



# Development of a Cost Effective Sensing Platform for the Detection of Phosphate in Natural Waters.

Andrew Donohoe, Gareth Lacour, Peter McCluskey,  
Margaret McCaul, Dermot Diamond

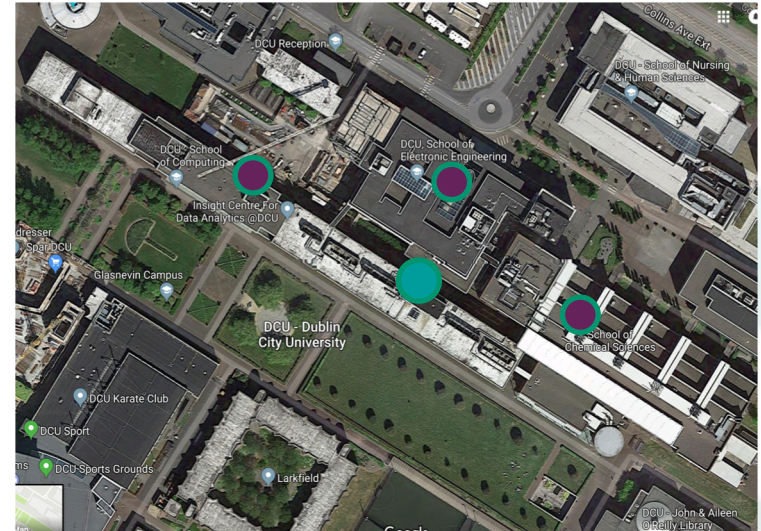
Innovation Partnership IP 2016 0502

This Research is co-funded by the European Regional Development Fund (ERDF) under Ireland's European Structural and Investment Funds Programmes 2014-2020



**PI Dermot Diamond**

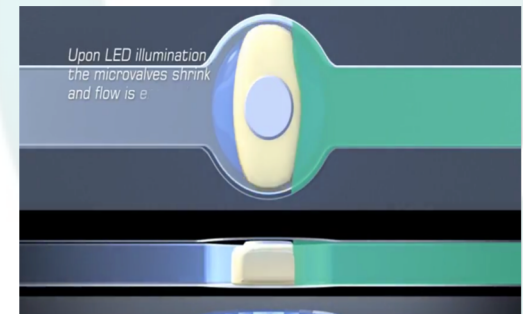
**Multidisciplinary Team of  
Analytical Chemists, Engineers,  
Material and Computer  
Scientists**



**Wearable  
Sensors**



**Environmental  
Sensors**



**Material  
Science**

## Environmental Sensors

Create cost effective sensors that can obtain accurate, real-time information about environmental status from the highly local to global scale.

This can only be realised through 'deploy and forget' models of use, in which the analytical platforms are:

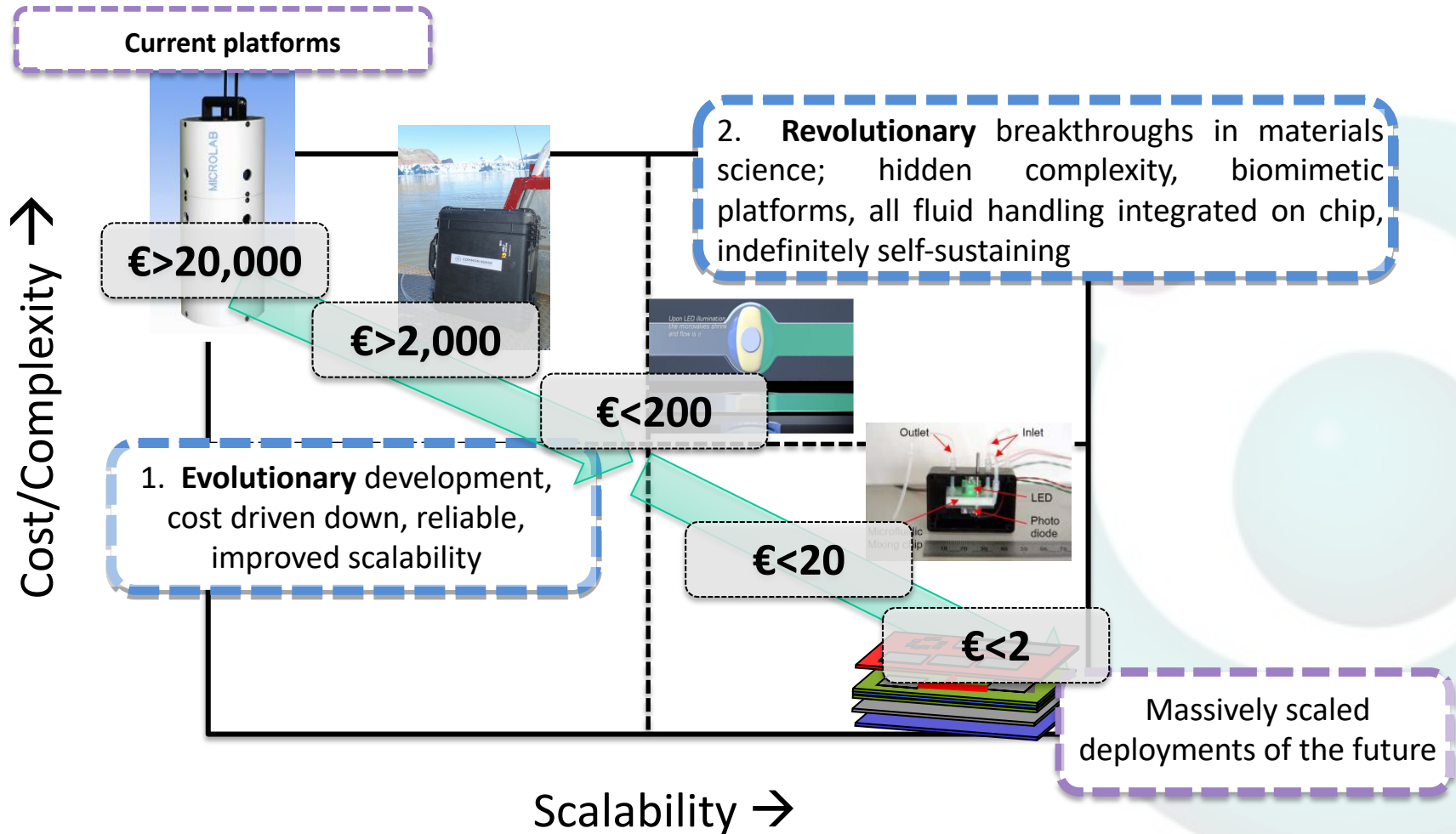
- i) capable of autonomous function for periods of months between servicing intervals;
- ii) provide validated analytical data over this period,
- iii) are relatively inexpensive to buy and maintain

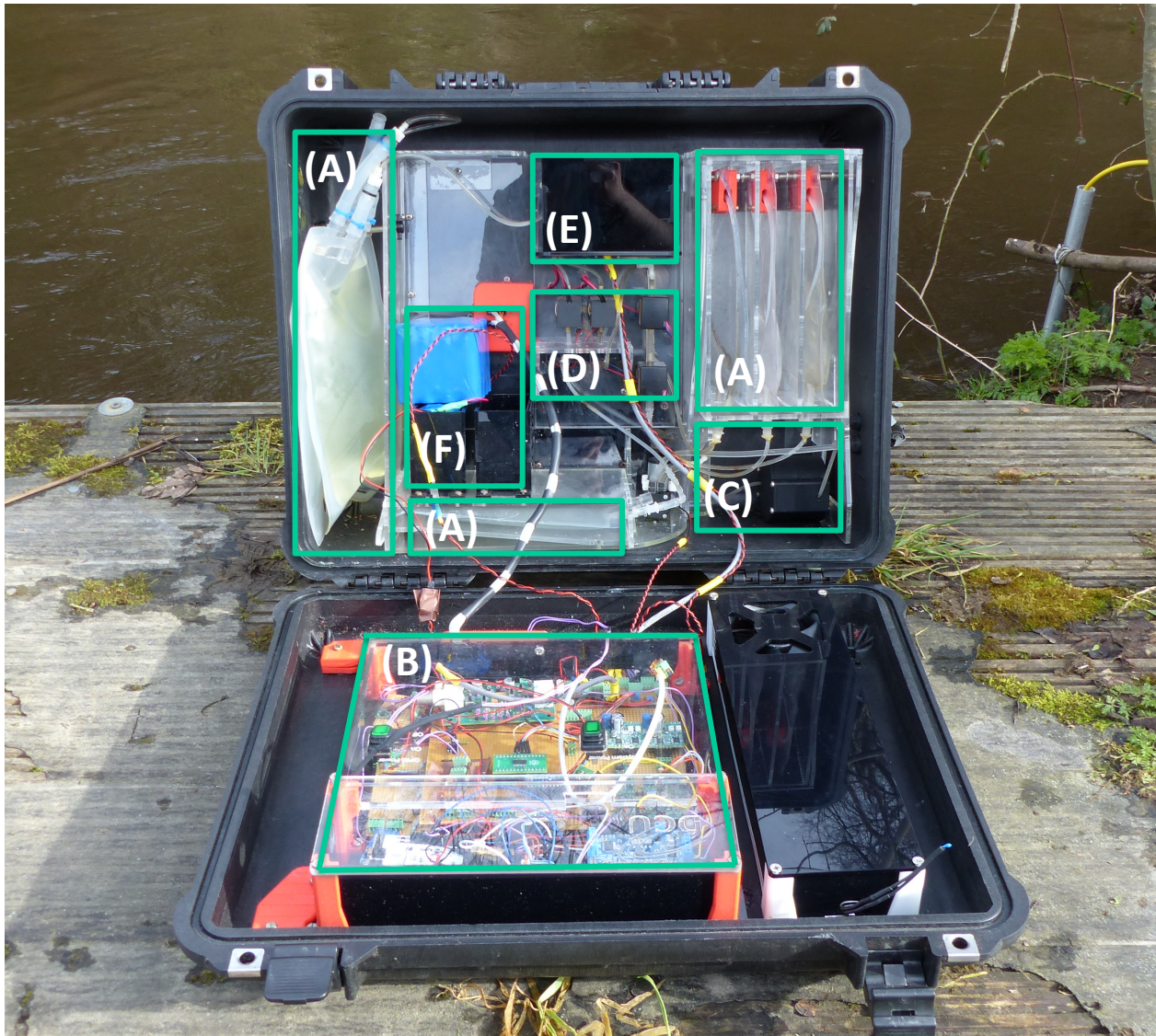


- Water Framework Directive Marine Strategy Framework Directive, and other EU policies
- EU Copernicus programme invest almost €1 Billion 2014-2020
- Nutrient Challenge , Alliance Coastal Technologies (ACT)
- \$210 Billion spent annually in the USA on impacts to drinking water quality and aquatic ecosystems
- Autonomous Nutrient platforms have the potential to offer higher resolution data in comparison to traditional methods





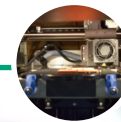
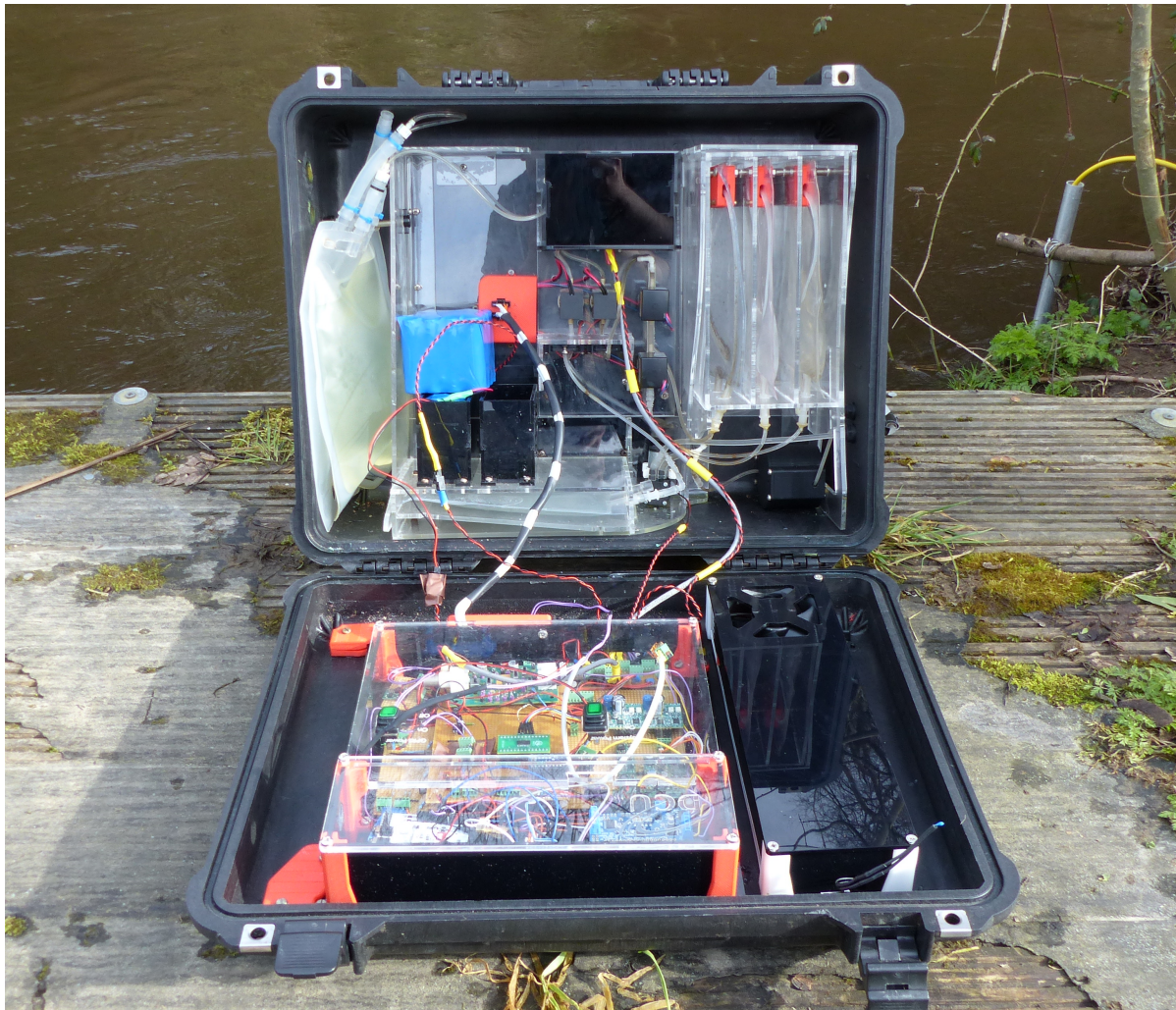




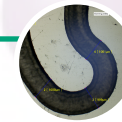
- A) Reagent, Calibration Standards, Waste**
- B) Electronics for Automation, Detection and Data Transmittance**
- C) Inlet System**
- D) Fluidic Handling**
- E) Fluidic Chip, LED, Photodiode**
- F) Battery**



# Nutrient Platform



**Rapid  
Prototyping**



**Microfluidics**



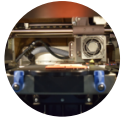
**Colorimetric  
Chemistries**



**Optical  
Detection**



**Electronics**



## Rapid Prototyping

### Rapid Prototyped Components

Use of 3D Printing, Laser Ablation and Micro milling techniques for rapid Prototyping

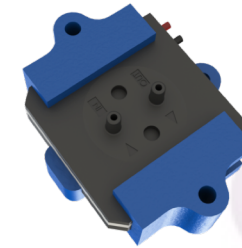
- Parts quickly and easily manufactured in house
- Reduces manufacturing time
- Reduces cost

3D Render

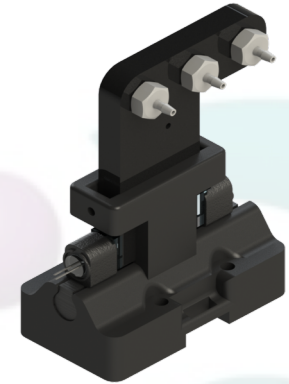
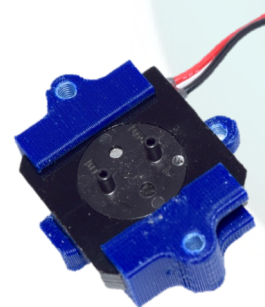


**Cuvette Holder with Led Alignment**

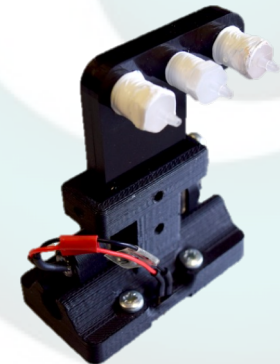
Manufactured part



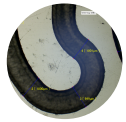
**Piezo Pump Mountings**



**Microfluidic Optical Chip**

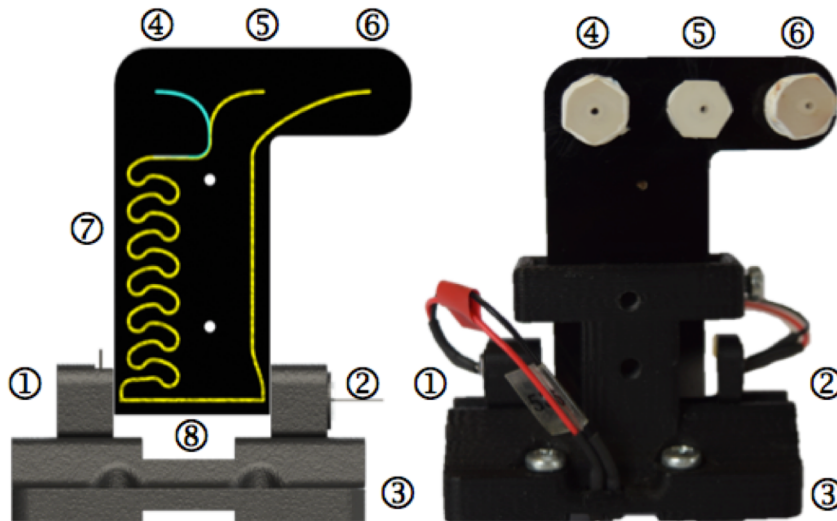
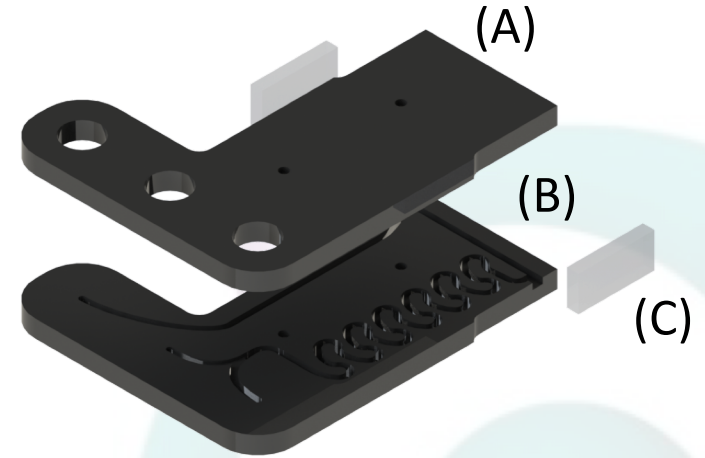






## Microfluidics

- 2 Layer PMMA Microfluidic Chip (A,B), Optical Windows (C)
- Manufactured using Precision Micro Milling
- Bonded using Heat and Pressure at transition temperatures
- Mixing Channels Induces chaotic advection
- 3D Printed Alignment Rail for Kinematic Stability

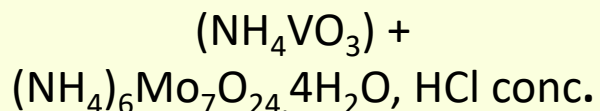


- ①. Photodiode
- ②. UV-LED
- ③. 3D Printed Mount and Rail
- ④. Sample Inlet
- ⑤. Reagent Inlet
- ⑥. Outlet
- ⑦. Serpentine Mixing Channel
- ⑧. Optical Detection Channel



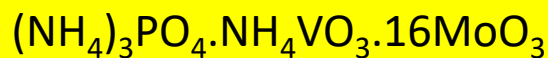
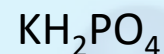


## Mixture (Reagent)



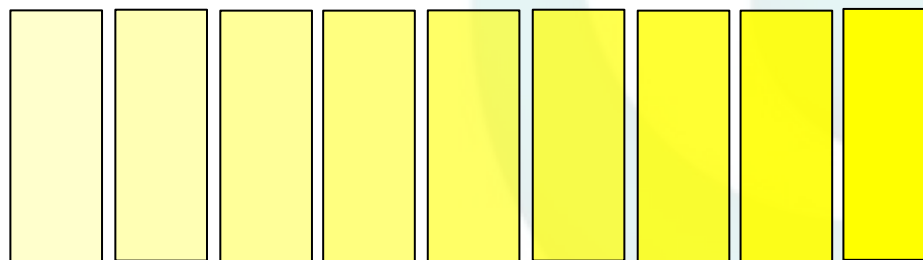
1:1

## Sample



### Yellow Method –

Vanadomolybdophosphoric Acid is formed when ammonium metavanadate and ammonium molybdate (mixture) reacts with phosphate (acidic conditions)



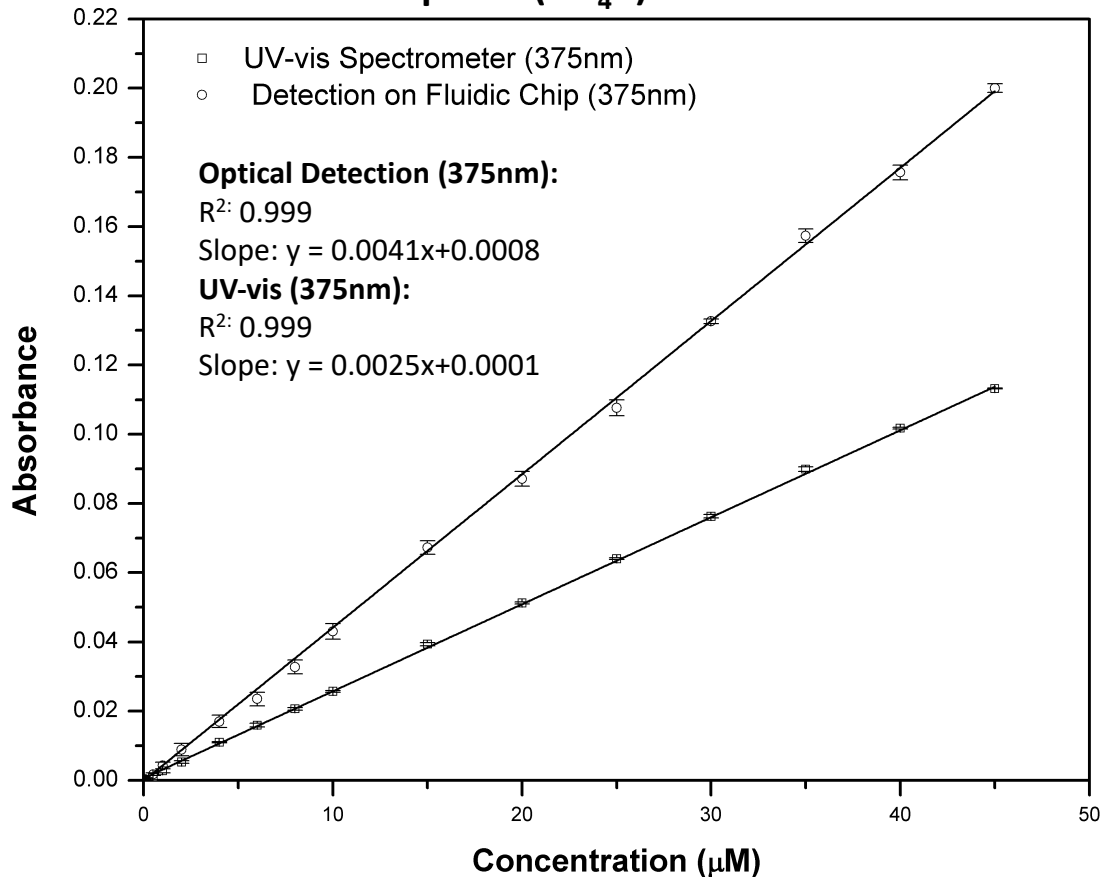
Increasing Nutrient ( $\text{PO}_4^{3-}$ ) Concentration  
Increasing Colour Intensity



## Optical Detection

### Optical Detection on Microfluidic Chip Vs UV-vis Spectrometer

#### Phosphate ( $\text{PO}_4^{3-}$ ) Detection



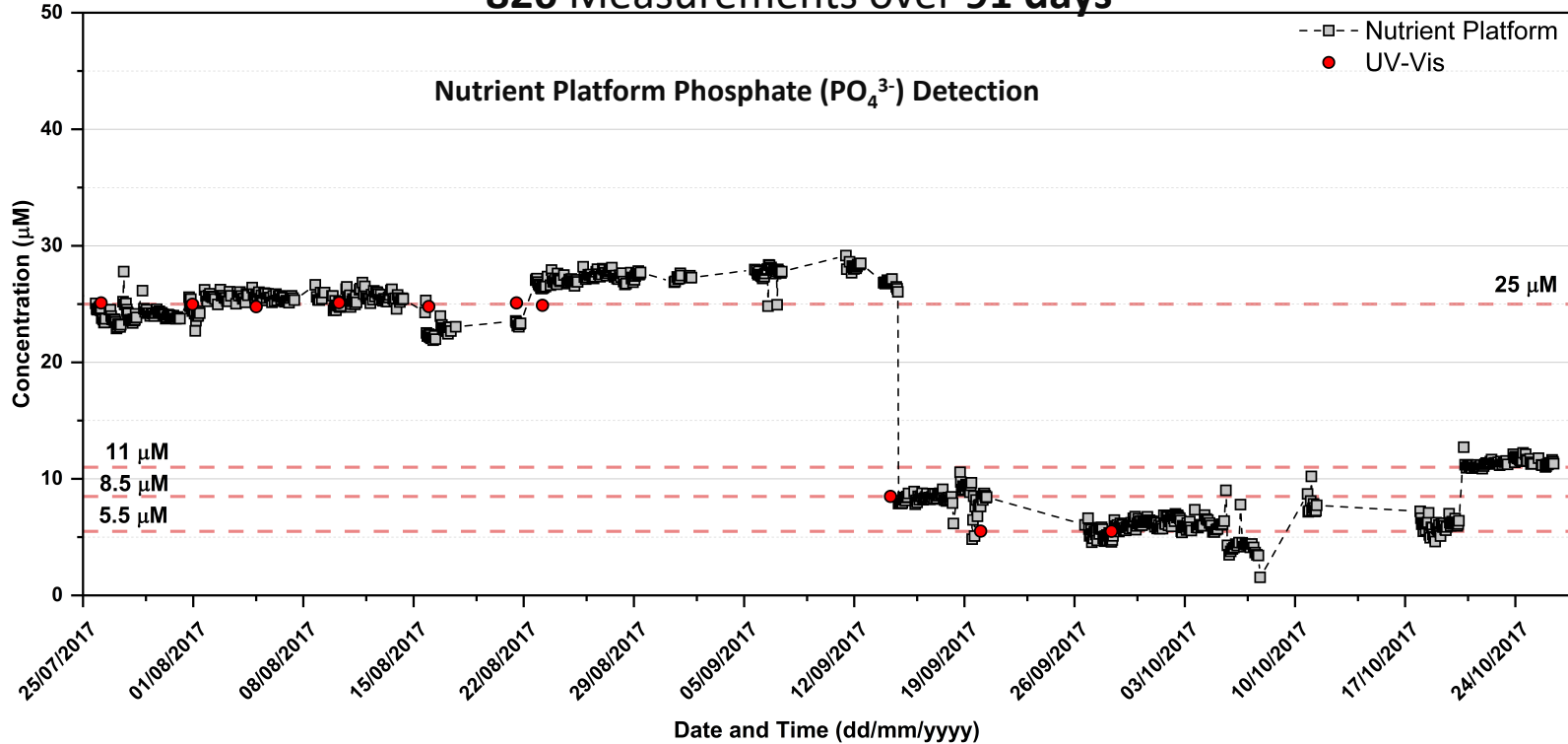
LED (375nm) Photodiode optical detection carried out on Microfluidic Chip

Phosphate ( $\text{PO}_4^{3-}$ ) Detected 0-45 $\mu\text{m}$  on UV-Vis(375nm) and on Microfluidics

Increased Sensitivity when detected on Microfluidic Chip vs UV-Vis Spectrometer

Validation carried out from the 25<sup>th</sup> of July to the 27<sup>th</sup> of October 2017

**826 Measurements over 91 days**



Nutrient Platform ( $\mu\text{M}$ )	$S_{\mu\text{M}}$
5.9 (n=139)	0.6
8.4 (n=71)	0.3
25.4 (n=408)	2.7

## 1: Milan WWTP, Italy

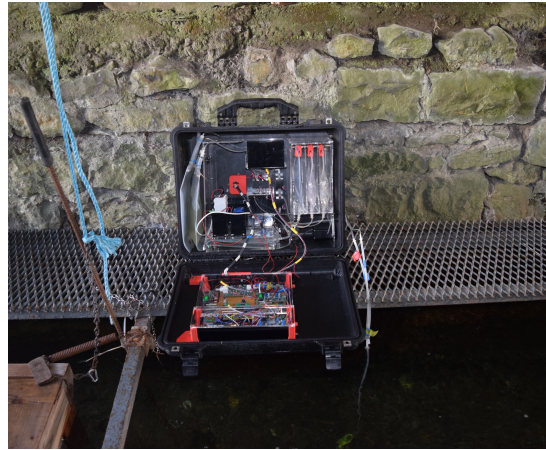


**Water Type:** Waste Water  
after 2<sup>nd</sup> stage processing

**Number of  
Measurements:** 14

**Date Deployed:** 4<sup>th</sup> – 5<sup>th</sup>  
May 2017

## 2: Lough Rea, Galway

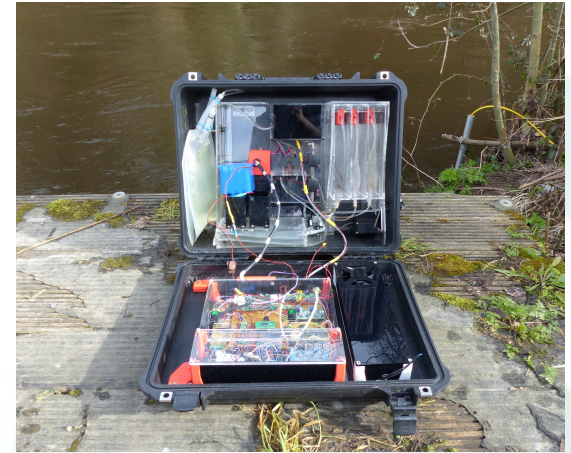


**Water Type:** Spring Fed  
Freshwater Lake

**Number of  
Measurements:** 55

**Date Deployed:** 5<sup>th</sup> – 10<sup>th</sup>  
Dec 2017

## 3: River Liffey, Palmerstown, Dublin



**Water Type:** Freshwater  
River

**Number of  
Measurements:** 224

**Date Deployed:** 21<sup>st</sup> Feb –  
20<sup>th</sup> Mar 2018



## Nutrient Platform Phosphate ( $\text{PO}_4^{3-}$ ) Detection



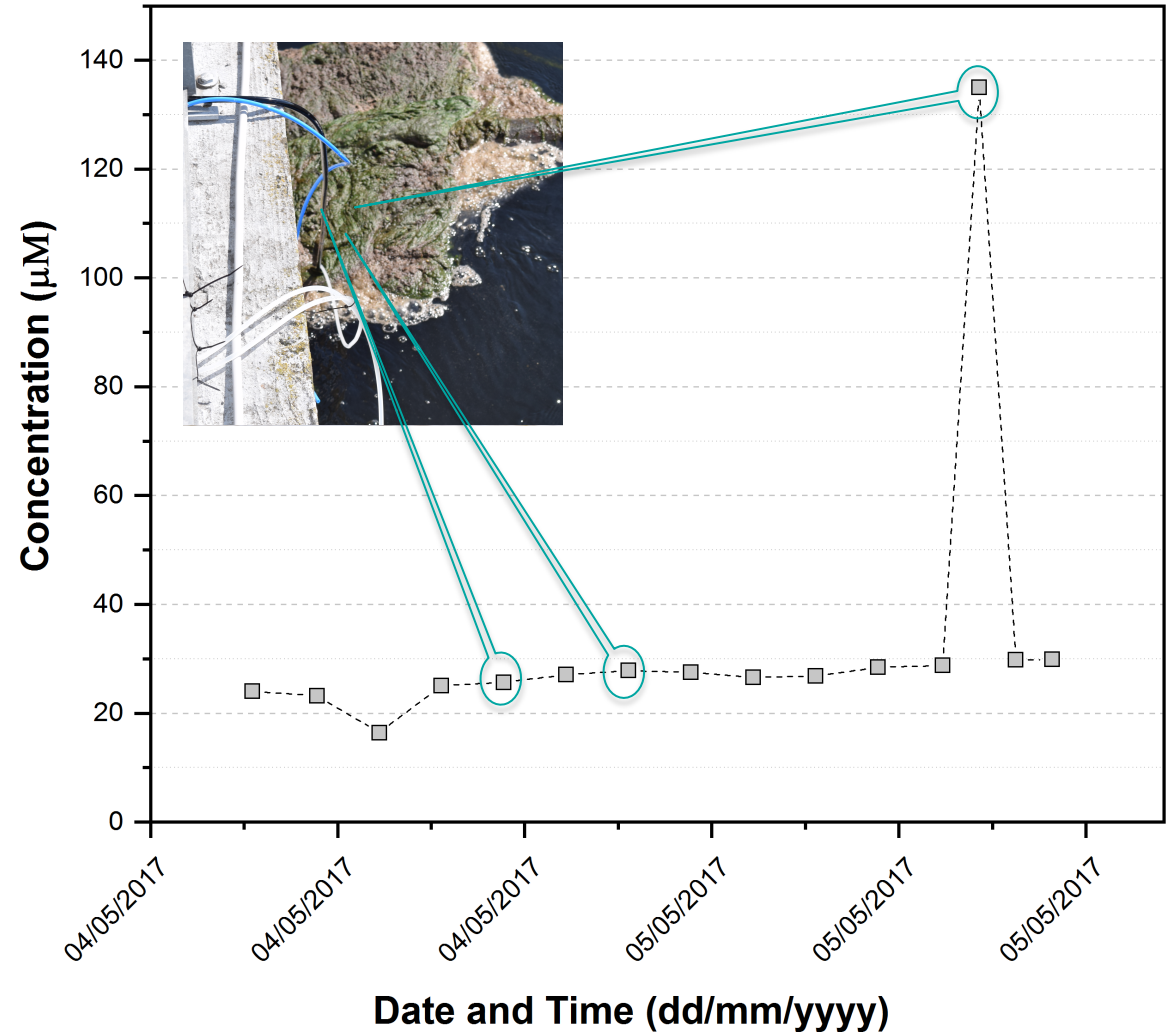
### Milano San Rocco WTPP

Sampling Point:  
Output Water after Clarifier

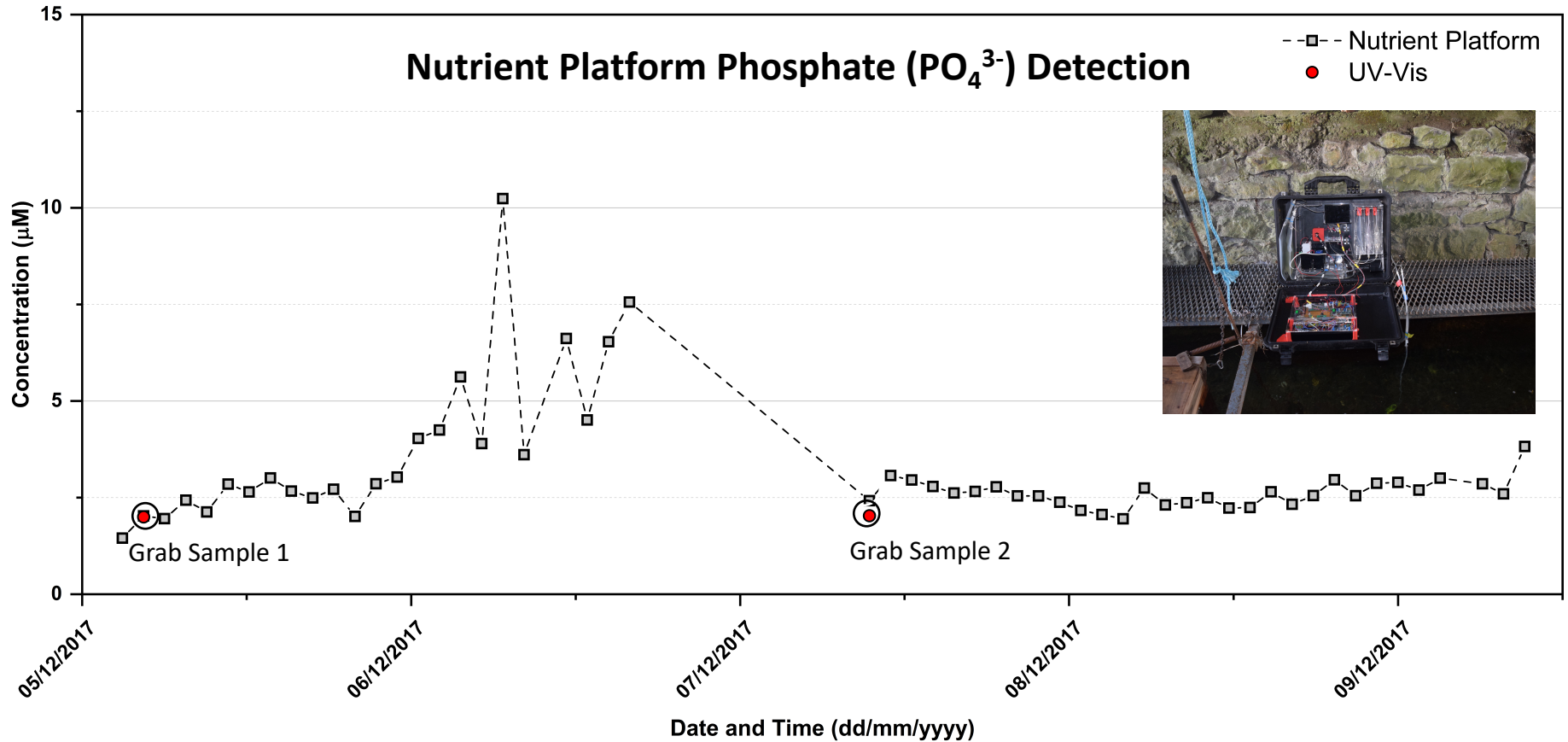
Typical levels:

10mg/L Suspended Solids

15 $\mu\text{M}$  Phosphate ( $\text{PO}_4^{3-}$ )



# Deployment 2: Lough Rea, Galway

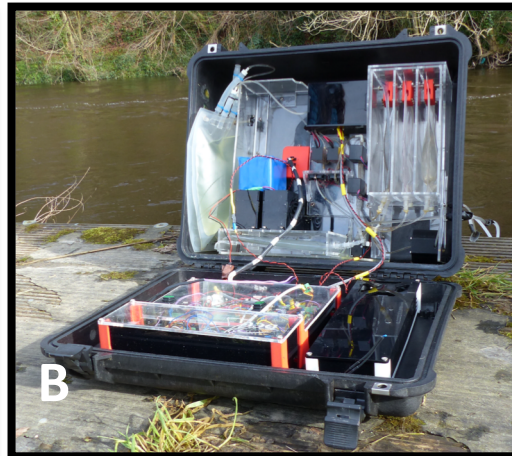
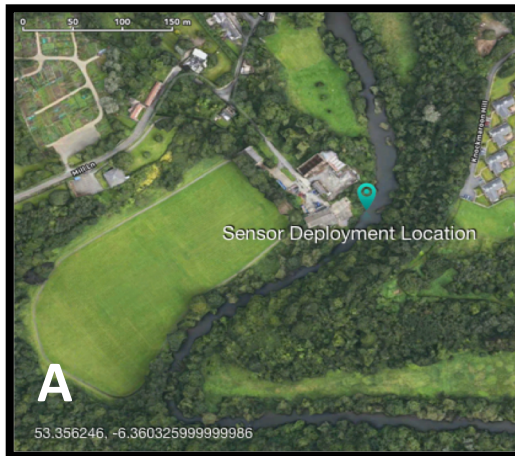


Spring Fed Carboniferous limestone lake  
**55** measurements over **5** days  
 Deployment ceased due to regulator failure

Grab Sample	1	2
Nutrient Platform ( $\mu\text{M}$ )	2.0	2.4
UV-Vis ( $\mu\text{M}$ )	2.0	2.0

# Deployment 3: River Liffey, Palmerstown, Dublin

- Sensor deployed on the River Liffey for 28 days (21/02/2018 – 19/03/2018)
- Measurements of Phosphate ( $\text{PO}_4^{3-}$ ) detected every 3 hours
- Environmental Temperature, Rainfall and Water level recorded



## Beast from the East: Status Red snow alert in place until Friday

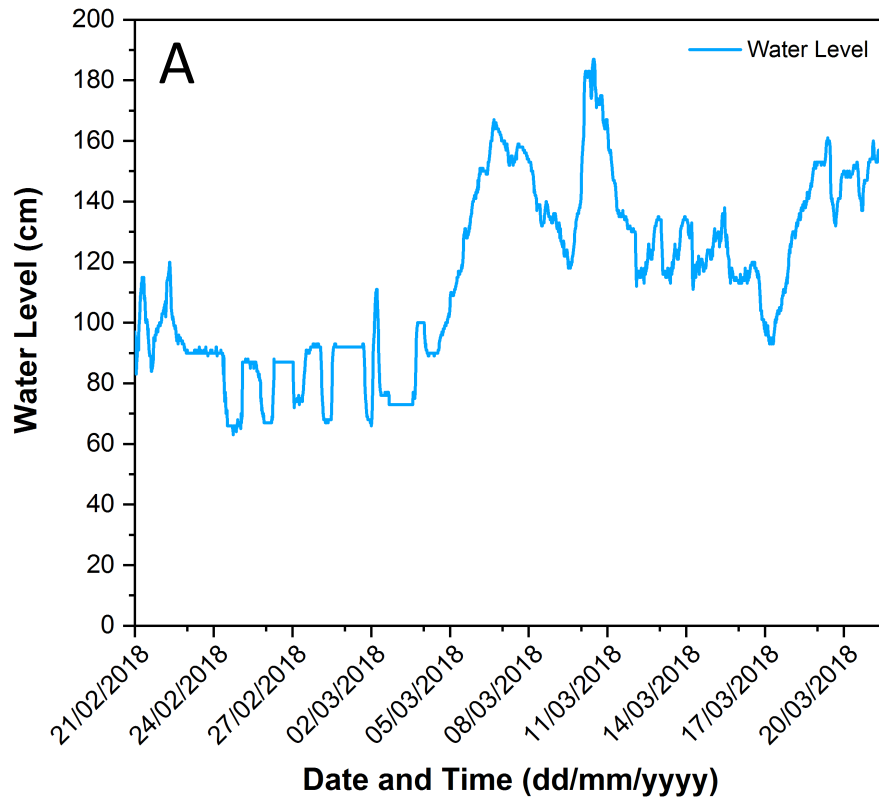
Varadkar says people 'should not venture out of doors' while the red level warning is in place

© Wed, Feb 28, 2018, 06:29 | Updated: Wed, Feb 28, 2018, 21:05

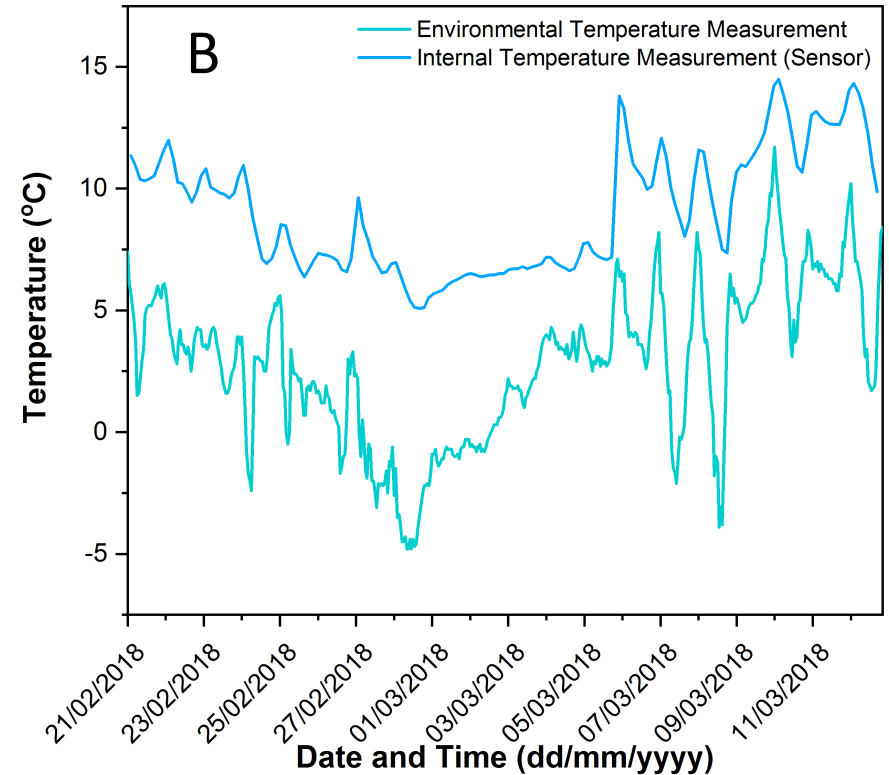
**D**

- A. Deployment Location
- B. Sensor Deployed
- C. Sensor Deployed by depth gauge
- D. Temperatures reach  $-4.5^{\circ}\text{C}$

# Deployment 3: River Liffey, Palmerstown, Dublin



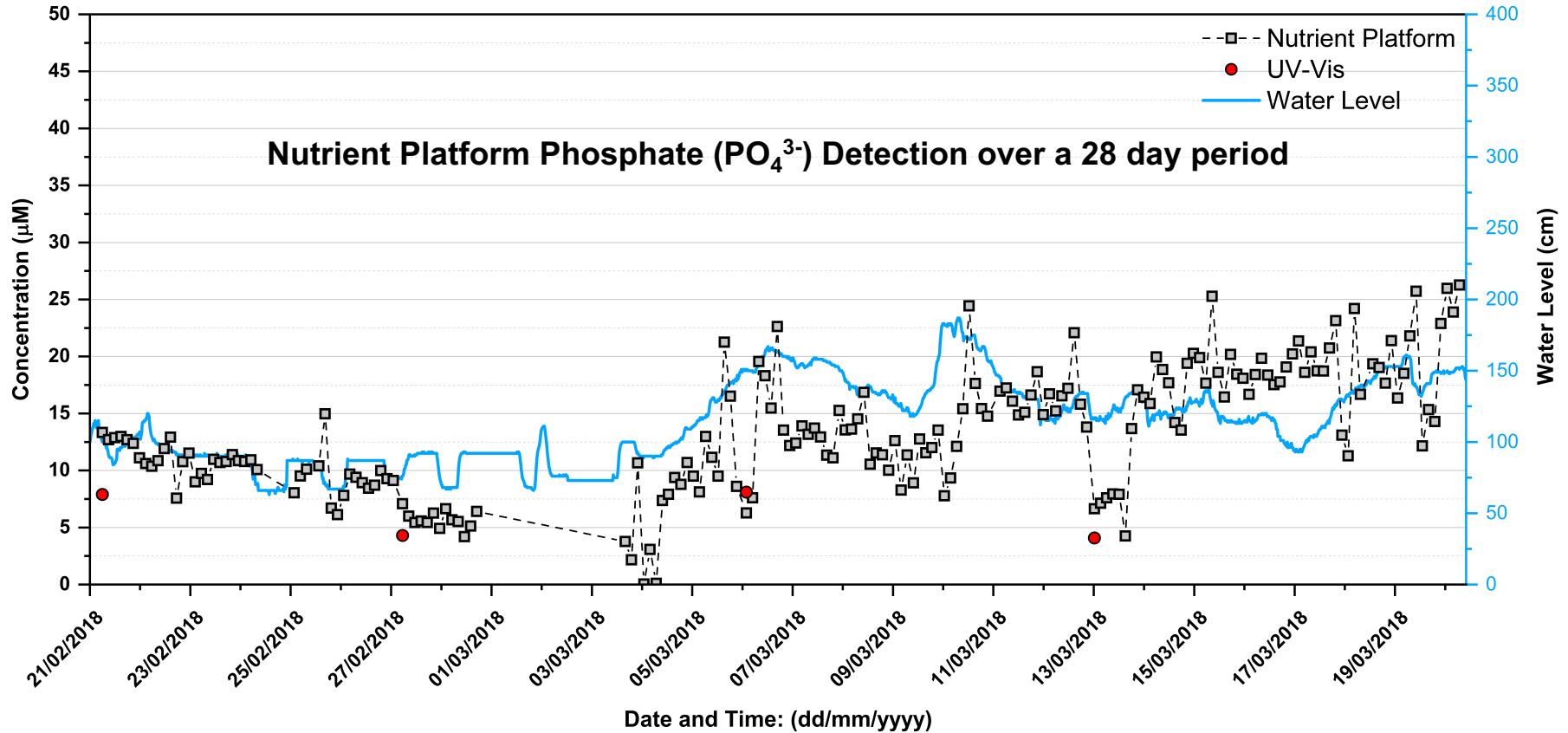
**A.** Water levels controlled by Leixlip Dam. Increasing water levels from the 5<sup>th</sup> Mar due to snow melt.



**B.** External vs Internal Temperature  
External lows of  $-4.5^{\circ}\text{C}$ .  
Internal lows of  $5^{\circ}\text{C}$ .

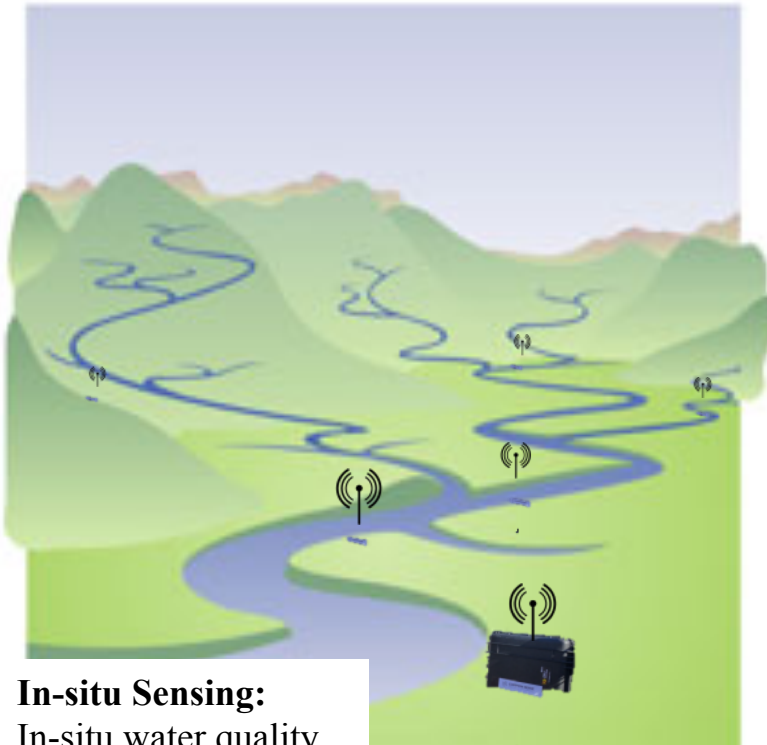


# Deployment 3: River Liffey, Palmerstown, Dublin



**636 measurements over 28 days recorded**

## Smart Environment Integrated Sensing Network



**Data Analysis:**  
Combination of in-situ and satellite data. Statistical Algorithms to develop test models

Real time information and predictive Models on water quality,

Development and Integration of Detection for Nitrite ( $\text{NO}_2^-$ ) and Nitrate ( $\text{NO}_3^-$ )

Further optimisation and cost reduction of autonomous nutrient platform

Dr Margaret McCaul, Prof Dermot Diamond and all in the  
Adaptive sensors group  
Enterprise Ireland  
National Centre for Sensor Research



Innovation Partnership IP 2016 0502

This Research is co-funded by the European Regional Development Fund (ERDF) under Ireland's European Structural and Investment Funds Programmes 2014-2020