In-situ and remote monitoring of environmental water quality

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Overview

- **Introduction**
  - Water quality monitoring
- **Autonomous monitoring systems**
  - Phosphate sensor
- **Remote monitoring**
- **Integration of data from in-situ and remote sources**
  - Status and challenges

Introduction

- Water pollution affects human health and reduces the quality of our natural water ecosystems and resources.
- Clean water resources are likely to be of increasing scarcity and importance in the future
- Increasing need for monitoring of environmental water quality

Legislation

- **Major driver for protecting and improving the state of our natural water resources**
- **EU - Water Framework Directive**
  - Aims to achieve "good status" of all European water bodies (lakes, rivers, transitional, coastal & groundwater) by 2015
  - Implemented on a catchment level
  - Related directives on Nitrates, Urban Waste Water Treatment, Drinking Water, Dangerous Substances, Bathing Water etc.
- **US - Clean Water Act**
  - Restoring polluted surface waters with the goal of making US waters fishable and swimable
  - Total maximum daily loads (TMDLs) for polluted waters
  - Shift from a source-by-source, pollutant-by-pollutant approach to more holistic watershed-based strategies

In situ monitoring – a long history

- Nilometer at Aswan, Egypt
- Water level → likelihood of successful crops → tax rates!

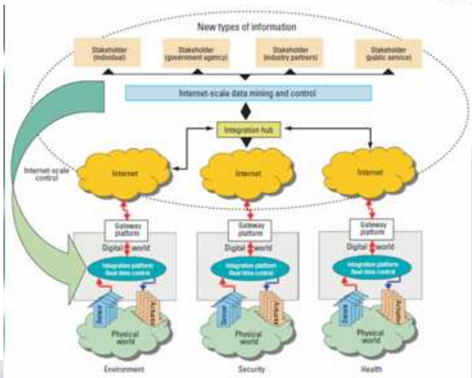
Sampling based monitoring

- **Current approach**
  - Manual collection of samples, followed by laboratory analysis using high-spec instruments
  - High manpower costs → Low measurement frequency, limited number of sites
  - Standards-based, highly accurate… **IF** appropriate sampling, storage and analysis protocols are followed
- **Portable instruments & reagent kits**
  - Still require human presence to collect sample & operate device

Autonomous monitoring devices

- Autonomous sensing systems can play key role by allowing high-frequency monitoring of remote locations at lower cost
- Even if in situ sensors do not achieve the same analytical performance as laboratory methods, the increased temporal and geographical resolution is likely to outweigh this
- Complementary to standard techniques

Internet-scale sensing



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Challenges

- Based on availability of large numbers of miniaturised, low cost, autonomous sensing devices
- Reliability over long-term deployments
  - Robustness in severe conditions
  - Biofouling
  - Changes in reactivity of surfaces / reagents over long periods → Need for calibration
- Deployment of large-scale wireless sensor networks in unpredictable and lossy environments

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Challenges

- Adaptive sampling
  - E.g. higher frequency based on trigger levels
  - Link to other devices measuring related parameters
- Data streams from a large variety of heterogeneous sources, with varying volumes and accuracies
- Need to develop a networked sensing infrastructure that can support the effective capture, filtering, aggregation and analysis of such data

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Microfluidic sensors

- Microfluidic technology provides a route to the development of miniaturised analytical instruments that could be deployed remotely, and operate autonomously over relatively long periods of time (months–years).
- Autonomous phosphate sensor developed at DCU
- Combination of technologies
  - Colorimetric chemistry (molybdenum yellow)
  - Microfluidic chip for performing mixing and reaction on micro-scale (22µL per analysis)
  - Optical detection based on UV-LED light source and photodiode detector
  - Wireless communications (GSM modem, Zigbee radio, Bluetooth)

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Phosphate sensor

- Can operate for 3 months at hourly frequency
- System has been successfully trialled at wastewater treatment plants and in environmental settings

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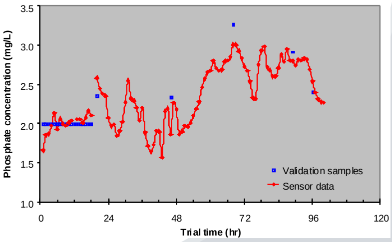
Broadmeadow Water trial



- Estuarine location 10km from Dublin city
- Elevated phosphate levels due to inputs from municipal wastewater plants and agricultural sources

SmartBay project

- SmartBay is a next-generation water management system (both marine and freshwater) established by the Marine Institute of Ireland.
- Key technological aspects currently under development by CLARITY and IBM's Global Centre of Excellence for Water Management
- Sensors
- Communications
- Data management systems

Combining in-situ & remote sensing

- Remote observations from satellites and aircraft can provide significant amounts of information on the state of the aquatic environment over large areas
- As in-situ deployments of sensor networks become more widespread and reliable, and satellite data becomes more widely available, information from each of these sources can complement and validate the other
- Increased ability to rapidly detect potentially harmful events, and to assess the impact of environmental pressures on scales ranging from small river catchments to the open ocean.

Remote sensing

- "the science of observation from a distance"
- Detection of
  - Acoustic waves
  - Force fields
  - **Electromagnetic energy**
- Techniques
  - Visible imaging (photography / videography)
  - Infrared (imaging / spectrometers)
  - Microwave radiometers
  - Microwave radar (RAR / SAR / SLAR)
  - Lidar (Laser radar)
  - Scatterometers

Remote sensing

- Platforms
  - Surface (ground / vehicles / masts)
  - Airborne (unmanned drones to heavy aircraft)
  - Space (orbiting satellites, deep space probes)
- Applications
  - Meteorology, Climatology, Geology, Soil studies, Agriculture, Land use, Built environment, Ecology, Conservation, Resource management
  - **Water in the environment**

Examples

- Wetlands monitoring
  - Surface water area
  - Plant communities
- Water quality parameters
  - Turbidity
  - Suspended sediment
  - Chlorophyll / Phytoplankton
  - Water temperature
  - Salinity
- Flood monitoring & management

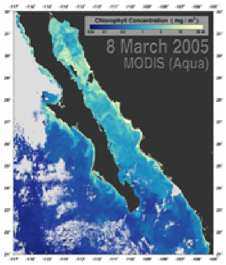
Precipitation monitoring

- Radar
  - Frequent, real time estimate of rainfall intensity
  - Met Eireann rainfall radar captured during phosphate sensor deployment

- In situ alternative - rain gauges
  - Sparsely distributed
  - Can give inaccurate estimates due to local variations
  - Important for calibration

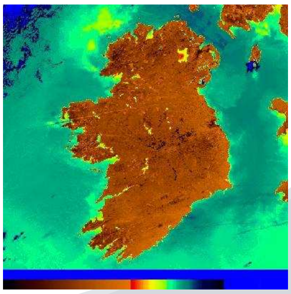
Chlorophyll / Phytoplankton

- Phytoplankton bloom in Baltic Sea (MERIS/Envisat, 13 July 2005)



- Chlorophyll concentrations in the Gulf of California (MODIS/Aqua, 8 March 2005)

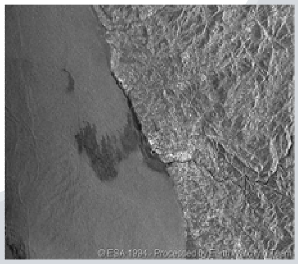
Surface temperature



- Ireland and surrounding ocean. Temperature range is about 277K (dark blue) to 292K (dark brown) (ATSR/ERS satellite)

Pollution detection

- Point sources
  - Airborne data used to identify and map discharge patterns from sewage outfalls and industrial complexes
- Pollution events
  - 2 October 1994, Oporto, Portugal, crude oil spill from tanker
  - The ESA ERS-1 satellite acquired this SAR image two days later



Treatment of remote sensing data

- Pre-processing
  - Geometric corrections (mapping)
- Processing
  - Selection of data subsets
  - **Calibration**
  - Enhancement of features of interest
  - Noise reduction etc.
- Analysis
  - Feature recognition
- Interpretation & decision-making

Calibration of remote data

- Pre-launch calibration of instruments
- Commonly performed w.r.t. in situ data
  - IS data must be statistically representative
  - Not always available, may be costly to obtain
  - Not always appropriate due to basic differences between the RS and IS datasets
  - Accurate positioning of both datasets is critical
  - Lack of standardization of IS data
- Training sets
  - Data (sub)sets with well-established features
  - New/unclassified data compared to these using a variety of algorithms

Limitations of remote monitoring

- Data available for limited range of parameters
  - In situ data essential for in depth analysis / chemical speciation
- Availability can be limited by natural factors
  - Cloud cover / flying conditions
- Frequency limited / fixed
- Resolution
  - Varies with source, measurement technique and parameter
  - Limits ability to monitor freshwater bodies

Data management / distribution issues

- Many national monitoring services are well developed, but they are customised to their country's territorial waters, and often based on proprietary or nonstandard solutions preventing smooth data exchange
- Need systems to provide access to data, including observations, derived parameters and model predictions of future conditions, and systems to retrieve, compare and analyze different types of data
- Range of users with different requirements
- Projects such as InterRisk and ECOOP moving towards pan-European systems

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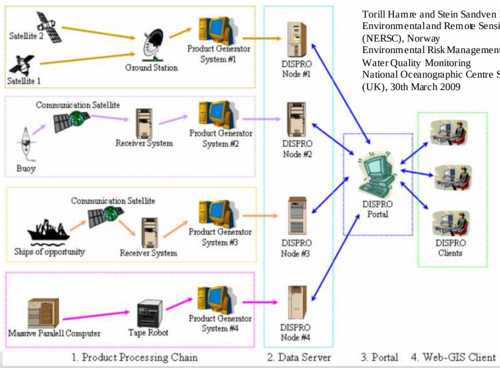
InterRisk Service Content



Torill Hamre and Stein Sandven Nansen Environmental and Remote Sensing Center (NERSC), Norway
Environmental Risk Management Tools For Water Quality Monitoring
National Oceanographic Centre Southampton (UK), 30th March 2009

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Conclusions

- Combination of in-situ and remote data has huge potential for improving environmental monitoring
- Need to improve data availability
- Interoperability of data systems to allow efficient access by users with varying requirements
- Need for mathematical models with the ability to utilise data from various sources to deliver reliable forecasts at scales from river catchments to the open ocean

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