Experiences and recommendations in deploying a real time, water quality monitoring system

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Abstract

Monitoring of water quality at a river basin level to meet the requirements of the Water Framework Directive (WFD) poses a significant financial burden using conventional sampling and laboratory based techniques. Wireless sensing systems offer the potential to reduce these costs considerably, as well as providing more useful, continuous monitoring capabilities by giving an accurate idea of changing environmental and water quality in real time. It is unlikely, that the traditional spot/grab sampling will provide a reasonable estimate of the true maximum and/or mean concentration for a particular physicochemical variable in a water body with marked temporal variability. When persistent fluctuations occur, it is likely only to be detected through continuous measurements, which have the capability of detecting sporadic peaks of concentration. Thus, in-situ sensors capable of continuous sampling of parameters required under the WFD, would therefore, provide more up-to-date information, cut monitoring costs and provide better coverage representing long-term trends in fluctuations of pollutant concentrations. DEPLOY is a technology demonstration project, which began planning and station selection and design in August 2008 aiming to show how state of the art technology could be implemented for cost-effective, continuous, real-time monitoring of a river catchment. The DEPLOY project is seen as an important building block in the realization of a wide area autonomous network of sensors capable of monitoring the spatial and temporal distribution of important water quality and environmental target parameters.

The demonstration sites chosen are based in the River Lee, which flows through Ireland's second largest city, Cork, and were designed to include monitoring stations in five zones considered typical of significant river systems – these monitor water quality parameters such as pH, temperature, depth, conductivity, turbidity and dissolved oxygen.

Over one million data points have been collected since the multi-sensor system was deployed in May 2009. Extreme meteorological events have occurred during the period of deployment and the collection of real time water quality data as well as the knowledge, experience and recommendations for future deployments are discussed.

Key-words; Wireless Sensor Networks, (WSN), multi-sensor system, real-time monitoring, water quality, biofouling, maintenance, deployment,

1. Introduction

We are facing exciting challenges [1] in the development of a water quality monitoring programme in Europe as part of the requirements of the Water Framework Directive [WFD]. At a time when technological advances are providing new sensor capabilities, novel network capabilities, long-range communications technologies and data interpreting and delivery formats via the World Wide Web, there is a significant opportunity to utilise next generation technologies integrated into intelligent systems to provide relevant data to assist in the decision making process of water management authorities . There are also particular specific benefits when the data is available at a higher degree of spatial and temporal granularity.

There is a growing acceptance that traditional spot/grab sampling is unlikely to provide a reasonable estimate of the true maximum and/or mean concentration for a particular physicochemical variable in a water body with marked temporal variability. When persistent fluctuations occur, it is likely only to be detected through relatively high frequency continuous measurements, which have the capability of detecting sporadic peaks of concentration. There is a view, that *in-situ* sensors capable of continuous sampling of parameters required under the WFD, would provide more up-to-date information, could reduce the cost of ownership and provide better coverage representing long-term trends in fluctuations of pollutant concentrations.

The success of a monitoring system that can provide real time data on a variety of water quality parameters over long periods of time, relies on the development of rugged intelligent systems of sensors and systems of a multidisciplinary nature and requires close collaboration within any team of researchers developing such systems, in particular when the requirement demands the scaling of that technology up in volumes, and validating its system performance.

The objective of the DEPLOY project was to implement a demonstration wireless sensor network of water quality monitoring stations and in doing so show how this technology could impact on the understanding of the processes in a catchment and how this could better inform decision making on a real-time operational basis. More specifically the DEPLOY project was designed to demonstrate the following:

- The benefit of data collected and delivered at a much higher temporal resolution than achieved with more traditional grab sample and site visits.
- The benefit of a multi-station network and how the inter-comparison of data and the fusion of data from different stations could help achieve a better understanding of the catchment.
- Show how real-time instead of delayed mode data could be used to help better manage the river and respond to incidents.

In addition there were some secondary achievements including the study of fouling on sensors, the management of power, the performance of sensors and the use of some sensors as surrogates for others. This demonstration of a truly heterogeneous water quality monitoring network system is one of the first of its kind in Ireland and shows how data could be collected from a number of locations and viewed in real or near real-time.

1.1 Current State of Knowledge

Water monitoring is required to measure and understand the chemical and biological quality of water, and for taking remedial action. The use of advanced monitoring technologies and strategies mean that proactive measures can be implemented to improve water quality [2].

Environmental and water quality monitoring is key to measuring and understanding the chemical and biological quality of water and for taking reactive remedial action as appropriate. Over the coming years, monitoring of water bodies will increase within Europe, in order to comply with the requirements of the WFD, (Council Directive 2000/60/EC), [3,4,5,6,7] and globally owing to pressure from climate change. The establishment of high quality long-term monitoring programmes is regarded as essential, if the implementation of the WFD is to be effective [8,]. The ideal monitoring system of the near future might consist of a network of sensors deployed at key locations, capable of autonomous operation in the field for a year or more. [9,10,11,12,13] The data from the monitors is communicated by wireless technology for processing and interpretation. Although some elements of this ideal system are in place, ongoing research and development is required in several areas relating to both sensor development and field-testing.

1.1.1 Current Monitoring methods:

While there are limited examples of operational sensor networks a number of studies have been reported for water quality monitoring in the literature, but also many interesting approaches have been reported for other applications - using wireless sensor networks. The approaches in wireless technology may be developed as generic technologies having applications in many areas. A prototype network of meteorological and hydrological sensors has been deployed in Yosemite National Park, traversing elevation zones from 1,200 to 3,700 m. The results are proving useful in monitoring snowmelt in the Sierra Mountains, and in areas with varied elevations. An aqueous sensor network is described, consisting of an array of sensor nodes, which can be randomly distributed throughout a lake or drinking water reservoir [14]. Beyond ensuring drinking water safety, possible applications for the aqueous sensor network include advanced industrial process control, monitoring of aquatic biological communities and monitoring of waste-stream effluents. For the protection of wells and a groundwater recharge an early warning system was developed by Fleishman and co-workers [15]. The monitoring network design is based on sensor measurements only. For this purpose, a submersible spectrometer has been tested for multi-parameter measurements directly *in situ*. It is reported that the developed system can easily be upgraded with other new sensors. Calibration and validation data are supplied by conventional grab sampling and laboratory analysis, a validation approach used by all researchers in the area of sensor technologies for water quality monitoring. The entire system is equipped with remote control and the internet based user interface enables control of the different aspects of the sensor network. All data measured from the nine sites are available in real time on the internet. Electronic instruments are ideally suited to gathering information regarding transient events [16]. Data loggers equipped with water quality sensors are reported to offer an opportunity to study events on fine time scales, which cannot be sampled using other means.

While many systems have been developed in the laboratory, they may not have been fully validated in the field or fully validated. The long-term deployment of multi-sensor systems in the field is faced with many challenges. Besides fouling, on-line calibration of aquatic sensors, methods to reduce sensor drift, wireless technologies implemented and data aggregation are of high importance for remote sensors [17.] The US EPA's EMPACT (EPA's environmental monitoring for public access and community tracking) programme was established in 2001 for the Mystic River watershed. The project includes five water quality monitoring stations at various locations in the Mystic River watershed. Each station has a series of sensors connected to a data recorder and radio transmitter. The monitoring equipment automatically measures a number of water quality parameters (depth, temperature, pH, conductivity, dissolved oxygen and turbidity) every 15 minutes, with the data transmitted via radio to a server on the Tufts University campus, which are then available for display on the project website. In the UK, The National Monitoring Plan (now called the National Marine Monitoring Programme) was initiated in the late 1980s to co-ordinate marine monitoring in the United Kingdom among a number of organisations. Cefas have developed these marine environmental real-time observation systems (MEROS) with funding support by Defra for collecting the high-frequency, near real-time data needed for the NMMP. The Cefas-developed SmartBuoy is one of an array of automated *in situ* instrumentation systems that can be deployed for extended periods at a mooring. Data is published on the Internet to give rapid access to other collaborators and the public. Following successful deployment experimental programmes over two years to ensure reliability, and to produce a robust logistics and infrastructure support, Cefas is now using the SmartBuoy with spatial systems from other participating research groups in a series of pan-European collaborative deployment programmes [18].

In Australia in 2006, the CSIRO reached its first anniversary of continuous operation of a network of independent wireless sensors at the CSIRO ICT Centre, Brisbane [19]. Australia's Water Resources Observation Network (WRON) plans "to integrate a diversity of water data maintained by many agencies across Australia", and is involved in research in projects such as "the Australian Dam Levels Monitor, next-generation sensor networks and a report card framework for water quality" [20]. SmartBay [21] is an automated test and demonstration laboratory based in Placentia Bay on the South Coast of Newfoundland, Canada, that provides a facility for sensor/equipment testing and the integration of new technologies with innovative methodologies for resource and coastal management.

While there are limited examples of long-term operational sensor networks, a number of studies have been reported as above for environmental and water quality monitoring.

2 The DEPLOY Project

Driven primarily by the requirements of the WFD, this demonstration project represents an important collaboration between research centres, industry partners and local authorities with technical and analytical expertise to deploy maintain and evaluate a series of multi-sensor systems to assess the effects of long-term sensor deployment on water quality monitoring systems and sensor data. This process involves collecting a continuous data set of environmental and water quality variables from a number of sites to provide the necessary degree of spatial and temporal granularity of data over an extended period of time.

2.1. Deployment Description

The demonstration sites chosen are based in the River Lee, which flows through Ireland's second largest city, Cork, and were designed to include monitoring stations in five zones considered typical of significant river systems from estuary to source, figure 1. The River Lee is one of the largest rivers in southwest Ireland, with a total catchment area covering approximately 1500 sq km; the river rises in the mountains near Gougane Barra to the west of Cork and flows into Cork Harbour some 85 km to the east.

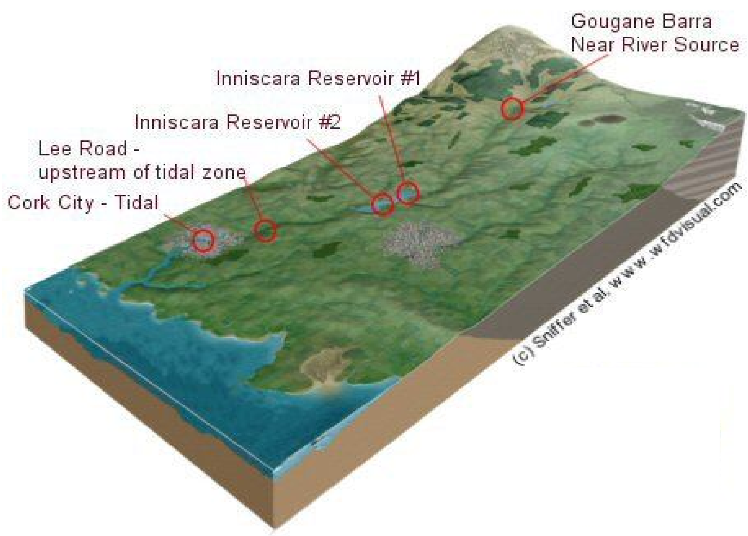

Figure 1. Deployment sites located in river basin catchment (courtesy of http://www.wfdvisual.com)

The local area networks generally comprise of a series of single- hop star-based networks based on a combination of technologies, the Tyndall Programmable System on Chip (PSoC) based 433MHz ISM band systems and the commercially available IDS DataPOD implemented by project partners IDS monitoring. The Tyndall PSoC controls the sampling of water quality parameters and transmission of the data to the IDS DataPOD for GPRS based telemetry to the system backbone and the data servers. Once data from the two substations has been received, the readings are compiled into a message format by the Tyndall Hub, which is connected to the IDS DataPOD, where it is date and time stamped, logged and then transmitted to the DEPLOY Data Server. The interface between the Tyndall system and the IDS data logger is a serial interface and communications are carried out following the ACKnowledgment protocol every 10 minutes.

Site 1: Lee Maltings

This site is located on the north channel of the River Lee at the Tyndall National Institute. This site is near the upper end of the estuary and located on a left-hand bend of approximately 70º. This site is tidal, with a tidal range of approximately 4m. *Parameters Monitored*: Conductivity, Chlorophyll-*a*, Dissolved Oxygen, Temperature

Site 2: Lee Road

This station is located at the Cork Corporation Water Works, which is located opposite Cork County Hall. The site is approximately 300m upstream of a weir and about 500m upstream of where the River becomes tidal and estuarine. *Parameters Monitored*: Conductivity, Temperature, pH, Chlorophyll-*a*, Turbidity, Dissolved Oxygen

Site 3: Inniscarra Pumphouse

Inniscarra Reservoir is located approximately 13km from where the River Lee enters the estuary in Cork City. This station is on the northern shore of the reservoir and approximately 2km upstream of Inniscarra Dam. The system is located in the intake tower of Cork County Council's water treatment plant. *Parameters Monitored*: Conductivity, pH, Chlorophyll-*a*, Dissolved Oxygen Temperature

Site 4: Inniscarra Reservoir Buoy

These stations are located on the Inniscarra Reservoir. The buoy is moored in approximately 20m of water upstream of the pumphouse station and downstream of where the river Dripsey enters the reservoir. *Parameters Monitored*: Dissolved Oxygen, Temperature, Chlorophyll-*a*

Site 5: Gougane Barra

This station is located approximately 3km downstream of Gougane Barra lake, at the source of the River Lee. This is also approximately 3km upstream of Ballingeary, which is the first urban settlement on the River Lee. This stage of the river is quite spaty and the water level rises quickly. *Parameters Monitored*: Conductivity, Temperature, pH

2.2 Technology Implementation

The technology demonstration involved the integration of a group of water quality sensors, as described above, into a distributed communication network for data processing and for transmission of this data to the web. This system is described in three parts – the core network electronics, the physical infrastructure deployed and the data servers and web application.

2.2.1 Core Electronics

The heterogeneous nature of the system implementation is realized by a combination of technologies developed by the project partners, including reconfigurable low power PSoC based Plug and Play sensor interfaces [22], the Tyndall modular WSN prototyping system [23,24], shown in figure 2, and the IDS DataPOD technology developed by industrial partners IDS Monitoring. This heterogeneous system incorporates a combination of ISM band wireless transmission capabilities, GSM data transmission from WSN backbone hubs to the data warehouse, and multiple processor types (Atmel Atmega 128l and Texas instruments MSP430). The demonstration of a truly heterogeneous water quality monitoring network system is one of the first of its kind in Ireland and shows how data could be collected from a number of locations and viewed in real or near real-time.

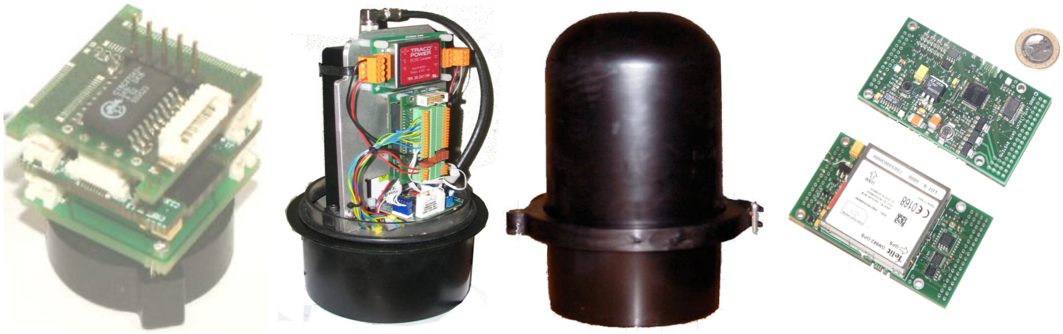

Figure 2. PSOC reconfigurable sensor interface on the Tyndall Stack and IDS DataPOD electronics

A key component of the wireless sensor system is the implementation of intelligent sensors incorporating TEDS (Transducer Electronic Data Sheet), which allow the sensor to identify and describe itself to the control unit within the transceiver system. The TEDS is a machine-readable specification of the characteristics of the sensor, with the intention to easy sensor installation and replacement. This allows TEDS-enabled sensors to be interfaced with the systems in a Plug and Play fashion. This TEDS implementation is based on the IEEE 1451 standard and the sensor interface can be dynamically configured by the system allowing for: sensor modularity and compatibility, sensor aggregation, sensor inter- operability, sensor fault tolerance and dynamic calibration.

The transceiver layer has an integrated ATMEL ATMega128 microcontroller coupled with the Nordic nRF905 Single chip 433/868/915 MHz Transceiver chip with a highly optimized RF section to ensure long range transmission distance (up to 4km).

Power consumption and robustness are important in the development and deployment of long lifetime sensor networks. In terms of power consumption, the goal is to minimize system power as much as possible. In order to achieve that, various solutions were evaluated. For instance duty cycling of wireless sensor nodes with long SLEEP times minimises energy usage. Characterisation of the Tyndall mote platform demonstrates, that even with a 1 minute cycle time for an 864 milli-second ACTIVE mode, the sensor module is already in SLEEP mode for almost 99% of the time. For a 20 minute cycle time, the energy utilisation in SLEEP mode exceeds the ACTIVE mode energy by almost a factor of three and thus dominates the module energy utilisation, thereby providing the ultimate limit to the power system lifetime [25] focussing on the ISM band data telemetry.

Table 1 provides detailed data of the calculated energy utilisation for the wireless sensor in both ACTIVE and SLEEP mode. The wireless system undertakes a full operation of sampling, processing and transmission in 864 milli-seconds. It is interesting to note that, although the transceiver has by far the largest power consumption for the embedded part of the system, in this application, some of the sensors dissipate significantly more energy than the transceiver. The water quality monitoring sensors are in general of high power consumption, as is the GSM based backbone of the telemetry system. For instance, when operating the sensors consume probably about 20mA on average, so a system with 4 or 5 sensors could consume 100mA or more for up to about 20 seconds. To this end, power saving strategies have also been implemented in the Programmable System on Chip (PSoC) [26] sensor interface, such as duty cycling and optimization of the power consumption of the PSoC for each sensor utilizing the reconfigurable nature of the PSOC system.

To meet the requirements of the long duration deployment scenario envisaged, the communications mechanism being implemented in the system is of a heterogeneous nature, utilizing low power consumption proprietary 433MHz ISM band star-based single-hop networking protocols and higher power consumption GSM communication backbone. This enables networks of sensor systems to be implemented giving the required granularity of sensor information (spatially and temporally) for extended periods.

Table 1. Tyndall Mote Power Consumption analysis

	Voltage (V)	Power (mW)	Time (S)	Energy (mJ)	Duty Cycle	% Energy Consumption
Active Sensor & Radio	3.0	96.2	0.039	3.75	0.065%	53.6%
Sleep	3.0	0.0541	60	3.24	99.935%	46.4%
Average	3.0	0.116	60.039	6.99	100%	100%

2.2.2 Packaging for deployment and reliability

The electronic systems were packaged in IP67 enclosures and deployed in a configuration suitable for the stations. At the Lee Maltings site the system deployed comprised of a pumped system that extracted water from the river into a tank on the quayside – this facilitated easier servicing of the instruments and was considered the most appropriate solution because of the large tidal range at this site. The stations at the Lee Road and Gougane Barra were implemented in a robust wall-mounted enclosure with the sensors mounted at the bottom of a steel pole that extended into the river. The station located at the intake-tower in Inniscarra involved a continuous flow through tank system and the reservoir station involved a small inshore data buoy. The stations at the Lee Maltings and at the Inniscarra intake tower have mains power supply available, the stations at the Lee Road and Inniscarra reservoir were powered by solar power and the Gougane Barra site ran on batteries only. Minor maintenance has been required on these systems, but as the systems had been initially designed for long term deployment, major maintenance has not been required.

2.2.3 Data Servers and Web Applications.

The DEPLOY website (http://www.deploy.ie) presents the project data collected from the five project station sites. Data is collected and displayed on the website and the user can select combinations of the different parameters to view at each site. The Data Servers and Web Application implement in DEPLOY are part of the IDS Monitoring DataLINK system. In the DEPLOY Implementation data is received from the sensor network backbone GPRS access nodes using an FTP protocol and are written to a project FTP server. A series of server apps continuously scan for incoming data and once detected it is parsed, validated and written to the DataLINK SQL Server Database. The data validation checks the message structure for completeness and origin, and - once accepted - the parameter values are checked against an expected-value-range table. Any data values falling outside the expected thresholds are processed as normal but flagged as suspect outliers. Once written to the database the DataLINK alert manager checks all data against alert criteria established by system users and in the event that alerts are triggers, the appropriate action is taken (e.g. email or SMS issued). Once data is written to the database it can be viewed graphically, exported, annotated and compared with other stations on the web by authorized users, as determined by the system administrator. A mobile device version of the website was also implemented to demonstrate access to the data anytime, anywhere. The latency between data collection and delivery to the website can be configured to be as low as a few seconds but typically in DEPLOY is about 30 seconds.

3. Sensor Maintenance & Bio-fouling

Most objects placed in coastal zone waters, brackish waters or even in lakes will become covered with organisms after a period of time. Biofouling can be specific for the geographical site and directly related to the bio productivity and environmental conditions that affect the site. Therefore, no unique solution exists to control biofouling and the choice of the method will have to take into account not only the site characteristics, but also, the general design of the monitoring station. There are different ways to prevent biofouling, such as, passive ways, choosing certain construction material, painting with antifouling coatings, or active ways such as using electric fields.

It is important to understand the characteristics of the site in order to identify the type of biofouling, and the site conditions that can foster it. For example, enclosed areas (such as marinas) are more likely to produce more biofouling than areas where tidal flushing occurs, and warm waters will foster more biofouling than cooler waters.

Sensor maintenance occurred regularly throughout the course of the field trial, with the length of time between sensor maintenance visits decided by sensor data readings observed on the project website and by the time of the year. Maintenance involved the removal of the sensors from the water where they were gently cleaned and sensor readings were compared with calibrated hand held water quality sensors and standard laboratory methods carried out subsequently off-site. The effects of biofouling (see figure 3) were noticeable within days of deployment and the sensors required regular maintenance throughout the year. Biofouling is an important problem decreasing the operating lifetime of sensors in the field and introducing a degree of error into the collected data. Frequently used mechanical methods are not ideal for application in sensing – where power consumption is a limiting factor in deployment of devices for extended periods of time in the field.

It was found that by preventing the initial bacterial attachment to surfaces greatly reduces the impact of biofouling on surfaces. Thus, we focussed efforts in this study to prevent bacterial adhesion by using anti-microbial agents in our material design. Materials included long-chain plasticisers, surfactants, nanoparticles and natural products, all of which showed promise in microbial tests, but fouling still occurred after materials were exposed to the environmental waters. Where copper coatings were used fouling was greatly reduced.

Figure 3. Biofouling associated with estuarine conditions on standard sensors

3 Results and Data Analysis

3.1 The benefits of high temporal resolution data

There are several examples at all sites where the understanding of the process and river conditions are vastly improved by the availability of higher resolution data. To illustrate we have selected a single example looking at pH in the upper reach of the catchment. Figure 4a below shows what a traditional scientist might find, even if they were able to take one sample per day of pH at this site (in reality one sample per week is more realistic using grab and spot sample methods). From this graph covering fourteen days it is not possible to see and detail or achieve any understanding of the overall river condition from the spot samples. However, when we study the data when sampled once every 10 minutes for a two month period (Figure 4b), we see much greater detail and achieve a better understanding of the fluctuations occurring in the river catchment area.

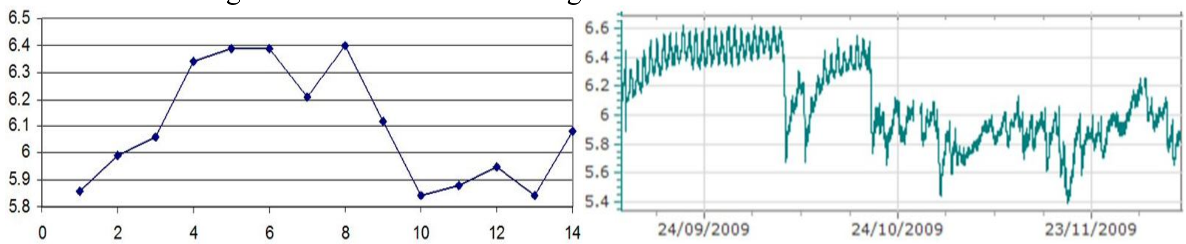

Figure 4. Graph Comparing low and high temporal resolution pH sensor data

On this second graph we see a clear diurnal signal in the data for the first number of days and this corresponds to a calm weather period with low run-off and low flow in the river. In early October the sudden fall corresponds to sudden run-off from the surrounding peatlands in the upper catchment because of heavy rain followed by a recovery period with the diurnal signal returning. Around the 23 of October, we see the level drop with increased run-off and river flow and this continues for about one month until on the 19th of November the effects of prolonged heavy rainfall caused extensive flooding downstream in Cork City.

3.2. Multi-sensor (Multi Site) System Performance

Over the course of the deployment, trends were observed in the data collected arising from tidal changes, temporal variations and fouling of the sensors from the station at the Lee Maltings. One such example concerns an explanation of DO levels at the Maltings site and how these were impacted not just by the incoming tide but also by the release of fresh water from the hydroelectric dam at Inniscarra located 13 km upstream of the site. In figure 5 below we see a period where the incoming tide produces a salt water wedge that has significantly lower DO levels. However by studying this graph alone it is not clear why the wedge does not appear on every incoming tide and also why the low tide levels before a missing salt wedge are elevated. If now using the benefit of our sensor network user interface capability we superimpose the water levels at the Lee Road (about 2KM

upstream), and superimpose a 4th trace, we get a clear understanding of what is happening within the catchment as a whole.
The bottom trace of this graph shows water level upstream and the highs represent increase fresh water flows associated with discharge from Inniscarra Dam. It is clear from this why the low water is elevated on some tidal cycles and this explains the absence of the salt water wedge. In addition it also shows how the absence of a discharge for a number of tidal cycles results in a prolonged salt wedge and reduced DO levels. Without this data from upstream an explanation for this situation would be based purely on speculation.

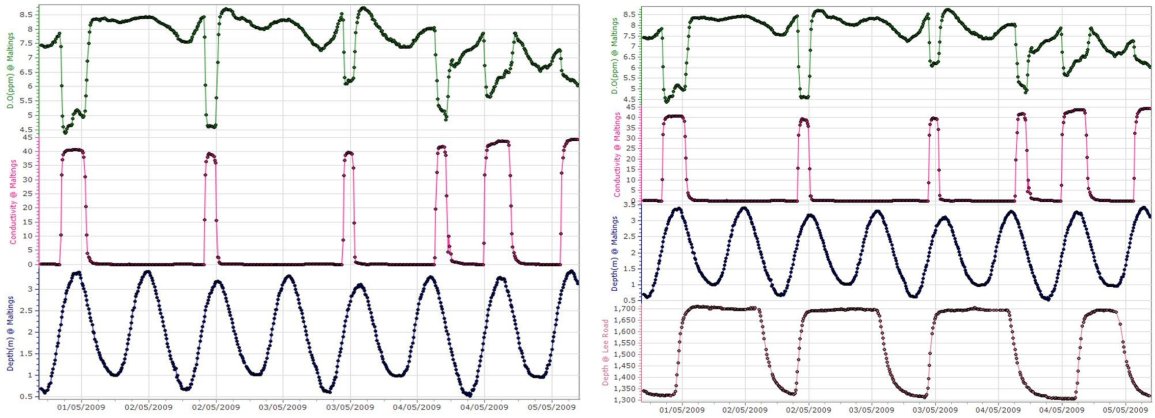

Figure 5. Multi parameter data and fusion of data from the Lee Maltings and Lee Road site

3.3 Event Monitoring- The value of real time data

The DEPLOY sensor network was successful in demonstrating its benefits in this regard. There were several examples during the project where short-term events were identified in real-time and which could be used as decision support information in managing the river. Examples include the impact of dam discharge on the water quality downstream; this impact on water quality was seen as both positive and negative on different occasions. For example in the graph below we see that a discharge from the dam depicted by increased water depth result in a reduction in conductivity (purer water) in the river. This type of information can be a key tool in determining the duration of a discharge to flush the river if conductivity levels are elevated. This is beneficial for water treatment facilities.

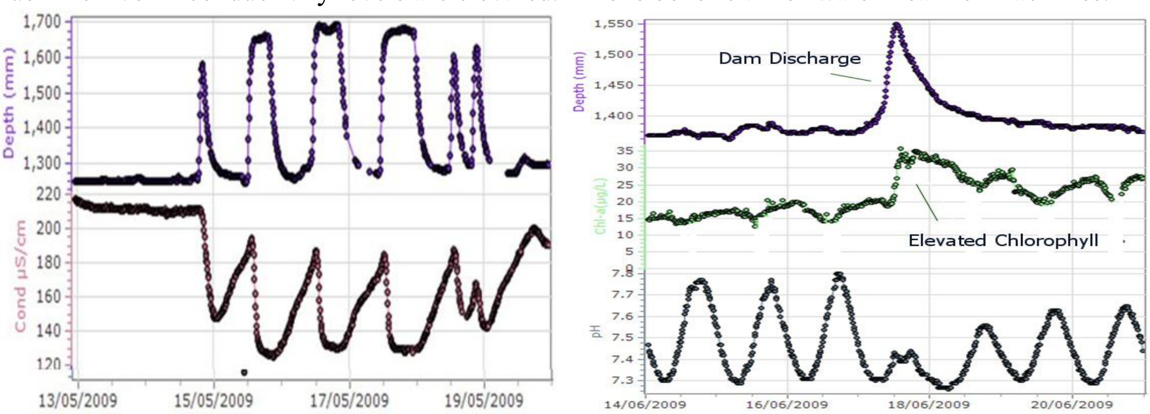

Figure 6. Data from the Lee Road Waterworks showing the impact of dam activity on water quality

However if on the other hand there is a water quality issue upstream of the dam then care must be taken to ensure that no lasting damage occurs because of short discharges. To demonstrate the potential consider the second graph in figure 6b. This shows a short discharge which appears to have brought with it elevated chlorophyll-*a* from an algal bloom that occurred upstream of the dam. If the discharge from the dam is too short the effect is that the algae coming over the dam will not flush from the downstream river and may develop into a serious environmental issue. By having real-time data from downstream stations it is possible for the dam facility managers to monitor the impact of their actions.
A second more significant example where the benefit of such a monitoring network can be seen concerns the flooding. While this was not a priority for the DEPLOY project we can see from data at the source and data downstream that such a network could play a key role in advanced warning. Early warning for flood management is critical in reducing the impact and associated costs. Research shows that 4 hours advanced notice can reduce the cost of damage by 10% and a 12 hour warning can

achieve over 23% saving. The multi-sensor systems have been deployed in the River Lee since May 2009. During this time they have experienced normal environmental degradation standard in any aquatic deployment as regards gross biofouling from leaves, branches etc. In addition they have been exposed to extreme meteorological conditions throughout the year. Ireland experienced a particularly harsh winter including in a major flood event, which occurred in November 2009 [27]. In figure 7 below are data sets from some of the deployments involved in the project during the flood events. As can be seen, adverse conditions did not affect system performance at the Gougane Barra site (Figure 4) where data was logged without interruption, and associated data sets from the Lee Maltings deployment site for this time period. Figure 7 below shows the sudden rise in depth resulting in submerging of the sensor system during the flood event pictured.

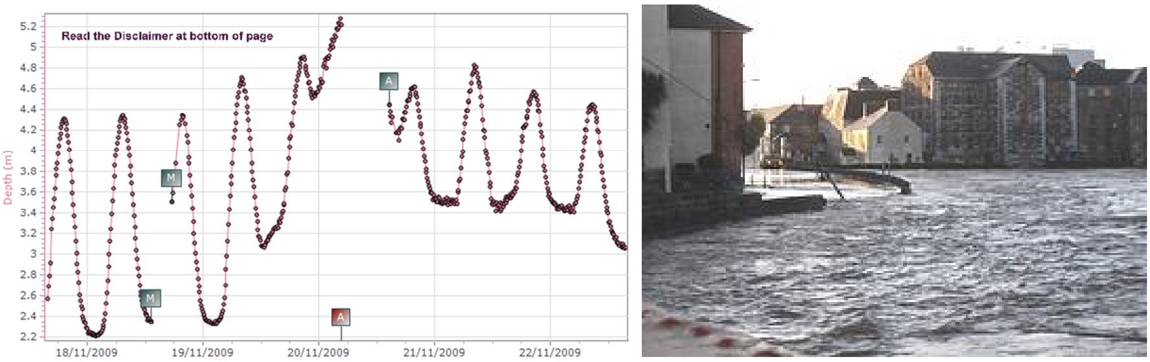

Figure 7. Real time monitoring of flood events at the Lee Maltings site, Graph shows depth data.

4 Conclusions and Recommendations

During the development of the DEPLOY project, the project team acquired knowledge in a number of key areas. These include the current water quality monitoring status in Ireland and globally, the needs of the appropriate users from a water quality monitoring perspective, technical issues relating to long-term monitoring systems, communication capabilities currently available and communication requirements. The data sets collected and archived and currently under analysis are highlighting to environmental scientists the importance of data collection, interpretation and reporting in addressing gaps in the area of water quality monitoring in Ireland.

The key advantages demonstrated by the use of wireless sensor networking technology – such as that described - are in the higher temporal resolution of the data than traditional methods can provide, the benefits of data streams from multiple sensor types in a multi-station network and how the intercomparison of data and the fusion of data from different stations could help achieve a better understanding of the catchment as well as the value of real time data for event monitoring and catchment behaviour analysis.

The DEPLOY Project has highlighted the potential of wireless sensor systems, enabling the scientist to observe and monitor environmental variables of interest. Data from monitoring stations can be analysed and communicated by wireless technology, for statistical processing and interpretation by expert systems, from the office. Rising trends for any constituent of interest or breaches of Environmental Quality Standards (EQS), will alert relevant personnel who can intercept serious pollution incidents, by evaluating the change in water quality parameters measured numerous times every day – as an alarm sent to their mobile phone or by e-mail, or lead to other appropriate response. This does not mean, however, there will be less field work carried out, as it will still be required to design, install and maintain the sensor systems. The capability of the developed DEPLOY multi-sensor system to continuously sample and communicate up-to-date information, will enable monitoring costs to be reduced, while providing better coverage of long-term trends and fluctuations of parameters of interest. It is envisaged that the deployment of sensor systems similar to DEPLOY will allow a new approach to study the environment, new field methods to be conceptualised, and new solutions to scientific problems.

The value of extensive site survey cannot be underestimated, as can be seen from the data being delivered from the Lee Maltings site, where the subtle interplay of the various data streams is most apparent. The analysis of such sensor streams can give environmental scientists an overview of the behaviour of the catchment area, and allow detailed study of the interaction of the parameters of interest in real time. How the parameters of the sensed data from that site change over time can help in monitoring of events which occur in the catchment area under investigation.

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