Optimising water quality monitoring network design for bidirectional river systems

Professor Yong Yue, from Xi'an Jiaotong-Liverpool University, and his research team are using computational modelling to turn the tide of water quality management in bidirectional river systems, leading to improved pollutant sensitivity and faster detection times. Their work could help water quality management bodies, including governments and primary industries, develop efficient, sustainable and low-cost monitoring networks that promote public health and support environmental protection efforts.

Freshwater river systems play a vital role in sustainable community development, often acting as a source of drinking, cooking and cleaning water for the public while also supplying water for agriculture and other key industries. Living and industry practices, however, are filling rivers with faecal matter and other organic pollutants, which are known to carry infectious disease-causing agents as well as harmful pesticides, heavy metals and other chemicals that have been linked to cancer. Furthermore, excess nutrients can produce toxic algal blooms that cause water discolouration and reduce available oxygen in the water, killing fish and other organisms living in affected river systems.

WATER QUALITY MONITORING NETWORKS

Researchers have been working on water quality management programmes since the 1940s, but much of this work has focused on unidirectional river-flow. Scientists have wrestled with technological and financial restrictions and sifted through countless possible sensor locations in their quest to develop optimal water quality monitoring networks (WQMNs) that would help ensure public health, support environmental protection efforts and aid in sustainable freshwater use.

A truly optimal WQMN would account for the depth, flow rate and direction of the river in question, among other variables. To try to simplify the problem, scientists have based their WQMN design on unidirectional rivers. Some rivers, however, such as those in east China's Taihu Lake Basin, are tidal and so have bidirectional flows. This can affect the existing monitoring networks' ability to detect pollutants and change optimal sensor locations, therefore limiting pollutant detection in bidirectional river systems and potentially increasing the risk to public and environmental health.

A NOVEL OPTIMISATION ALGORITHM

Professor Yong Yue of Xi'an Jiaotong-Liverpool University and his research team found that the influence of bidirectional water flows on the design of WQMN had not been investigated to date. They also recognised that bidirectional water flows, affected by regular tides, perform a vital part in surface river systems. The research team have employed optimisation theory to develop a new algorithm to help optimise WQMNs for tidal river systems. This novel approach can reduce redundant monitoring nodes and save the expense of building and operating a monitoring network.

The new algorithm is incorporated into the design of an optimum WQMN for tidal rivers with bidirectional water flows. The research team employ two optimisation objectives: minimum pollution detection time and maximum pollution detection probability, in their optimisation algorithm. The researchers have taken the existing Multi-Objective Particle Swarm Optimization (MOPSO) algorithm and developed new fitness functions to compute both the pollution detection time and the pollution detection probability.

Fishing boats sailing on Taihu Lake.

An example of water pollution.

SIMULATING THE RIVER SYSTEM

Instead of modelling the 120,000 km of river networks in the Taihu Lake Basin, the XJTLU team required a relatively small river system to demonstrate their algorithm. Fortunately, one already existed in the literature that was 8.53 km in length. Utilising this hypothetical river system also allows the research team to compare experimental results with those from the literature.

Pollutants were 'added' using a dynamic rainfall-runoff simulation model, the Storm Water Management Model (SWMM) which is used for single and continuous runoff events primarily in urban areas. These pollutants were detected using three 'monitoring devices', deployed within 12 possible locations as in the previous studies.

VALIDATION OF RESULTS

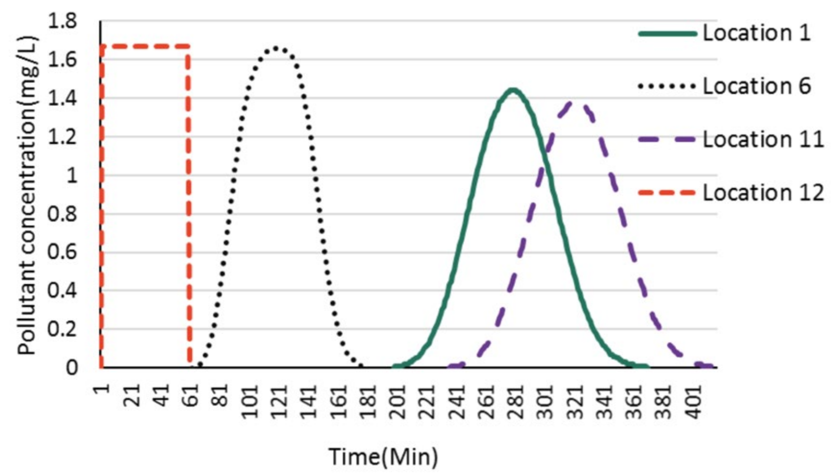
Simulations of unidirectional river-flow, reversed unidirectional river-flow and bidirectional water flows were carried out. The researcher ran the simulation several times to validate that the simulation was producing steady results. To determine whether these results were optimal, the Pareto frontier, that is the set of optimal parameters, was generated. The team also developed an enumeration search algorithm, which was used to confirm that the new optimisation algorithm found the full Pareto frontier and didn't leave anything out. Both the new algorithm and enumeration search algorithm obtained the same results confirming the suitability of their algorithm for the optimum design of a water quality monitoring network.

RESULTS

The researchers found the optimisation results for both unidirectional river-flow directions to be quite different. This supports their claim that the water flow direction has a significant effect on optimisation results, even for the same river system. The XJTLU team recommends that bidirectional water flows are considered when designing an optimisation monitoring network for a river system that is regularly affected by tides.

Large rivers, like the Ganges in India, are relied on by people around the world - despite high levels of pollution.

The influence of bidirectional water flows on the design of WQMN had not been investigated to date.



Changing process of pollutant concentration at location 12 when pollution event occurs at locations 1, 6, 11, and 12 respectively.

BIDIRECTIONAL FLOW
While investigating the previously unexplored bidirectional flow, the researchers recognised that while water flow directions can be changed regularly due to tides within a river system, the duration for each flow direction may not be equal. They therefore considered two scenarios: that both water flow directions have the same probability in a river system, and alternatively, that the two water flows occur with different probabilities.

The results show that even when the probabilities were exchanged, the same optimal monitoring locations and detection probability were produced.

CONCLUSION
The research team was able to establish that bidirectional water flows have a significant effect on the optimal design of the water quality monitoring network and that the results were considerably different from unidirectional water flow in the same river system. The probability of bidirectional water flows, however, does not affect the optimum monitoring network design, but it will have a slight effect on the mean pollution detection time.

The monitoring sensor's pollution detection threshold was also found to have little effect on the design of the optimum water quality monitoring network while the threshold is smaller than the maximal pollutant concentration. Conversely, the design is affected when the sensor's pollution detection threshold is larger than the maximal pollution concentration.

The XJTLU team have focused on theoretical-mathematical modelling methods in designing their multi-objective optimisation algorithm for bidirectional rivers. They have completed a variety of simulations and experiments in order to verify its accuracy and global optimisation capability and have achieved the same optimal solutions with other simulation models.

The XJTLU team observes that a real river system can be much more complex than the hypothetical river network employed in these experiments, but the research team have been able to apply their new algorithm to real river systems. Their novel algorithm produces better optimisation results when applied in conjunction with accurate hydraulic simulation results. They will employ powerful hydraulic simulation software to simulate complex hydraulic situations (e.g. dams, wetlands, simultaneous pollution events, varying slopes and widths etc.) and obtain more accurate pollution detection times.

The XJTLU team also draws attention to the importance of the selection of sensors for a real water quality monitoring network. They select special sensors based on a variety of factors such as the type of pollutants being monitored, the required pollution detection threshold and the available budget for building the monitoring system.

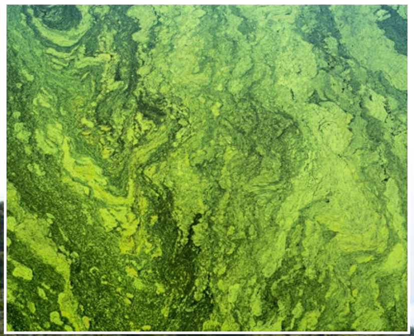
The rapid development of computer science and communication and sensor technologies has helped to significantly improve monitoring capabilities and efficiency, thus allowing researchers and technicians to remotely access large amounts of data in real-time. However, building and operating automatic monitoring centres are still costly. An optimal WQMN, therefore, needs to be low-cost as well as highly accurate, reliable and efficient.

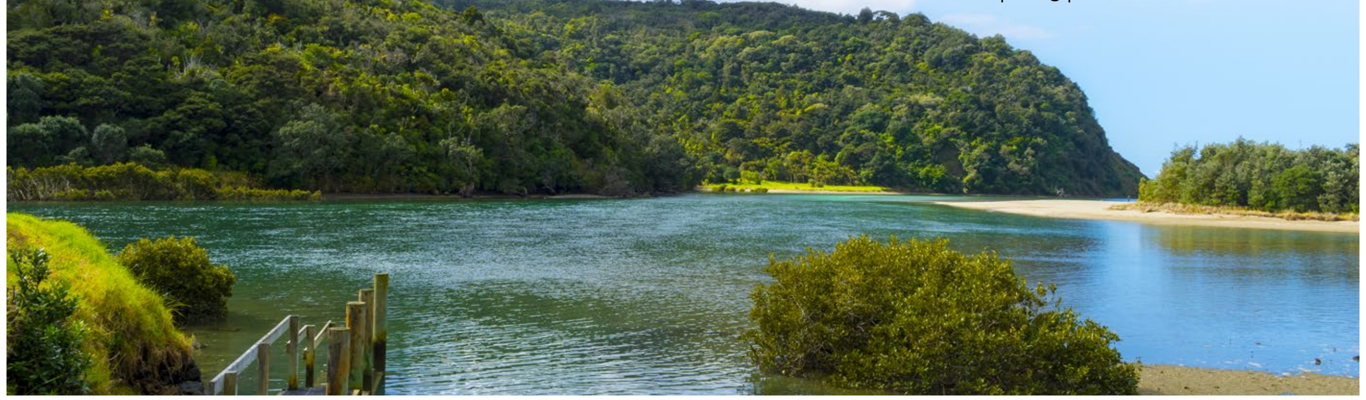
The research team are currently collecting data so that they can apply their novel algorithm to more real water quality monitoring networks. They also plan to carry out further research in order to redesign the velocity and position functions in order to improve the computing performance.

The team have completed a variety of simulations and experiments in order to verify the model's accuracy and global optimisation capability.

The effects of pollution can be catastrophic for wildlife.

Increased pollution can lead to suffocatingly high algae levels.





Behind the Research

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Research Objectives

The XJTLU team use computational modelling to improve water quality management programs, particularly in tidal, bidirectional rivers.

Detail

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Bio
Professor Yong Yue, PhD, FIET, FIMechE, Professor, Head of Department of Computer Science and Software Engineering, Xi'an Jiaotong-Liverpool University, has a comprehensive experience of learning and teaching, research and enterprise as well as management in both industry and academia. His research interests are in CAD/CAM, computer graphics, robotics and AI applications.

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Personal Response

What inspired you to investigate the effect of bidirectional water flows on the design of WQMNs?

" River systems play a vital role in sustainable community development while water pollution has become a key issue. Research has been focused on unidirectional river-flow for pollution detection. Given that bidirectional water flows, affected by regular tides, perform a vital part in surface river systems, it is important to investigate the influence of bidirectional water flows on the design of WQMN. The team have completed a variety of simulations and experiments in order to verify its accuracy and global optimisation capability. "

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