or "stormwater reuse" as referred to by some) is not just an arid-climate issue. The discussion in this webinar reflected the fact that there are many drivers for stormwater capture and use, that this is a national topic of interest, and that this is an area of growing interest and likely investment. A barrier for widespread implementation includes the ability to capture the monetary and non-monetary benefits of these types of projects, one of which includes corporate sustainability. An example is Google who is experimenting with a stormwater retention pond as a source of water to cool its systems to alleviate the potential impact on local groundwater sources when addressing water-cooling needs for their data center in South Carolina.[82] Blockchain technology could help to capture the volumes of rainwater and stormwater that have been used for water-intense processes and uses in the corporate world. This low-transaction cost and high-credible way to account for these volumes can make data reporting more accurate as well as compelling when making the bottom-line case for reducing the use of potable water. In addition, corporate responsible actors will wish to showcase their reduction on local water resources through blockchain-based reporting. Opportunities to identify ways for corporations to reduce their water footprint either through stormwater capture and use or other similar measures are likely to increase in the future.

INVESTOR INFLUENCE AND CLIMATE CHANGE/RESILIENCE

The development of responsible investment has helped catalyze growth in sustainable development. Responsible investment is an approach to investing that incorporates environmental, social, and governance (ESG) factors into investment decisions, to better manage risk and generate sustainable, long-term returns.[83] Governments, businesses, and investors worldwide are more committed to financing, investing, and facilitating activities that create sustainable growth, accelerate environmental solutions, and build more resilient infrastructure and communities.

Furthermore, investment firms and asset managers are increasingly using direct engagement strategies with companies to place ESG factors such as climate-related risks at the forefront of corporate-investor conversations, embracing a tougher approach to hold businesses accountable with tangible consequences (e.g., shareholder resolutions on climate-risk governance; direct divestment for inaction and inadequate responses). One group of investors, ClimateAction 100+, a coalition with over $35 trillion in assets under management, is using their leverage to ensure that corporate greenhouse gas emitters take necessary action on climate change. They are engaging with the world's largest 100 "systemically important emitters," who account for two-thirds of annual global industrial emissions, to influence corporate action toward curbing emissions, strengthening climate-related financial disclosures, and improving climate-risk governance, all cited as critical for the low-carbon economy transition.[84]

Responsible investor influence has become a driver for business transition and capital reallocation toward more sustainable development and stable, long-term returns. Emerging responsible investment platforms, indices, and product analytics are enhancing market transparency on ESG factors and providing every level of investor (i.e., from individuals to institutions) with the information and resources needed to improve decision-making and drive future market growth toward sustainable outcomes.[85]

Across the nation, increases in heavy precipitation over the last three to five decades have increased the likelihood of inland flooding. The heaviest rainfall events have become heavier and more frequent, and since 1991, the amount of rain falling in very heavy precipitation events has been significantly above average.[86] Some examples include:

- Texas updated their storm event probabilities – Houston 100-year went from 13" to 18" and Austin went from 11" to 13", the previous 100-year in Houston is now the 25-year event[87].
- The frequency of nuisance flooding for a number of coastal cities (Annapolis, Baltimore, etc.) has increased by 300%-900%[88].
- The frequency of extreme rain events in the Midwest has doubled over the last 50 years[89].

The impacts of increased flooding in coastal and inland areas are not only costly due to impacts to infrastructure and loss of human lives, but there is now an increasing risk of communities paying more for needed investments in all areas of public investment due to a lack of planning and investment in flood resilience. An example is Toms River, New Jersey, which has accumulated more National Flood Insurance Program (NFIP) claims as a single municipality than 38 states, including California.[90] As a result, Moody's downgraded Toms River from Aa2 to Aa3 shortly after Hurricane Sandy. After Hurricane Katrina, Moody's downgraded New Orleans' general obligation rating down to Baa3 rating.[91, 92] While these examples are reactions to specific events, it is becoming clearer to many communities that the financial impact due to credit worthiness is likely to become a long-term, rather than simply an episodic, threat. Leaders with the City of Virginia Beach, Virginia have stated that, "inaction is more expensive than being proactive; City Council has made sea level rise and chronic flooding a priority," and a statement made by a senior level analyst with Moody's referring to Virginia Beach was that "planning and adaptive investments would need to continue to maintain property tax revenue to allay credit downgrades".[93]

Technologies exist (some have already been presented in this paper, with RTC as an example) that are designed to increase resilience. Smart stormwater systems use a variety of integrated technologies, such as cloud-based computing, big data, and actuated controls in BMPs, to optimize not just a single stormwater infrastructure feature, but a family of BMPs within a watershed. The driver of investors and credit worthiness is compelling when it is realized that the cost of implementing these types of systems will reduce direct costs from flooding as well as indirect costs due to increases interest rates for municipal bonds.

ASSET MANAGEMENT/AGING INFRASTRUCTURE AND INNOVATIVE PROJECT DELIVERY

Asset Management and Aging Infrastructure

There are some drivers for technology that are specific to the MS4 sector and do not apply to the ag sector. These drivers are significant enough to present here without the contrast with the ag sector.

The MS4 sector relies on infrastructure elements such as drainage inlets, pipes, ditches, ponds, manufactured treatment devices, and green stormwater infrastructure practices. These features are valuable assets that collect, convey and treat or manage urban runoff. In most infrastructure sectors, these assets would be identified using a consistent standard with the location, description, age and other information included to describe each asset. This type of information ties into an asset management program that tracks problems with assets and projects when asset maintenance and/or replacement is needed that generates the estimated costs associated with actions needed to maintain the level of service targeted for the overall system. Associated with asset management is the issue of aging infrastructure. While the MS4 sector is relatively young compared to many other infrastructure sectors, aspects of MS4s can reflect significant aging. For instance, stormwater control measures used to treat urban runoff pollution are likely to be 30 years old or younger (since the MS4 program was first promulgated in 30 years ago); however, runoff collection and conveyance systems can be significantly older.[94]

In the MS4 sector, however, the use of asset management is less common than in other infrastructure sectors. The 2020 MS4 Needs Assessment Survey led by the Water Environment Federation, and supported by NMSA, found that approximately one-half of MS4s use some type of asset management program to track and manage stormwater assets.[95] When asked to rank the topics of greatest technical resource need, asset management was ranked 2 with 49% identifying this need as high or very high. Also, when MS4s were asked to rank the top MS4 program challenges, aging infrastructure was identified as the most challenging topic.[96] As the MS4 sector continues to mature and assets age, asset management will become more critical, and the use of asset management will broaden. A growing list of asset management technologies has emerged to meet this growing demand. Examples include radio-frequency identification (RFID) to locate sub-surface assets and GIS-based software that provides a platform for efficient mapping of assets and enhanced asset management planning. The data produced by these platforms can feed into data dashboards that can be used to provide real-time data access to municipal staff, consultants, and the public as well. The integration of these types of technologies into MS4 programs will become more common in the future.

Innovative Project Delivery

The traditional approach to developing stormwater infrastructure designs and implementing these is through the “design-bid-build” (DBB) process, which separates the designer from the contractor in the project delivery process. Specifically, designers submit bids to produce design documents needed for a project identified by the public sector client which leads to the selection of a design team that produces designs that are used to inform those contractors who seek to construct the design through a competitive bid process. This process has developed over time and has its roots in the Miller Act of 1935, which requires contractors on Federal contracts to post both a performance bond and a labor and material payment bond to provide protection for subcontractors and others whose labor and materials go into Federal construction grants.[97] The effect of the Miller Act was to separate design and construction services, and while the Miller Act only applies to Federal projects, states quickly adopted "Little Miller Act" legislation that follows the principles of the Miller Act closely.[98]

While the DBB process provides protection to subcontractors during times when protection was a premium, the efficiency of this process has been found to be limited when compared to other frameworks that integrate multiple services together, such as design-build contracts. These inefficiencies are even more impactful when DBB procurement is required for a large volume of physically distributed projects, such as stormwater infrastructure. The steps for procurement targeted for a wastewater facility to be constructed would only require two bids (design and construction), which may be all that is required to treat wastewater in a community. Stormwater, to contrast, requires multiple projects to be built in order to provide the required level of management and treatment. Over time, stormwater projects have become even more distributed with the advent of green stormwater infrastructure (GSI). Treating each GSI practices as a separate project increases the overall cost of delivering GSI projects and slows this process down significantly.

To address these inefficiencies, the Community-Based Public-Private Partnership (CBP3) program was created by EPA and adopted by Prince George's County, Maryland in 2014 and now referred to as the Clean Water Partnership (CWP).[99] This program drives costs down by 40% or more, significantly increases the pace and scale of stormwater project delivery and drives enhanced benefits to the community through performance targets for local workforce and local/small/minority-owned business utilization.[100]

A feature of the CBP3 program approach is that the use of performance targets aligns the interests of the public and private parties. For instance, both parties seek cost efficiencies in designing, building, and maintaining integrated gray and green stormwater infrastructure as cost savings are reinvested into the program to do more work overall. This aligned-interest structure drives innovation within stormwater programs. For instance, the CWP collects a significant amount of data on the progress of project delivery that is uploaded to their public-facing data dashboard once a day. This type of data sharing showcases a level of transparency that engenders public and political trust. Another example is the use of QR codes for each stormwater infrastructure practice installed and maintained. To identify information on a specific BMP, a maintenance worker simply scans the QR code and the background on the BMP as well as the maintenance history of this BMP is provided immediately.[101] When work is performed, the data is immediately updated to a cloud-based database. This type of innovation reduces the costs of maintenance, which saves money overall.

Lastly, the CWP relied upon the Water Resources Registry (WRR), also developed by EPA to streamline the process to identify, map out, and gather information on natural resources and waterbodies across an area.[102] The WRR is a GIS-based platform that includes coverages on watershed extents and types, stormwater practice location and other stormwater-related information that allows the CWP to quickly identify strong candidate locations for stormwater and GSI implementation. The scale of stormwater infrastructure invested will be increasing in the future in order to address water quality and quantity issues, many of which will be exacerbated by climate change. The CBP3 program approach can facilitate this type of large-scale investment in stormwater and GSI practices efficiently. The use of technology is critical in the performance in these programs, and it is anticipated that these programs will develop and leverage new technologies in the future for even greater beneficial impacts.

SECTION 3: CASE STUDIES

The following is a non-exhaustive set of notable companies, partnerships, and innovative market programs elevating the opportunity for widescale sustainability outcomes through harnessing the power of data. It showcases an in-depth view of the real-world application of these data-driven technologies and marketplaces within and beyond the agriculture and stormwater sectors. Each is unique and informative in its own right, but together, they build a growing portfolio of digital solutions to address the most complex environmental challenges of the 21st century.

FARM-LEVEL DATA GENERATION

The Challenge

Agricultural data is fragmented, and industry players face challenges with generating and collecting high-quality farm-level data in a meaningful way. A primary obstacle is creating a technology that will collect, integrate, and standardize data from a multitude of equipment and systems. Moreover, lack of reliable broadband and cellular coverage in rural areas, coupled with existing inefficiencies of data storage and portability (e.g., standard thumb drives remain a common way to handle ag data), present obstacles for ensuring data completeness and quality in collection.

The Solution

Marketed as an independent farm data company, Farmobile's advanced technology delivers a "collect-share-monetize digital strategy." Farmobile specializes in collecting second-by-second, geo-tagged agronomic and machine data from a mixed fleet of ag equipment. Its key hardware is the Passive Uplink Connection (PUC), an IoT-enabled device that generates and streams data – similar to a Fitbit for farm equipment. Installing this advanced aftermarket technology across a mixed fleet for planting, spreading, spraying, and harvesting, enables flexibility and overcomes the data collection and standardization challenge across multiple systems.[103] Ultimately, data standardization increases interoperability and improves scalability.

Quality of collected data is foundational to effective big data solutions. Farmobile defines "good quality" data as being complete, standardized, dense (with multiple data layers), portable, detailed, and accurate. To ensure high-quality data collection, the company approached fundamental issues such as lack of reliable broadband coverage and inefficient portability from its outset. By streaming bits of collected data from its IoT device, while saving and streaming during broadband connectivity interruptions – similar to Netflix – Farmobile achieved completeness, reliability, and high-quality data transfer in real-time.[104]

Collected data is then made available through Farmobile's DataEngine, a big data cloud computing technology and digital platform that organizes the data into live, real-time views of farming operations. Raw data is processed into viewable and shareable Electronic Field Records (EFRs), a complete, digital record that is automatically standardized, geospatially organized, and captures full growing-season results through collection of multiple data layers (e.g., as-planted, as-applied, and as-harvested data). This comprehensive set of information builds a digital twin representation of a farm's operations.

Farmobile also creates value for farmers and the marketplace through the monetization of standardized data. Farmobile's platform incentivizes farmers to license and monetize certified farm datasets (i.e., EFRs) as digital assets through its DataStore – similar to the iTunes model. The availability of timely, on-demand access to data is attractive to a wide-range of market participants from commodity traders and research firms to insurance underwriters and big data modelers. It enables more efficient quantitative insights, risk management, and decision-making when compared to other publicly released data sources. Meanwhile, farmers are in complete control, approving all transactions while remaining anonymous.[105]

Real-World Application

Since launching its PUC device in 2014, Farmobile has become an industry leader collecting multi-source, point-by-point farm data including detailed agronomic data (e.g., planting, foraging, spraying, spreading and harvesting), field data (e.g., boundaries, variety, and crop type), and location data.[106] This has equated to over 470,000 harvested acres using Farmobile's data collection technology between January and November 2019. Moreover, the monetization of this collected data opens new doors for the ag industry. Since launching its DataStore in 2016, several hundred farmers have received in excess of $500,000 in revenue from transacting digital assets.[107]

In July of 2019, Canada-based Ag Growth International (AGI) invested $15 million in Farmobile. Beyond its minority investment, AGI and Farmobile decided to partner for expanded collaboration and integration. The investment allows for Farmobile's DataEngine to integrate with AGI's IntelliFarms SureTrack farm management and grain exchange platform – a business tool available for growers that deploys a suite of sensors collecting real-time data from the field to grain bins. Its grain exchange integration allows farmers to seek favorable pricing and market products based on the data-driven characteristics of their grain.[108]

Why It Matters to MS4s

Farmobile's technology has simplified data collection, access, and sharing. Its digital technology removes key barriers of data quality and standardization and creates a new value proposition for farmer engagement, all necessary to unlock wider access, adoption, and benefits of real-time information. Moreover, mixed-fleet compatibility tackles a primary hurdle enabling aggregation of standardized data from multiple sources. This helps scale interoperability, while providing reliable data as feedstock for digital tools and creating increased value of data-sharing for the market to consume.

High-quality, multi-layered, and verified farm data is foundational to unlocking new innovation and sustainable outcomes. Farm-level data collection opportunities for enhancing farm sustainability are vast. Data points on fertilizer, energy, and water use, conservation practices (e.g., tillage, cover cropping, runoff controls), and soil type is all critical for uncovering farm management impacts on soil health and how conservation practices can improve crop resilience.[109] Likewise, this information is critical for market-based opportunities in need of real-time, verifiable performance data. Partnerships like Farmobile-AIG will capture more data-driven insights and transparency along the crop commodity supply chain – from field to aggregation and distribution – which should reap new rewards as market drivers continue to demand this depth and completeness of information. Since 2019, Farmobile has received three patents (two from the U.S. and one from the Canadian government) to exclusively use their blockchain and distributed ledger technologies to track and audit data across the agricultural value chain.[110]

Like the ag sector, data collection in the stormwater sector presents a challenge. Multiple types of stormwater practices scattered across a landscape create logistical challenges in collecting data in a centralized manner. Furthermore, numerous water pollutants of interest exist in many stormwater programs, and a lack of standardized data across programs leads to inconsistencies, resulting in an inefficient regulatory review process and limited ability to estimate and verify program performance in real-time. Technologies inspired by Farmobile that are tailored to the MS4 sector would further the capacity to collect real-time data on a variety of parameters significant to program performance. A step further would be a platform to collect consistent and standardized data across a range of stakeholder sources including within proximity of a regulated community. This consistency of data standards, format, and quality would encourage cross-sectoral transactions and coordination, leading to stormwater program cost efficiencies and benefits for local residents through internalized investments tied to multiple positive outcomes – the basis of value for taxpayers and ratepayers.

DIFFERENTIATED COMMODITIES

The Challenge

Global markets today do not receive timely and accurate information about the environmental and social impacts associated with commodity production. Sectors such as energy, agriculture, and others have historically been characterized by fungible, indistinguishable, monolithic commodities – such as natural gas, grain, steel and cement – that are, by definition, uniform and interchangeable. Valuable production-level data about the constituents and impacts of commodity production have been invisible, thereby forcing market participants to act on incomplete information. How can markets maximize the full potential of informational data associated with each, individual unit of a commodity to drive competition and better value sustainability?

The Solution

Xpansiv CBL Holding Group (Xpansiv) combines cryptography, data science, and distributed-ledger technologies to transform physical commodities into Xpansiv's "Intelligent Commodities".[111] Where limited information prevented differentiation, digital transparency can now reveal and differentiate attributes such as sustainable production practices. Xpansiv set out to transform the commodities market, redefining transparency and unlocking a magnitude of potential for more sustainable procurement and market-driven environmental mitigation.

Xpansiv is powered by its "Digital Feedstock", a new data format of separately traded commodity attributes that combines real-time production monitoring, standards, and data science, with blockchain technologies to refine, characterize, and convert data into digital assets that can be transacted without risk to counterparties.[112] The digital twin representation of commodity attributes includes the physical and environmental elements of production, transportation, storage, and consumption. Thus, commodities can be distinguished based upon verifiable environmental profiles – how and where commodities are produced and the sustainability and climate characteristics of their production and distribution to market.[113] This data- and market-driven transformation of how commodities are priced and procured offers a widescale opportunity for the marketplace to properly incentivize and reward more sustainable production and development of agricultural, energy, and other resources.

Real-World Application

In October 2019, Xpansiv completed a groundbreaking, exchange-driven transaction for an energy commodity based on its environmental impacts (i.e., responsibly produced natural gas).[114] Ultimately, participants will have the ability to sell whatever Digital Feedstock product the market demands – either separately or coupled with physical volumes of commodities. The platform is the first marketplace dedicated to mapping, buying, and selling unique digital attributes that are permanently traceable from source to market, allowing for the creation of a complete commodity profile that will account for its true cost and value.[115]

Why It Matters to Ag and MS4s

Xpansiv's technology allows markets to differentiate, value, and price assets and commodities based on life cycle attributes and performance. Applicable to agriculture, sustainability attributes pertaining to water, fertilizer, conservation practices, non-deforestation, and so on, are all critical metrics that can be transformed into tradable digital assets.

The power of transparency and evolving consumer and corporate preferences for more sustainable goods should certainly benefit and scale through the ability to harness data and provide the market with verifiable information on demand. High-quality, decision-useful data is once again foundational. Digital platforms that provide buyers with this level of transparency and choice could provide the non-regulatory, bottom-up, and market-driven opportunity to incentivize commodity producers such as farmers at a scale that could result in the acceleration of environmental performance outcomes beyond the current regulatory and political realities can achieve.

Technologies that can securely and transparently facilitate the transaction of data, for instance capturing attributes associated with water quality conditions such as pollutant loads or thermal conditions, have the potential to drive significant value, particularly for the MS4 sector. A clear area where digital tools like blockchain technology can be utilized in the stormwater context is for offsets and market-based mechanisms. The potential of these offsets for point-nonpoint offset programs has, in many ways, not been fully realized for reasons such as complexity in establishing and verifying credits as well as high transaction costs, among other factors.[116] Market-based mechanisms are not limited to a point-nonpoint context, as several communities across the country are considering or have already implemented policies and platforms that allow for land developers or others who must meet stormwater regulations to purchase or transact with those who generate excess stormwater capacity[117]. This type of mechanism allows for flexibility within a single MS4; however, there are examples where MS4s can potentially engage with other MS4s through the use of digital technologies (one example from the City of Cudahy, Wisconsin is presented in this report).

Digital platforms and blockchain technology may be perfectly suited to address these challenges by enabling the credibility of information associated with both point and nonpoint offsetting credits. Further, it has been shown that a clearinghouse construct to facilitate nonpoint-oriented market-based and offset transactions is more efficient and successful than bilateral transactions.[118] Digital tools have the capability of enhancing the efficiency of a clearinghouse while further reducing transaction costs and adding transparency and credibility to transactions. Signals from U.S. EPA show an openness to enhanced flexibility to encourage various offsetting options to flourish.[119] Between these potential policy shifts and the development of data collection and digital technologies, market-based mechanisms may expand to become part of portfolio of programs that can lead to improved downstream water quality conditions.

DIGITAL STORMWATER ASSET MANAGEMENT AND PLANNING

The Challenge

Effective stormwater management is commonly a missed opportunity for communities across the U.S. to help supplement water supplies, recharge groundwater tables, and protect local aquatic ecosystems. Nearly every city in the U.S. is required to comply with stormwater regulations through permitting under the Clean Water Act, but many cities struggle to comply with changing regulations due to lack of budgetary resources and limited capacity.

The Solution

Companies like 2NDNATURE Software are empowering municipalities and regulators with digital capabilities to more effectively manage their stormwater resources and build healthy, sustainable communities.[120] 2NDNATURE Software deploys a digital platform, serving as a scalable accounting system that measures progress towards water quality improvements. Its software, titled 2Nform, is an open-data platform, purpose-built for stormwater managers to standardize data collection and streamline MS4 permit compliance. 2Nform enables local land managers, public agencies, and regulators to simplify water resources management, planning, and reporting. The software also links urban landscapes to their receiving waterways, tying urban areas to their rural counterparts for an integrated watershed-based system.[121]

The platform empowers officers to integrate specific stormwater program elements around a municipality's hydrogeography coupled with automated workflows, providing permit holders with the necessary and accurate data and information for quick compliance. Further, 2Nform enables municipalities to efficiently monitor and evaluate stormwater best management practices (BMPs), which are various activities to control urban landscape effects on water resources. BMPs range from street sweeping and litter reduction programs to pollution prevention initiatives and green infrastructure development, all implemented to control runoff and pollutants at the source, or intercept and remove pollutants from stormwater.[122] 2Nform's rapid asset management tool generates objective, standardized, and repeatable evaluations of how BMPs are functioning – an invaluable tool as most cities struggle to efficiently monitor and analyze BMP performance to inform which practices are succeeding or need to be addressed.

Real-World Application

Since 2Nform's launch in early 2017, over 55 municipalities across 13 states – of which 30 are based in California – have adopted the digital technology. The City of Salinas is a notable example. Salinas, with a population over 150,000 and serving an active role in California's agricultural and farming economy, was surrounded by impaired waterways and routinely struggled with MS4 permit compliance. Typically, Salinas's stormwater managers would spend five months each year gathering data from twelve city departments to comply with reporting requirements.

Deploying 2Nform, the City of Salinas now has an integrated stormwater program that generates real-time data and provides information about where stormwater improvements are needed most and accurate estimates of BMPs, operations and maintenance budgets, and required inspections. Moreover, the digital platform uses hydrographics, enabling Salinas's stormwater managers to apply a watershed context to all their stormwater decisions and regulatory reporting. Harnessing a digital strategy, Salinas has been able to optimize stormwater asset management, build stronger runoff and pollutant loading models, and generate transparent mapped views of the city – all contributing to a more efficient and effective program compliance and allocation of limited city resources.[123] Implementing 2Nform has saved Salinas two times their prior annual stormwater expenditures and allowed it to re-allocate resources towards improving urban land management.[124] Finally, as more California municipalities adopt 2Nform, Salinas can use the software for regional collaboration with neighboring municipalities to enhance regional watershed-scale stormwater management.

Why it Matters to MS4s

The 2NDNATURE platform digitizes all permit requirements and generates smarter data outcomes to inform more effective expenditures and systematically measure, report, and verify progress toward water quality objectives and compliance (e.g., through Digital MRV). Digitally enabled water technologies like 2Nform will transform stormwater management in urban, rural, and agricultural communities, helping to reduce the cost and complexity of tackling stormwater objectives. Along with their app., the platform is accessible, enables efficient data collection, allows for public involvement, and can apply to any geographic location with the integration of all permit requirements within the area. Digital technologies will continue to enhance effective communication to stakeholders (e.g., city councils, technical staff, and the public) about the beneficial impacts that stormwater programs can have on local communities and its receiving waters – a simple, yet effective way to spread the message about the importance of stormwater management.

PERFORMANCE- AND INFILTRATION-BASED STORMWATER PRACTICES ON PRIVATE LANDS

The Challenge

The premise of performance for stormwater products and practices is typically based upon a presumption of treatment or infiltration capacity. For manufactured stormwater products, this can mean that products are tested following standard protocols to determine if the product meets a treatment threshold. If it does meet that threshold, or is higher, it will be granted a treatment capacity consistent with that minimum threshold. For public domain practices, this process is typically even simpler. A state environmental agency will research the performance of various public domain stormwater practices and provide a treatment performance based upon a specified design standard. In other words, if a designer uses a specified design standard and a contractor builds the practice consistent with this standard, it is assumed that the practice will have a certain treatment capacity.

When a community is attempting to meet a permit requirement or address a TMDL reduction requirement, these assumed treatment capacities are typically used to determine the number and type of practices that are needed to meet the outcome. But what if a community wants to take the approach that treatment reduction for a product or a practice can be based upon measured and monitored performance? This option is rarely used by communities, which stifles innovation. If a community were bold enough to provide this approach to meet treatment reduction requirements, and if there were product or practice representatives or owners confident enough on the treatment reduction performance of their product/practice, there is a potential to break through this innovation limitation. This performance-based approach would be even more viable if it were shown to be financially profitable.

The Solution

A technology has been developed by P4 Infrastructure that uniquely monitors and records the performance of an infiltration system lined with articulating concrete block (ACB). The set up for this approach utilizes a rainfall monitoring system to capture precipitation inputs to the ACB feature (P4 Rain-mX), a water-level monitoring system (P4 INFIL-Tracker), and a remotely controlled control valve connected to an overflow pipe (P4 Flow-RTC).[125] This configuration provides a way to measure the input-response of the catchment generating flows into the ACB feature and the performance of the system in the ability to exfiltrate captured runoff into the soil, and how often there is a need to utilize the overflow pipe to allow for excess runoff volumes to pass through the system.

Real-World Application

The City of Cudahy, Wisconsin, which is located in the suburban Milwaukee area, is required to meet TMDL reductions for total suspended solids (TSS) and total phosphorus (TP). The modeling program, Source Load and Management Modeling (SLAMM) is an open-source tool commonly used by communities in Wisconsin as the basis for TMDL and MS4 compliance. Cudahy is led by innovators who asked if they could develop an approach that would not only meet TMDL requirements but exceed these requirements to potentially create a credit that would generate a financial return. In this context, a project using an ACB system was envisioned to capture and treat runoff generated and conveyed to Van Norman Alley to reduce stormwater runoff downstream.[126] The design includes ACB with a subsurface stone reservoir gallery connected to an underdrain system. The soils in the area were identified as being problematic for infiltration capacity, which led to an assumed infiltration rate of 0.04 in/hr when following the traditional approach for analyzing BMPs in the context of SLAMM. BMP design guidance in Wisconsin assumes 65% and 35% removal of TSS and TP, respectively, for all stormwater filtered by the BMP and discharged through underdrain. For a site with higher infiltration capacities capable of infiltrating 100% of the runoff are credited with 100% pollutant removal from the surface water environment entirely.

The City and P4 worked with Wisconsin DNR (the regulatory agency in Wisconsin that administers the MS4 program) to allow for crediting above the 65%/35% presumed treatment levels if the system proved that the capacity of the ACB system to infiltrate was above the assumed rate and that drawdown times consistent with DNR guidance were met. The ACB system and P4 monitoring, sensor, and control devices were installed and monitored for more than one year. The result was that the underdrain system was never utilized as the underlying soils have much greater capacity than was assumed for infiltration. By not activating the underdrain system, the Cudahy and P4 team captured the actual pollutant removal through the use of a 100% crediting for TSS and TP. The result is that the assumed-performed scenario would remove 282 lbs/yr of TSS in the Van Norman Alley project resulting in an estimated treatment unit cost of $100/lb, which compares with the 2,310 lbs/yr of actual treatment reducing the unit cost of treatment to $14/lb/yr.[127] An analysis by the P4 and Cudahy team of TSS loading in areas within the City of Cudahy using a P4-ACB-type system can create an excess of TSS removal (i.e., excess TSS credits) that has the potential to be potentially purchased as an offset by other parties who have challenges in meeting their own requirements, whether that party is a municipality or a land developer.[128]

Why it Matters to MS4s

Performance-based approaches are on the rise in the stormwater sector. The severe lack of funding in this sector drives the need for cost-efficient solutions. An opportunity provided by the stormwater sector in this context is the use of technology-based approaches for permit compliance with presumed treatment/management capacity. Smart stormwater systems that utilize digital technologies have the capacity to cost-effectively measure the actual performance of systems rather than relying on presumed performance. In scenarios where incentives exist, such as fee rebates or credits can be generated for sale or offsetting, the use of smart stormwater system may not just save money providing enhanced water quality and quantity management but can generate revenues as well.

A webinar hosted by NMSA titled, "Maximizing Smart Stormwater Infrastructure for Public and Private Benefit," featured a Cudahy representative as well as a staff member from P4 Infrastructure who described the potential for the approach described in this section to be utilized on private property.[129] This arrangement could incentivize industrial and commercial property owners, who often have large properties with significant amounts of impervious cover, to implement this type of performance-based smart stormwater system to reduce stormwater fees and potentially generate revenues through excess on-site treatment. Considering that a majority of properties in the U.S. are privately held and the high incidence of stormwater infrastructure located on these properties, it is not surprising that there is a significant amount of focus on arrangements in the stormwater sector that can unlock the opportunities for investment on private properties. The advent and growth of digital solutions that support smart stormwater solutions is a likely key to turning the corner on this challenge.

SECTION 4: CONCLUSION

The ag sector is a significant source of pollution that impacts downstream waters across the county in watersheds such as the Chesapeake Bay, and EPA has referred to urban runoff as, "one of the fastest growing sources of pollution".[130] Both sectors are blossoming in the amount and variation of digitally-based technologies that have been developed to focus on issues related to water pollution, sustainability, and resilience and climate change. In some instances, the experience gained from a digital solution in one sector can inform the potential application in the other sector. In other cases, a digital solution in one sector can benefit the other sector directly. This report has focused on these dynamics and what the future may be for digital solutions in the ag-MS4 sectors overall.

BRINGING IT ALL TOGETHER

Reducing Ag Pollutant Loads through Digital Solutions to Benefit MS4s

There are several nexus points between the ag and MS4 sectors where digital technologies upstream can reduce downstream pollutant loadings. One example is the use of precision agriculture technologies that can not only make agricultural operations more efficient but can reduce the delivery of nutrients and other pollutants of interest to downstream suburban and urban areas. Another example includes programs in the ag sector that officially recognize or certify farming operations that invest in practices and approaches that reduce sediment, nutrients, and other pollutants delivered from their site. Digital solutions are making these programs more credible and remotely managed, which adds more value to these types of programs overall.

Consumers are increasingly demanding ag products to be grown or raised following operations that are more environmentally friendly. Digital tools can better capture these aspects of operations in a more efficient, transparent, safe, and credible way, which can add value to environmentally sensitive agricultural commodities when they go to market. Through more effective branding of these products, farmers may see the option of protecting water resources as part of an effort to meet environmentally-oriented consumer branding as all the more beneficial to their bottom line as well as the environmental protection of local and downstream waters.

The benefit of reduced loads of nutrients and sediment, as well as other pollutants, from upstream ag areas to downstream urban and suburban areas is clear. The general principal of water pollution control is that the management of pollutants closer to the source of the pollutant is the more cost-effective approach. Beyond reducing pollutants generated by farming operations is the opportunity to eliminate pollutants from being introduced to the environment in the first place. Pesticides include high amounts of heavy metals, for instances, and traditional insecticides have been shown to impact pollinators.[131] By identifying and using replacement options for these substances through "green chemistry", toxic pollutants can be eliminated from the environment. Digital platforms can track the usage of these environmentally benign options as well as keep a ledger on the reduced usage of fertilizers, both aspects of which will benefit local and down-shed waters. Reduced upstream loadings is less expensive and reduces the need to spend more to treat drinking water in situations like the Racoon River Watershed in Des Moines, Iowa, where nitrate levels from upstream ag areas were so high and efficiently conveyed through tile drains that the Des Moines drinking water system was forced to spend millions of dollars to reduce the levels of nitrates to avoid public health impacts due to "blue baby" syndrome.[132]

The larger impact of ag pollution includes the hundreds of "dead zones" in coastal areas around the country. These have impacts on local economies related to tourism, fishing, and shellfish industries, and others who rely on the health of coastal waters for economic and social well-being. More and more evidence shows the toxic nature of algae associated with excessive nutrients and sediment driven by the ag sector primarily[133], thus the ag sector plays a significant role in solving this problem along with urban and suburban runoff management. As the ag sector reduces pollutant loadings, the urban waters that receive these pollutants should improve and the challenge of urban runoff programs to carry the burden of enhancing local waters should become easier and more equitable. Digital solutions presented in this report can help to reduce loadings from both areas for more holistic water management, and it can be beneficial to people and profits as well.

MS4 Adaptations of Digital Ag Solutions

There are ways that the ag sector's early investments into developing digital solutions for efficient and effective farming operations can benefit MS4 programs. For instance, the standardization of data in the ag sector and the capturing of critical standardized data streams through blockchain illustrates the value for the MS4 sector to push for a standardized approach to data schemas and information on stormwater assets and associated performance information. In the ag sector, there are market forces and corporate and consumer-based reputational factors to consider, which differ in some ways with motivations in the MS4 sector.

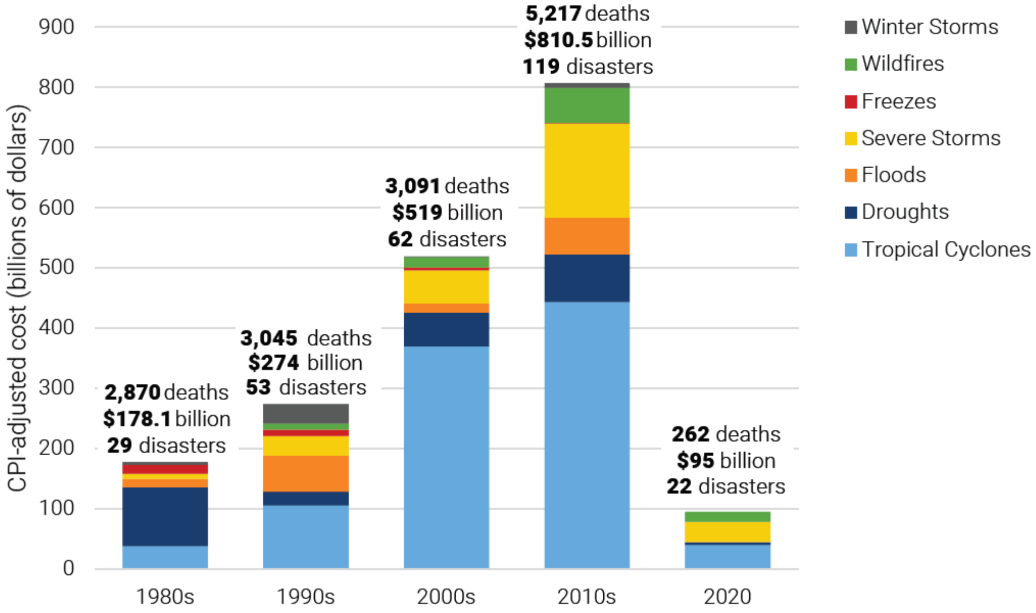
While stormwater systems don’t generate products for retail purchasing, drivers for stormwater system performance improvement and optimization are real and growing. The drivers of climate change, increased emerging pollutants, evolving regulations, and continued declining water quality conditions in many areas underpin these motivations. The American Society of Civil Engineers’ (ASCE) 2021 Infrastructure Report Card included the stormwater sector as a separate infrastructure sector for the first time, and a grade of “D” was assigned to this sector.[134] The needs are clear, and the funding is severely limited, as noted by the Water Environment Federation’s 2021 MS4 Sector Needs Assessment Survey, which found that the existing estimated municipal budgets for stormwater investments in MS4 programs range between $18B and $24B, with an annual funding gap estimated to be $8.5B.[135] Using a midpoint in the budget range of $21B, the funding gap is 40% of existing budgets – the need for investment is clear as is the need to find ways to maximize the value of stormwater infrastructure through digital solutions.

Smart stormwater systems that use low-cost sensors commonly applied in the ag sector (such as soil moisture probes) along with actuated control systems that dynamically limit the flows into and out of stormwater conveyance systems and treatment practices, optimize the performance of urban drainage catchments. New regulatory flexibility, such as the Wisconsin DNR example, is allowing for the crediting of monitored systems that over-perform to export excess treatment to other jurisdictions or parties. In this way, stormwater programs have the potential to “harvest” credits to reduce costs and/or gain revenues. The MS4 sector can learn from the advanced digital solutions being used today to more efficiently capture not only the commodities of excess treatment, but potentially other environmentally- or socially-driven positive externalities, such as carbon sequestration, reduced urban heat island impacts, and reduced flooding impacts and durations. The value of stormwater and green infrastructure investments is often not captured, as these co-benefits are not easily recorded or tracked. But the advent of digitally based technologies has the potential to break through this challenge and provide the data needed to illustrate the underlying value of stormwater infrastructure.

VISION FOR THE FUTURE

The technologies and digital solutions identified and described in this report represent the leading edge of approaches in the ag and MS4 sectors. In the future, it is likely that some of these technologies will become mainstream and commonplace. How and when this happen is unclear, but the growing drivers outlined in this report suggest that the adoption of advanced technologies and digital solutions in the ag and MS4 sectors will occur in a broader context with greater urgency than that envisioned just a decade ago.

The current Presidential administration is advocating for a "once in a generation investment in America," that includes a multi-trillion-dollar investment in infrastructure.[136] The Brookings Institution suggests that this effort should not simply be a reinvestment in America's infrastructure but a "reimagining" of infrastructure.[137]



Source: Brookings analysis of NOAA National Centers for Environmental Information (NCEI) data
Note: Climate disasters refer to droughts, floods, freezes, winter storms, severe storms, tropical cyclones, and wildfires costing at least $1 billion each

Figure 4 - Rising Costs of U.S. Climate Disasters, 1980-2020 (Brookings Institution, 2021)

Figure 4 illustrates the growing impact of disasters that drive the need for increased resilience in the face of changing climate. If we choose to simply replace the existing infrastructure using the same approaches that underpin this existing infrastructure, this will be a major opportunity lost. To contrast, if we choose to find ways to improve upon these existing infrastructure sectors by incorporating new and innovative materials, approaches, and technologies to make this truly 21st Century infrastructure, then we will see an increase the resilience and value of our infrastructure systems overall. This is an opportunity to not only replace infrastructure, but it provides a platform to show proof of concept of these new and emerging technologies. Hopefully, we will take advantage of this and truly reimagine the ag and MS4 sectors through digital technologies and solutions.

APPENDIX

Table 1: Recent Federal legislative and administrative policies impacting agricultural and water systems, data strategies, digital technologies, and data-centric solutions.

Data-Centric Policies	
Foundations for Evidence-Based Policymaking Act	▪ Enacted in Jan. 2019 and contains the OPEN Government Data Act, requiring all non-sensitive government data to be made available by default in open and machine-readable formats.[138] ▪ Requires agencies to develop a "comprehensive data inventory" that provides a clear and full accounting of the data assets in the possession of an agency.
U.S. Federal Data Strategy	▪ Delivers a consistent approach to Federal data stewardship, use, and access. ▪ All agencies, including the USDA, EPA, DOE, and Interior, are required to designate a Chief Data Officer, and OMB is directed to establish a Chief Data Officers Council to promote best practices for data management across the federal government.
American AI Initiative Executive Order	▪ Signed in Feb. 2019, EO 13859 directs federal agencies to invest in the development of artificial intelligence (AI) technologies.[139] ▪ Involves a multipronged approach emphasizing 1) investment in AI R&D, 2) public access to Federal R&D resources, 3) setting AI governance standards, 4) building the AI workforce, and 5) international engagement and protecting our nation's AI advantage.
National AI Research and Development Strategic Plan	▪ Released in June 2019, the White House updated its existing strategic plan to ensure American leadership in the development of emergent technologies.[140] ▪ Includes eight priority areas, focusing on the increasing importance of effective partnerships between the Federal government and academia, industry, and other non-Federal entities to generate technological breakthroughs in AI.

Agricultural Improvement Act of 2018 (2018 Farm Bill)	▪ Enacted in Dec. 2018, the Farm Bill directs USDA to identify its available datasets regarding the use of conservation practices and the effects of such practices on farm and ranch profitability, including such effects relating to crop yields, soil health, and other risk-related factors.[141] ▪ Requires a report within one year to include datasets identified, and necessary steps, safeguards, and privacy protections to enable data access and sharing.
Market-Centric Policies	
EPA and USDA Joint Memo Addressing Nutrient Pollution	▪ Released in Dec. 2018, the agencies are working to identify opportunities for meaningful reduction in nonpoint nutrient losses and improvements in water quality.[142] ▪ Promotes and incentivizes states, tribes, and stakeholders to engage the agencies and use all tools available to address excess nutrients in watersheds, including non-regulatory and market-based programs.
EPA Memo Promoting Market-Based Mechanisms for Water Quality Improvements	▪ Released in Feb. 2019, EPA Office of Water provides additional flexibility to states and tribes to encourage stakeholders to consider how market-, incentive- and community-based programs may supplement their water quality improvement efforts.[143] ▪ Promotes flexibility and accelerates adoption of robust and defensible market-based programs (e.g., water quality trading) that will incentivize implementation of technologies and land use practices that reduce nonpoint pollution and increase investment in conservation actions.
USDA Regional Conservation Partnership Program (RCPP)	▪ Provides financial and technical assistance for voluntary conservation projects created through partnerships among ag producers, USDA, and water utilities that protect source water and natural resources.[144] ▪ 2018 Farm Bill increased RCPP funding and mandates that 10% of funds be allocated to protect drinking water sources, increasing incentivizes for ag producers to collaborate with water utilities to implement source water protection practices.[145]

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