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Real-time control of dissolved oxygen in a stormwater network

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Short abstract. Real-time control may enable stormwater networks to manage stormwater pollution and create optimal conditions for aquatic life. The limited number of real-world case studies has hindered the acceptance and adoption of these autonomous solutions. In particular, no studies have explored the in-situ, real-time control of water quality directly. To that end, we present a novel dissolved oxygen monitoring and control system deployed in a municipal stormwater wetland in Ann Arbor, Michigan, US. This study shows how dissolved oxygen levels are influenced by real-time control, and we discuss the implications of the results to future system-level control studies.

Keywords. Dissolved oxygen, real-time control, stormwater networks

1. Introduction

Autonomous technologies are transforming stormwater infrastructure systems by allowing them to be controlled in real-time to manage pollution and flooding. The addition of sensors and actuators (valves, gates, pumps, etc.) to existing stormwater infrastructure enables watersheds to adapt dynamically and autonomously to changing pollutant loads [1]. These smart stormwater assets can be coordinated at the watershed-scale to improve water quality by maximizing pollutant treatment and creating optimal conditions for aquatic life [2].

The limited number of real-world case studies has hindered the acceptance and adoption of autonomous stormwater infrastructure within the water resources community [3]. Control case studies have shown that real-time control can extend retention time to improve sedimentation [4], manipulate the shape of the hydrograph [5], and optimize the soil moisture content in a bioretention cell for nitrate treatment [6]. However, to the best of our knowledge, no studies have demonstrated water quality control directly – using water quality parameters like dissolved oxygen (DO).

DO is the level of free oxygen present in water and is vital for the survival of fish and other aquatic life. Because of this, it is a critical indicator of water quality. To that end, we present a DO monitoring and control system in an urban watershed in Ann Arbor, Michigan, US. The contribution of this paper is a first-of-its-kind experimental system used to directly control dissolved oxygen in a stormwater network.

2. Materials and Methods

The experimental system consists of sensors and wireless valves, which work in tandem to measure and control DO in a constructed stormwater treatment wetland. The entire control system is designed and built by our research team, with components shared as an open-source project.

2.1. Sensors

We designed a wireless water quality sensor node to measure DO and temperature (Figure 1). This device is based on the open-storm stack, detailed in Bartos et al. 2018 [3]. An ultra-low power consumption ARM Cortex-M3 microcontroller (*Cypress* PSOC) manages peripherals (sensors and actuators) and receives and transmits messages. Data is transmitted over cellular networks using a 4G LTE CAT-4 cellular modem (*Nimbelink* NL-SW-LTE-TC4NAG) embedded within the printed circuit board. Dissolved oxygen is measured using a galvanic probe (*Atlas Scientific* #ENV-40-DOX) that generates a voltage (0-60 mV) depending on the oxygen saturation of the PTFE sensing membrane. The voltage is converted into milligrams per liter of DO via a calibration equation. Temperature is measured using a platinum thermistor (*Atlas* KIT-301). Both sensors transmit readings to the microprocessor using a UART communication protocol. The microcontroller and sensors are powered by a 3.7 V lithium-ion battery (*Tenergy* 31059) which is recharged by a solar panel (*Adafruit* 500). The electronics enclosure (19 x 14 x 12 cm) is attached to the top of a steel pole.

The *Atlas* sensors were validated using an industrial grade optical DO and temperature sensor (*In-Situ* RDO PRO-X). The sensors were calibrated in water for several weeks. During the validation period, the *Atlas* DO sensor readings were ± 0.2 mg/l the readings of the *In-Situ* DO sensor.

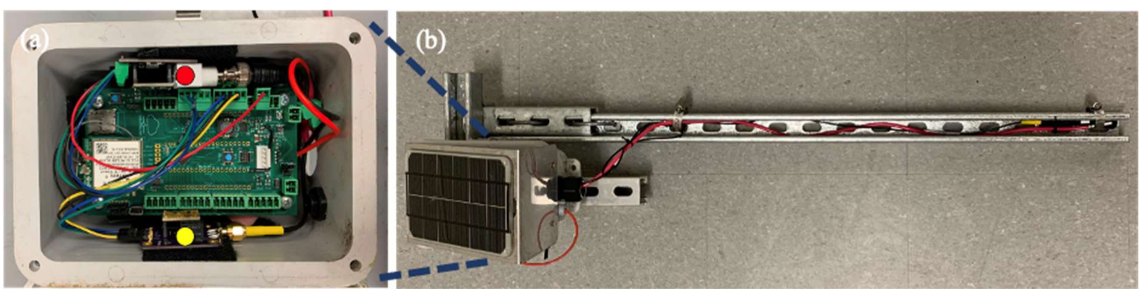

Figure 1. The *Atlas* DO (yellow dot) and temperature (red dot) sensor circuits inside the node enclosure (a). The architecture of the water quality sensor node (b).

2.2. Valve

The control system includes water level sensors and a butterfly valve (*DynaQuip* Series 70/72) (Figure 2b, 2c). The valve is controlled remotely over the Internet using a custom circuit board and cellular modem. Communication and power are similar to that of the water quality sensor node, except that the valve actuator requires 12 V supply and a dual solar charger (*MorningStar* SunSaverDuo SSD-25). The control system receives commands (e.g., percent orifice open) from the server. The valve position is measured using a wiper potentiometer and compared to the received command. If the valve's position needs to be updated, relays with built-in step ups (*SparkFun* KIT-13815) are used to allow the 3.7 V microprocessor to move the valve's actuator. If the control system loses connection to the server, a backup level controller is implemented on the device. The level controller uses an ultrasonic distance sensor (*MaxBotix* MB7383).

2.3 Case Study

The water quality sensor nodes and control valve are deployed in a case study network located in Ann Arbor, Michigan, US (Figure 2a). Ann Arbor has a four-season climate with average temperatures ranging from -7°C to 28°C. Ann Arbor averages 96cm and 137 days of precipitation per year.

Precipitation occurs somewhat evenly in all four seasons. The network includes a 3,240 m^2 constructed wetland with a capacity of 7.5 ML. The wetland has a concrete control structure (Figure 2b), which was retrofitted with a butterfly valve at its outlet (Figure 2c). Just before entering the wetland, the influent stream diverges and forms a stream that bypasses the wetland. This stream later rejoins the wetland effluent downstream.

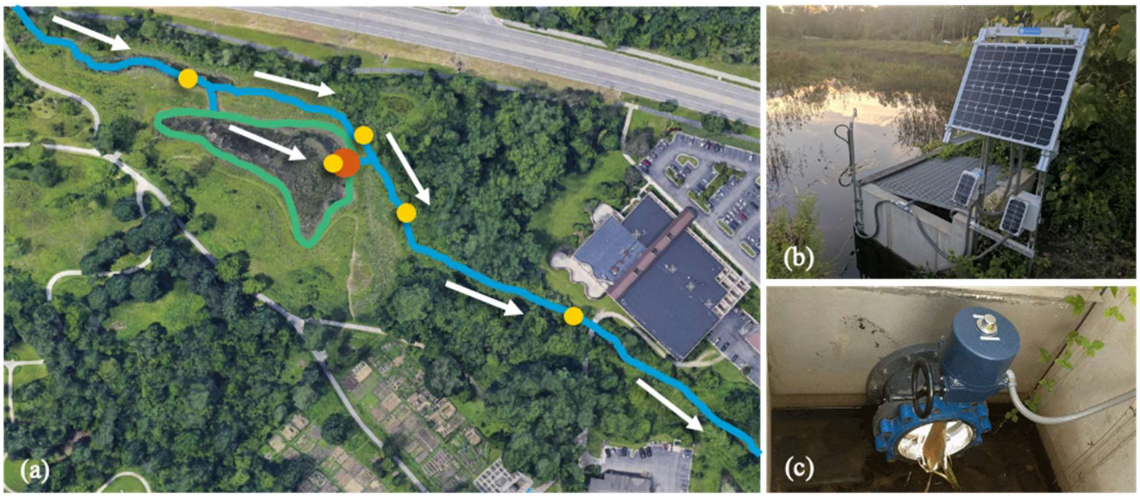

Figure 2. The case study stormwater network includes the constructed wetland (outlined in green) and channels (lined in blue) (a). The yellow dots indicate the locations of the water quality sensor nodes, and the orange dot indicates the location of the control structure. The control structure (b) and butterfly valve (c) on the wetland's outlet.

3. Results and Discussion

3.1 Performance

A water quality sensor node measured and reported DO and temperature in the constructed wetland (Figure 3) while the valve was being controlled. The sensors were configured to make measurements every ten minutes and transmit data to the server every hour. The DO sensor did not experience any data gaps, biofouling, or sensor measurement errors during the measurement period. The temperature sensor had a few gaps but worked sufficiently well to capture daily dynamics.

Summary statistics for the measurement period of 40 days were calculated for both sensors. The mean DO and temperature measurements were 3.71 mg/l and 13.6°C, respectively. DO levels ranged from 0.38 to 9.46 mg/l and temperature ranged from 7.99 to 18.1°C. The preliminary data suggests DO levels can be improved in the stormwater network. In the constructed wetland, average DO below 5 mg/l indicates harmful conditions for fish and aquatic life. The site also experienced hypoxic conditions (i.e., DO levels below 3 mg/L) for about a quarter of the measurement period.

The control valve received commands from the server and updated the position of the valve accordingly during the measurement period. The commands were either to close (0%) or partially open (~75%) the valve (Figure 3). By modulating the valve's position, the water depth in the wetland was manipulated (Figure 3).

3.1 Impacts to DO from real-time control

As shown in Figure 3, the control of the valve has a direct relationship with DO fluctuations. Namely, as the valve is opened, DO concentration increases. Effectively, lower concentration water is released from the system, while turbulent mixing may also lead to more oxygen being introduced into the system. As such, real-time control may be able to improve DO by controlling retention time as well as flushing out hypoxic layers of water from the constructed wetland. More research is needed to quantify these dynamics across varying regimes and storms. To our knowledge, our study is the first to capture these dynamics in a real-world municipal stormwater system and builds the initial foundation for future experiments.

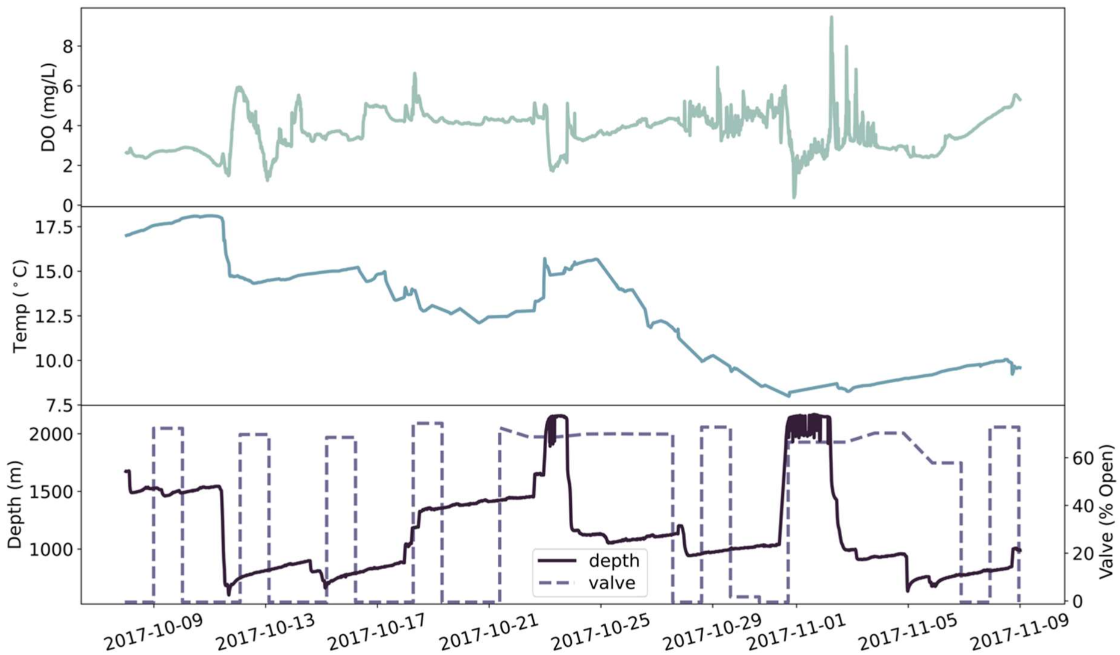

Figure 3. DO (top) and temperature (middle) data from a water quality node and water depth and valve position (bottom) in the constructed wetland.

4. Conclusion

We have introduced a novel, open-source water quality monitoring and control system that provides real-time data on dissolved oxygen, temperature, depth, and valve position. We presented preliminary data for these four parameters from the constructed wetland. Future work will characterize the ability of the control site to shape internal and downstream DO concentrations. To our knowledge, this will be a first-of-its-kind, water quality-based, real-time control case study. In the future, we expect to quantify to what precision dissolved oxygen can be manipulated with a controllable valve.

References

[1] B. Kerkez *et al.*, 2016, Smarter Stormwater Systems, *Env. Sci Technol*, vol. 50, no. 14, pp. 7267–7273

[2] A. Mullapudi, B. P. Wong, and B. Kerkez, 2017, Emerging investigators series: building a theory for smart stormwater systems, *Water Res. Technol.*, vol. 3, no. 1, pp. 66–77, 2017

[3] M. Bartos, B. P. Wong, and B. Kerkez, 2018, Open storm: a complete framework for sensing and control of urban watersheds, *Water Res. Technol.*, vol. 4, no. 346

[4] J. R. Middleton and M. E. Barrett, 2008. Water Quality Performance of a Batch-Type Stormwater Detention Basin, *Water Environ. Res.*, vol. 80, no. 2, pp. 172–178

[5] A. Mullapudi, M. Bartos, B. P. Wong, and B. Kerkez, 2018, Shaping Streamflow Using a Real-Time Stormwater Control Network, *Sensors*, vol. 18, no. 2259

[6] P. P. Persaud, A. A. Akin, B. Kerkez, D. T. Mccarthy, and J. M. Hathaway, 2019, Real time control schemes for improving water quality from bioretention cells, *Blue Green Syst.*, vol. 1, no. 1, pp. 55–71