A Paper Microfluidic Device for Monitoring Harmful Algal Blooms: A Small Solution to a Big Problem

WATERLOO ENGINEERING

Group 17: Robert Bennett, Sarah Chan, May Yin (Ashlyn) Low, Michael Mierzejewski

Project Consultant: Dr. Christopher Backhouse

Nanotechnology Engineering, University of Waterloo

UNIVERSITY OF WATERLOO

Motivation and Purpose

- **Harmful algal blooms (HABs):** excessive growth of algae in a body of water that produce toxins that are harmful to human and aquatic life
- The **Ontario Ministry of the Environment** estimates HABS in Lake Erie alone could cause up to **$272 million in damages annually**

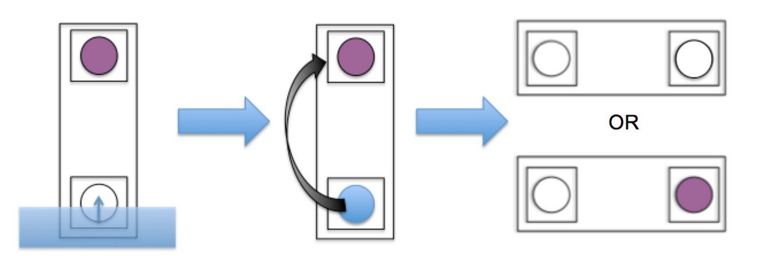
An aerial view and close up views of the algal blooms found in Lake Erie.

- **Nitrogen species,** in the forms of **nitrite** (NO_2) and **nitrate** (NO_3), have been identified as significant contributors to HAB formation
- **Problem: Lack of public awareness** and **limited data collection**
- **Solution**: An **easy to use, portable** device that can be distributed to **citizen volunteers** to raise public awareness and increase data collection to find areas most susceptible to algal bloom formation

Design and Operation

Nitrite sensor

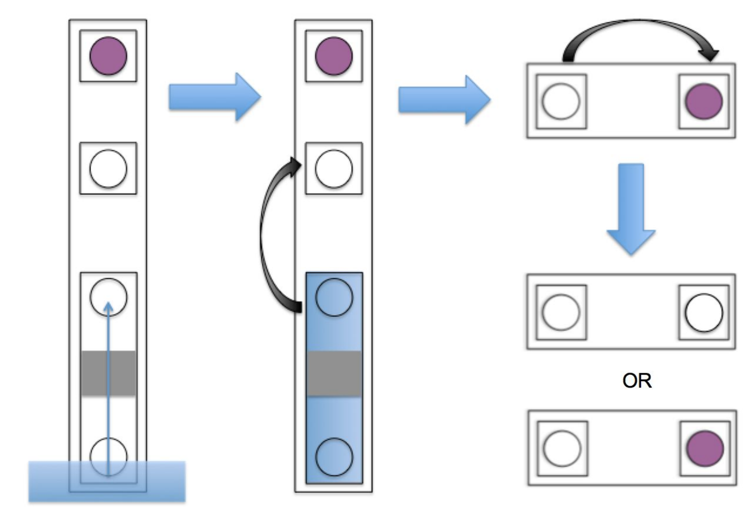
- **1,2-diaminoanthroquinone** (DAQ) is a dye that has been shown to **sense for nitrites** in solution
- DAQ is naturally **purple and turns clear** in the presence of nitrite
- An **acidic environment** is required for the reaction to take place
- DAQ is deposited onto the paper reaction well and a strong acid is deposited on the inlet



- The device can be dipped in the sample water, collecting water at the inlet and then transferred to the reaction well, resulting in a **colour change**

Nitrate sensor

- Addition of a longer inlet area with deposited **zinc** dust to **reduce nitrate to nitrite**
- Uses same sensing mechanism as nitrite



- The device can be dipped in the sample water, which passes through the zinc filled channel and then transferred to an acidic well and follows the same operational procedure as the nitrite sensor

Evaluation of Our Device

To evaluate the usefulness of our device, we compared its capabilities to alternative, current solutions

	Easy to use?	Inexpensive?	On-site?	Rapid detection?
Taking samples to lab to analyze	✗	✗	✗	✗
MPC Buoy (current commercial sensor)	✗	✗	✓	✓
Electrochemical techniques	✓	✗	✓	✓
Our paper microfluidic sensor	✓	✓	✓	✓

Design Considerations

	Target	Ideal	Optimal
Limit of detection (NO_2)	71 µM	9 µM	900 nM
Limit of detection (NO_3)	710 µM	120 µM	2.4 µM
Cost	$1.00	~ $0.50	< $0.10
Complexity of Use	Light training required	No training required	No training required

Why Paper Microfluidics

INEXPENSIVE
< $0.10 per test

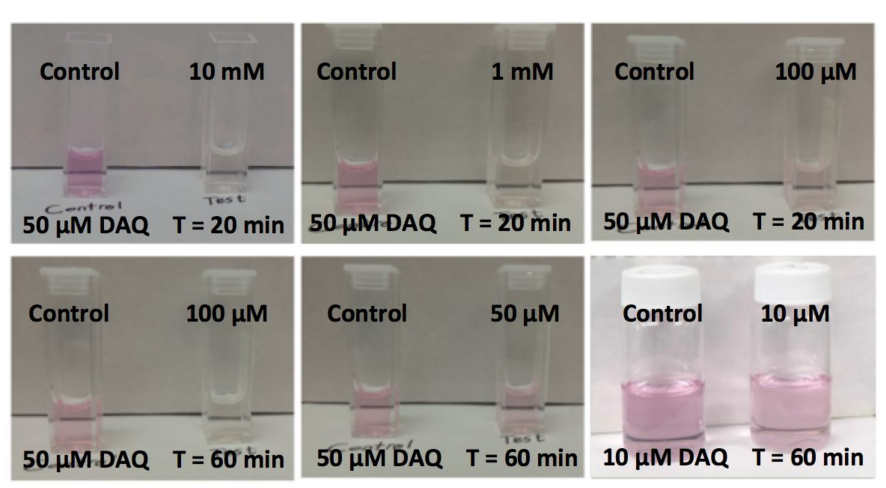
COLOUR BASED
Easy to use and understand

LIGHTWEIGHT
Portable, enables on-site use

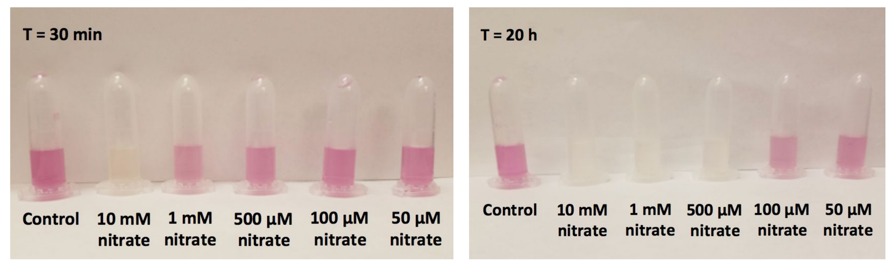
Results

In solution assay results

- Current **limit of detection for nitrite sensing** (by eye): 10 µM
  - Reaction time: 60 minutes



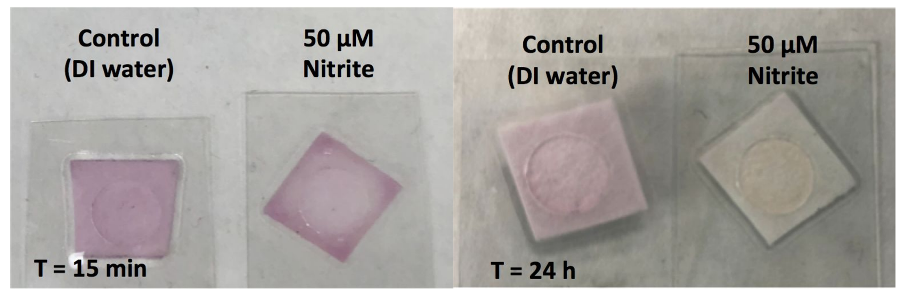
- Current **limit of detection for nitrate sensing** (by eye): 500 µM
  - Reaction time: 5 minutes for nitrate reduction; 20 hours to completion



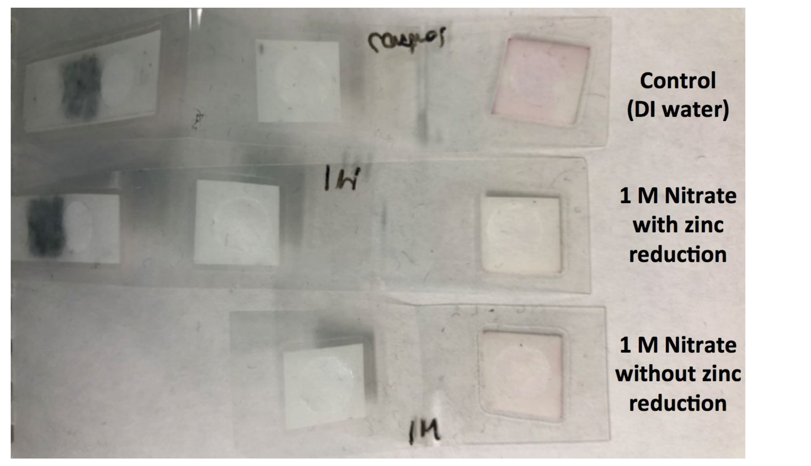
- **Nitrate conversion efficiency**: < 10% after 30 minutes; > 20% after 20 hours
- **Cost of test**: > $0.30 for a 1 mL test + shipping costs + lab technician labour

Paper sensing results

- Current **limit of detection** of the **nitrite sensor** (by eye): 50 µM
  - Reaction time: < 15 minutes
  - Device mass: ~0.25 g



- Current **limit of detection** of the **nitrate sensor** (by eye): 1 M
  - Reaction time: 5 minutes for nitrate reduction, < 10 minutes for colour change
  - Device mass: ~0.4 g



- **Cost of test** including distribution: < $0.08

Next Steps

- Improve **repeatability** and **reproducibility** of results by using **automation** for manufacturing
- Lower the **limit of detection** of sensors and demonstrate **selectivity** of the on-paper sensors
- Optimize **nitrate reduction** on paper
  - Investigate alternative **reducing agents** for nitrate to nitrite conversion
- Enable **quantitative analysis** using a portable **RGB sensor**
  - Optimize **calibration** of the device for consistent colour measurements
  - Increase sample pool to better **correlate colour change** of the sensor to **concentrations** of analyte
- Pivot from lamination to **wax printing** for sensor fabrication
- Develop similar paper sensors for other nutrients involved with algal bloom formation, such as **phosphates** and **calcium**

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