Spring 2019

Artificial Intelligence in Wastewater Treatment Facilities: Implementing Practical New Technologies for the End User

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Honors Research Project
April 26th, 2019

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Glossary

AI - artificial intelligence
CSO - combined sewer overflow
CSS - combined sewer system
DCS - distributed control system
RTC - real-time control
RTDSS - real-time decision support system
SCADA - supervisory control and data acquisition
WRF - water reclamation facility

Abstract

Design phase operator input can prove useful; however, it is not essential in every application, as Akron's treatment plant implemented AI to increase treatment capacity without design-phase operator input. They implemented a system flight simulator, a few hours training, and have communicated with the designer to make system tweaks as needed. In larger applications, the owner may benefit greatly by incorporating design input from operational staff. Those representing a municipality as a project owner for a treatment plant upgrade should always maintain an active role in the design of smart water infrastructure. They must keep the operators in mind when reviewing the drawings and specifications to ensure practicality whether there is a large infrastructural upgrade or just the implementation of the smart systems. Though AI water treatment monitoring and control offers great benefits, the question of how to overcome these obstacles remains.

Objectives

- Explain the need for increases in wastewater treatment and the role of AI
- Discuss operator feedback relating to the implementation of AI and the need for operator training
- Conduct a case study investigating AI in the Akron treatment plant and analyze findings
- Discuss the best recommended practices for a community implementing AI

Acknowledgement

A special thank you to those who offered their time in assisting with this project:

- Dr. Christopher M. Miller
- Jesse Rufener, PE
- Dr. Stephen Duirk
- Dr. David Roke
- Tom Sanderson
- Tim Shearer, PE
- Patrick Henthorn

Background

In 2012, global water demand was predicted to increase by roughly 55% by 2050 due to more countries developing, increases in manufacturing and energy production, irrigation, population boom, and the effects of climate change. Engineers are now counting on AI to maximize water outputs and meet increasing demands [3].

Many communities have begun implementing AI smart water infrastructure in their water collection and reclamation facilities. The goal of the implementing such infrastructure is to maximize the efficiency of existing infrastructure and to eliminate the need for costly offline improvements (new construction). Benefits include improved water quality, reduced energy usage, resource management, and prevention of CSO events. There are also benefits in reducing operational costs while maintaining effluent quality; there is less need for human monitoring once AI is implemented as the system can be monitored remotely [2]. Inadequate training and education is one of the most common ways that the usefulness and benefits of smart water infrastructure can be hindered [4].

RTC systems can adjust a facility's operations automatically based on the data collected in both dry and wet weather events. For example, the pipes, pumps, and valves can shift flows to different areas of a plant as needed. RTCs are often employed in facilities which are over-sized due to a factor of safety. Different parts of the facility can be utilized as needed, as dictated by AI algorithms and data. Other parts may still be manipulated manually by plant operators [2].
One of the main uses of real-time data monitoring is to produce *actionable information;* that is, data with a recommended operator action attached to it [7]. An alarm will sound an alarm with the action displayed on the RTDSS. An example of an alert at the Akron WRF is shown in *Figure A.* Similar alarms will also give the operator and an action which needs completed [6].

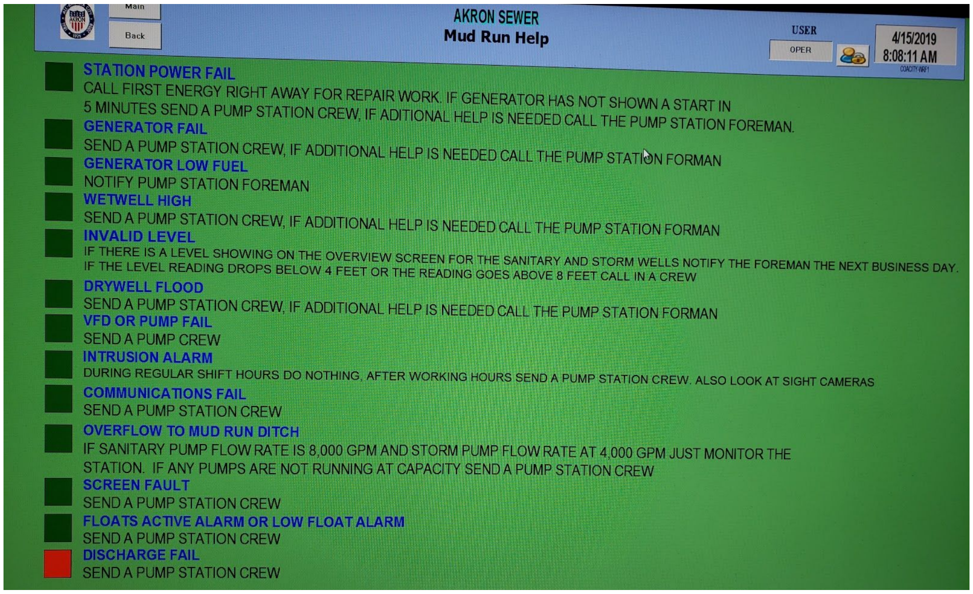

Figure A, “DISCHARGE FAIL” alert, Akron WRF

Old vs. New Data

Traditional design of water collection and reclamation facilities is based on *old data,* which as the name suggests, is data collected in the past. Engineers refer to regional wet weather data to collection systems, storm sewers, and collection basins to formulate the capacity of a system. In theory, this capacity will prevent the system from overflowing during wet weather events. Likewise, engineers also design sewers based on historical wastewater discharge data and peak dry weather events. These are examples of *old data* reliance.

Enter *new data.* AI smart water systems use algorithms and collects massive amounts of data to generate *new data* in real time. This new data can be combined with weather forecasts to predict future dry and wet weather events. The distinction between old and new data lies in the adaptive nature of forecasting. Even when humans employ *old data* meticulously in the design phase, it may not suffice in the future. Today, there is much population increase, urbanization, and change in climate patterns which increase water demand. AI allows for efficient massive data storage and the ability to stay one step ahead of the changes in dry and wet weather events, as well as increased water demand. Smart water systems are *proactive,* rather than *reactive* like traditional systems are. Although it cannot always be avoided, building additional collection infrastructure is a *reactive* means of handling the increases in water collection and demand [2]. *Figure B* displays the type of data which can be analyzed by AI to predict incidents and forecast future conditions.

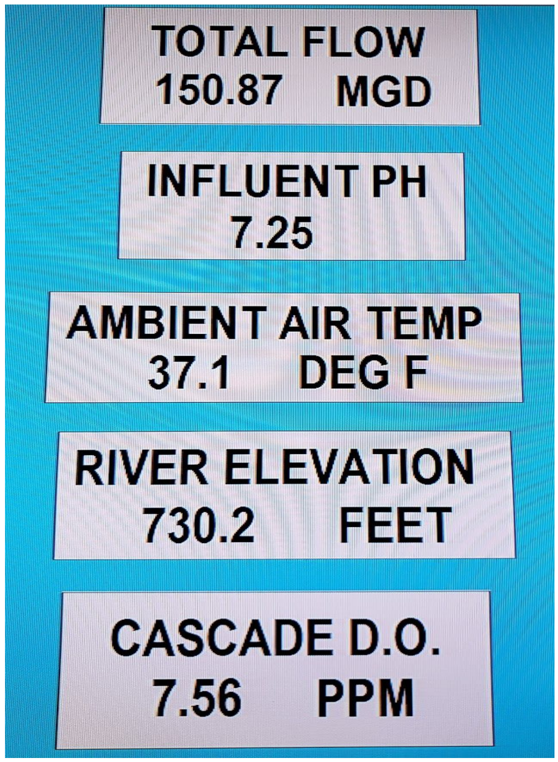

Figure B, real-time data module

Smart Data Collection

Collected data is only reliable when collected by accurate information inputs. Input strategies, when used properly, are tools that may help answer important questions that allow for optimization of the collection system and treatment facility [2].

Collection input strategies include the following:

- Level monitoring
- Flow monitoring
- Rainfall monitoring [2]

Monitoring is typically done continuously. It is a relatively basic process which includes flows, water levels, and rainfall conditions; equipment status is also monitored. It can cut operational costs when relevant data and or visualizations are produced by the data, thus allowing for better asset management and planned maintenance. *Level monitoring* must be designed for specific locations, water environments, and water conditions including sediment concentration, obstacles, and FOG (fats, oils, and grease). Multiple (redundant) sensors are often used for the sake of precision. Errors within the data can be detected and deleted automatically. *Flow monitoring* is a physical measurement of the amount of flow running through a pipe, which can be done by both submerged and non-contacting sensors. *Rainfall Monitoring* utilizes a specific number of monitors employed per unit area (eg. one monitor per thousand acres). This is useful for CSS and large-scale collection systems [2].

Wastewater Treatment and AI

Consider the speech-enabled smart device: it is designed to respond to human input (speech) with human-like responses. Many such devices and applications have gained popularity due to their intuitiveness and practicality; they offer a completely hands-free user interface and numerous functions. For operators to use and to accept AI and RTDSS in wastewater treatment facilities, the new systems must likewise be intuitive and practical. AI algorithms must align with the information, goals, and constraints which are of focus to the decision maker. It is beneficial to consider operator input in the design of intricate smart water systems [1].

New advances in wastewater collection and treatment systems include faster CPUs, smaller and more accurate sensors, data storage efficiency, and wireless data transmittal. As the system collects data, it shrinks the data into more meaningful and less redundant graphs and diagrams. When the system detects a data anomaly, it sends a message to the operator, or may sound an alarm if it is urgent [2].

The first steps in designing a smart water system must revolve around envisioning the future and how controls could be utilized at a specific plant. Time must be allotted for implementation and allowing the staff to accept the changes. Officials must then evaluate the desired technology and prove its benefits. Then, they must fund and implement the new technology. Design, procurement, training, and use are all case by case; there is no “one size fits all” smart water system. Training, including continuous training, of the staff remain one of the biggest hurdles in implementation [2].

Operator Response

Studies suggest that humans tend to override results from predictive or “smart” algorithms, especially when they do not have faith in the AI system at question. The most accepted approach for combating this is to consider human judgement in the design of these systems. Complete automation would mean the removal of a human’s ability to override, but this approach is not always acceptable as many applications require human cognition to consider every necessary variable. Smart water infrastructure are generally equipped with fail-safe systems, which can make automatic system changes to avoid catastrophic damage [1].

To prevent operators overriding the system’s recommendations, training must focus on *why* the system is making them. Trainers must focus on the data that was collected and use it to support the case that they are making: that the AI is smarter than the person. In other words, a trust in the system must be established during training. Operators often have a tendency to switch the system into auto when training on the automation is lengthy. This due to the operators developing a confidence in the system and believing that it can function in auto all the time [7].

While the benefits of AI smart water systems are widely accepted, there are obstacles that remain and must be properly addressed in the design phase. There must be a plan tailored for each system once it is online; the operating staff for a treatment plant must be properly trained and willing to accept changes to their system. Any new technology must be learned, as they perpetually exceed human understanding. It takes careful design of user interfaces for new technology to be used as a tool and practicality is key to integration. The RTDSS must provide clear and understandable visualizations and alerts for operational staff [2].

Case Study: Akron Water Reclamation Facility

Background

In 2009, the US EPA handed the City of Akron a Federal Consent Decree forcing the city to undergo a massive overhaul of its wastewater collection and treatment processes. As a result, ground broke on numerous projects throughout the city beginning in 2015, which were designed to maximize the collection, storage, and treatment of sanitary and combined sewage. With water quality in mind, Akron began building CSS infrastructure to reduce CSOs and discharges into local waterways. In a CSS, the wet and dry weather flows are combined during collection and are the influent of a common reclamation facility [5]. Akron called upon EmNet to help the treatment plant implement AI software (DCS and SCADA) and allow them to increase treatment capacity [7].

Investigation

As part of the consent decree, the Akron treatment plant was required to double its treatment capacity from 110 MGD to 220 MGD, with a peak flow of 280 MGD. This feat would have been impossible without the use of SCADA and DCS. Two software programs are currently being used. The collection system has been monitored by *Prophecy iFix* (SCADA) for roughly 25 years, whereas the rest of the plant recently started being monitored by Emerson's *Ovation* (DCS). Despite the long-time use of SCADA, its application at the Akron treatment plant is much greater than it had been for many years; it was initially used to monitor just three gates and three valves [6].

The DCS allows the operators to switch its activated sludge treatment stage from a plug flow to a step feed process. The system automatically shifts to step feed during peak hours, allowing for more sludge to undergo secondary treatment rather than being bypassed. The operators must manually switch it back to plug flow to return the system to homeostasis; therefore, switching back is a judgment call. The ability to switch to and from step feed allows much more water to be treated [6].
The software involved no operator input during the project design phase. However, training for it was quick: it lasted just a few hours on two consecutive days. It is fairly intuitive and is tailored to the needs of the Akron treatment plant. Since the system first went online, there has been continuous dialogue between the plant operators

and the designers. The operators find a lot more use out of *functional descriptions* rather than engineering plans; they detail exactly what a piece of equipment is and what it is used for [6].

The operators requested new user interfaces, better data organization, and some aesthetic changes. For example, the operators wanted a new interface which detailed each gate's state of being open or closed. The now integrated information, as shown in *Figure C,* had been scattered across different modules within the DCS. Before this interface was implemented, it had taken several minutes to be able to check all of the gates, whereas the new interface allows for this to be accomplished in seconds [6].

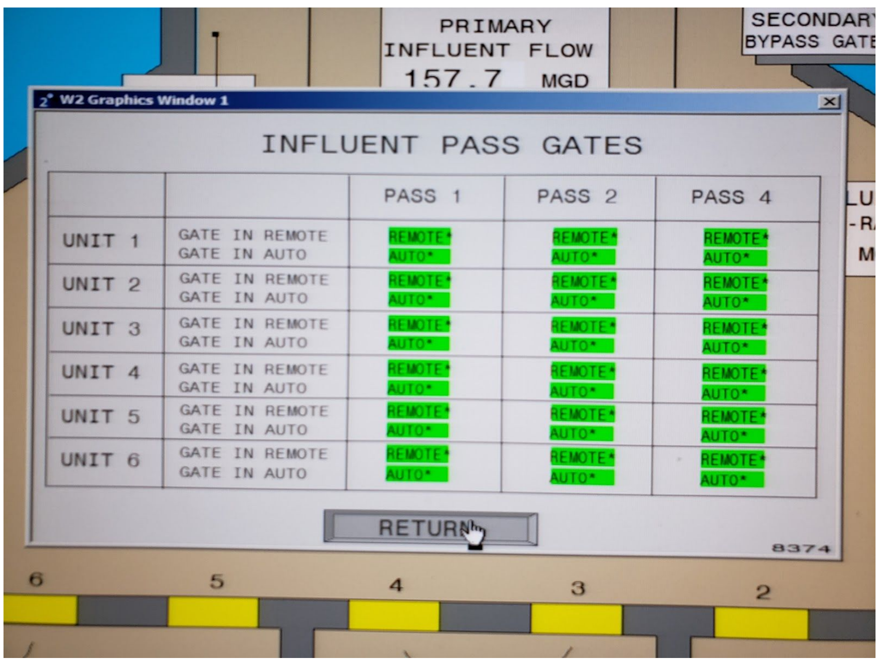

Figure C. Akron WRF Gate Interface

On the design side, it is difficult to anticipate how long training will take and specifications will often require standardized periods of time for training to ensure that training is adequate. For example, the specifications may call for two hours of training on a particular piece of equipment and how it is manipulated using the software. There are instances in which the allotted time is much greater than what is needed. Training is only effective when it is practical, or relevant to the tasks associated with the operator's job. Otherwise, training time will be filled with information that is either not useful or not practical. Within the SCADA system at the Akron treatment plant, there is a series of gates and valves that may be opened or closed at the push of a button. It is the only function that the gates have and, therefore, it required little training for operators to learn how to operate the gates [6].

In addition to the SCADA and DCS technology, the operational staff at the Akron treatment plant also have access to what is referred to as a flight simulator, which was designed by EmNet. Equipped with a schematic of the treatment plant and the collection system, the simulator allowed the operators to experiment with real-time controls in a system that mimicked real alerts. Whether the actions were obeyed or overridden, resulting changes to the plant would occur over a simulated time interval. EmNet also provides post-procurement training services, in-person follow-ups and consulting, smart system modifications, webinars, and other forms of hands-on training [7].

Analysis

The Akron treatment plant only needed a few hours to train its operational staff to use the DCS after it went online despite having no involvement during the design phase. The functionality of Akron's SCADA and DCS are limited compared to some other communities. However, thanks to some recent infrastructural upgrades, the plant can switch to steep feed. As a result, the plant's treatment capacity has doubled from 110 MGD to 220 MGD. It would be impossible for the operational staff to monitor the new infrastructure without AI [6]. The flight simulator allowed operators at the Akron treatment plant to get a feel for real-time controls prior to controlling the system itself, eliminating any potential errors that may have otherwise occurred [7]. To learn all functions of the job, training of new operators at the Akron treatment plant lasts about sixteen weeks just to learn the basics. It may take up to a full year of experience for an operator understand the entirety of the plant's operations [6]. Since it only takes a few hours, SCADA and DCS training puts a relatively small strain on the plant. In the case that an operator becomes negligent and lets the system run on auto, AI is capable of preventing catastrophic damages and CSOs with the implementation of fail-safe systems [2]. This shows that automation can also make the system *safer*, in addition to being more cost effective.

Discussion

The demand for wastewater treatment is rapidly increasing and this trend is expected to continue. The Akron treatment plant, for example, has doubled its treatment capacity. This feat was made possible through the implementation of AI in the form of SCADA and DCS for monitoring and failsafe automation.

In design-bid-build, the role of the designer is mostly finished once the drawings are accepted by the owner. Smart water AI may not be online until one to three years after design. The owner must therefore be cognizant of the practicality of AI operator use when reviewing plans. Much time can be saved on operator training and system modifications if the owner takes an active role during the design phase. This may not always be feasible, however; during design review, as the owner has many considerations at hand and may not have the time to worry about the smart water system once it is online.

While other communities have seen benefits in incorporating operator feedback during the design phase [8], a treatment plant such as Akron's can suffice with only post-construction operator feedback. This is because the application of smart water technology is somewhat limited in Akron at the present time. However, the continued dialogue between operators and designers remains vital to optimizing the practicality of smart water infrastructure. In communities other than Akron, there must be a great focus on design-phase operator input, pre-online-system training and simulations, and on implementing practical and user-friendly interfaces and modules. When systems are practical and properly learned, training takes less time. This allows communities to achieve a much better cost-to-benefit from implementing smart water infrastructure.

Rather than throwing operators straight into the weeds, it is important to expose them to the software *before* a system goes online. This allows them to understand how the software is used and can prevent accidents and damages related to the treatment plant. This was seen using the flight simulator at the Akron treatment plant. It can also help to reduce the amount of time spent on *ongoing operator training* after procurement. It also allows the plant to mitigate the risk of having a brand new system with untrained operators. Training must be sufficiently long, but no longer than needed to avoid excessive downtime costs and trainee burnout. Training should focus on establishing trust in the system amongst operators.

Citation

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Appendices

Appendix A: Correspondence with Tom Sanderson, *Operator Supervisor*, Akron WRF

April 12, 2019. Phone Interview.

1. Tom, what is your position at the Akron WRF and how long have you been employed there?

    I have been with the plant for thirteen years and my current position is operator supervisor.

2. What recent improvements or new construction has the plant undergone in recent years?

    Most recently, we underwent Phase II of our Step Feed project. Step feed was designed to increase our plant's treatment capacity from 110 MGD to 220 MGD with a peak flow capacity of 280 MGD. In short, the project was successful. We had to retrofit existing tankage, change clarifier equipment, modify the activated sludge process, and increase our treatment capacity without increasing our footprint. This phase of the project cost about $37 million. The project was a part of Akron Waterways Renewed - as part of the EPA consent decree.
    The whole purpose of establishing a step feed process was to reduce secondary bypass; in other words, we needed to treat more influent wastewater than allowing it to bypass secondary treatment.

3. What AI systems does the operational staff currently use?

    Right now, we are using the SCADA system called *Prophecy iFix.* It monitors all the pump stations, the rack overflow levels, and the new detention basins. Alarms will sound on the SCADA if there are any issues. As time goes on, we have begun to use SCADA more and a new system is currently being built. Back in 2005, the SCADA system went online to allow the sewer maintenance department, which is a separate entity from us, to monitor the Cuyahoga Street collection system. This system was monitored by sewer maintenance up until two years ago when the responsibility fell on us at the treatment plant.

4. How did the operators respond to the implementation of SCADA?

    Like I said, the sewer maintenance department was using the system until recently. That being said, the system itself was designed long before our crew was involved. There was not a long time commitment with learning how to use the SCADA because it was only being used to monitor three gates and three pumps. The gates and pumps had an on and off state and that's it. The system had a very small learning curve since it was so simple.

    Now, SCADA monitors the whole collection system. When SCADA took this on, the operators had already been familiar with the Cuyahoga Street monitoring screens. It took two training sessions, each one being an hour and a half to two hours. The training included site visits to learn exactly what the SCADA was manipulating.

    The SCADA is very self-explanatory and displays icons which tell the operators what needs to be done. We expect to see more SCADA screens to be implemented as more collection systems go online due to Akron Waterways Renewed.

5. Do you believe that there are any benefits to the operational staff being involved in design?

    On most projects, I do not care to look at the drawings and specifications. Someone who speaks *Prophecy* can handle all of that type of work. What I and the operators care about is the *functional descriptions*. It is important, however, to have someone who is capable of reading the drawings as well as the functional descriptions in training. The functional descriptions are used to teach the staff how a part operates within a system.

Take the step feed process for example. The functional description says that a DO probe will be used to measure the DO concentration every second. The collected data will be transmitted into the logic network and give the operators recommendations, perhaps to open up a valve if the flow needs to be regulated. It is vital to have functional descriptions on hand in case of a failure in the AI such as a server crash. Like any technology, the system are bound to go down at some point. When the system can no be automated, the operators can call up the functional descriptions to understand how a gate or a valve can be opened manually.

For the step feed equipment, engineers designed DCS screens for the operators. I sat down with some of the engineers to discuss ideas. I would take their ideas for modules and user interfaces, show it to my operations team, have them make comments for changes, and try to get their ideas integrated into the system. We wanted a system that worked for us. If there was a part of the system that they wanted changed or if there were any bugs, it was fairly easy to request changes.

6. How does the step feed process work?

Step feed is a semi-automated system. In the event where too much solid waste is entering the treatment system, the DCS will automatically switch the system from plug flow to step feed. It is able to process a lot more solids this way and prevent bypasses. The switch to step feed is automated as a failsafe. It will not, however, switch back to plug flow automatically and switching back is up to the discretion of the operator. The treatment system essentially resets once it is back in plug flow. Step feed forces the solids to undergo longer treatment in the aeration tank. If the system does not return to plug flow, it will result in a huge solids buildup.

7. How have the operators responded to using the DCS?

In general, the operators like using the DCS; however, they do not use all of its features because there are simply too many. They prefer the DCS over the SCADA system. The operators wanted failsafes, so they were very accepting to having them in the system.

One operator comment that led to a change was that it was cumbersome to locate the status of a gate. All of the gates statuses (there are 18 of them) were scattered across different parts of the DCS. It would take several minutes in some instances to locate this information, which is not sufficient when you're dealing with the possibility of an overflow. Operator feedback led to a module which integrated all of the gate statuses onto a single screen. The module is logical, more elegant, and designed completely by the operators. A designer may never envision such a module.

April 15, 2019. Akron WRF In-Person Interview Notes

In this module, you'll see that there is an alarm stating that there is a discharge fail, which means that the pump is not pumping enough water either in or out. The operator must send a pump station crew to fix the issue.

The DCS is used to integrate multiple parts of the treatment system and uses control logic to do so. The name of the software is Emerson Ovation. The step feed controls were not very easy to use at first, as the software included an excessive amount of data and options. It could take upwards of ten minutes to locate an action that you were looking for, which can lead to unsatisfactory or unsafe conditions.

Only *approved* training should be used and it should be based on practicality and system troubleshooting. Operator training takes a long time in general - about sixteen weeks to learn the basics and up to one full year to understand the treatment plant fully.

There can be one, two, or even three years between the final design being accepted and the smart system going online. The individuals who design the systems may leave their firm, leading to very few people still working there who have a profound knowledge of the system. As a result, ongoing training is a must. Designers generally do not see the systems in action and training is not usually a great concern during the design phase. The *best* way to train an operator on DCS or SCADA systems is by using a flight simulator and then transferring that experience into the real thing once its online.

When the owner (municipality) reviews drawings, they have many considerations at hand including infrastructural disturbances, and public notification and perception. They may not have time to worry about the DCS and SCADA once they are online. Lastly, doubling our treatment capacity would have been impossible without DCS automation.

Appendix B: Correspondence with Patrick Henthorn, Project Innovator, EmNet.

1. What is your position with EmNet and how long have you been with the company?

    My current title is *Project Innovator* and I have been with the company for four years. I work directly with clients to offer smart water solutions both during and after design. Previously, I had worked for the City of South Bend, Indiana, which served as a test city for EmNet controls.

2. Aside from the design and procurement of smart water infrastructure, what other services does EmNet provide?

    We offer general startup and training services as well as materials including manuals, webinars, and in-person follow ups after training. For example, we implemented a system flight simulator for the operators at the Akron treatment plant. Here's how it works: it's essentially a model of their actual plant. It furnishes simulations of real-life operational situations. The operators are given recommendations on what to do, for example, open a valve to relieve a storage basin as it begins to fill up. Whether or not the operator chooses to act based on the recommendations, the simulation will change accordingly. In the instance of the basin filling up, it would overflow if not relieved. This allows the operators to establish a level of "trust" in the AI, which is essential when the systems are online.

3. Describe *actionable information* as it relates to real time monitoring.

    Actionable Information is defined exactly how it sounds: it is simply data that has an action attached to it.

    Take a level monitoring sensor for example. It displays the level in a pipe or basin in real-time. But if not for actionable information, this data isn't very useful. How does the operator know if there's an issue? In Akron's storage basins, there are sensors within the collection system that the provide actionable information necessary to make changes within the system. Certain tanks may not be in use all the time, but may be switched on by opening a gate or valve during an increase in influent flow. The "action" is a recommendation or a displayed automated action. The automation can be overridden by an operator if it not necessary.

4. Have you observed any instances in which operators believed themselves to be smarter than the AI?

   Yes, as a matter of fact. Due to lengthy training and/or burnout, operators may tend to flip the system into auto. To combat operators using their override privileges too often, this must be a focal point of training. In a training platform such as the flight simulator, us as trainers can point to the generated data to back the AI recommendations and automated actions.

5. What type of input or dialog happens during the design of smart water AI form operators, managers, and project engineers?

   At EmNet, we believe that co-design is the best design. We want the system to be the *client's* system, so there is often quite a bit of input from the end user. If not, there is continued dialog, training, and system modifications. At Akron, there was little dialog prior to implementation of the SCADA. It began as a relatively complex dashboard that was modified for the use of the operators. As the system was in use, the Akron plant operators began requested aesthetic changes and some key data to be displayed differently. For example, we created a brand new module to display data for the gates across the entire collection system and treatment plant in one place.

6. How well to operators respond to these systems if not for design input? How accepting are the operators of a brand new system?

   In short, it varies quite a bit. However, our systems are equipped with user interfaces that tend towards great user friendliness. We are continually learning better ways to leverage operator comfort level with new technology. Operators generally accept our technology and ask for small tweaks here and there falling into two categories: cosmetic changes and new ideas. We will always implement a new idea so long as it is feasible. For example, one client requested that we implement a new rain gage to reflect DCS wet weather forecasting. The only difference is that they wanted the wet weather to be forecasted as a heat map, like one that you would see on the weather channel or smartphone app. This change allowed the client to be able to understand the data as it is provided intuitively.