McGill

Food for Thought: Issues in Global Water, Food, and Environmental Security

Shiv Om Prasher

James McGill Professor
Bioresource Engineering
McGill University, Montreal, Canada

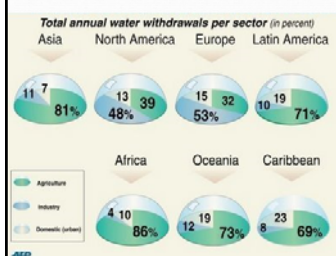
Humanity's Top Ten Challenges

- Energy
- Water
- Food
- Environment
- Poverty
- Terrorism & War
- Disease
- Education
- Democracy
- Population

Compiled by Dr. R. E. Smalley
- *University Professor, Rice University, smalley.rice.edu/Houston Museum.pdf*
- *1996 Nobel Prize winner in chemistry*

Kalita (2011)

Worldwide Water Withdrawals



- Agriculture consumes the largest share of freshwater
- Industry is a major consumer in North America and Europe.
  - More efficient irrigation systems
  - **Industrial economy**
- Africa, Asia and Latin America
  - **Agricultural economy**
  - Irrigation systems not always efficient
  - **Booming economies** (China, India, Brazil) will influence the ratio.

Water Requirement/Use

- **Virtual water**
  - Water embedded in food products
  - 1,000 liters for one kg of grain
  - 15,500 liters for one kg of red meat

http://www.economist.com/world/international/displayStory.cfm?story_id=13447271

Virtual Water

Virtual Water

Virtual Water

Virtual Water

Virtual Water

Virtual Water

Virtual Water

Virtual Water

Vegetarian vs Non-Vegetarian

VS

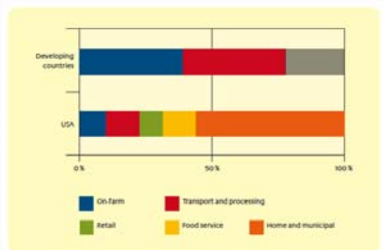
- How much land and water resources are needed to feed a **non-vegetarian** and a **vegetarian person**?

Water and Land Requirements for Vegetarian vs Non-Vegetarian Diets

Vegetarian	Non-Vegetarian
• A **vegetarian diet** can be produced with **900-1,200 m³** of water per person per year	A **meat-based diet** requires well over **2,000 m³** of water per person annually (≈ 100% ↑)
• A vegetarian diet requires no more than **700-800 m² of land per capita**	A diet, with **15 percent animal foodstuff**, requires **1,100 m² /capita** (≈ 50% ↑)

A **western-type diet,** with its **high** proportion of **meat consumption and dairy products,** requires up to **4,000 m² /capita (> 500% ↑)**

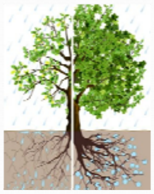
Food Waste is Water Waste



Note: The grey part of the developing countries bar represents the combined percentage of the retail, food service, and home and municipal categories.

Super Absorbent Polymers or Hydrogel

- Retain Water
- Retain nutrients

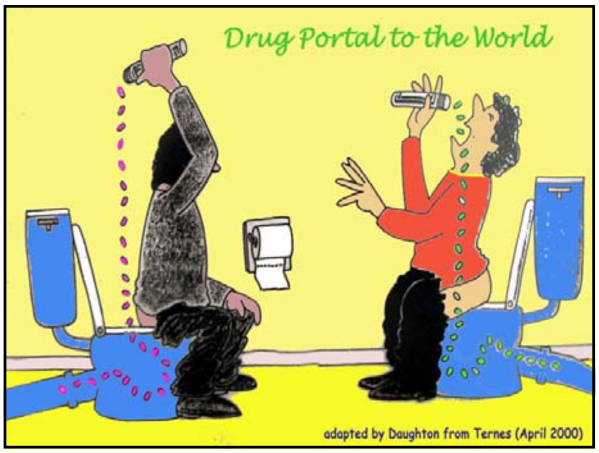


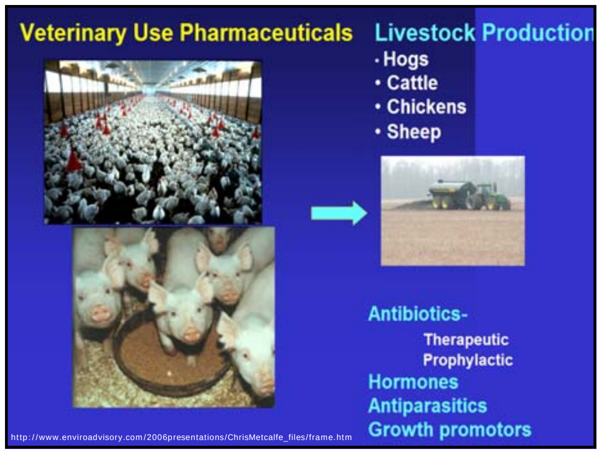
How does it work?

- Supply on demand

Root Analysis

0.5% SAP vs 0% SAP (50% reduced watering)

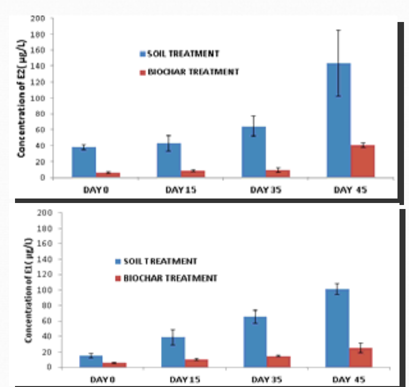




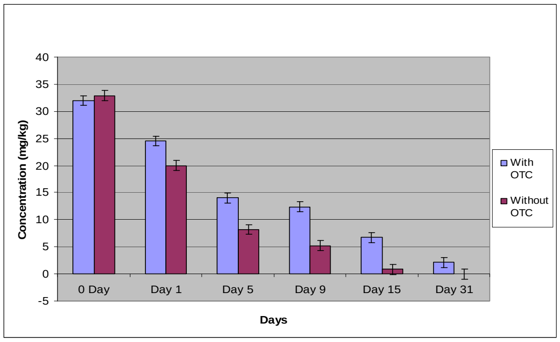
Biochar

climateforce.net

Estradiol and Estrone in leachate samples



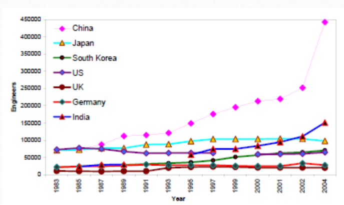
Metribuzin Concentration at the Soil Surface, With and Without Antibiotic OTC

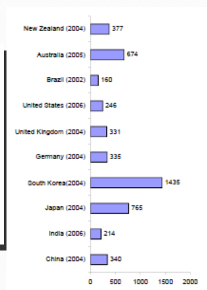


Current Projects

- Biochar and other Additives
  - Effect of biochar on the fate and transport of antibiotics and hormones
  - Pesticide persistence and movement in soil affected by biochar treatment
  - Effect of biochar amendments on the fate and transport of pathogens in soil
  - Use of super absorbent polymers in agriculture – agronomic and environmental impacts
- Computer Modeling – Field and Watershed scale
  - Antibiotics, Hormones, Pesticides, Fertilizers, Pathogens
  - SWAT, DRAINMOD, HYDRUS, RZWQM
  - Stakeholder engagement in physical modeling
- Development of Best Management Practices (BMPs)
- Water Quality Monitoring of Freshwater Bodies - FishNet

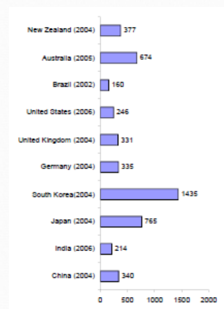
Number of Engineers in Different Countries





Muley (2008)

Engineers *versus* GDP/capita



Country	GDP per Capita (2004) $
New Zealand	21,600
Australia	28,900
Brazil	7,600
United States	37,800
United Kingdom	27,700
Germany	27,600
South Korea	17,700
Japan	28,800
India	2,900
China	5,000

Macdonald Campus
www.mcgill.ca/macdonald

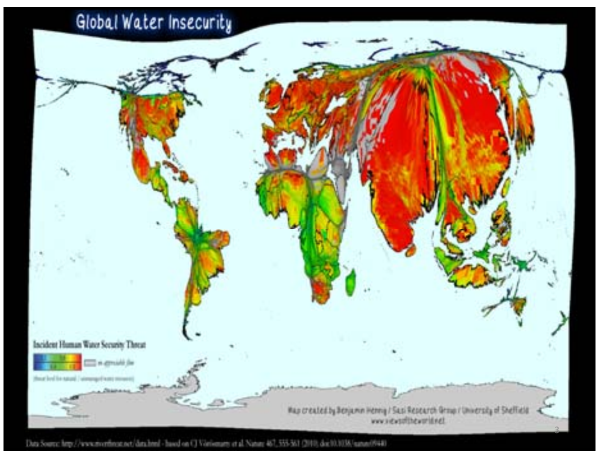
Environmental monitoring and water quality heterogeneity

Dr. Abdul Mannan, Michael Saminsky, Dr. Luan Pan
Dr. Shiv Prasher
Dr. Viacheslav Adamchuk
Department of Bioresource Engineering
Dr. Asim Biswas
Department of Natural Resource Sciences
McGill University

Presented for BGS Seminar

Overview

1. Global & local water quality
2. Environmental monitoring in small ponds
   a) Agricultural nutrient loading
   b) Temporal dynamics
   c) Spatial Dynamics
3. Acoustic sensory telemetry
   a) System components
   b) Sensors
   c) Automated testing platform
   d) Tests
4. Conclusions



Bring it into agricultural/ Quebec domain

Station number	Total phosphorus	Suspended solids	Turbidity	Ammonia	Nitrate + nitrite	Total nitrogen
1	▼	■	▲	■	■	■
2	▼	■	■	▼	■	■
3	▼	▼	■	▼	▼	▼
4	▼	■	■	▼	▼	▼
5	■	▼	■	■	■	■
6	▼	■	▲	■	■	■
7	▼	■	▲	■	▼	■
8	▼	■	■	■	■	■
9	▼	■	■	▼	▼	▼
10	■	■	▲	▼	■	■

Note: Concentrations with significant correlation with flow ($p < 0.1$) are flow-adjusted for trend analysis.

Patoine et al. (2012)

Current state of WQ monitoring

Method	Pros	Cons
Manual 	•dynamic (can sample multiple spots) • Relatively easy •Well-developed	•Labor-intensive •can't be automated •Expensive •representative?
permanent/ semi-permanent structures 	•automated •real-time •remote	•static •requires maintenance •can be expensive •representative?
Remote Sensing 	• low-cost when infrastructure exists •actively advancing field	• potential for high uncertainty •expensive to build, run and operate •difficult to interpret

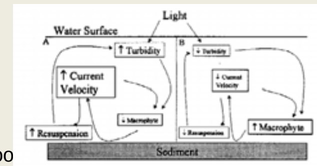
Transition to project

Spatial and Temporal Assumptions

Spatially

-Large-Scale Dynamics

-Sediment-water column interaction



Madson et al. 2001

Temporally

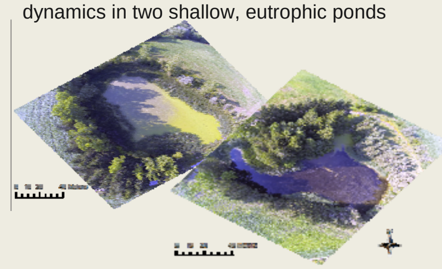
-Post-ice, bloom onset, bloom magnitude, bloom subsidence.

-Monthly

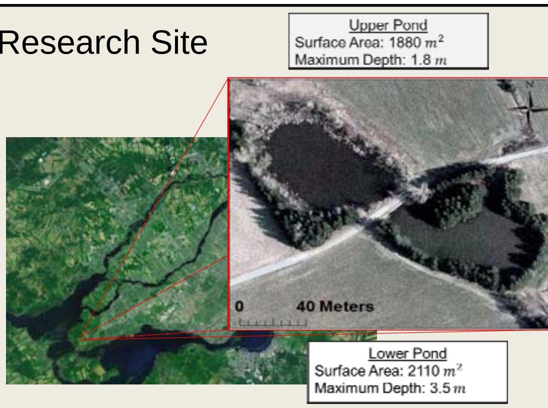
Bottom Line: Cost of sampling limits application

Objective

Identify small-scale spatial and temporal nutrient dynamics in two shallow, eutrophic ponds

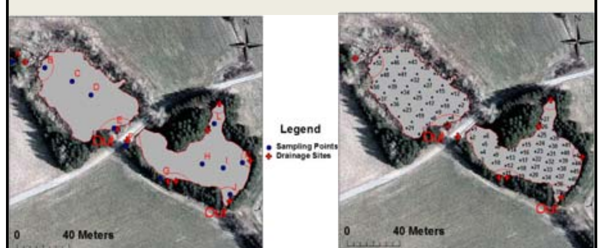


Research Site



Experimental Design: Sampling Sites

Temporal study | **Spatial study**



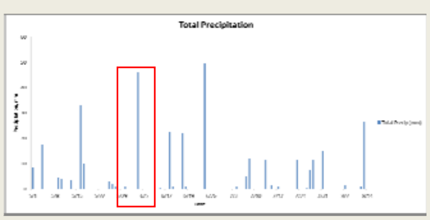
12 points total

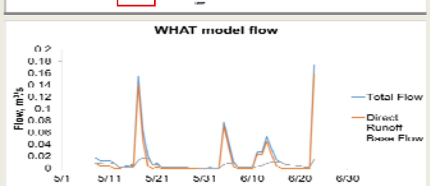
1/Week, 8 events

3 sampling depths

50 ± 3 points per pond

2 events





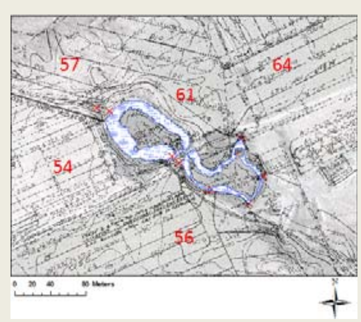
Fertilizer Application

Field 54
May 15 - 151kg/ha (28-26-0)
June 19 - 425kg/ha (27-0-0)
- 225kg/ha (46-0-0)

Field 56
May 23 - 200kg/ha (46-0-0)
- 75kg/ha (46-0-0)

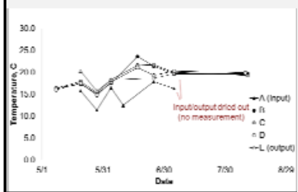
Field 61
May 8 - 150kg/ha (21-0-0)

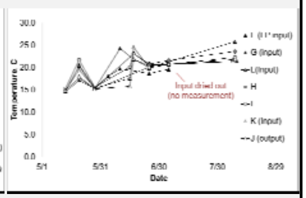
Field 64
May 21 - 175 kg/ha (46-0-0)
May 23 - 75 kg/ha (46-0-0)

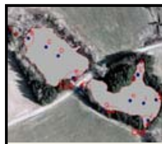


Temperature

Methodology: *in-situ*
Replicates: 1

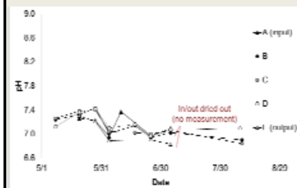


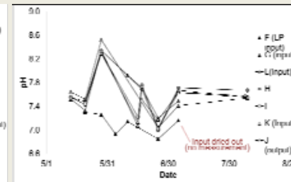




pH

Methodology: *in-situ*
Replicates: 1

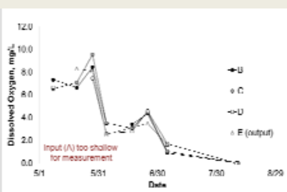


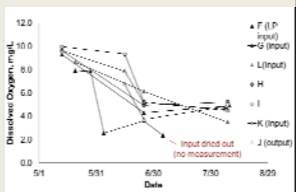


Increased pH: N solubility increases
Increased pH: P solubility increases (until higher pH of ~10)

Dissolved Oxygen

Methodology: *in-situ*
Replicates: 1

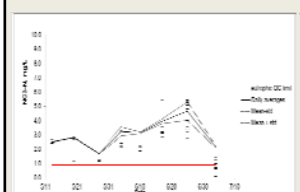


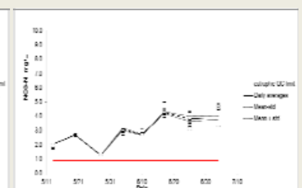


m1

NO_3-N

Methodology: Lab
Replicates: 3

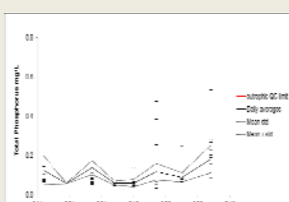


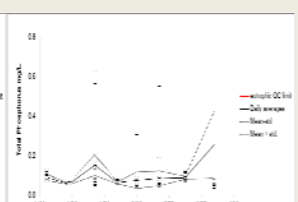


Upper Pond | Lower Pond

Total Phosphorus

Methodology: Lab
Replicates: 3





Upper Pond | Lower Pond

Physical indicators of chemical change

Upper Pond

May 25 (same as May 28)

June 01

Lower Pond

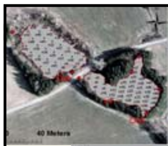
May 25 (same as May 28)

August 07
June 01

Slide 16

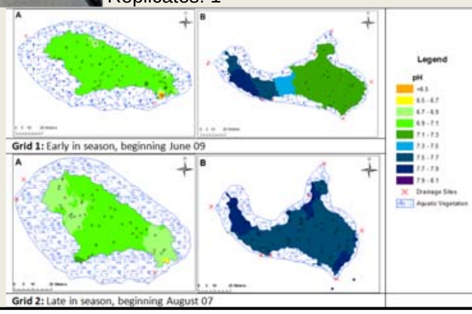
m1 add methodology (in-situ vs lab) and # of reps per point (1 vs 3)

make 3 lowercase
Michael, 1/22/2015



pH

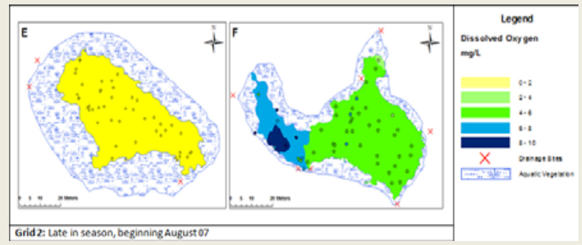
Methodology: *in-situ*
Replicates: 1

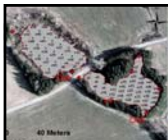


Dissolved Oxygen

August 07-09,2014

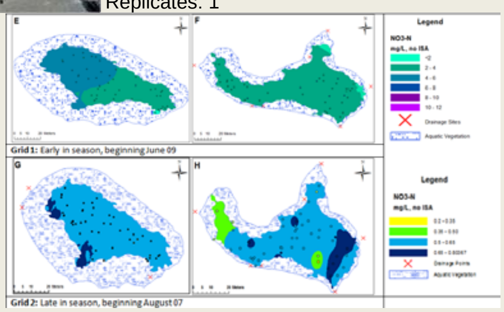
Methodology: *in-situ*
Replicates: 1





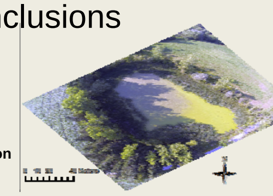
NO_3-N

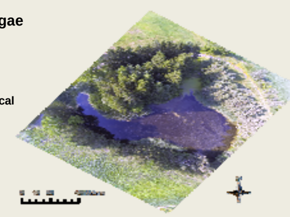
Methodology: *in-situ*
Replicates: 1



Conclusions

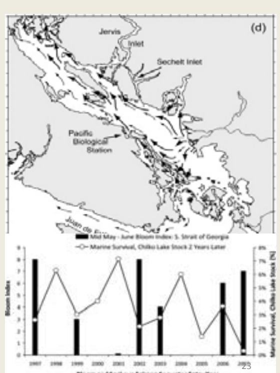
- **Diurnal water quality patterns and movement of boat can have effect**
- **Spatial and temporal patterns do exist on small scales**
- **Duckweed could be outcompeting algae for light in upper pond**
  - **Drives water quality changes**
  - **relationship is critical in understanding local pond dynamics**



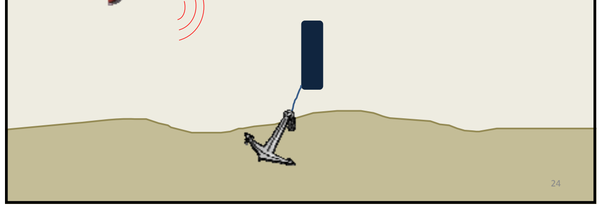


McGill

Acoustic Sensory Telemetry

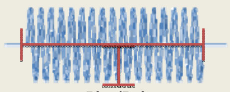


Acoustic Sensory Telemetry



The signal moves from tag to receiver

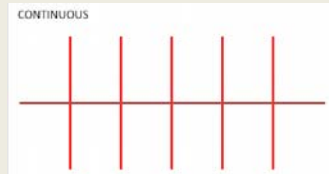
1. Tag transduction
   electrical energy → acoustic energy
   ultrasonic: 20-500 kHz
2. Signal propagation
3. Receiver transduction
   acoustic energy → electrical energy

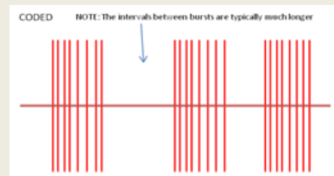


Ping/Pulse

Fixed	Variable
1. Amplitude 2. Pulse Length 3. Phase	1. Pulse Quantity 2. Pulse Rate

Coded signals provide additional information





Materials

Vemco Tags

- Variable sizes
  - 2.9-37g
- 69kHz transmitting frequency
- 1-10 year battery life

Temperature Sensor		
Range	Accuracy	Resolution
-5 to 35 °C	±0.5 °C	0.15 °C
-4 to 20 °C	±0.5 °C	0.1 °C
0 to 40 °C	±0.5 °C	0.15 °C
10 to 40 °C	±0.5 °C	0.12 °C

Pressure Sensors (at room temperature)		
Max Depth	Accuracy	Resolution
17 m	±1.7 m	0.08 m
34 m	±1.7 m	0.15 m
68 m	±3.4 m	0.3 m
136 m	±6.8 m	0.6 m
204 m	±10 m	0.9 m
340 m	±17 m	1.5 m
680 m	±34 m	3.0 m

Materials

Vemco Receivers

- Bluetooth Compatible
- 69kHz receiving frequency
- 15 month battery life
- 8MB storage (1-million detections)
- Deployable too 500m below surface

Advantages

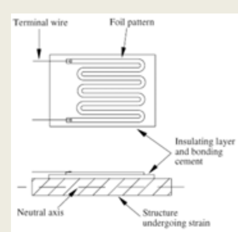
- Continuous sampling
- Automated
- Low-Cost
- Dynamic
- Non-disruptive

Disadvantages

- Representative?
  – Fish avoidance

Adding sensors to acoustic telemetry

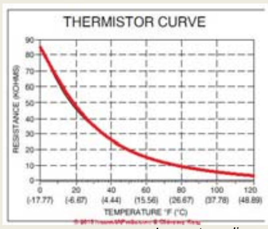
Depth- strain gauges



USGS - USGS.gov

Adding sensors to acoustic telemetry

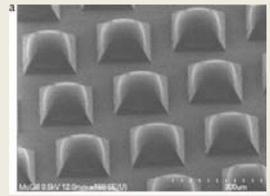
Temperature- thermistors



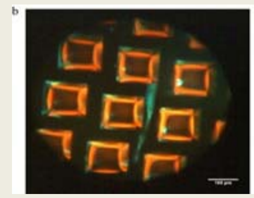
Inspectapedia.com

Adding sensors to acoustic telemetry

Fluoremetric Spectroscopy



Xero-gel film, no excitation

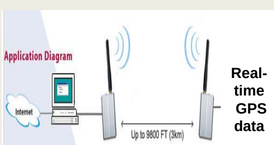


Xero-gel film, LED excitation

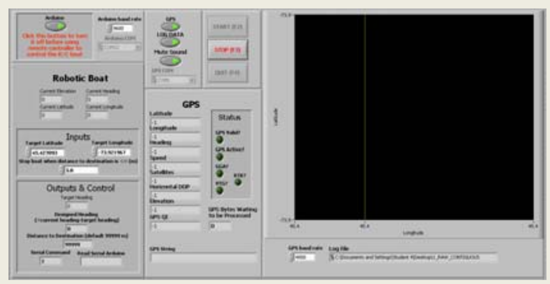
Daivasagaya et al. 2011

Autonomous Testing Platform

Remote Control Boat Specs
Length: 1000 mm
Width: 300 mm
Height: 270 mm
Weight: 2.6 kg
Motor: 36-60 size 1604
kv Watercooled brusless
ESC: 125A watercooled



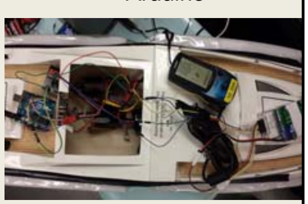
Wireless Radio Specs
Frequency range: 429.00-433.30 MHz
Size: 80*45*19 mm
RS-232 level interface
Power supply: 5VDC
Operating system: Windows XP or higher



Remote Control vs. Arduino set-up

Remote Control

Arduino



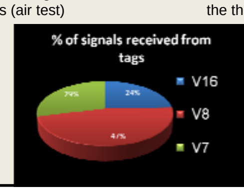
Tests: Range & Power

AST tag	Communication range (m)
V7	0.06
V8	0.22
V16	0.60

Table 1. Communication range for the three tags (air test)

AST tag	Communication range (m)
V7	63
V8	149
V16	170

Table 2. Communication range for the three tags (water test)



Tests: Temperature, Pressure, & Control

Conclusion

- Spatial heterogeneity exists even at small-scales
- Improved monitoring technologies needed to effectively assess water quality dynamics

Thank You!

Dr. Viacheslav Adamchuk
Dr. Shiv Prasher
Dr. Asim Biswas
Vemco Systems
Natural Sciences and Engineering Research Council

Acoustic Sensory Telemetry

Picture References

http://pubs.usgs.gov/twri/twri8a3/#N104AB - USE OF SUBMERSIBLE PRESSURE TRANSDUCERS IN WATER-RESOURCES INVESTIGATIONS

Daivasagaya, D. S. *et al.* Contact CMOS imaging of gaseous oxygen sensor array. *Sensors and Actuators B: Chemical* **157,** 408–416 (2011).

3.

Lacroix, G. L. & McCurdy, P. Migratory behaviour of post-smolt Atlantic salmon during initial stages of seaward migration. *Journal of Fish Biology* **49,** 1086–1101 (1996).

4.

Jack Rensel, J. E., Haigh, N. & Tynan, T. J. Fraser river sockeye salmon marine survival decline and harmful blooms of Heterosigma akashiwo. *Harmful Algae* **10,** 98–115 (2010).

Crazy map- http://www.viewsoftheworld.net/wp-content/uploads/2010/09/GlobalWaterInsecurityMap.jpg

Map of quebec watersheds - Patoine, M., S. Hébert, and F. D'Auteuil-Potvin. 2012. "Water Quality Trends in the Last Decade for Ten Watersheds Dominated by Diffuse Pollution in Québec (Canada)." *Water Science & Technology* 65 (6): 1095–1101. doi:10.2166/wst.2012.850.

Photo credit: buoy WHOI - http://www.whoi.edu/science/MCG/aerosols/Buoy_photo-int.gif

http://www.worldometers.info/world-population/

- Nature paper: http://www.nature.com/nature/journal/v467/n7315/pdf/nature09440.pdf
- Sediment-nutrient dynamics http://www.jlakes.org/web/Interaction-watermovement-sediment-macrophyte-H2001.pdf

- http://web.fisheries.org/proofs/tel/Sec7.1_pincock.pdf
- http://vemco.com/wp-content/uploads/2012/11/acoustic_telemetry.pdf
- http://adamchukpa.mcgill.ca/bgstech/bgstech_presentation/1402.pdf
- http://adamchukpa.mcgill.ca/bgstech/bgstech_presentation/1411.pdf
- http://adamchukpa.mcgill.ca/bgstech/bgstech_presentation/1404.pdf

Fluorescence based Optical pH Sensors

Dr Abdul Mannan, Dr Mark Andrew, Dr Shiv Prasher and Dr Adamchuk
Department of Chemistry &
Department of Bio-resource Engineering
McGill

Outline

- Introduction
- Objective of Study
- Methodology
- Results
- Future Studies

INTRODUCTION

- pH is a frequently measured parameter of immense importance in many application fields, such as environmental monitoring, Chemical Industries, bio-processing and biomedical diagnostics.
- The measurement of pH is usually performed using the glass electrode. however, the electrochemical method suffers from many drawbacks.

Glass Electrode Limitations

- Susceptible to electromagnetic interference
- Difficulty in miniaturisation.
- Limitations of measurement in aqueous suspensions of organic matter.
- High power requirements.
- Bulky design

ADVANTAGES OF OPTICAL PH SENSORS

- Higher sensitivity and selectivity
- Insensitive to electromagnetic interference.
- No need of reference electrode.
- Highly suitable for low power and remote applications.

Objective of Study

- Develop a optical pH sensor having the following Characteristics

Characteristics	Range
pH Range	5-9 (6-8)
Reproducible	Yes
Resolution	0.06-0.08
Device Stability	➢ 1 month
Dye Stability	Stable
Interferences	Ionic independent

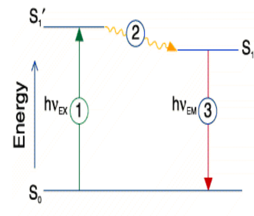
Principal of Optical pH Sensors

- Optical sensors are based on reagents that change their optical properties on with the change in pH of the analyte.
- The most commonly measured optical properties
- Absorption
- Fluorescence intensity

Fluorescent pH indicators offer better selectivity and sensitivity than absorption-based pH indicators.

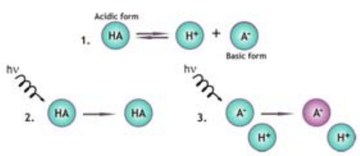
Fluorescence

- Electron excited form ground state by absorption of light
- Fluorescence observed as electron decays – photon release
- Energy lost so light emitted at a longer wavelength



Principal of pH Indicator

- pH indicators are typically weak organic acids or bases with distinct optical properties associated with their protonated and deprotonated forms. In most cases, pH sensitivity is based on a fluorescence intensity change with a change in the concentration of hydrogen ions.



Some Fluorescent Dyes and their pH Range

Dyes	pH Range	Excitation	Emission
Fluorescein	5-9	494 nm	521 nm
Resurufin (7-Hydroxyphenoxazin-3-one)	4-8	460 nm	573 nm
HPTS (pyranine (8-Hydroxypyrene-1,3,6-Trisulfonic Acid, Trisodium Salt))	5-8	450 nm	505 nm
DHPDS (1,3-dihydroxy-pyrene-6,8-disulfonic acid)	5-8	450 nm	505 nm

Fabrication of Optical pH Sensing Films

- pH sensors consist of a proton-permeable solid matrix in which the pH indicator is encapsulated.
- pH is measured as a function of reversible changes in the fluorescence intensity of the indicator.
- Polymers, Sol-gel materials are widely
- used as immobilisation matrices for pH-sensitive fluorescent indicators

Immobilization of the Flourescent dye on Polymer matrix

- The immobilization of the indicator is probably the most important factor that governs the lifetime and signal stability of the sensor. Poor immobilization causes leaching of the indicator. and, consequently, a drifting of the signal which, in turn, leads to the breakdown of its sensing ability in the extreme case. The most effective immobilization technique is to bind the sensing molecules covalently to the supporting material, which makes leaching virtually impossible under normal conditions

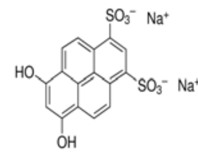
Methodology

Properties and Structure of DHPDS (6,8-dihydroXy-1,3 pyrenedisulfonic acid disodium salt) Dye

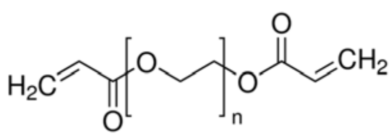
High quantum yield

pH range 5-9

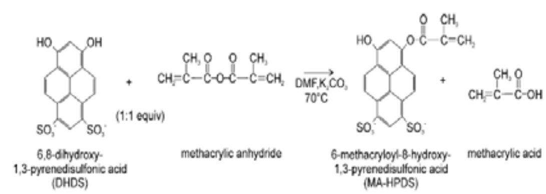
lack of toxicity



Polymeric Support for Sensor
Polyethylene Glycol Diacrylate (PEGDA)

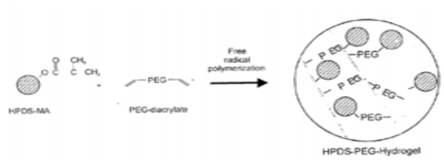


Modification of MA-HPDS dye



Scheme 1 Reaction scheme for the preparation of methacryloyl-modified HPTS analog.

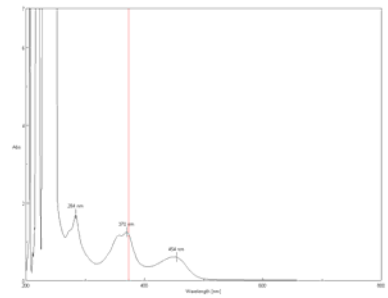
Co-Polymerization of MA-HPDS Dye with PEGDA



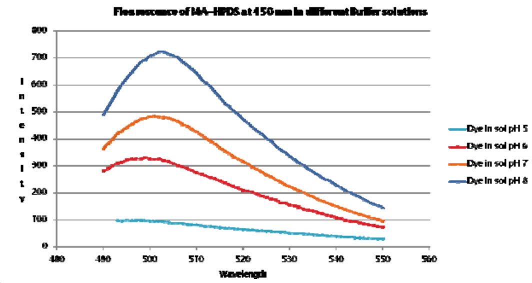
Study of Optical charactaristics of Sensor thin films

- Optical characteristics of the Thin films prepared were analysed on
- UV-Vis Cary 5000 Spectrophotometer
- Flouro-Max-2 Horiba (Capacity to hold solid samples)

Absorption Spectra of MA-HPDS Dye



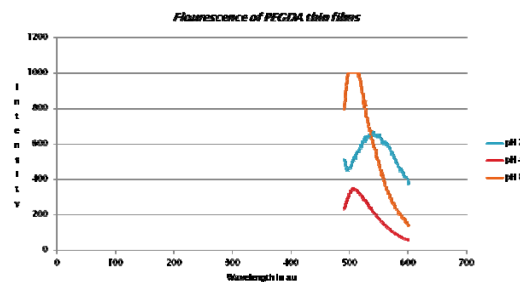
Emission spectra of MA-HPDS Dye in different pH Buffer solutions



pH Sensor Patches

Optical pH Sensing Films (pH =3 (Left) pH =9 (Right)

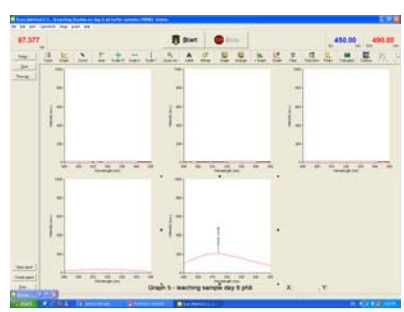
Emission spectra of Optical sensing thin films in different pH Buffer solutions



Leaching Behaviour of pH sensor in different buffer solution

- Leaching behaviour of PEGDA +Dye Thin films was tested in different buffer solutions for a total period of 9 days. A very small amount of leaching only at pH 8 was observed for all nine days. However, no leaching of dye was observed for buffer solutions of pH 4,5,6 & 7.

Leaching Behaviour of pH sensor in different buffer solution



Future Studies

- Optimization of thickness of pH sensing thin films for maximum performance
- Development of Optical setup to perform real time fluorescence intensity
- Study the behaviour of sensing films in the presence of different ions on the pH measurements.
- Study the effect of temperature on the pH sensing thin films.
- Study the photo-stability and temporal stability of the pH sensing films

THANK YOU FOR YOUR PATIENCE