Big data and smart sewers—Is the technology ready? Is the industry ready? Are you ready?

MIKE BONOMO, ADS Environmental Services, Monroe, Connecticut
KEVIN ENFINGER, PE, ADS Environmental Services, Huntsville, Alabama

ABSTRACT | Read the latest blog post, sit in on a conference presentation, or talk to people active in wastewater collection systems. When you do, you will come across a discussion on smart sewers—a confluence of intelligent technologies designed to provide a higher level of insight on your wastewater collection system, tracking and optimizing performance with greater efficiency, reliability, and peace of mind.

Smart sewer technology is in early adoption. Researchers, entrepreneurs, innovators, and forward-thinking utilities are taking the latest technologies—sensing, cloud computing, machine learning, and the Internet-of-Things (IoT)—and using them to solve problems in wastewater collection systems. This article discusses these core technologies and their status today. No doubt these technologies will be transformational, but is the wastewater collection system industry ready to be transformed by them? We share insights on what we have learned, what problems we have faced, and the "adoption interface" where organizations and individuals wrestle with changes to long-held processes and procedures that smart sewer technologies imply for wastewater collection systems.

KEYWORDS | Smart sewer, blockage prediction, sewer overflows

Remote-controlled collection systems communicating one node to another; operating gates and valves, controlling the Water Resource Recovery Facility (WRRF) headworks, and regulating the inflow of stormwater from storage systems, all through a centralized neural network. Imagine how clean our waters would be if we could eliminate overflows with such technology, achieving the water quality goals of swimmable and fishable communities throughout the United States and around the world. While this may sound somewhat Sci-Fi, it is a world imagined by visionaries in our industry. Technology, innovation, science, engineering, policy and politics, and operation and maintenance (O&M) must all come together to achieve this vision of zero overflows. This technology is being developed and implemented by clean water utilities who are willing to push forward, through trial and error, through discovery and learning, to improve the way we operate and maintain wastewater collection systems. Real time, actively monitored and controlled collection systems are in their infancy, but the reality of "zero overflow" capability is clearly in view.

So how would such a network look? How would it work in real time, and how close are we, really, to this Sci-Fi thriller?

FUTURE OF WASTEWATER COLLECTION

Figure 1 presents a high-level view of a smart sewer network with sensors, using Artificial Intelligence (AI) to control valves, wet weather storage systems, and a hosted control system. A dense sensor network sends real-time measurements to a central data management and decision-making system, which is an integrated component to the supervisory control and data acquisition (SCADA) system. Reliable communication is critical; the smart sewer network can, in real time, select the optimal communication network available including cellular, satellite, local area network (LAN), or wide area network (WAN) to send information back and forth.

This highly reliable communications network sends level data, flow data, and various other physical, chemical, and biological parameters to the SCADA system along with conditions at wet weather storage systems. Continuous, real-time weather forecasts are also received by SCADA. The system has integrated modeling capabilities that allow operators to view simulated wet weather forecast scenarios and prepare to manage the collection system. Operators monitor the system, but decisions are made using sensor data, weather forecasts, real-time model simulations, and an AI decision process to prevent overflows. To achieve this, remote-controlled valves are regulated to hold and release flow as system capacity is available.

While extreme events in sewer systems may require occasional maintenance, the sensors in a smart sewer will require much less maintenance than a traditional sewer, and the work is also easier and safer.

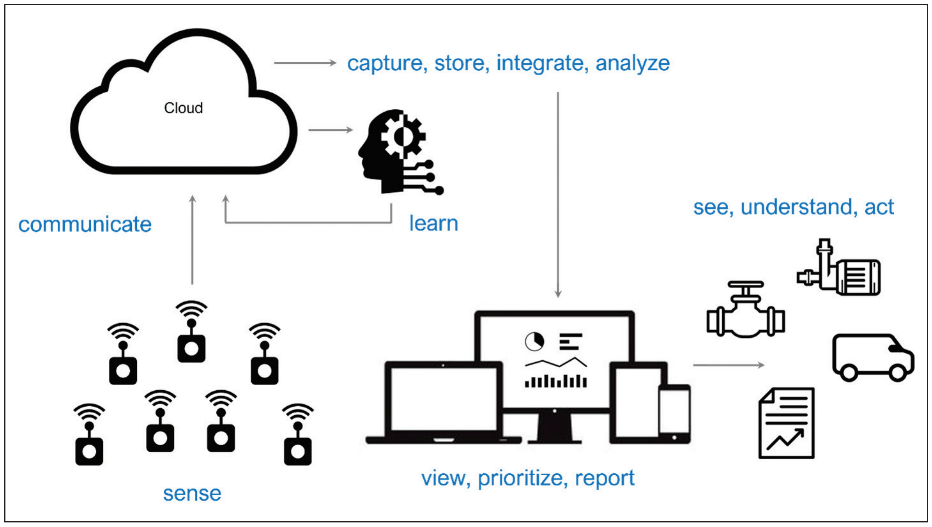

Figure 1. Various technologies that make up a smart sewer

FROM CONCEPT TO APPLICATION

While we are not yet at zero overflows, smart sewer technology has evolved from concept to early adoption. Our first steps into smart sewers have focused on reducing or eliminating overflows caused by debris buildup in the collection system by identifying developing blockages and allowing them to be resolved well before they can cause serious problems. While not fully developed to include remote control gates, weather forecasts, and feedback loops, this system indicates what the future holds.

Blockages are predicted in a smart sewer setting using a level monitor installed upstream from a location of interest and measuring sewer flow depth at regular time intervals. These data are transmitted periodically to the cloud where a machine learning (ML) algorithm evaluates the data for signs of developing blockages. The results are available on a website application (app) in an intuitive, easy-to-use format.

The blockage status of each location is conveyed by one of three simple icons:

1. A blockage is not detected based on the ML algorithm. There is no urgency, and no action is needed.
2. A blockage is probable based on the ML algorithm and is in its earliest stage of development before the sewer has surcharged. The urgency level is proactive, and you may have between a few days and a week or more to intervene and prevent a sanitary sewer overflow (SSO).
3. A blockage is probable based on the ML algorithm and is in a more advanced stage of development after the sewer has surcharged. The urgency level is reactive, and you may have a few days or less to intervene and prevent an SSO.

The case study below shows an example of this blockage prediction technology at work. The hydrograph in Figure 2 shows flow depth data measured in a 15 in. (38 cm) diameter sewer. A developing blockage

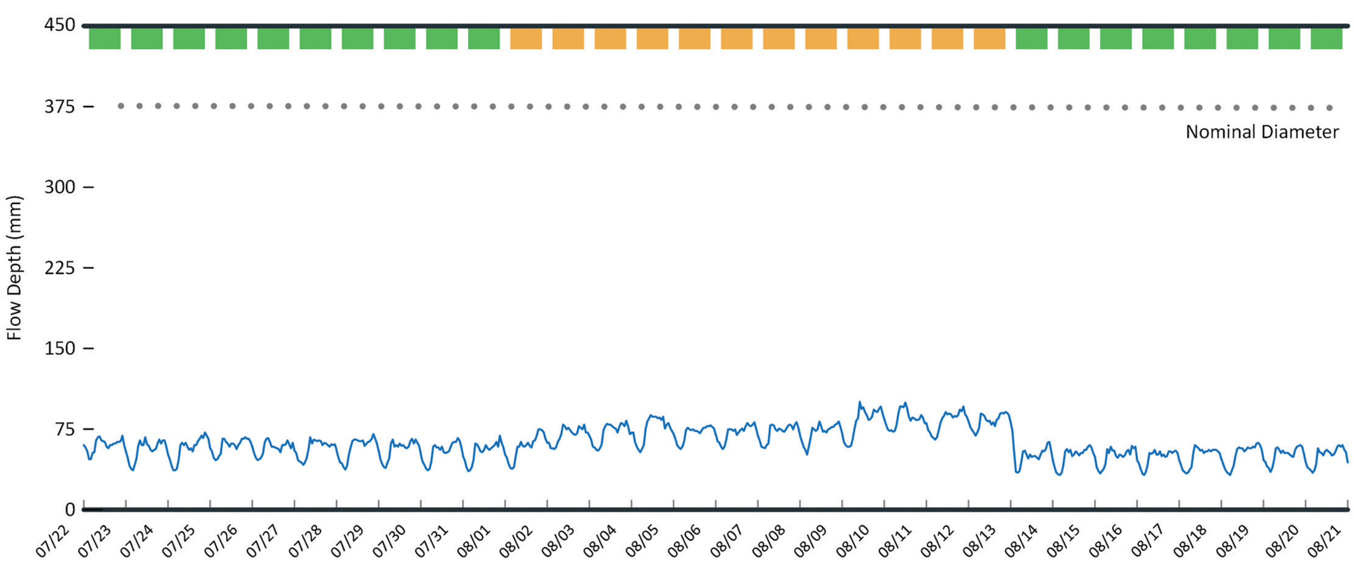

Figure 2. Developing blockage in a sewer identified with smart sewer technologies

Figure 3. Smart sewer technologies identify developing blockages before a problem arises

was identified by the ML algorithm and followed over a 12-day period, when a field crew was then sent to investigate. What was the problem? A stick was lodged at the outgoing sewer in a downstream manhole and was collecting debris, as shown in Figure 3. After removing the stick and debris, flow conditions returned to normal. The blockage detection and resolution all happened before the sewer ever surcharged and before an SSO could occur. This incident was remarkable in that it was unremarkable—an SSO was averted by detecting and resolving a developing blockage well before most even knew a problem existed. This is just one example of the power of smart sewer technologies at work.

IMPROVEMENT THROUGH INSIGHT

While developing our first smart sewer application, we learned key insights that are useful to those developing other smart sewer apps or those looking to implement them. When first researching various approaches to blockage detection, we soon recognized that flow depth was an important indicator. However, we also recognized that flow depth alone would not provide a sufficient answer. *How* the flow depth changed over time was important. We also noted that, while an experienced person can correctly identify if a blockage is present or not by looking at a hydrograph of flow depth data, other sources of information, such as weather, were implicitly used to arrive at a conclusion. Recognizing what information is used and how it is processed guides the ML process for smart sewer apps. We also learned that ML requires a vast amount of data to thrive. Having extensive access to sewer flow monitoring data allowed our team to leverage these data to label historical data as "blockage" or "no blockage" as they trained and evolved our ML algorithm. We were fortunate to have this extensive database, but it certainly took more data than we first imagined to start up our smart sewer app.

Perhaps the most important takeaway we learned is that smart sewer apps *must* change the way organizations operate, and this change is often transformational. However, this change can be hard, especially when established processes and procedures are involved. It may seem counterintuitive, but initial discomfort with smart sewer apps is often a subtle sign you are headed in the right direction. Nevertheless, successful smart sewer apps should be designed with this initial discomfort in mind. One thing we observed with blockage prediction was an initial reluctance to suspend regularly scheduled cleaning in favor of data-driven cleaning. While there are significant economic benefits to reducing cleaning frequency, blockage prediction represents a paradigm shift that disrupts established preventive cleaning procedures. That change alone is enough to cause concern. Also, the suspension of scheduled cleaning often causes an initial anxiety viscerally—fear of change and fear that smart sewer technology may not work. In our case, we eased the anxiety by incorporating data visualization to build confidence and familiarity in the ML algorithm while coupling it with more traditional high-depth alarms.

NEXT STEPS

With the promise we have seen, the technology that is here today, and the vision we see on the horizon, what has to happen before wide-scale implementation of smart sewer technologies occurs? How much of this is today's reality? How far are we from "zero overflow"? Although the technology is possible and the need exists for implementation of data-driven, automated O&M of collections systems, what are the impediments to rapid adoption? What must happen to make this vision a reality?

COST

Municipal budgets are already stretched, and state funding will continue to be limited. The federal infrastructure spending bill will help, but more action is needed to improve affordability. We have seen supply chain issues dramatically increase component costs. To drive costs down, monitoring devices must be simplified and be easily replaceable, but be connected to a hardened, robust communication and data network. This low-cost, accurate sensor must be robust enough to withstand the harsh sewer environment. It must work in partially full and surcharged conditions. Many manufacturers have inexpensive pressure sensors, and others have relatively inexpensive radar or ultrasonic sensors, but very few combine technologies that will work in varied sewer conditions. AI is one potential solution to this cost challenge, as it could take control when sensing extreme sewer conditions that would not support inexpensive sensors. If AI can fill this gap, it could enable the use of lower cost equipment that relies on hosted AI to fill data gaps.

UNINTERRUPTED SENSOR COMMUNICATION

Most commercially available sewer level and flow monitoring equipment uses the cellular communication network. While cellular service has vastly improved over the past 10 years, areas still exist where the network strength is weak and cellular service can be interrupted, especially during severe weather. A few commercial vendors use satellite technology for sewer level and flow monitoring, and this technology provides uninterrupted service as long as line of sight is maintained. Radio frequency (RF) is also widely used and, while more expensive to install, results in fewer service interruptions when equipped with an uninterrupted power supply. LAN, WAN, long range radio (LoRa), and other such versions are also available but can be expensive to install and must be maintained by the host provider, often either a contracted entity or specialized municipal staff. There will be a trade-off between cost and control of the network, which is why most commercial providers use the lower-cost cellular network. Owing to the widespread use of cellular communication and the increasing dependency on cellular technology by numerous utilities, financial institutions, government agencies, and other entities, further hardening of the cellular network is anticipated. The cost trade-off between cellular and another owned-and-operated communication network must be evaluated case by case.

MAINTENANCE-FREE SENSORS

There has long been a desire for "maintenance-free" sensors in sewer systems based on the safety risks, cost, and downtime associated with installed sensor maintenance. Sensors installed "in the flow"—so-called "wetted" sensors—are more likely to require routine maintenance. Non-contact sensors, whether installed at the crown of the sewer or in the manhole, are less subject to fouling and therefore can have a reduced maintenance requirement compared to wetted sensors. However, even these non-contact sensors require maintenance, especially after a surcharge. Even if the location never surcharges, some maintenance will likely be required to clean the sensor and maximize functionality and useful life. Reliable, accurate, non-contact sensors are the closest we have to a reduced maintenance sensor. If the technology can evolve to where a sensor can be installed from the street level, is wetted to achieve maximum accuracy, can be easily retrieved without personnel entry, does not catch debris, never fouls, and requires little to no maintenance, we will have reached the next level in the drive to a maintenance-free sensor. While it sounds ambitious to develop this type of sensor, the technology may be closer than many people think.

LOW POWER, SUSTAINABLE POWER SOURCE

Alternating current (AC) power is rarely available in sewer systems, except at pump stations and at the WRRF. Typically, in-manhole sensors, data loggers, and communication devices use direct current (DC) battery power and are designed for low power consumption. This requires a relatively long battery life depending on the technology and what it is asked to do. Devices can run anywhere from three months to five years on a single battery; however, once frequent communication to a web host is needed, battery life tends to be about one year or less. In cases where even this is too much of a maintenance issue, a sustainable power source will be necessary. Solar power can be used in many cases and is technologically a viable option, but the solar panels face vandalism and other physical damage in both populated urban areas and remote regions near an urban area. Solar power is frequently used to power rain gauges as they are on rooftops and less subject to traffic or vandalism. Rechargeable batteries are not viable if they cannot be recharged in situ with solar power or some other renewable energy source. As the technology develops to use alternative renewable energy in a form less subject to physical damage, we will get closer to achieving the low power, maintenance-free power source.

AI THAT HAS LEARNED THE MYRIAD OF CONDITIONS AND RESPONSES

AI is a wonderful tool that, when deployed correctly, can help operators make better decisions; in some cases it can make decisions on its own to redirect, hold back, or increase flows. However, AI requires a learning process that is best developed using historical data, learned experiences, and fine-tuning the AI as it encounters different scenarios. An available data set is a treasure trove to data scientists and engineers to learn the patterns and signatures of the myriad of depth and velocity combinations in the collection system. Data scientists have used our enormous database to learn patterns to alert operators of blockages as they are forming and long before they cause a backup or overflow. The AI must learn each pattern, and to do that, human review and confirmation is first necessary. Engineers, along with data scientists, have reviewed many thousands of flow, level, and other patterns and confirmed whether the pattern represents a blockage. As the AI learns, it steadily improves at predicting a real pending blockage rather than a false positive or false negative. Only by constant feedback and correction is the AI refined enough to be viable for alert notifications. So yes, AI is possible, and it is powerful, but it requires a large enough database from which to learn and expert human partners to guide the learning.

PEOPLE

Perhaps the most challenging impediment to the adoption of smart sewers is people. The phrase "old habits die hard" is true and the development of "new habits," despite risk and uncertainty, will be necessary to advance the use of smart sewer technology. Adoption of new technology in any industry or walk of life is always driven by the early adopters, those who are the innovators and can steer behavior despite uncertainty. These early adopters will be critical to persuading others to more quickly "cross the chasm" from old behaviors, including schedule-driven cleaning, reactive maintenance, "best judgement" on wet weather management, and other non-data-driven decision-making. As we increase our reliance on automation, data-driven decisions, and AI, we will move toward a world of zero overflows and clean waters, a Sci-Fi dream that will become tomorrow's reality.

ABOUT THE AUTHORS

- Mike Bonomo is the director of strategic sales for ADS Environmental Services and has over 40 years of water project-related experience. Mr. Bonomo is a NEWEA past president.
- Kevin Enfinger, PE, is a senior region engineer for ADS Environmental Services and co-author of the ADS scattergraph poster. He has published many papers and articles on the use of flow and rain data for wet weather analysis and "Sewer Sociology."