SMART IOT-WSN WATER QUALITY MONITORING AND POLLUTION ASSESSMENT FRAMEWORK (SWMPAF)

Product Delivery and Handover

Report to the
Water Research Commission

by

Tom Walingo
Discipline of Electrical Electronic and Computer Engineering
School of Engineering
University of KwaZulu-Natal

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Obtainable from
Water research Commission
Bloukrans Building, Lynnwood Bridge Office Park
4 Daventry Street
Lynnwood Manor
PRETORIA

orders@wrc.org.za or download from www.wrc.org.za

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EXECUTIVE SUMMARY

The project is to conduct research and development of a Smart IOT-WSN Water Quality Monitoring and Pollution Assessment Framework (SWMPAF) for the Water Research Commission (WRC). The project is a research cooperation by the WRC and the University of KwaZulu-Natal Electrical Electronic and Computer Engineering.

The main aim of the project is to develop a practical remote water monitoring and reporting product. The system would collect data from sensors (temperature, pH, conductivity, chemical sensors, etc.) deployed in a water body (including rugged environments) and wirelessly transmit sensed data to the control room where it is managed by the developed software application.

The project is to be executed in six phases with six deliverables save for the inception report. Phase one is the development of a refined specification and implementation plan for the required SWMPAF. Phase two is a survey of the advancements, trends, and constraints in Smart Water Quality Monitoring Systems. Phase three is the design of the SWMPAF while phase four is the implementation. Phase five is the tuning of the software application and finally phase six the product delivery and hand over. Phase 6 is the product delivery and handover after successful completion of all phases and deliverables.

Summarily the project has developed and recommended the SWMPAF architecture and specifications. The project then produced a detailed report on the trends in water quality monitoring featuring the selection of water quality indicators, focussing on turbidity, potential of hydrogen, faecal coliforms, electrical conductivity, dissolved oxygen and temperature due to their applicability. The report delved into the development of soft sensors for parameters that cannot be electronically measured by employing Artificial Intelligence techniques. The report then presented the challenges and mitigation measures for water quality monitoring. With the research presented in the report, various recommendations were made for the design and implementation of the SWMPAF. The project then went into the product development phase starting from R&D to the deployment of final product. The Design, testing and reimplementation was successfully done for the SWMPAF. Field tests site visits and stakeholder's acceptance were conducted successfully. The final product was delivered with fully functionality. However, the soft sensors will need more data to improve their accuracy.

The outcomes of the project were successfully achieved and include the following: A detailed report on the trends of water quality monitoring with recommendations. Development of a SWMPAF product featuring all stages of research and development, design, testing and implementation. The successful product was adopted by industrial stakeholders and has led to more funds for further development and commercialization of the product. Technologically the paper has produced journal research publications in reputable journals in the field thus contributing to the knowledge on water quality monitoring. For capacity development the project has produced postgraduate students with some still to graduate. Personnel from different stakeholders have been trained on different aspects of water quality monitoring. The repository for the research outputs, hardware and software is given.

We can conclude that the project was successful in almost all aspects. The success of the project was aided by the fruitful cooperation of Electrical Electronic and Computer Engineering at the University of KwaZulu-Natal, The Water Research Commission, the project reference

members, The UKZN's WASH centre and all the many people who were directly or indirectly involved. They all have put the product to a different level awaiting commercialisation. This will be a significant contribution for water quality monitoring in the country. No such commercial product is deployed in the country and this is pioneering work. The available international solutions are expensive and difficult to maintain.

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ACRONYMS & ABBREVIATIONS

ADC	Analog-to-digital converter
AI	Artificial Intelligence
DO	Dissolved Oxygen
E. coli	*Escherichia coli*
EC	Electrical Conductivity
GSM	Global System for Mobile Communications
GUI	Graphical User Interface
ML	Machine Learning
pH	potential of Hydrogen
RF	Random Forest
SWMPAF	Smart IOT-WSN Water Quality Monitoring and Pollution Assessment Framework
SWQM	Smart water quality monitoring
T	Temperature
TDS	Total Dissolved Solids
Turb	Turbidity
UKZN	University of KwaZulu-Natal
WQM	Water Quality Monitoring
WRC	Water Research Commission
WSN	Wireless Sensor Network

GLOSSARY

Graphical User Interface (GUI). Is a user interface that allows a user to interact with devices using graphic icons, audio prompts, etc.

Media Access Control (MAC). Is the layer that controls hardware responsible for the communication with wired, wireless, optical transmission medium.

Random Forest (RF). Is a type of prediction modelling built by decision trees to classify data.

Transducer Electronic datasheet (TEDS). Set of standardised electronic data located in a chip on a transducer thus, enabling the transducer to describe itself to a network.

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

The project is to conduct research and development of a Smart IOT-WSN Water Quality Monitoring and Pollution Assessment Framework (SWMPAF) for the Water Research Council (WRC). The project is a research cooperation by the WRC and the University of KwaZulu-Natal (UKZN) Electrical Electronic and Computer Engineering. Following a series of meeting, deliberations, and evaluation of facts on the ground by the two key stakeholders, the design of the project, the implementation and the hardware and software training this report is the final documentation for the project. It provides an overview of all aspects of the project. The repository of the software and hardware developed are provided. For detailed knowledge in a particular aspect one should consults the individual deliverable reports. This report provides an overview of the successfully developed SWMPAF for water quality measurements.

1.2 PROJECT AIM

The following were the aims of the project:

1. Provide a comprehensive critical literature review on IOT water quality monitoring systems, trends, opportunities, risks, and policy.

2. Provide proof of concept on the development of specifications and technologies for Smart IOT-WSN Water Quality Monitoring and Pollution Assessment Framework (SWMPAF) for a designated water body.

3. Provide a design and prototype of the SWMPAF. This involves fabrication of the SWMPAF hardware and development of software. Develop and test the designed SWMPAF hardware and software.

4. Develop and deployment of the pilot SWMPAF product, testing and management monitoring, and software application at the Umgeni River lagoon.

5. Explore ways of commercialization and deployment of the product for national water monitoring.

1.3 SCOPE AND LIMITATIONS

The developed prototype will be implemented at a selected site. The wide deployment of many sensors in several remote sites is not covered in this project.

CHAPTER 2: TRENDS IN WATER QUALITY MONITORING

2.1 INTRODUCTION

Water quality monitoring has evolved starting with time and technological advances from manual sampling and lab testing. The second phase was the improvement in laboratory testing techniques. This has now been followed by the introduction of wireless sensor networks for sensing. Due to the unavailability of physical sensors for some parameters, the technology has evolved to soft sensors aided by artificial intelligence. This is at the infancy and still not accepted by the industry. A summary of the current trends in water quality parameters, wireless sensors constraints, challenges, and possible solutions associated with these WSN water quality monitoring systems has been extensively explored in the report of deliverable two and the published journal paper. Below we summarize the recommendations for this literature.

2.2 OBSERVATIONS AND RECOMMENDATIONS ON TRENDS IN WATER QUALITY MONITORING

1. There are diverse WQM indicators; physical (temperature, salinity, suspended solids, dissolved solids, turbidity, and colour), chemical (dissolved oxygen, pH, nutrients, organic and inorganic compounds), biological (algae and bacteria), aesthetic (colour, odour, taints, and floating matter) and radioactive (alpha, beta, and gamma radiation emitters). Their importance and usage ranges depend on the water usage category; domestic, industrial, agricultural, and recreational and are stipulated in international, national and local water standards.

2. The main measurement techniques for water quality indicators are chemical/biological/electrical based measurements; algae, turbidity, clarity, TDS, pH, total hardness, chloride, faecal coliforms*, E. coli,* Faecal Streptococci, Coliphages, Electrical Conductivity, Dissolved Oxygen, Temperature, Oxidation Reduction Potential, Odour. The industrial acceptable methods of measurements of these parameters are stipulated in international, national, and local water standards.

3. Water quality monitoring has evolved from the manual laboratory systems to the wireless sensor- based systems. The wireless sensor-based systems are limited in terms of sensor parameters due to the unavailability of sensors. Currently the manual laboratory-based systems are still the base and wireless systems are used as complementary systems in special cases.

4. Due to the unavailability of electronic sensors for some parameters, soft sensors are being developed. The following can be measured by electrical sensor-based methods, Turbidity, Total Dissolved Solids, pH, Total Hardness, Electrical Conductivity, Dissolved Oxygen, Temperature and Oxidation Reduction Potential. Artificial intelligence techniques are used to develop soft sensors due to their relation to other sensors or by learning the environment. This is the direction sensing is going though

still not standardized and accepted by the industry.

5. A recent trend in WQM has been the introduction of Artificial Intelligence (AI) in determining the quality of water. Machine learning, a subset of Artificial Intelligence (AI). Machine learning algorithms create mathematical models, that can predict or make decisions based on training (sample) data. In wireless sensor networks, the use of supervised machine learning algorithms can greatly bolster data interpretation, classification, early warning, and water quality parameter prediction. Whilst ongoing

research still faces the challenges of high-power demand, increased quality of computational resources to generate results, and increasing the size of training data to improve the performance of machine learning algorithms, the need for these techniques do outweigh the challenges. Recent implementations of AI in WQM can be found in the journal or report.

6. There are recent trends in the sensor technology with the advance of technology. New effective sensors are being developed with time. This traditional sensor technology for laboratory-based measurement equipment includes potentiometric, mass spectrometric, ion-sensitive electrodes, conductometric, amperometric, etc. This is evolving with new methods such as fibre optic, fluorescence detection, electromagnetic wave, biosensors, lab-on-a-chip, infrared (IR). Furthermore, soft sensors based on AI are on the way.

7. There have been advances in WQI measurement methods. For several of the WQI, there has been an advancement or change in trend for the chemical measurement of the WQI. The main method/s of measurement are stated in international, national, and local standards.

8. There have been advances in smart water quality monitoring in terms of, wireless technologies, electronic hardware and software advances, data analytics advances. This have led to tremendous improvements in water quality measurements due to their inherent advantages.

The full document of the trends in water quality monitoring can be found in the Appendix of submitted files.

CHAPTER 3: DEVELOPED SWMPAF SONDE HARDWARE

3.1 INTRODUCTION

This following chapter provides an overview of the developed SONDE where the SONDE hardware is presented. The intricate details, specifications, design and testing are not provided. They can be found in the provided reports while some are still under copyright protection. The product is still to undergoing the commercialization phase.

3.2 SWMPAF HARDWARE

The specifications of the developed SONDE are still subject to rigorous testing before the final tested specs are given.

Table 1. Sensor specifications

Sensor	Expected lifetime	Calibration frequency	Operational temperature range	Operation range
Temperature	More than 2 years	12 months	-5 to 50 degrees	*as specified by the manufacturer
PH	More than 2 years	12 months	-5 to 50 degrees	*as specified by the manufacturer
Turbidity	More than 2 years	12 months	-5 to 50 degrees	*as specified by the manufacturer
Conductivity	More than 2 years	12 months	-5 to 50 degrees	*as specified by the manufacturer
TDO	More than 2 years	12 months	-5 to 50 degrees	*as specified by the manufacturer
Battery	More than five years	NA	Rechargeable Lithium-Ion > 15 hours (powering full EXO3) 9 hours (from 0 to 100%)	

Due to the variety of sensors available, it is not practical to provide instrument-specific advice on storage, calibration and maintenance in this document. The manuals should always be consulted for sensor specific information.

The implemented SONDE system utilises electronic probes for electronically measurable parameters, turbidity, total dissolved oxygen, pH, electrical conductivity, and temperature. The implemented system features one soft sensor for *E. coli*. The measurements are predicted from the electronic probes through artificial intelligence techniques. The implemented system is as shown in Figure 1.

Figure 1. Developed SONDE product.

The implemented system follows the star topology of Figure 2. with nodes connected to the gateway. The nodes communicate to the gateway with Lora technology.

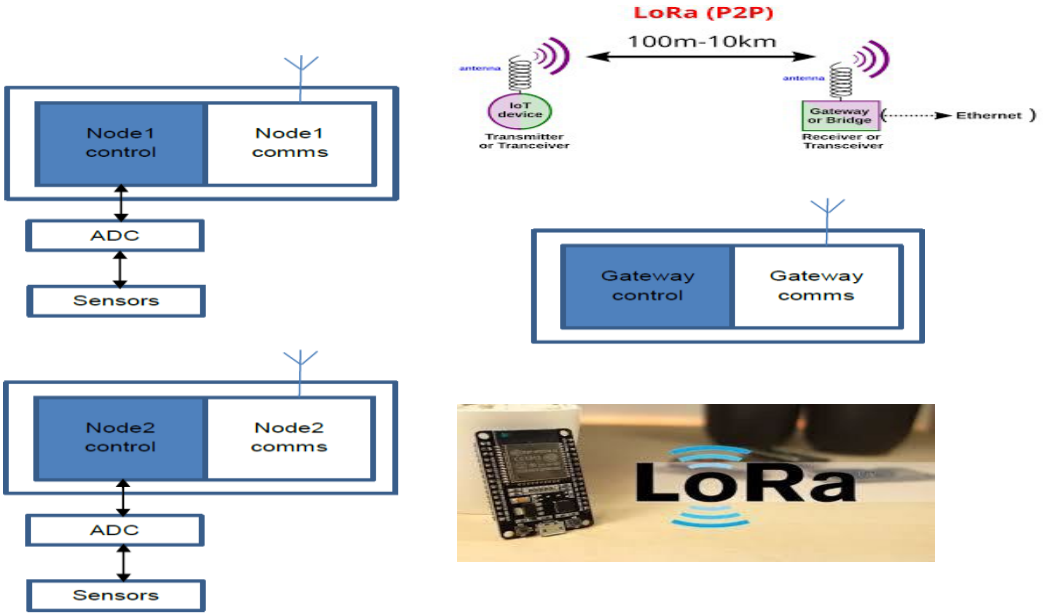

Figure 2. Product topology.

The practically implemented system deployed at the Midmar dam is as shown in Figure 3.

Figure 3. Field implementation.

The current implemented hardware can be found in the Appendix of submitted files. A complete usage manual is in its completion stages.

CHAPTER 4: DEVELOPED SWMPAF SONDE SOFTWARE

4.1 INTRODUCTION

This following chapter provides an overview of the developed SONDE where the SONDE software is presented. The intricate details, specifications, design, mathematical equations, artificial intelligence algorithms, testing, etc. are not provided. They can be found in the provided reports while some are still under copyright protection. The product is still to undergoing the commercialization phase.

4.2 GENERAL DESCRIPTION

The following specifications were implemented for the software. Database communication – Links the user to the MySQL database. Allows the user to view the data stored in the MySQL database from the sensor networks. Data from each of the different sensor networks can be viewed separately on the application. Provides the user real-time viewing of sensor network data both current and previously logged instances. Provide the user with different methods of graphically viewing data.

4.3 DATABASE

The database was created using PHPMyAdmin. PHPMyAdmin is a free, open-source administration tool. PHPMyAdmin is accessible over internet and uses MySQL and MariaDB. It utilises a GUI that allows administrators to access, create, and edit databases. This enables a user-friendly experience in database management. SQL statements can be injected directly into a provided terminal to manage databases if the administrator does not wish to use the GUI of PHPMyAdmin. A database page for the SONDE is shown in Figure 4

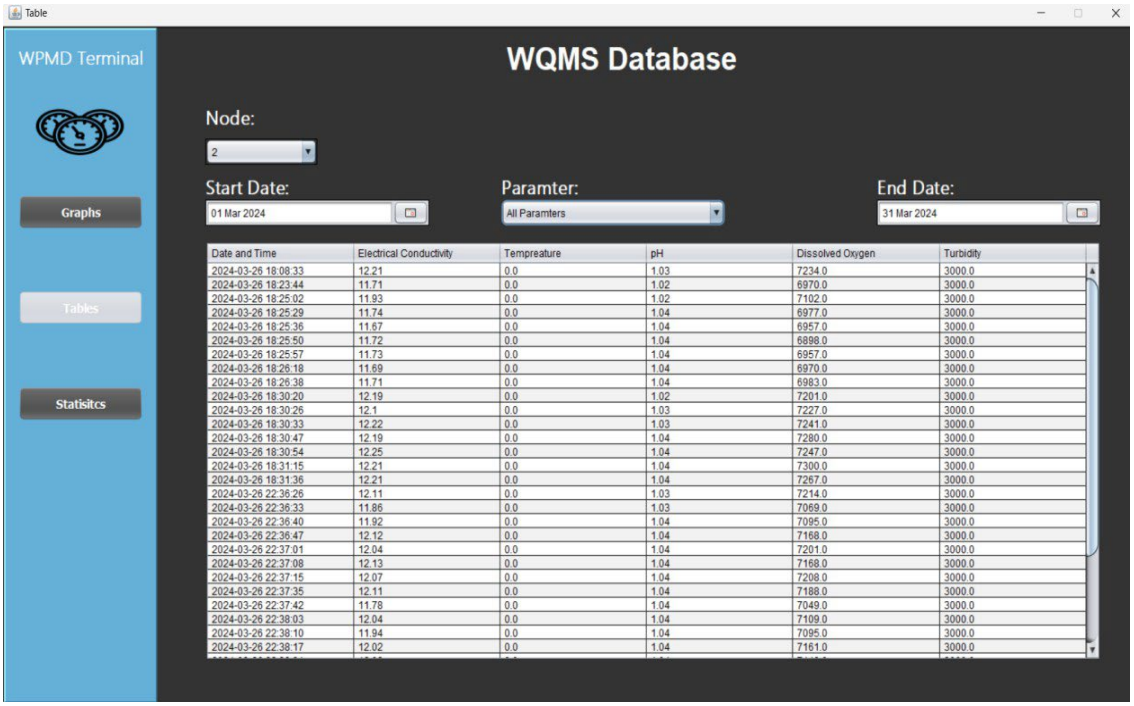

Figure 4 Database Tables

4.4 SONDE GUI

The home page of the SWMPAF allows the user to navigate between the different sensor network pages. The home page can be seen in Figure 5.

Figure 5. Home Page of Desktop Application.

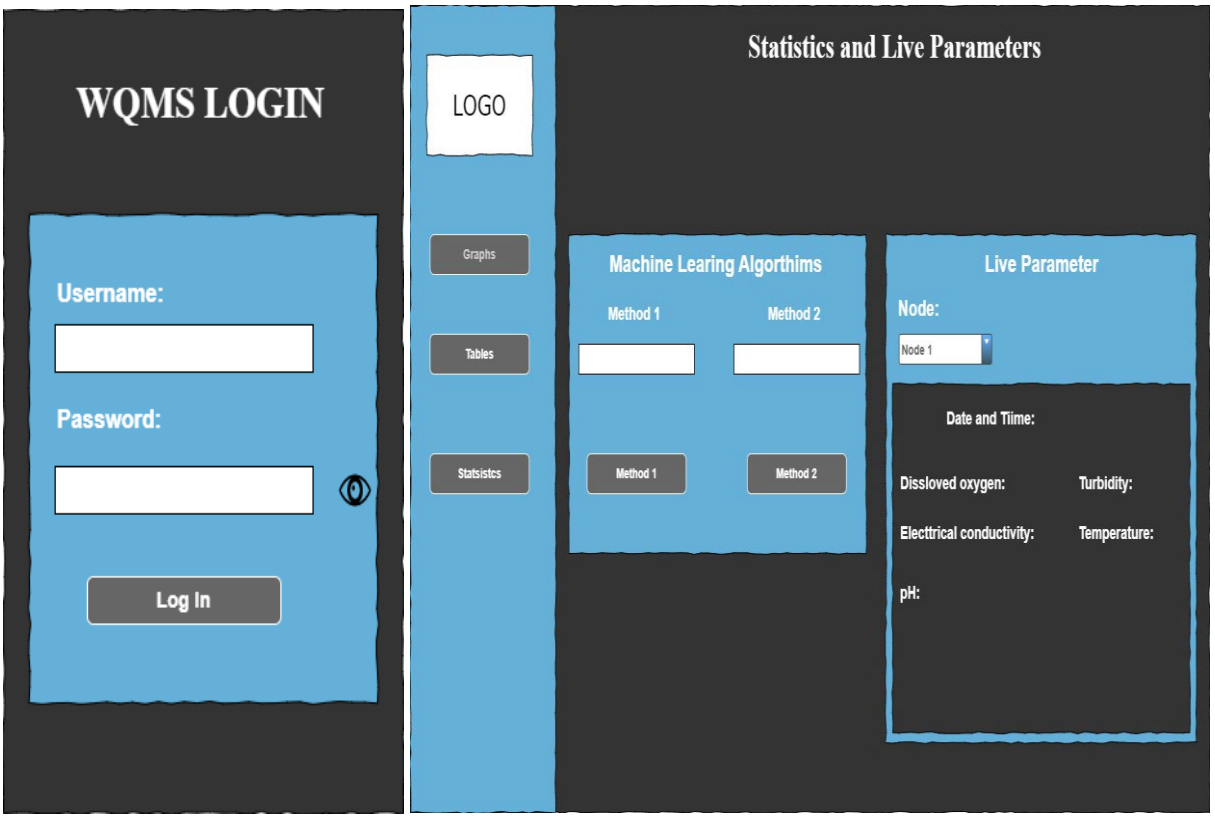

Figure 6. SONDE GUI Pages.

4.5 SENSOR NETWORK PAGE

The sensor network page allows the user to view current and previously captured parameter data. The user can navigate between viewing their parameter data on a graph or table on the sensor network page. The sensor network page can be seen in Figure 7.

Figure 7. Sensor Network Page for Desktop Application.

4.6 SENSOR PARAMETER VIEWS

The sensor parameters can be viewed from the menu of Figure 8.

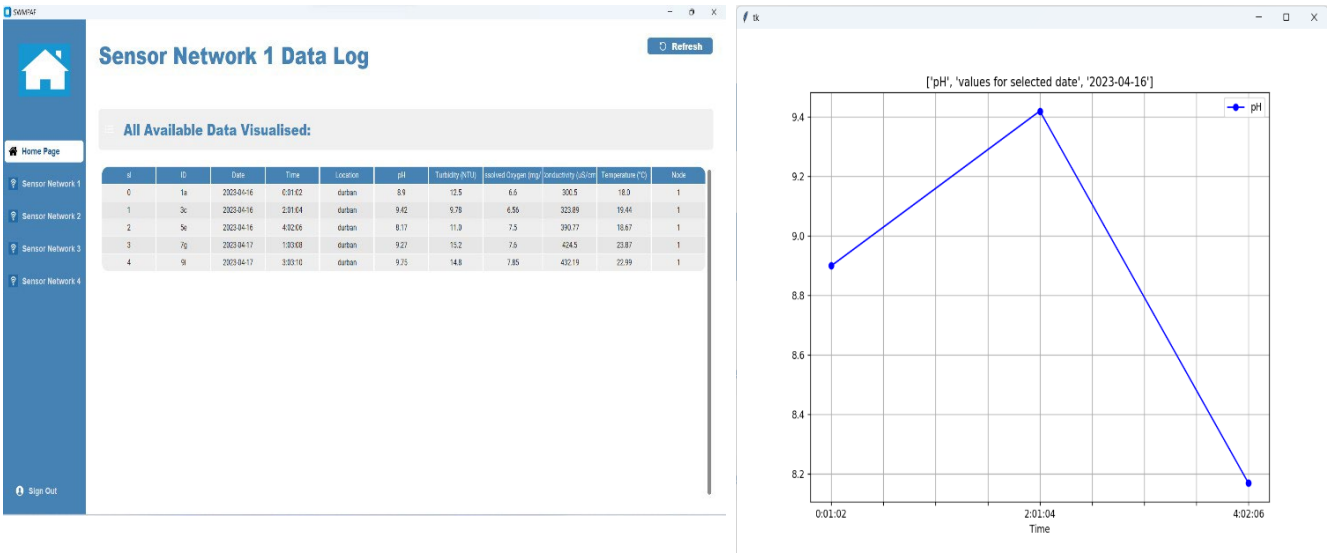

Figure 8. Displayed table and graph with parameter data on desktop application.

The current implemented software can be found in the Appendix of submitted files.

CONCLUSION

A SWQMF product was developed that measures pH, Conductivity, Turbidity, temperature was designed developed and implemented. A framework for collecting data towards the software implementation of *E. coli* measurement was developed. Different IOT communication protocols were investigated and functional systems developed. Research and implementation papers for this technology are in the pipeline. The repository for the developed software and hardware is given. This is the first time such a SONDE has been developed in the country. We hope to commercialize it towards assisting in water quality monitoring in the country. This has received interest with potential funding from a key stakeholder in the water industry.