Spring 2022

Barriers to Technology Adoption in the Water Treatment Industry

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Submitted to

Williams Honors College, University of Akron

Honors Undergraduate Research Project 2022

Course 4200:497

Submitted on 22 April 2022

Executive Summary

The drinking water treatment industry is constantly evolving, and water systems must be vigilant to keep up with the ever-changing regulations and available technology. The latest advancement to reach the water sector is the rise of digital twins and artificial intelligence. Although these technologies are available and have been shown to be effective, very few systems have integrated these new software options. Through evaluating case studies and other literature, several potential barriers to technology adoption in the drinking water treatment industry have been identified. These options are as follows: satisfaction with current technology, lack of awareness of technology options, lack of understanding of technology capabilities, lack of funding, lack of staff expertise, lack of customer assistance from vendors, lack of available training, prior investment inhibiting future investment, resistance to change, lack of understanding of technological trends, concern over jobs becoming obsolete, difficulty of learning to use new technology, lack of communication between staff and management, and cybersecurity concerns. Prior research has identified lack of funding and lack of staff skills to be leading barriers [3] but fails to consider other factors such as cybersecurity issues. They also do not address any specific piece of technology. Instead, they opt to speak generally about digital development. To better understand these aforementioned barriers, a survey of superintendents, managers, chief operators, and others, was taken for water systems primarily in Ohio, but also in Pennsylvania and Indiana. The respondents were asked to rate each of the barriers on a scale of one to ten, with a ten indicating the barrier has a strong effect on technology integration and a one indicating no effect. The average response for each barrier was determined, and the barriers were ranked in order of effect on technology integration, In descending order of impact, the barriers were ranked as follows: cybersecurity concerns, prior investment, lack of funding, lack

of staff expertise, lack of understanding of technological trends, lack of training, lack of customer support, resistance to change, difficulty learning new technology, lack of communication between staff and management, and concern about jobs becoming obsolete. The barrier with the greatest affect, cybersecurity concerns, received an average response of 8.25, while prior investment and lack of funding received ratings of 7.07 and 6.86 respectively. The least impactful barrier, concern about jobs becoming obsolete received an average response of 3.54. The survey also gathered data specifically for artificial intelligence and machine learning tools and found similar results. Again, cybersecurity and lack of funding are large barriers, but confusion about AI and its capabilities is also a significant obstacle. 27% of respondents indicated that funding is the greatest obstacle relating to AI integration while cybersecurity concerns received 23% of responses. Conversely, lack of customer assistance, lack of training and lack of staff expertise were determined to be the least impactful barriers to artificial intelligence integration.

Introduction

Over the last century, the drinking water treatment industry has evolved from a field primarily relying on manual processes into an industry with access to cutting edge technology. The technology utilized by water systems range from simple data management software to advanced artificial intelligence and machine software platforms. The rise of new technology options such as digital twins and machine learning tools have been shown to increase plant efficiency, leading to numerous benefits [10]. Recently developed artificial intelligence systems have saved plants as much as 25% in chemical costs [10]. Despite the growing availability of these products, many drinking water treatment plants have not integrated newer, more advanced forms of technology. Operations that rely only on a simple technology foundation for data management and treatment planning can encounter efficiency issues that negatively impact the treatment plant's daily operation.

In an attempt to explain why certain plants have not integrated new technology, many factors will be considered. These factors include both practical issues, such as availability of funding, and workplace psychology issues, such as resistance to change among water treatment plant employees. In addition, an inquiry into the decision-making process behind technology decisions will be made in an attempt to understand this process and determine how it affects new technology integration. These questions will be applied both to technical upgrades in general, as well as artificial intelligence. By better understanding the barriers to technology integration in this field, superintendents, software vendors, regulators, and others, will be better prepared to overcome these obstacles as the available technology options continue to improve. Ultimately there is room for improvement in the efficiency of the drinking water treatment industry and integrating more capable technology can only improve this issue over time. Firsthand experience working with the Ohio Environmental Protection Agency has spurred much of the interest in this topic and has provided meaningful context for the following inquiries.

Background

The technological resources used in drinking water treatment plants vary significantly from plant to plant. Some utilize newly developed artificial intelligence (AI) platforms while other use more traditional technological resources. While upgrading technology can be difficult for many reasons, once completed, the rewards can be great.

Understanding Current Technological Capabilities of Water Systems

The first and most obvious reason for lack of further technology integration is that no new technology is needed. If a plant is already acting at peak efficiency, it is not economically sound to make an investment that will yield little to no reward. Although this might be the case for a select few water treatment plants, a study conducted by Dodge Data and Analytics indicates that widespread improvement is possible across the drinking water treatment industry [3]. The survey asked water treatment plants to rate their capabilities in eight areas of digital maturity [3]. These categories include information mobility, digital management of asset information for operations and maintenance, real time digital asset management, and use of digital twins and others [3]. In all categories, only a small percentage (less than 13% in all categories) rated their capabilities as very good or excellent [3]. In fact, 47% of respondents described their ability to digitally manage asset information in real time as limited or no ability at all [3]. Even the least digitally complex category, information mobility through the organization, had 22% of respondents indicate no or limited capabilities [3]. The responses to the survey indicate that the digital maturity of drinking water treatment plants across the United States has room for improvement. Although some plants exhibit excellent capabilities in these categories, the vast majority would greatly benefit from new technologies. Clearly one or many factors is inhibiting further technological growth in this field despite many examples of new technology leading to improved water quality and overall plant efficiency.

Campbell, Ohio Water Treatment Plant Case Study

Fontus Blue, a company providing software solutions to drinking water treatment plants, has conducted several case studies that display the numerous and sometimes unexpected benefits of embracing new technology [4]. One notable case study reviews the cost savings and water quality improvements witnessed by the Campbell, Ohio treatment plant [4]. Routine sampling of Campbell's distribution system revealed a spike in trihalomethanes (THMs), a form of disinfection byproducts caused by chlorination of water during treatment [4]. While being hazardous to public health, elevated THM levels can also violate rules instituted by the Ohio Environmental Protection Agency (Ohio EPA). In this case, Campbell was using a strategy of increased chlorination to fight microcystin levels caused by harmful algal blooms (HABs) [4]. Initially, Campbell reached out to Fontus Blue to develop a strategy for controlling microcystin levels [4]. The initial response was an improvement but limiting THMs was still an issue [4]. Again, Campbell reached out to Fontus Blue and this time a comprehensive plan was instituted to fight both microcystin and THMs simultaneously [4]. The software developed by Fontus Blue allows operators to input various water quality parameters and simulate in real-time different treatment strategies all from the cloud [4]. The implementation of the new software immediately correlated to an improvement in THM levels and Campbell eventually recorded the lowest THM level in plant history [4]. This case study reveals many of the potential benefits of integrating new technology, but questions remain about the technology integration process as a whole.

The decision to invest in the software supplied by Fontus Blue resulted in an immediate and lasting improvement in the quality of Campbell's water [4]. Fontus' involvement also ensured that Campbell was in compliance with the Ohio EPA's rules and regulations [4]. The field of drinking water treatment is constantly evolving due to technological innovation as well as regulatory changes. These regulation changes are constantly growing to include different items, such as the new Lead and Copper Rules unveiled in late 2020. Due this reality, working with an adaptable partner like Fontus Blue is an extremely important factor in keeping up with emerging compliance standards. The comprehensive capabilities of the software not only provide a solution to Campbell's quality and compliance goals, but also allow the plant to better manage other water quality parameters, such as pH, in ways that they could not before [4]. The new software led to more efficient use of expensive powdered activated carbon (PAC), used for removal of organic material [4]. Despite the great results, it appears that the Campbell team underestimated the effect new technology could have on their water quality and overall plant efficiency. In the case study, Joe Tovarnak, the plant superintendent, is quoted as saying, "We didn't realize that Fontus could help of fix both (the THM and HAB) problems [4]." This highlights a potential barrier to technology integration: that water plant employees are sometimes unaware of the capabilities of new technologies. Perhaps if water treatment plants become more aware of the diverse offering of technological tools available to them, they can benefit from improved efficiency sooner, rather than upgrading when a specific issue arises.

Another key aspect of technology integration mentioned in this case study is the need for operators to be able to efficiently use and understand the benefits of using new technology. Joe Tovarnak, plant superintended, again offers insight into this issue when he says, "Once operators understood the meaning behind the numbers and strength of the tool, they used it constantly. It's much better than a ‘plug-and-chug’ spreadsheet [4].” Plant management, engineers and IT professionals can make all the upgrades they want, but if the operators struggle to use the tools, then the upgrade is meaningless. In this case study, Fontus Blue ensured this was not an issue by having a team member work with Campbell to implement and calibrate the new models [4]. Fontus Blue also trained the Campbell team on using UV-254 analysis to measure organic levels and they continue to support the Campbell team by providing training to new operators [4]. This success story of implementing new technology underscores the importance of software vendors offering support and training to their customers. A lack of this could act as a barrier to technology adoption. Operator comfort also needs to be considered both in terms of the practicality of learning to use new tools and organizational issues stemming from trust deficits. In a recent presentation, Baywork recognized the important role adequate training can have on organizational trust [13]. Baywork recommends implementing operator training throughout the software selection process and selecting vendors and consultants that care about training [13]. This case study is successful in part because of the emphasis both Campbell and Fontus put on training. Both the practical issues of learning to use new software and organization concerns could represent significant barriers to technology integration.

Funding as a Barrier to Technology Integration

With any improvement to a chemical process, a capital investment must be made, and in the drinking water treatment industry this can be a difficult proposition. Many water systems subsist off public funding, which is often limited. Combined with the fact that water is underpriced compared to its value, water systems often struggle with funding [1]. In fact, the need for additional drinking water treatment funding in the United States is so great, that the American Water Works Association estimates that a $1 trillion invention must be made to meet all the immediate needs [1]. This is not a new problem and over the last several decades drinking water treatment plants have learned to maximize the efficiency of their operation. As demonstrated by the Campbell, Ohio case study, new technology can dramatically improve efficiency but overcoming the initial capital investment can be a challenge. Due to the severe and long-standing nature of this issue, it seems logical that lack of funding acts as a significant barrier to technology adoption. Recent survey data collected by Dodge Data and Analytics confirms this idea [3]. The survey shows that 74% of respondents think lack of funding is a significant functional challenge [3]. Furthermore, respondents identified lack of funding as the single greatest challenge facing capital planning and the fourth greatest challenge in Operations and Maintenance [3]. Lack of funding is a broad issue that affects many aspects of plant operation. Naturally, many other barriers to technology integration arise from this issue.

As identified by the Dodge Data and Analytics study, knowing what technology to invest in is a critical issue for water systems [3]. Obviously, this issue applies to many fields, but in drinking water treatment it is vital due to industry wide funding issues. Thus, decision makers must be highly efficient with their spending choices and when an investment decision is made, they must be extremely confident in their decision. Due to this reality, a lack of understanding of technological trends can be a notable barrier to technology integration. In other words, not knowing where to invest limited capital is a significant barrier to further integration. According to the same survey, 66% of respondents indicated this issue is at least moderately significant with 29% reporting high or very high significance [3]. Understanding current technological trends is important but this is not enough. The Campbell, Ohio case study reveals that not fully understanding the capabilities of available technology is also a significant barrier to further integration. By highlighting these two similar but distinct barriers, it becomes clear that the internal decision-making process is critical in these situations. Thoroughly understating the nuances of how water systems decide to invest their capital is critical to breaking through these barriers.

Organizational and Psychological Challenges as Barriers to Technology Integration

Besides the decision-making process, other organizational issues also have the potential to act as barriers to technology integration. The Dodge Data and Analytics study again highlights several key ideas, including a lack of alignment on digital goals and organizational structure issues [3]. The study showed that 64% of respondents think lack of alignment of digital goals has at least moderate significance in preventing water systems from meeting digital priorities [3]. Furthermore, 35% indicate this issue has high or very high significance [3]. Again, a sound decision-making process is integral to having internal alignment and having strong communication within the organization is also important. As shown by the Campbell, Ohio case study, operators and management need to be in alignment when investing in new technological resources. This can only occur through communication and trust throughout the organization.

Other than internal alignment there are many organizational challenges but the most significant is resistance to change [3]. The Dodge Data and Analytics survey revealed that 70% of respondents indicate that resistance to change has as least moderate significance in stifling digital growth, while 41% indicate high or very high significance [3]. People often feel uncomfortable with change and with constantly changing compliance standards and best practices, water utilities are vulnerable to this issue [13]. Learning new skills can be difficult and sometimes employees struggle with having the confidence to adapt to a changing environment [1]. Another factor to consider is certain jobs becoming obsolete. As technology becomes more advanced, many workers fear that they will be replaced [1]. This issue has been exacerbated in recent years with the rise of AI. These fears are largely justified as new artificial intelligence systems have displaced many jobs in the manufacturing industry [8]. Once again, it is the responsibility of the organization to offer support in the form of technical training and other developmental opportunities [1]. Many of these organizational challenges do not have straight forward solutions but through competent leadership and offering support to employees, many of these issues can be solved.

The Rise of Artificial Intelligence and Machine Learning in Drinking Water Treatment

As previously noted, the drinking water treatment industry is constantly evolving to incorporate new regulations and integrate new forms of technology. An example of this is the rise of new AI and machine learning platforms. AI is already commonly used in several industries and is expected to become an integral part of industry worldwide [8]. Although very few water systems have adopted these new systems, their power and capabilities have already been shown to dramatically increase efficiency and improve water quality [10]. Despite the clear benefits, AI is often viewed with a negative connotation due to confusion about its capabilities [11]. Often people struggle to trust the results presented by AI and machine learning systems [6]. The same issues of confusion and lack of understanding also apply to the water treatment industry [1]. Determining how well water treatment plant employees, managers and superintendents understand AI is an important step in breaking down this barrier to integration.

Digital Twins and Artificial Intelligence

Connected with the rise of artificial intelligence is the evolution of the digital twin tool in water treatment. A digital twin is a digital tool that can model the past, present and future behavior of a water system [12]. Digital twins have existed longer than these new AI platforms but in recent years they have grown to incorporate machine learning. In a presentation from early 2022, James Cooper of Arcadis categorized water systems by breaking them into four distinct groups: digital twin ready, informational twins, operational twins and connected twins [2]. A full description of these terms can be found in the appendix. These categories begin with a basic digital twin ready system and increase in complexity up to connected twins [2]. The more complex categories utilize live data streams and offer process optimization, while more basic systems utilize historic or static data and help with design support [2]. In exchange for more advanced functions, these systems have more sophisticated requirements that make it impractical for many systems to invest in the more complex categories. However, this presentation illustrates that digital twins are applicable to water systems with a wide variety of existing tools.

There is a significant amount of mystery and uncertainty around what AI and digital twins actually are, and this can impact how water systems invest [2]. Often people incorrectly assume that AI is too complex for their needs. Cooper's presentation indicates that is often not the case and AI and digital twins are applicable in a variety of situations with a wide range of starting equipment [2]. Cooper describes the capabilities of digital twins in four categories: asset health twin, predictive, twin, security twin and immersive twin [2]. These terms succinctly describe the current capabilities of digital twins, which range from real time monitoring to virtual simulations and forecasting [2]. A full description of each term can be found in the appendix. These tools have the capability to improve plant efficiency, water quality, and much more [2]. Ultimately, utilizing a digital twin allows for an intersection of AI and human intelligence to problem solve in new and more efficient ways [2].

Akron Water Supply AI Integration Case Study

A case study of Fontus Blue working with the Akron, Ohio drinking water treatment plant exhibits specific examples of the many benefits AI can bring to a water system [5]. Akron is a large surface water plant, tasked with producing approximately 30 million gallons per day [5]. Akron has a long history of extremely high water quality and operates with great efficiency yet integrating machine learning software still resulted in great improvements in both areas. The first challenge was adapting to the new lead and copper testing requirements enforced by the Ohio EPA in 2020 [5]. With assistance from the new software, Akron reduced their lead content to the lowest level in 28 years [5]. The AI tool also assisted with optimizing chemical dosing to limit disinfection byproducts and remove manganese [5]. The improved efficiency resulted in a 25% reduction in chemical costs in 2020, with a total cost saving of $1.2 million [5]. This is an incredible development given the previously discussed financial struggles of the water sector. Fontus Blue recognizes the challenges facing integration of machine learning, citing complexity, resistance to change and lack of confidence in project outcomes as primary obstacles [5]. However, as success stories like this spread throughout the industry, more water systems will be willing to invest in emerging forms of machine learning and data analytics.

Since beginning work with Akron in December of 2019, Greensboro, North Carolina and Mentor, Ohio have partnered with Fontus Blue to implement AI systems [10]. Greensboro began integrating the new systems in June of 2021 and has already seen reduced averaged settled turbidity in addition to approximately 15% chemical cost savings in the fourth quarter of 2021 [10]. Mentor has seen similarly successful results with a decrease in average settled turbidity and 23% chemical cost savings in 2021 compared to 2020 [10]. Both Greensboro and Mentor both produce approximately 6 million gallons per day, which is significantly less than Akron's 31 million gallons per day [10]. The contrast in size between these plants illustrates that AI systems have the potential to improve water quality and significantly reduce chemical costs in plants of all sizes. It should be noted that while many plants are AI ready, others still struggle with data collection issues [1]. A substantial amount of live and historical data is required to maximize the capabilities of AI [1], so improving data collection and building a digital foundation is required before a meaningful investment can be made.

Fontus Blue recognizes the challenge of integrating potentially confusing and intimidating technology such as AI, and they have developed a simple engagement process to help facilitate a smooth transition to the new software [10]. To bridge the gap between management and operators, Akron, Mentor and Greensville all hold facilitated meetings between management and opertors with varying frequency [10]. These plants also keep consistent records of decisions and actions resulting from the new software [10]. Through these steps and other actions, the plants hope to catalyze an organizational culture change resulting in greater acceptance and understanding of digital tools [10].

Cybersecurity Concerns in the Drinking Water Treatment Industry

With increased reliance on digital tools, the importance of cybersecurity in the water sector has grown significantly over the last several years. Drinking water plants are considered critical infrastructure and have often been the subject of attacks or other security issues [7]. Cybersecurity concerns are not new to water systems, but the complexity and prevalence of threats have increased over the last several years and are likely to continue increasing [7]. Many utilities lack the IT specialists to counter these new threats, and despite new training from regulatory agencies, water systems are still at a disadvantage [7]. In addition, many of the recommended security systems have not been implemented in numerous plants [1]. As with general technology integration, funding also affects implementation of cyber security safeguards [1]. There are numerous types of cyber security threats, but in recent years ransomware attacks have emerged as the fastest growing malware threat [7]. An example of a ransomware attack is the Fort Collins-Loveland Water District incident [7]. Hackers gained control of plant data and made a ransom demand to unlock the data [7]. The water system refused the ransom demand and were able to restore access to the data after a few weeks [7]. With the increased use of data reliant systems including AI, protecting historical data is an important part of technology integration. Even a short outage can be costly, so implementing data segmentation and segregation is an important safeguard to consider [7]. Unfortunately, there are many other examples of ransomware affecting utilities, many of which have sophisticated cybersecurity safeguards including firewalls and antivirus software [7]. Clearly cybersecurity is an area of growing concern and should be considered when investing in new technology. However, this is not always the case and new tools can be difficult to integrate into a preexisting cybersecurity system [1]. Investing in technology already introduces uncertainty, which is exacerbated by increased cybersecurity issues. Thus, it is important to consider cybersecurity concerns as a potential barrier to technology adoption.

Data Collection Methods

Through analyzing case studies and reviewing literature, the following items have been identified as potential barriers to technology integration in the drinking water treatment field: satisfaction with current technology, lack of awareness of technology options, lack of understanding of technology capabilities, lack of funding, lack of staff expertise, lack of customer assistance from vendors, lack of available training, prior investment inhibiting future investment, resistance to change, lack of understanding of technological trends, concern over jobs becoming obsolete, difficulty of learning to use new technology, lack of communication between staff and management, and cybersecurity concerns. To better understand the impact of these potential barriers, a group of superintendents, water quality mangers, plant managers, chief operators and others, were surveyed regarding these topics. The group surveyed are primarily from Ohio, but some responses from Pennsylvania, Indiana, and North Carolina, were recorded. Many respondents are current customers of Fontus Blue and have experience integrating new software systems. The survey received 28 total responses, and many induvial messages were included to provide additional context for their answers.

First, they were asked to rate the extent to which the aforementioned barriers affect technology integration. A ten-point scale was used with ten corresponding to a great extent and one corresponding to no extent. Questions were asked regarding technology integration in general, and again specifically for AI. Relating to AI, respondents were also asked to indicate their level of digital twin readiness, and what type of digital twin they are interested in, if any. As mentioned in the discussion, understanding the decision-making dynamic for investing in new technology is important. Respondents were asked who is generally involved in the decision-making process relating to technology adoption. Respondents were also asked if they were satisfied with the level of communication between staff and management. These two questions provide additional context to the organizational barriers to integration. Through analyzing the responses to these questions, the barriers to technology integration in drinking water treatment will be better understood, and superintendents, software vendors, regulators and others will be better prepared to meet these challenges.

Data and Results

The survey results indicate that on average the respondents are happy with their current level of technology use. They are also aware of other technology options and have a good understanding of these options.

Table 1: Displays survey results for 28 respondents. The table displays the average survey response. A rating of 10 indicates a high level while 1 indicates a low level.

	Average Rating
Level of satisfaction with current technology	7.07
Level of awareness of other technology options	7.11
Level of understanding of other technology options	6.79

As shown in figure one, the barrier with the greatest effect on technology integration is cybersecurity concerns. There is a fairly large margin between cybersecurity concerns and the second greatest issue, prior investment. Cybersecurity concern also has the second lowest standard deviation of all the responses, indicating that the respondents have a good deal of agreement on this topic. The next greatest barriers are prior investment and lack of funding, although lack of staff expertise, lack of understanding of technological trends, lack of training and lack of customer assistance all received similar responses. It should be noted that lack of funding has the greatest standard deviation off all the barriers, indicating a wide variety of responses. Concern about jobs becoming obsolete received the lowest average response, indicating it has the lowest impact on technology integration out of all the potential barriers. The standard deviation values for each barrier are found in the appendix.

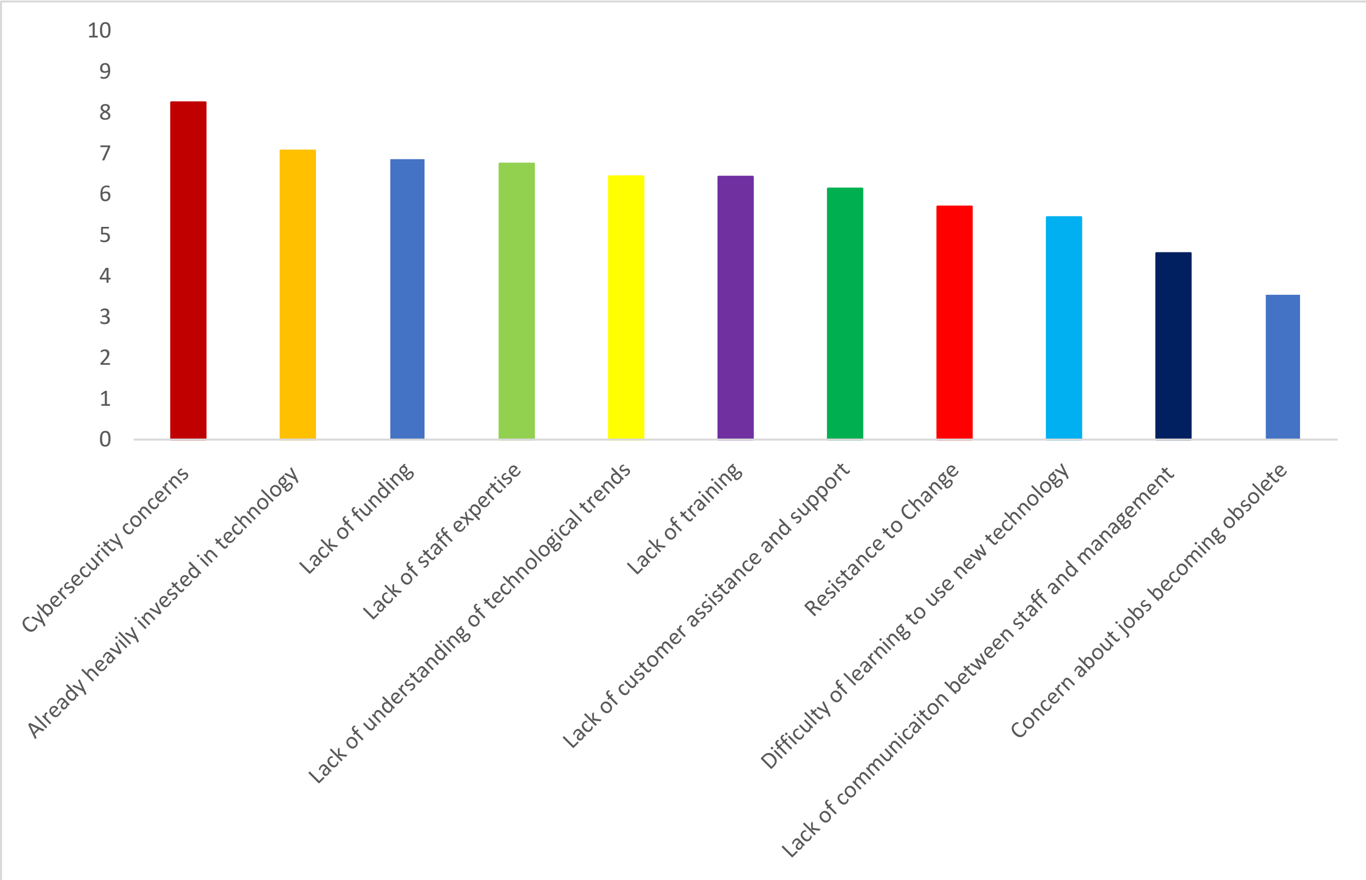

Figure 1: The figure displays the survey responses for all the potential barriers to technology integration. A response of 10 indicates a great effect on further integration of technology, while a 1 indicates no effect. The figure displays survey results for 28 respondents. The exact values are displayed in the appendix.

The respondents indicated what technology they currently use (Figure 2). Nearly all water systems use Microsoft Excel or a similar software while very few are currently using AI or digital twins. Many respondents answered that they use other software not listed, with the most popular write in response being Supervisory Control and Data Acquisition (SCADA) systems.

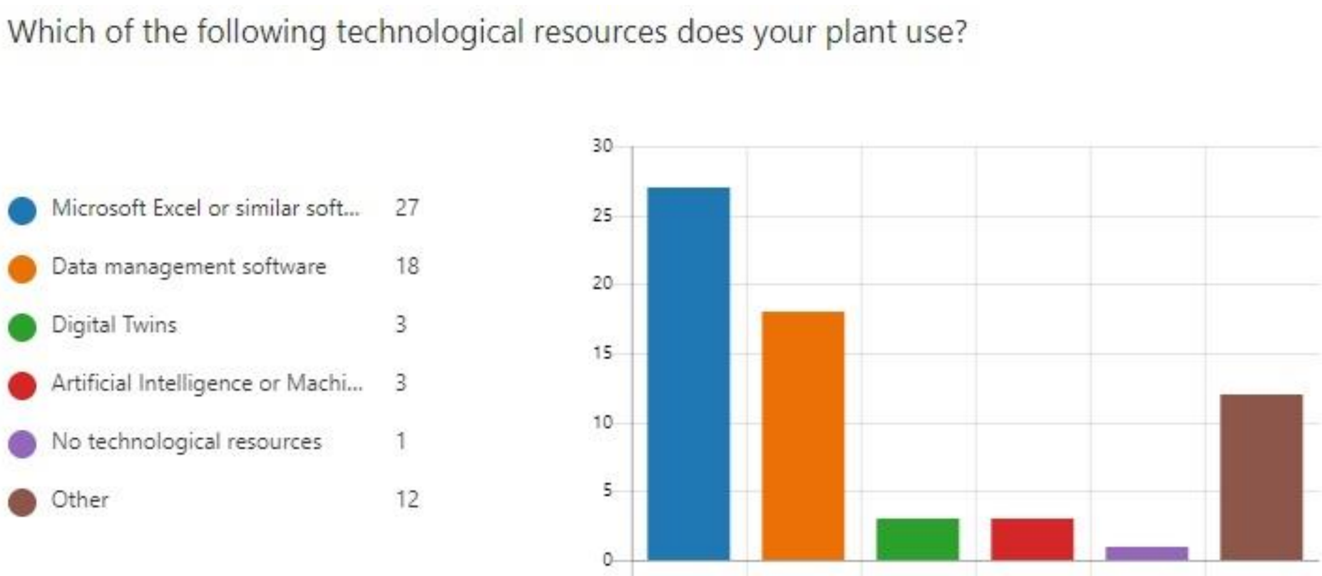

Figure 2: The figure displays which technological resources are currently used by the respondents The figure displays survey results for 28 respondents.

The respondents learn about new technology in a variety of ways but the most common is conferences or other meetings (Figure 3). In addition, learning from co-workers and management, current software vendor, marketing and information from the EPA all received a significant number of responses.

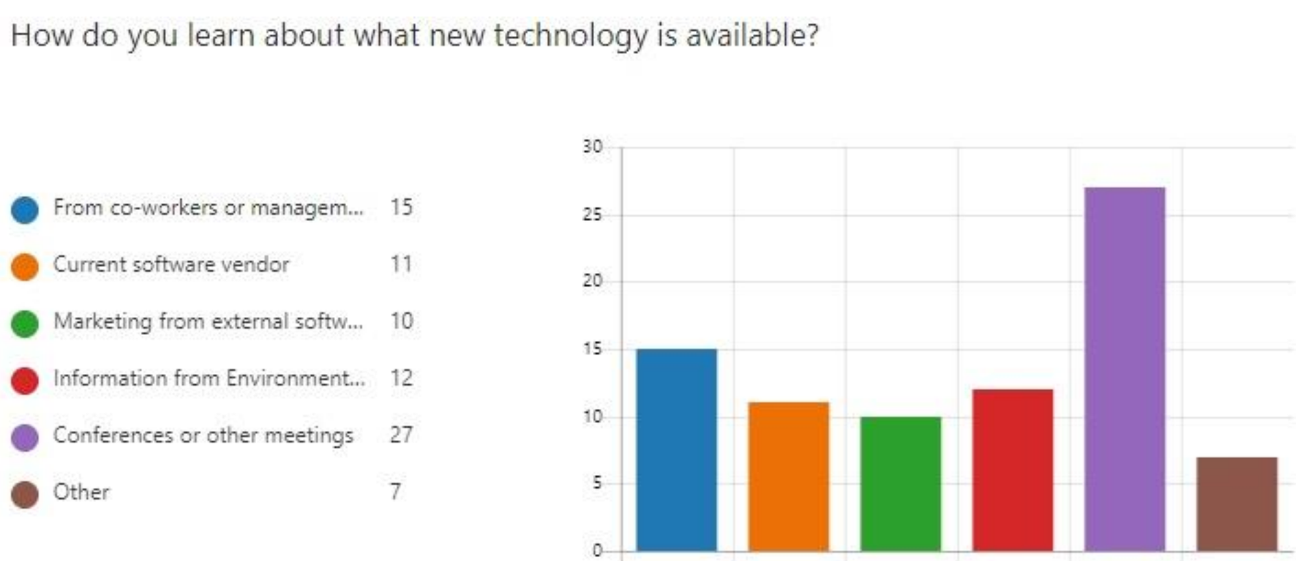

Figure 3: The figure displays how the respondents learn what new technology is available. The figure displays survey results for 28 respondents.

The respondents indicated who is involved in the decision-making process for investing in new technology (Figure 4). Management is involved in all decisions, while IT professionals are involved in the majority or decision. Engineers and operators are involved in less than half of the responses.

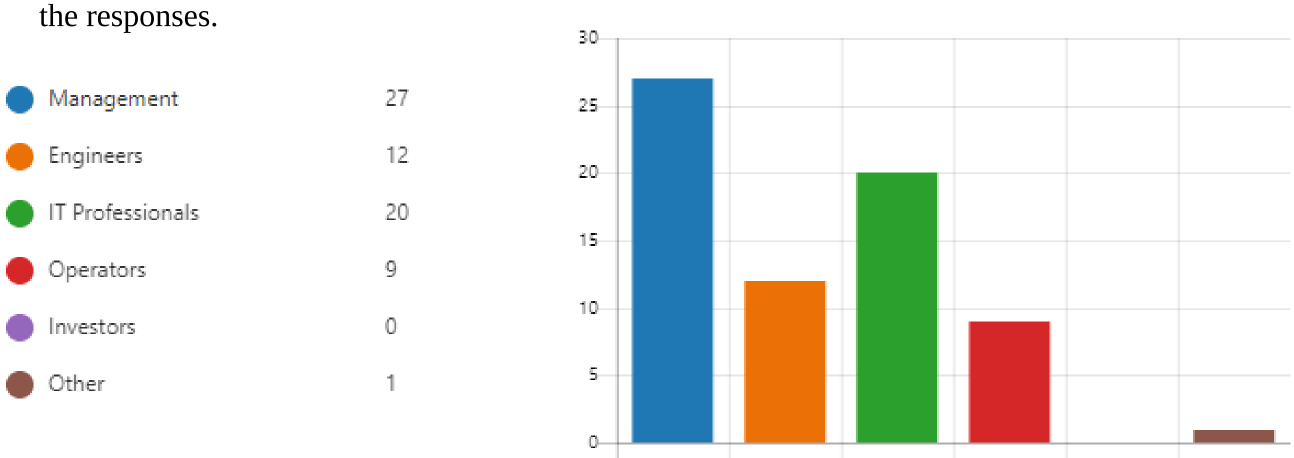

Figure 4: The figure displays who is involved in the decision-making process to invest in new technology. The figure displays survey results for 27 respondents.

Relating to decision making, respondents indicated if they are satisfied with the level of communication between management and staff relating to technology integration (Figure 5). The majority indicated that they are satisfied with their communication

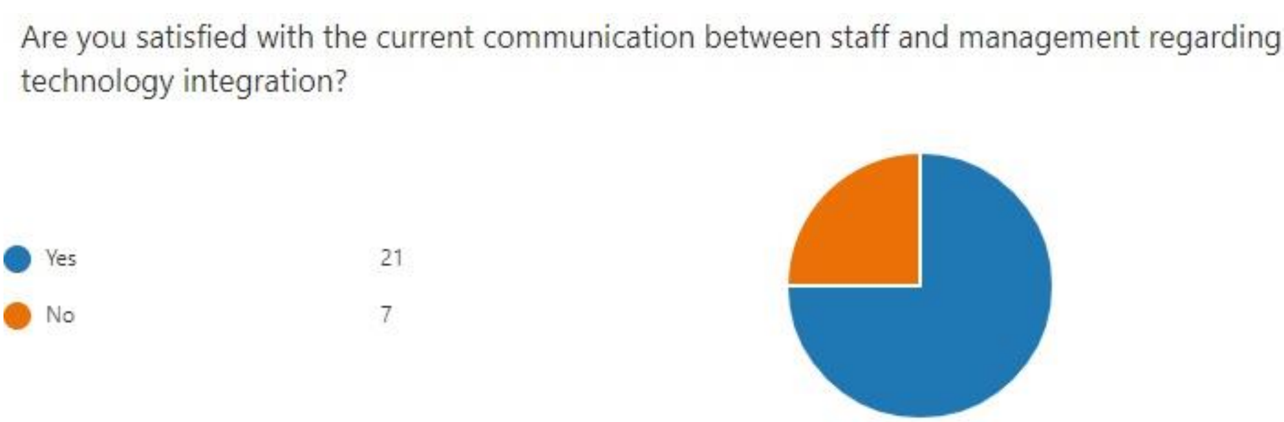

Figure 5: The figure displays the responses to the above question. The figure displays survey results for 28 respondents.

The respondents indicated which type of digital twin they are interested in using, if any (Figure 6). The descriptions of digital twins are included in the appendix. Nearly half of the respondents are not interested in using a digital twin, while asset health and predictive twins each accounted for approximately 25% of responses.

Figure 6: The figure displays which type of digital twin respondents are interested in using. The figure displays survey results for 28 respondents. Some respondents indicated that they are interested in using more than one type of digital twin. See the appendix for a full description of the digital twin terms.

The survey also asked respondents to indicate their plant's level of digital twin readiness (Figure 7). The responses indicate that most are digital twin ready while an equal amount are ready to use operational twins. Descriptions of the terms are found in the appendix.

Figure 7: The figure displays the respondents' levels of digital twin readiness. The figure displays survey results for 20 respondents. See the appendix for a full description of the digital twin terms.

The respondents indicated how familiar they are with artificial intelligence in general and specifically relating to water treatment (Table 2). They also answered if confusion about AI affects further integration. The responses indicate a below average understanding of AI, but confusion is not as significant a barrier as many of the barriers included in figure one.

Table 2: Displays survey results for 27 respondents. The table displays the average survey response for the three questions found in the table.

	Average Response
How familiar are you with Artificial Intelligence and machine learning in general?	4.69
How familiar are you with Artificial Intelligence relating to water treatment?	4.23
To what extent does confusion about AI affect further integration of AI systems?	5.12

Applying the same barriers as in figure one, the respondents were asked to indicate which of the barriers apply to AI (Figure 8). They then selected their top three most impactful obstacles (Figure 9), followed by selecting the single greatest obstacle (Figure 10).

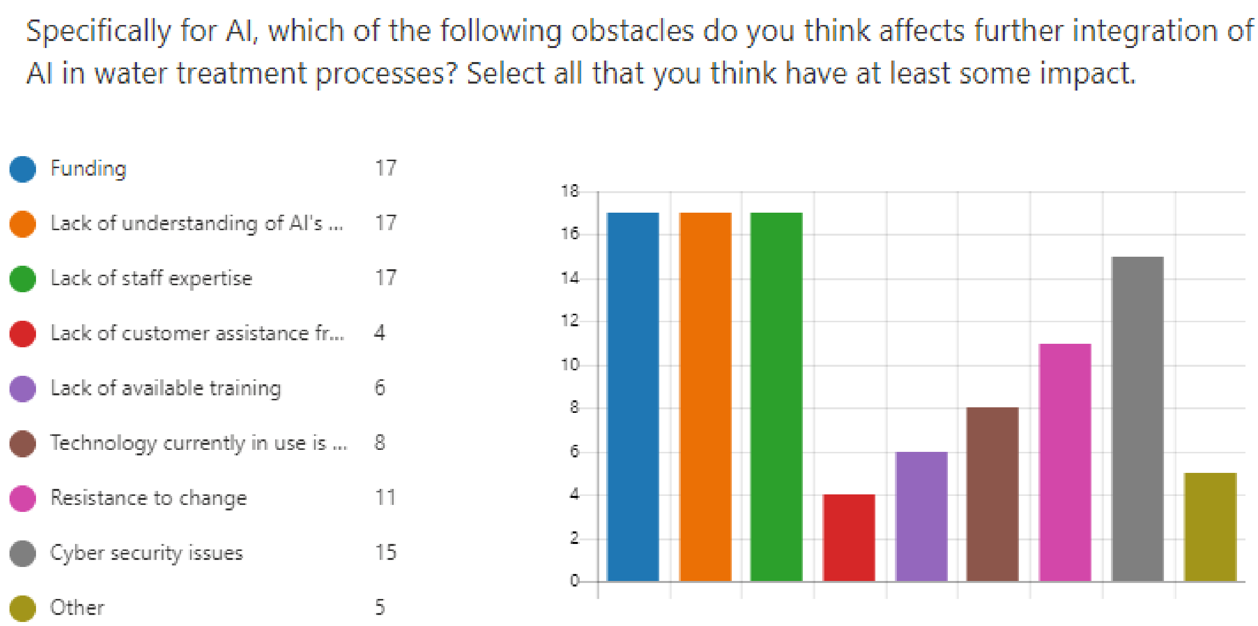

Figure 8: The figure displays the responses to the above question. The figure displays survey results for 26 respondents.

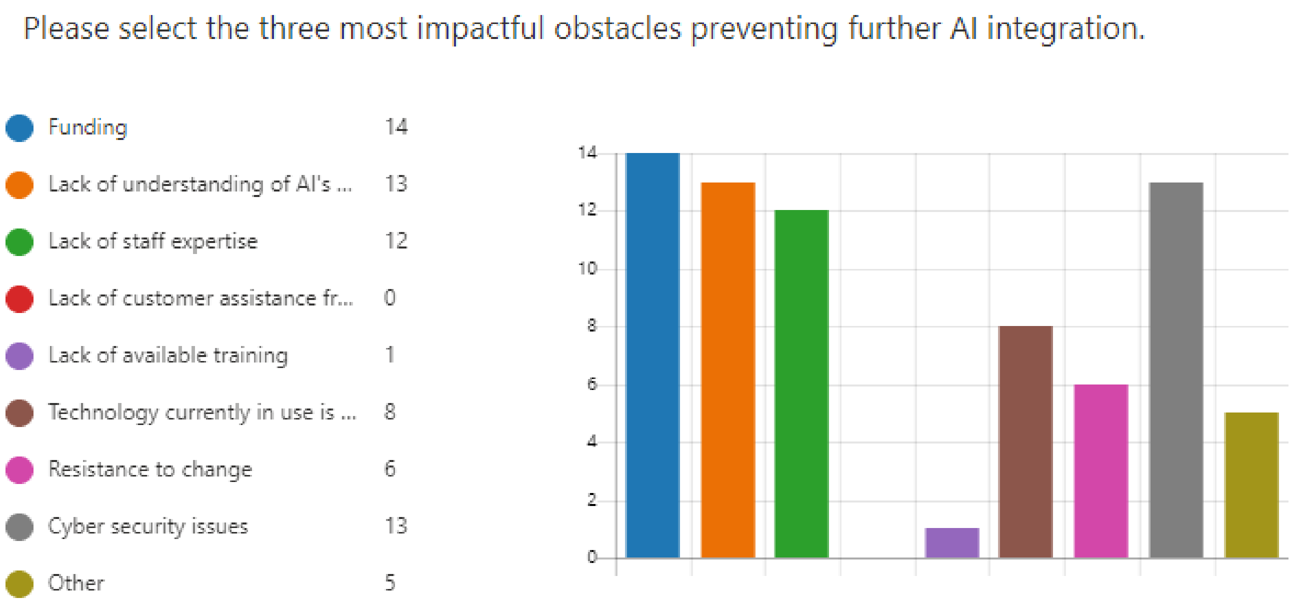

Figure 9: The figure displays the responses to the above question. The figure displays survey results for 26 respondents.

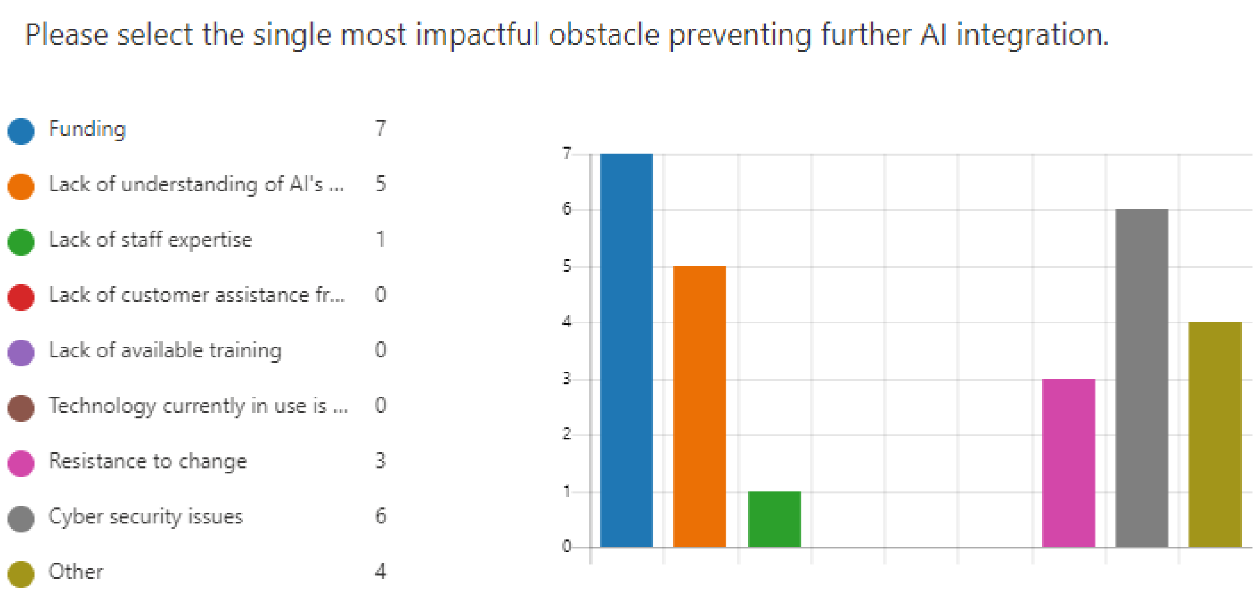

Figure 10: The figure displays the responses to the above question. The figure displays survey results for 26 respondents.

The results indicate that all the barriers have at least some affect. Funding received the most responses for the most impactful obstacle while cybersecurity concerns received the second most votes.

Discussion

As mentioned in the background, drinking water treatment plants are often subject to significant budget constraints [1]. This reality makes it extremely important for systems to invest their money efficiently, and to do this they must be aware of what technology options are available to them. The survey results, displayed in table one, show that on average plants have a good understanding of available technology, with an average rating of 7.07, and they have an above average to good understanding of these options, with an average rating of 6.79. Although these responses do not indicate an extremely strong understanding, it does indicate that on average systems are aware enough of technology options that this likely does not serve as a particularly severe obstacle to additional integration. Plants also indicate that on average they are satisfied with their current technology. Again, due to financial constraints, plants already operate with strong efficiency, which correlates to satisfaction with the process. The responses also indicate that despite a feeling of satisfaction, many systems recognize that improvement is possible.

As demonstrated by the case studies and other literature, processes can often improve on their efficiency in unexpected ways [4]. The responses displayed in figure two show that although on average systems are happy with their current technology, only three systems have invested in digital twins and AI systems. It should be noted that there is a discrepancy between the results shown in table one, regarding technology in general, and table two which specifically references AI. The responses in table two indicate that respondents are significantly less familiar with AI than traditional technology options. The survey results show an average rating of 4.69 for understanding of AI in general and a rating of 4.23 for understanding of AI relating to water treatment. The responses indicate that on average, systems have a below average understanding of AI, which is notable when compared to their overall good understanding of technology options in general. Despite the apparent confusion, the responses indicate that on average, water systems do not perceive lack of understanding of AI to be a leading obstacle preventing AI integration, with an average response of 5.12.

Regarding technology integration overall, figure one shows that cybersecurity concerns is the largest barrier to technology integration by a wide margin. Cybersecurity concerns received an average response of 8.25 compared the second highest result of 7.07. As noted in the results section, cybersecurity concerns also have the second lowest standard deviation, as shown in table three. This indicates that this is a universal issue for most respondents. Given the rise of ransomware attacks in recent years, these concerns are logical and should be investigated further. Following cybersecurity, prior technological investment is the next largest barrier. This result indicates that many systems are beholden to their preexisting infrastructure and cannot overcome this commitment to invest in a new and more advanced product. This is consistent with the results of the Dodge Data and Analytics survey which also identified this a significant barrier [2]. They also identified lack of funding as a significant barrier [2], and the results in figure one agree with this. Lack of funding received the third highest average response of 6.86 which is reasonable given the chronic lack of funding facing the water sector. The results for this obstacle yielded the highest standard deviation of the group, which indicates a rating disparity. Many of the larger plants that responded, such as Akron and Youngstown, responded with values well below the survey average. The two respondents from Akron provided an average rating of 5.5, while the respondent from Youngstown replied with a rating of 4. Meanwhile, Delphos City, a smaller facility producing under a million gallons per day, rated lack of funding as a 10. It should also be noted that all six respondents that answered 10 for lack of funding have a total plant capacity under five million gallon per day. This indicates that perhaps larger operations are less likely to be affected by funding issues than the average water system. Although no exact budgetary data was collected, this issue can potentially be attributed to greater budgetary resources and preexisting infrastructure. In any event, understanding the exact nature of the discrepancy between small and large systems in their ability to integrate new technology is a relevant topic for future research.

The results identify lack of staff expertise as the fourth greatest barrier, with an average response of 6.75. This is something that technology and software vendors need to consider. As shown in the Fontus Blue case studies [5], the intuitive use of the software is just as important as the capability of the software. Despite training and intuitive technology, new systems can still be difficult to master, which represents a slightly different barrier. Difficulty learning to use new technology is similar to lack of staff expertise but includes the initial learning curve associated with new systems. Difficulty learning to use new technology received an average rating of 5.44, which is significantly lower than lack of staff expertise. In fact, this issue received the third lowest average rating. Clearly the respondents are confident in the ability of their peers to quickly adapt to new technology. These results indicate that the ability of operators to comfortably use software is an important factor to consider. In many scenarios a learning curve is unavoidable, but it is less of an issue than many other barriers to technology integration.

The next several barriers are indeed noteworthy but not as impactful as the first four obstacles mentioned. Lack of understanding of technological trends and lack of training received nearly the same average response with results of 6.44 and 6.43 respectively. Understanding trends relates to a lack of funding, as comprehending the overall technological landscape relating to drinking water and the trends associated with it, is integral to making an economically sound investment. As previously mentioned, being highly invested in technology acts as a significant barrier to future investment. Understanding trends allows the water system to invest in technology that has the capability to grow and incorporate new functions as the technology becomes more advanced, lessening the impact of both barriers. Lack of training is noteworthy as it relates to lack of staff expertise but includes training from internal and external sources. Obviously, engagement from software vendors is extremely important, but there is also training available from the Ohio EPA and other external sources. Perhaps a greater variety or training more specific to new technology will be beneficial in minimizing this issue. Lack of training also relates to lack of customer assistance and support, which received an average response of 6.14. This issue speaks to the importance of a prolonged partnership with the technology vendor. This relationship includes help troubleshooting issues and providing training to new employees, but also updating or providing new software. The field of water treatment is constantly changing and having active support from a vendor is important for both meeting new compliance standards but also in implementing new technology.

The next several barriers received three of the lowest average ratings. Despite this fact, these barriers should still be considered and can affect certain organizations more than others. Resistance to change is the next largest barrier with an average response of 5.7, indicating a moderate affect. On average the respondents have over 25 years of experience in the drinking water treatment industry and have experienced firsthand the constantly changing landscape of regulations and technology. Perhaps this barrier is less impactful in the water sector because change is such an integral part of their daily operation. Concern about jobs becoming obsolete is also not regarded as particularly impactful. In fact, it is the lowest rated barrier in the survey with an average rating of 3.54. However, it should be noted that the vast majority of respondents are superintendents or managers, and their jobs are relatively unaffected by this issue. This obstacle is likely more impactful to the operators actively using the software. This can be investigated more in the future but given the nature of the water treatment industry it is likely that the survey result accurately reflects the extent of this issue. As mentioned in the Fontus Blue case studies [4, 5], new software is meant to be used in conjunction with human workers, with employee engagement playing a key role in the effectiveness of the new technology.

Another obstacle with a moderate effect on technology integration is lack of communication between staff and management. This received an average rating of 4.56, which is the second lowest in figure one. This is logical given the results shown in figure five which indicates that 75% of respondents are satisfied with the communication between staff and management. This is an interesting result when compared to the responses displayed in figure four. According to this figure, management is involved in all technology integration decision with IT professionals being involved in 20 out of 27 cases and engineers offering input on 12 out of 27 cases. This distribution makes sense given the wide variety of respondents and the differing human resources available to them. However, operators are only involved in 9 out 27 or $1/3^{rd}$ of cases. Given the recommendations of Fontus Blue and previous discussion about the importance of making operators comfortable with new technology, this number seems quite low. It calls into question the quality of communication between management making the decisions and operators. Employee engagement is not only a significant factor in integrating new technology, but also in optimizing the use of current technology. Strong communication throughout the organization is an important part of this and involving operators in the decision-making progress appears to be a logical way to increase engagement.

Digital twins and other AI tools are a unique case of technology integration, as they are subject to many of the previously mentioned barriers, but also have an air uncertainty surrounding them. The data in figure six shows that despite evidence and case studies of the usefulness of digital twins, many are not interested in using them. Nearly half of the respondents fall into this category, and only three are currently using a digital twin. Of the remaining respondents, eight are interested in using an asset health twin while seven are interested in using a predictive twin. These twins offer real time updates of assets, and simulation calculation capabilities [2]. Given the popularity of these two options, it appears that software vendors should focus efforts on meeting these needs and be able to adapt to fill the needs of the security and immersive twin in specific scenarios. Similarly, efforts should be focused on meeting the needs of level zero and level two systems, as shown in figure seven. This indicates that systems are poised to use both historical and live data streams. Process optimization and compliance management should be the primary goals of the software in addition to design support and traditional planning. The new information from the survey can provide direction to software vendors, but digital twins are still falling victim to barriers to technology integration evidenced by the low level of interest shown in figure six.

The obstacles preventing further integration of AI are similar to those affecting traditional technological resources but are skewed slightly because of the lack of understanding of AI shown in table two. Figure eight indicates that all the previously mentioned barriers affect AI, although lack of customer assistance and lack of available training received relatively few votes. Figure nine narrows the scope and calls attention to lack of funding, lack of understanding of AI's capabilities, lack of staff expertise and cybersecurity concerns. Figure ten identifies the respondents' single most impactful barrier, which reveals funding and cybersecurity concerns as the two most impactful obstacles. This is similar to the results shown for traditional technology in figure one, where lack of funding and cybersecurity concerns make up two of the top three barriers. According to figure ten, lack of customer assistance, lack of training, and lack of staff expertise are not to be regarded as the most impactful issue. Resistance to change should be noted as an important but secondary barrier. Unsurprisingly, lack of understanding of AI's capabilities is a significant obstacle. As shown in figure ten it received the third most responses for the most impactful barrier. This is to be expected given the previous discussion. By identifying these issues, hopefully water systems and software vendors can adapt to overcome these barriers in the near future.

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Appendix

Digital Twin Purpose	Description
Asset Health Twin	Informed by real-time, IoT and sensor-based data streams for a live pulse on physical asset and operational conditions
Predictive Twin	Replicate and simulate scenarios based on actual operational data to inform of future conditions
Security Twin	A distributed ledger representing physical and digital systems access, usage and uptime
Immersive Twin	A living virtual representation of an asset that includes all major functional services, often connected across domains

Figure 11: The figure displays the diagram explaining the different purposes of digital twins. This diagram was used in a 2022 presentation by James Cooper of Arcadis [6].

Digital Twin Levels Matrix

	Level 0 **Digital Twin Ready**	Level 1 **Informational Twins**	Level 2 **Operational Twins**	Level 3 **Connected Twins**
Key Components	GIS, BIM, SCADA	• Interoperable environment • Multiple data sources/historians • Hydraulic model	• Interoperable environment • Live data streams • Asset and external data sources	• Interoperable environment • Live data streams • Asset and external data sources
Data Sources	Historical or Static	Historical or Static	Live Data Streams	Live Data Streams
Functionality	Tool-specific functions	Data access, master planning, long-term planning	• Operations support • Real-time analytics	Enterprise-wide solutions
Business Value	• Ops monitoring • Design support • Traditional planning	• Vert. Asset mgmt. (BIM+CMMS) • Horiz. Asset mgmt. (GIS+CMMS) • What-if scenarios, training	• Process optimization • Compliance management	Interdepartmental coordination for resources and infrastructure
Requirements	• Established tools • Data management	• Data governance/security • Integration framework	• Utility data plan • Utility communication network plan	• City-wide data plan • City-wide communication network plan

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Figure 12: The figure displays a matrix explaining the different levels of digital twin readiness. This diagram was used in a 2022 presentation by James Cooper of Arcadis [6].

Table 3: The table displays the exact average values for the data found in figure one. It also includes the standard deviation values.

Potential Barriers to Technology Integration	Average Response	Standard Deviation
Cybersecurity concerns	8.25	1.9
Already heavily invested in technology	7.07	2.11
Lack of funding	6.86	2.64
Lack of staff expertise	6.75	2.15
Lack of understanding of technological trends	6.44	2.15
Lack of training	6.43	1.9
Lack of customer assistance and support	6.14	2.34
Resistance to Change	5.7	2.42
Difficulty of learning to use new technology	5.44	2.2
Lack of communication between staff and management	4.56	2.45
Concern about jobs becoming obsolete	3.54	2.41