Sensors and Sensing Systems for Water Quality Monitoring

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Research objectives

Deployment of novel low cost sensors and sensing systems in the environment and remote locations to wirelessly monitor water quality in real-time.
Major outcomes of sensors developed and deployed in the environment are summarized below.

Sensor development

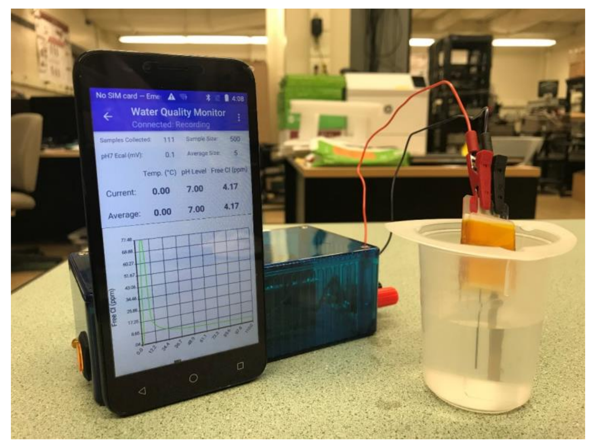
A Fully Integrated Free Cl⁻ Sensor

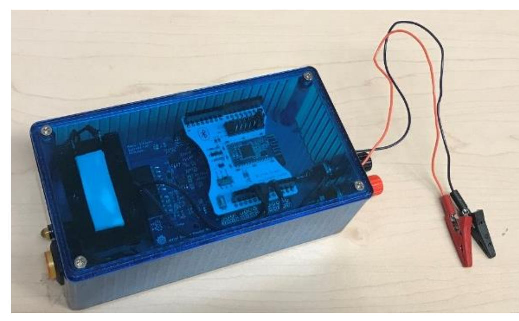
Three major parts of the IFCSS*[1]

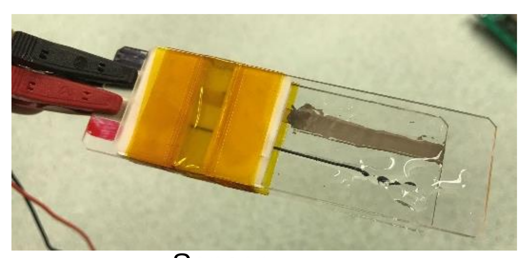
Sensor: Pencil lead and Ag/AgCl based electrodes. Sensing is based on electrochemical reactions of free chlorine with pencil lead.

Data-Logger: Microcontroller based analog-to-digital converter circuits with Bluetooth wireless system

Smartphone App: Android application for wireless reception of free chlorine measurement data, calibration, display and storage




Data-Logger

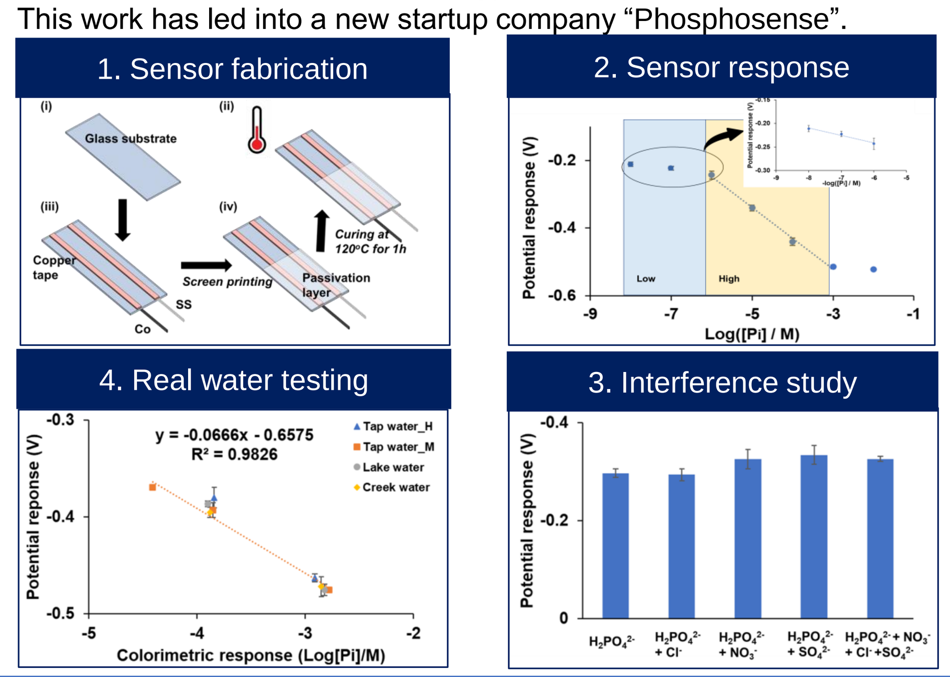

Sensor

Free Cl⁻ sensing on water samples from Six Nations

Number	Locations	Type of Water	Measured by Six Nations	Measured by Cl⁻ Sensor
1	Adult Base Centre	Water line	1.10 ppm	0.95 ppm
2	Health Centre	Water line	0.23 ppm	0.19 ppm
3	Long Term Care Centre	Water line	0.17 ppm	0.12 ppm
4	Human Resources	Water line	0.40 ppm	0.31 ppm
5	Birthing Centre	Cistern	N/A	0 ppm
6	Kawenní:io High School	Drilled Well	N/A	0 ppm

Phosphate Sensor

A highly sensitive new electrochemical sensor for phosphate allows detection as low as 10^-7 M. Prototype is ready and field tested*[2]. This work has led into a new startup company "Phosphosense".



Bioavailable Metal Sensor

DNA-based sensors (DNAzymes) for bioavailable lead monitoring in real waters*3-4

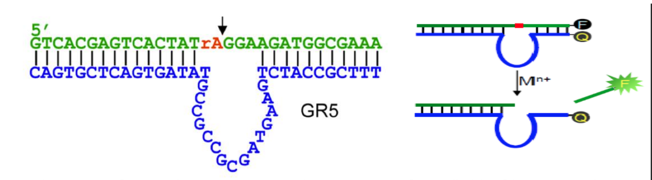


Figure 1: Secondary structure of DNAzyme GR5 (left). Cleavage site is represented by the arrowhead. Schematic representation of the metal induced cleavage reaction (right). Pb^{2+} is used to induce cleavage. F and Q labels indicate fluorescein amidites - labeled fluorophore and quencher respectively.

$$[\mathrm{Pb}^{2+}] = \frac{k_{obs}}{m1 + m2K_{OH}[\mathrm{OH}^-] + m3K_{cl}Cl_T}$$

Equation for the calculation of ionic lead based on measured rate constant of fluorescence signal (Figure 1 see F) and calibration parameters m1 for Pb^{2+} response, m2 for $PbOH^+$ response, m3 for $PbCl^+$ response and thermodynamic binding parameters K_{Cl} and K_{OH} and total chloride (Cl_T).

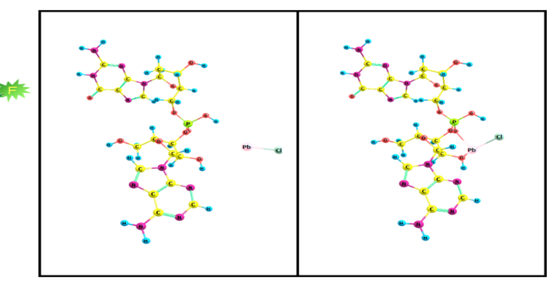
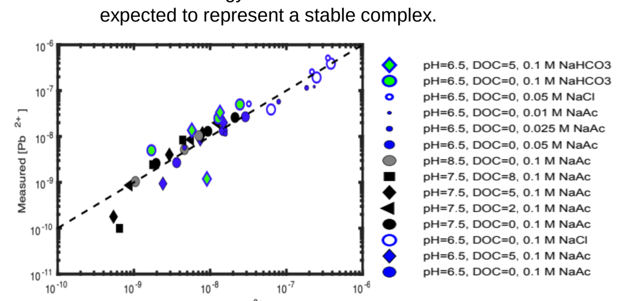


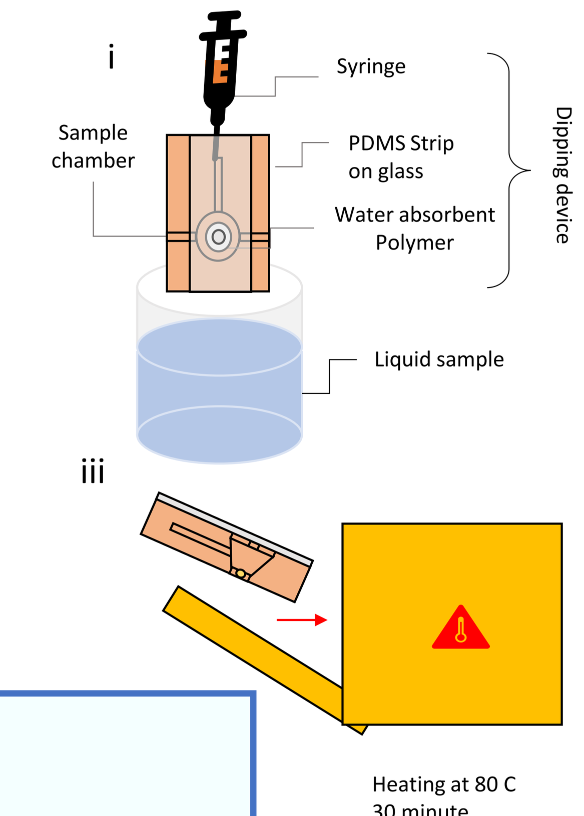
Figure 2: DFT structure showing the interaction between GR5 and $PbCl^+$ at the proposed binding site. The formation energy was found to be -0.075 eV and is thus expected to represent a stable complex.

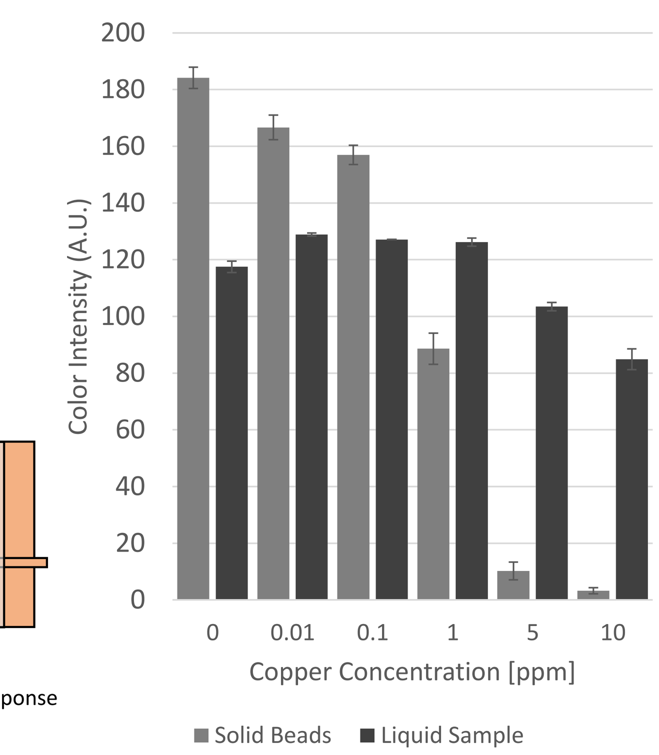
Figure 3 →
WHAM predicted [Pb^{2+}] compared to measured data, using k_{obs} and best-fit parameters of the 3 most important inorganic species using the multiple linear regression calibration equation. The dashed line represents 1:1 with an r^2 value of 0.883. The different water chemistries and electrolytes are indicated in the legend to the right of the figure.



Copper and Lead Sensor

A novel pre-concentration colorimetric approach to detect Copper and Lead at 1-10 ppb levels*[5].

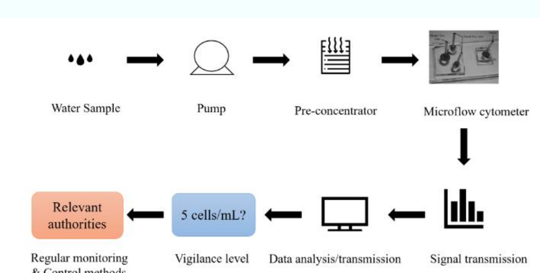




Sensor deployment, testing, and validation of water quality

Algal Bloom Detection

Development and Deployment of Fluorescent sensor and ESI sensor (Electrical Impedance Spectroscopy) to detect low concentration cyanobacteria to measure Chl-A and multiple algae species (Spirulina, Chlorella, mixed species) at the Buffalo Pound field site . This has important application for early warning of potential harmful cyanobacterial blooms.*6,7

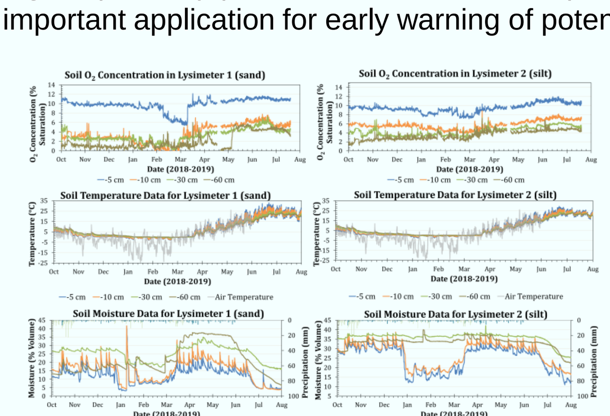


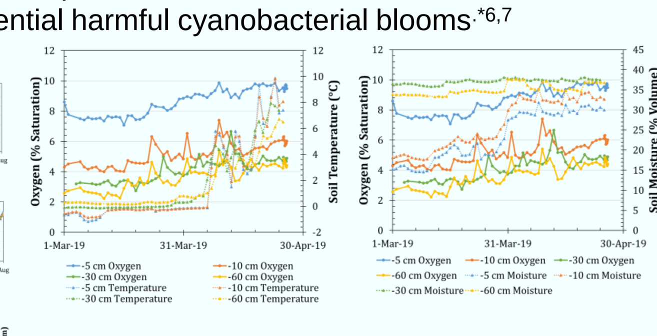
Sample	Concentration (cells/mL)	Retentate (cells/mL)	Retentate volume (mL)	Recovery efficiency (%)	Ratio
A	429 ± 5	394,000 ± 1,154	1.1	97.7 ± 5.8	909
B	39 ± 1	22,100 ± 153	1.5	85.3 ± 0.6	667
C	4.5 ± 0.5	3,050 ± 540	1.5	91.0 ± 6.8	667

Efficient communication protocol and dynamic clustering algorithm for IoT-UAV sensor platform is ready and tested for its performance

Soil O_2 Sensing

Development and Deployment of Fluorescent sensor and ESI sensor (Electrical Impedance Spectroscopy) to detect low concentration cyanobacteria to measure Chl-A and multiple algae species (Spirulina, Chlorella, mixed species) at the Buffalo Pound field site . This has important application for early warning of potential harmful cyanobacterial blooms.*6,7





The results show how the dissolved O_2 concentrations in soils are linked to soil moisture and temperature

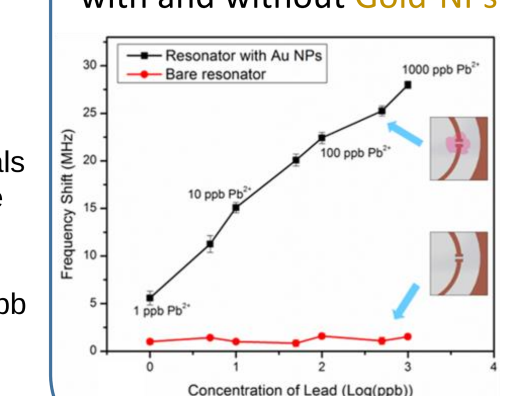
Selenium and Arsenic Bioaccumulation

Deployment of Libelium based network in lakes downstream of mining operations in collaboration with Orano (previously Areva Resources), a uranium mine in northern Saskatchewan) is performed to predict seasonal differences (summer vs winter) in selenium and arsenic bioaccumulation and trophic transfer. It is concluded that the estimated risk for aqueous arsenic toxicity was low and should not adversely affect aquatic invertebrates in downstream lakes. Selenium concentrations in most benthic macroinvertebrate taxa exceeded published selenium benchmarks at sites with greater effluent exposure.*[9]

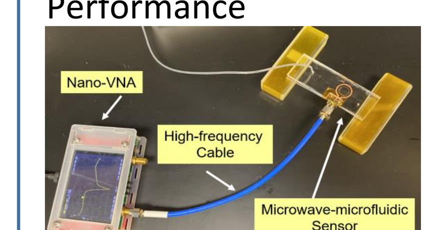
Microwave Sensor

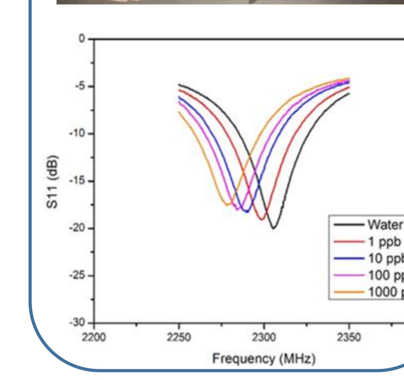
A Microwave Enabled Microfluidic Sensor, Incorporated with Nanomaterials for Real-time Lead Detection in Water at 1 ppb Levels.

Lead Sensing Using Sensors with and without Gold-NPs



Nano-VNA Setup and Performance





Biofouling Testing with LoRa Sensors along Rivers and Creeks of Six Nation

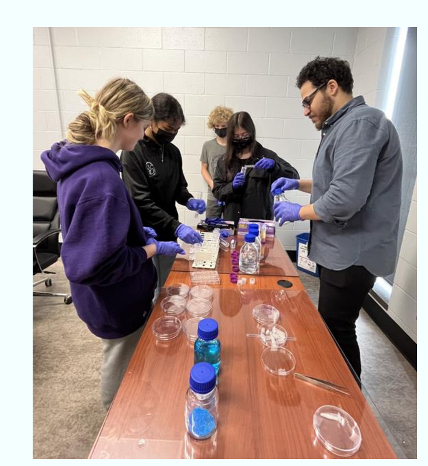
LoRa sensors, and enclosures for long-term continuous housing of sensors are designed and deployed for continuous monitoring of water quality along rivers and creeks of Six Nations. Biofouling in the lab on sensors is simulated to identify impact of biofouling and establishing ways to eliminate fouling on sensor surfaces. Sensors can be installed in more remote locations without the need to monitor and maintain as frequently, saving costs.*[10]

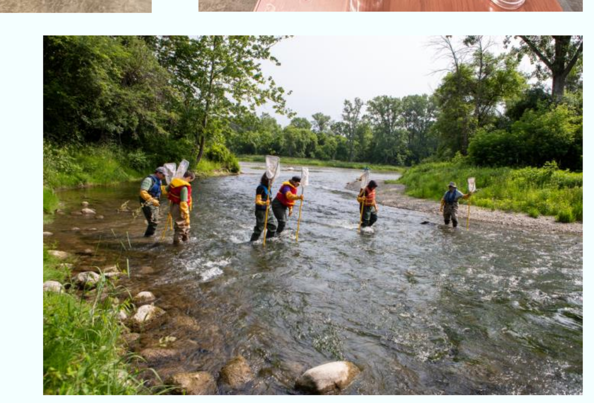
Prof de Lannoy, Erik Frechette, and STEAM Academy students installing sensors in the McKenzie Creek

Water Quality Monitoring in Six Nations

Dr. Dawn Martin-Hill's local focus on water security and environmental monitoring in Six Nations of the Grand River has facilitated*11-13:

- Testing and validating low-cost sensors in partnership with Six Nations Health Services.
- The development of a novel (and COVID-friendly) community engagement and knowledge dissemination strategy, Ohneganos: Let's Talk Water. This online vodcast series had many episodes heavily focused on water monitoring techniques and technologies.
- Educational initiatives designed to promote STEM learning for Indigenous youth. Accreditation for capacity-building is being developed and many researchers have already partnered with high schools to train students in environmental monitoring through experiential learning sessions.





References

1. Deen, M. J. et al.(2021). Analyst, vol. 146(8), pp. 2626-2631. https://doi.org/10.1039/D1AN00038A
2. Selvaganapathy, PR. Et al. Biosensors. 2021; 11(1):9. https://doi.org/10.3390/bios11010009
3. Juewen, Liu. Et al. (2022) Trends in Analytical Chemistry, 146, 116480, https://doi.org/10.1016/j.trac.2021.116480
4. Juewen, Liu. Et al. (2020). "DNA-Enabled Heavy Metal Detection in Water", Encyclopedia of Analytical Chemistry, R.A. Meyers (Ed.). https://doi.org/10.1002/9780470027318.a9747
5. Selvaganapathy, PR.et al. ACS ES&T Water (2022) (accepted)
6. Khan A. Wahid, et al. 2020, "LDAP: Remote Sensing, MDPI, vol. 12, pp. 1-21, doi: 10.3390/rs12193131 [IF: 4.509].
7. Rakibul I. Chowdhury, et al. (2020), IEEE Sensors, vol. 20, no. 13, pp. 7362-7371, doi: 10.1109/JSEN.2020.2978758 [IF: 3.076].
8. F. Rezanezhad et al. (2020) 3rd Global Water Futures (GWF) Annual Open Science Meeting. May 11 -13, Waterloo, Ontario, Canada.
9. Liber, K. et al. (2021) Abstract submitted on April 15th, 2021 to the GWF annual meeting.
10. Charles-François de Lannoy, et al. (2022) Separation and Purification Technology.
11.Looking Horse, M. (2020) Ohneganos: Let's Talk Water video series. Season 1-3. Accessible via YouTube https://youtube.com/playlist?list=PLV0pWnAsC2xCls5M628FY6AoZM54Pv2Zu
12. Dawn Martin-Hill, et al. (2020) Water Management through Co-Creation of Indigenous Water Quality Tools.
13. Dawn Martin-Hill, et al. (2020) Indigenous Water and Drought Management in a Changing World, 2020