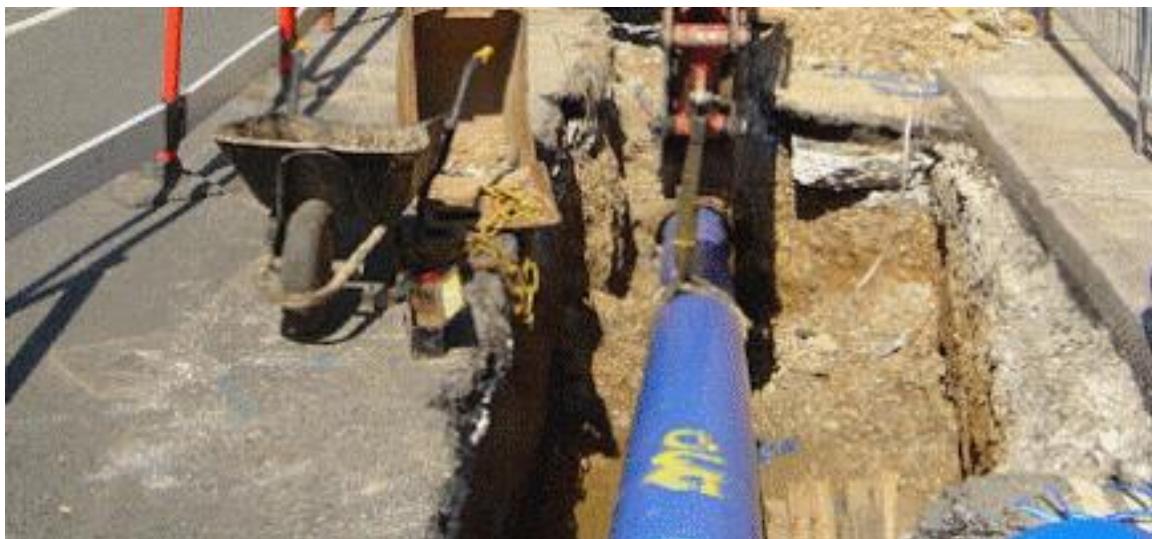


# RESILIENCE OF CLEAN AND WASTEWATER NETWORKS IN THE UK

## WORKSHOP REPORT



### Summary

This is a report of a Systems-NET workshop that discussed the resilience of clean and wastewater networks in the UK. The objective was to establish collaborative links between the systems research community and researchers in water issues. This report presents the outcomes of the workshop including researcher's presentations Quad Charts and key challenges identified in the areas of sensors for monitoring water flows, architecture patterns, framework for decision making, emergency response, quantitative assessment of performance and human intervention.

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### Purpose

The sustainability of water services in England and Wales relies on the resilience of clean and wastewater networks, but these are being threatened because the old infrastructure requires renovation and new networks are needed to service more housing developments, industry and commerce. At the same time there are continuous challenges affecting water availability including limited water resources, more stringent regulations for water abstraction, climate change, uncertain rainfall distribution and others. From a systems engineering perspective, the networks for water services form a large system that can be better understood and analysed with the participation of as many stakeholders as possible

Systems-NET aims to facilitate systems engineering research in the UK by establishing links between multidisciplinary research groups and industry to encourage understanding of large networked systems. The purpose of this workshop was to stimulate the formation of a systems network for water supply resilience bringing together researchers from the academic community, systems engineering researchers and partners from industry. We hope that the ideas and research discussed in this workshop will result in the formation of links to support collaborative work amongst the participants.

### Workshop

The resilience of the infrastructure for clean and waste water networks is a basic priority; renovating, expanding and maintaining the water infrastructure requires collaborative approaches from all the stake holders. Systems-NET invited researchers from systems engineering, urban water systems, water engineering, physical geography, environmental engineering, business and others as well as people from the water industry to meet together, get an insight into each other's research and priorities, and discuss how systems science and engineering can support the development of a water system that remains reliable in spite of population growth, increased demand and climate change over the next following decades. This workshop was a follow-up from the workshop "Water Supply Resilience in the UK" that took place in July 2014.

The first part of the workshop consisted of presentations by academics from the Universities of Manchester, Exeter and Loughborough covering current research (corresponding Quad Charts are given in appendix A). The second part of the workshop consisted of a plenary discussion with contributions from all the academic participants and Helen Pickett from Severn Trent Water who gave several valuable insights into the main challenges being faced by Severn Trent Water Company today. Her participation gave base to interesting ideas for future collaboration with several researchers.

## Research Presentations

The presentations from the academic research community were:

- Resilience of Clean and Waste Water Networks - Dr Gema Styles (Co-ordinator of Systems-NET), Advanced VR Research Centre, LU
- Novel, non-intrusive microwave sensors for water analysis – Vasiliki Koutsospyrou (School of Civil and Building Engineering), LU
- DANSE-Design for Adaptability and Evolution in Systems of Systems- Antara Bhatt (Research Assistant at Advanced VR Research Centre-Loughborough University), LU
- Online Modelling and Prediction in Water Distribution Systems- Dr John Brooke (Strategic Research and Software Development), Manchester University
- Safe & SuRe: Global Resilience Analysis of Water Networks - Dr Guangtao Fu (Senior Lecturer in Environmental and Water Engineering), University of Exeter
- Evaluating the resilience of critical infrastructure for emergency response to extreme flood events in Leicester City – Dapeng Yu (Department of Geography), LU
- Lack of competent and qualified staff in Developing Countries – Brian Reed (WEDC), LU
- Resilience and Innovation across the Water Energy Nexus - Dr Donna Champion (School of Business and Economics), LU
- Examination of household water demand determinants and exploration of the link between demand management programs and water conservation - Despoina Manouseli (Ph.D. Student- WEDC), LU

## Plenary Discussion

The presentations brought up several points for discussion. The presentations can be viewed in Appendix A. Some of the points discussed are the following:

- **Sensors to monitor water flow;** installing non-intrusive microwave flow sensors in the outer walls of pipe lines is considered to be very useful for the

water industry partly due to their immediate applicability, however the way in which power is provided to the sensors would require optimisation. Recharging or replacing the batteries to sensors in the field is a challenge due to the high cost of batteries and the associated journeys of qualified personal to pipelines (which can be difficult to access). Options for generating power locally i.e. via solar energy could be considered. The difficulty is harnessing energy which is also a common problem in many other sectors.

- **Architecture Patterns;** it is understood that natural systems develop ad-hoc, i.e. they don't follow an original plan. However statistical physics, which is one of the tools used in systems engineering, is based on the characteristics of universality and scalability of complex systems; it is believed that complex systems have properties that are common across disciplines or sectors and even scales i.e. the properties of complex systems may be universal and independent of the specific form of the interactions in a particular system. This leads to the concept of architecture patterns in complex systems being replicated in other totally different complex systems, patterns can be used to understand the behaviour of complex system or help to predict it. Their identification creates a source of knowledge that then can be used to transfer expertise in systems behaviour from one complex system to another and could benefit the layout design of future water networks.
- **Framework for Decision Making.** Another point of discussion was the creation of a framework for decision making with tools based on hydraulic simulation models that use mobile communication technology and local real time data from node points on a map. One server in Manchester is being tested under different experimental scenarios. It was discussed that this would be a powerful and useful tool for water companies particularly as several calculations can be performed at the same time and depending on the computational capability, solve local water distribution problems while taking into account the overall effect of failures over a whole extension of pipe lines, however intricate they are.
- **Emergency Response.** The city of Leicester is ranked 16<sup>th</sup> out of the 4,215 settlements in terms of surface water and flooding risks. Evaluating the resilience of critical infrastructure for emergency response to extreme flood events in Leicester is being studied through operational nodes that could be affected by extreme flooding in order to deliver a list of adaptation measures and contingency plans, some of them generic and transferable to decision makers beyond Leicester.
- **Framework for Quantitative Assessment of Performance.** Safe & SuRe at the University of Exeter aims to develop a new paradigm for 'Safe & SuRe' urban

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water management in response to emerging challenges and global uncertainties.

The specific objectives include:

- To develop a global resilience analysis framework to evaluate water network resilience to specific failures;
- To evaluate different design strategies for improving system resilience;
- To develop guidelines for building resilience in urban water networks.

Urban water infrastructure was built using the Fail-Safe paradigm, consequently its performance under extreme threats is not well understood. There is a need to develop guidelines or standards for building resilience in water supply and urban drainage networks

- **Human performance.** Another point discussed was that in spite of many technology advances the weakest link in the chain of progress is related to our human capacity to understand current systems, prepare and plan for future events. Collaboration between NGOs, Universities and Ministries has the potential to ascertain learning needs and produce curricula for learning and teaching materials to care for water quality and improve living conditions.

## Conclusions/Recommendations

The water industry in the UK is being challenged in regards of maintaining good customer relationships and public perception, managing assets and their condition, monitor and control pipes degradation, implementing sensors for new applications, engineering non-invasive methods for replacing pipes, lowering levels of leakages, dealing with blockages in sewerage pipes, optimising treatment processes to remove phosphorous and monitor nitrate substances at the same time as applying measures to harvest energy and many others.

Academic research is already providing answers to some of these problems however, continuous communication between industry and academia is very necessary in order to link research and industrial priorities in a way that it is beneficial for both parts.

Although there are several co-operation programs between industry and academia, these tend to link specific areas of expertise in both sectors and there is a danger that such isolated programs go through development and completion without awareness of other research programs and the priorities from other similar industries and research groups.

Clean and wastewater networks in the UK form a system that needs to be understood from a high level of abstraction in order to get the full view of its complexity and the factors influencing its behaviour. The following Quad Charts offer an insight into water research being carried out at various research groups in the UK. This material is intended to facilitate the understanding of different aspects of this complex system in order to spark interest and new direction for collaborative research.

## List of Invited Participants

|                       |  |
|-----------------------|--|
| Helen Pickett         | Severn Trent Water   |
| John Brooke           | Resilient Cyber Physical Systems-University of Manchester                      |
| Jon Kendall           | Castleton Consulting Ltd   |
| Matt Lovell           | Severn Trent Water   |
| Robert Pratchett      | DVN LG   |
| Laurie Reynolds       | Aquamatrix   |
| Dr Ivan Stoianov      | InfraSense Labs, Imperial College London                                       |
| David Butler          | Professor of Water Engineering, University of Exeter                           |
| Zoran Kapelan         | Professor of Water Systems Engineering University of Exeter                    |
| Sarah Bell            | Urban Water Systems UCL  |
| Robert Leonard Wilby  | Loughborough University  |
| Darren Cadman         | Loughborough University  |
| Brian Reed            | Loughborough University  |
| Donna Champion        | Loughborough University  |
| Ian Pattison          | Loughborough University  |
| Dapeng Yu             | Loughborough University  |
| Fu Guangtao           | Senior Lecturer in Water and Environmental Engineering<br>University of Exeter |
| Andrew Wheatley       | Loughborough University  |
| Roy Kalawsky          | Loughborough University  |
| Antara Bhatt          | Loughborough University  |
| Vasiliki Koutsospyrou | Loughborough University  |
| Gema Styles           | Loughborough University  |
| Despina Manouseli     | Loughborough University  |
| Tohid Efrani          | Urban Water Systems UCL  |
| Demetrious Joannou    | Loughborough University  |

## Appendix A

# Resilience of Clean and Wastewater Networks

## Problem Statement:

Over the coming 20 to 30 years, rising population, climate change and greater concerns for the environment will result in water shortages, especially in the South-east of England

### Challenges for Water Availability

### Solutions Sought

## Sufficient and adequate infrastructure to distribute water

### NORTH-SOUTH CANAL

GRAND CONTOUR CANAL  
EXTENSIONS INTO WALES  
AND SCOTLAND?



### Cast Iron Pipes

- 330,000 km length
- 60% from Victorian Era
- Life span of 40 to 100 years
- Leaks
- Health hazard
- Investment from 1990
- More than 20,000 km renewed pipes
- Polyethylene
- Lining water pipes
- 35% leakage reduction
- More investment is needed



### North-South Canal (Aecom)

#### North-South Canal

#### (Aecom)

#### Moving water from

#### Kielder Water in

#### Northumberland to the

#### Midlands and the

#### South-east.

#### Building canals along

#### 31 ft level spine

#### Water moves by

#### gravity

#### Canal cross section 25

#### meters

#### 600 km would contain

#### 68 million m³ water,

#### equivalent to a

#### reservoir 7.5 m deep ,

#### 9 km²

#### Estimated cost 14

#### billion

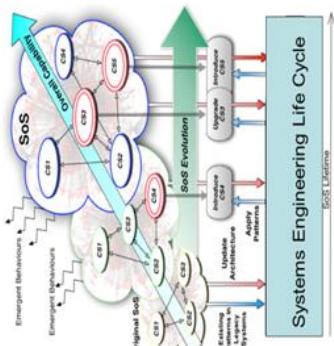
#### Gravity can't be relied

#### on across the country

#### Differences in water

#### chemistry would result

#### in ecological problems



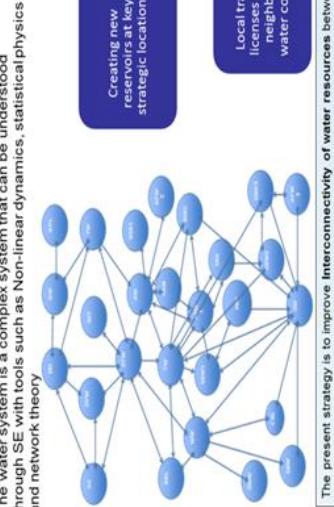
## Complex Stakeholders



Aim Bring research and industry together to create a systems approach to understand, analyse and predict the relationships and outcomes derived from changes to

- System Components: Water resources, water abstraction and treatment, associated infrastructure of water supply pipes, wastewater infrastructure
- Investment
- New water resources
- Water Networks
- Decision making policies

## Systems Approach



The present strategy is to improve interconnectivity of water resources between catchments so that local stakeholders should work through whatever arrangements best suit their local priorities and seek to optimise opportunities for integration or alignment, and agree appropriate pin up with neighbouring water companies.

**Funding Body:** EPSRC  
**Key Contact:** Dr Gema Styles, Systems-NET, g.styles@lboro.ac.uk

# DANSE- Designing for Adaptability and Evolution in Systems of Systems

**Problem Statement:** Israel's water supply network is a collection of independent, pre-existing, geographically distributed companies following their own goals. A more resilient and secure water supply network is required to manage the scarce water resources.

## Aims & Objectives:

- To create a systems architecture for a resilient water supply network
- To produce an executable model in order to optimize and select alternative system architectures
- To provide a system modeling environment that facilitates architecture evolution
- To create system architecture patterns for re-use by other water supply companies



**Water supply resilience:**  
• Sufficient infrastructure for delivering water  
• Changing infrastructure with changing needs

- A redundant system supplying water from more than one routes
- The AVRRC has developed a methodology to mine these patterns, and store them in an online repository in the form of SysML models for use by the tools provided by the DANSE project.
- Patterns can be used as building blocks for modeling other WDS.

## Research Details

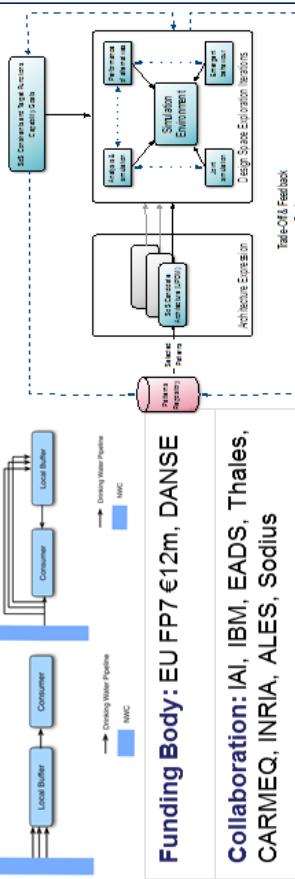
### Architecture Patterns:

Architecture patterns are useful tools for modeling systems of systems(SoS). Resilient Patterns can be mined from existing SoS and used for developing models for a resilient water infrastructure.

- The AVRRC has developed a methodology to mine these patterns, and store them in an online repository in the form of SysML models for use by the tools provided by the DANSE project.
- Patterns can be used as building blocks for modeling other WDS.

### Modelling & Simulation:

- Based on resilient patterns mined from the WDS midlands, WDS Sydney
- Alternative architectures can be mined as patterns.
- Trade off can be achieved between cost of installation and resilience



### Funding Body: EU FP7 €12m, DANSE

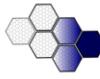
**Collaboration:** IAI, IBM, EADS, Thales, CARMEQ, INRIA, ALES, Sodium

**Application & Impact:** Water supply companies facing the challenge of changing the architecture of their systems can use architecture patterns as alternate architectures to model more resilient and robust systems.

- Creation of state of the art systems modeling and simulation environment with deployable tool-net
- Creation of Israel's systems architecture for water management
- Next generation IBM modeling tools
- Candidate solution to Israel's water supply problem
- Accessible online system of architecture patterns mined from WDS for re-use by other water supply companies



**Key Contact:** [Antara Bhatt](mailto:Antara.Bhatt@lboro.ac.uk), [a.bhatt@lboro.ac.uk](mailto:a.bhatt@lboro.ac.uk) , **Supervisor:** Roy S. Kalawsky, 6356678, [r.s.kalawsky@lboro.ac.uk](mailto:r.s.kalawsky@lboro.ac.uk) , **School:** Electronic, Electrical & Systems Engineering



## Online modelling and prediction in water distribution systems

University of Manchester, Oxford Road Manchester, M13 9PL

**Statement of the problem**

There is 330 000km of pipe infrastructure in England and Wales used to deliver the human necessity of safe clean potable water. With the advent of sensors that can communicate with computing infrastructure we can run models of the network that can be used for control of the system, however the actual mechanical processes of control still have to be implemented by human beings. Intelligent decision support tools are required at all levels.

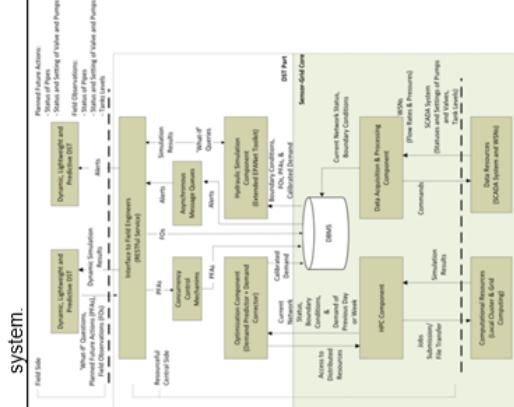
### System requirements

Since the water distribution network was laid down before the electronic age, and since it is mostly underground, it would be prohibitively expensive to re-engineer it to be subject to automatic control, for example for controlling valves, reservoir levels, pumping components. Therefore, the information provided by the monitoring and computation of the state of the system must be relayed to a human workforce who implement the control. This workforce should be able to make queries to the system to understand the effect of planned

actions, and sensors improve the system to enable third-party software to be included in the total system.

Since the water distribution network was laid down before the electronic age, and since it is mostly underground, it would be prohibitively expensive to re-engineer it to be subject to automatic control, for example for controlling valves, reservoir levels, pumping components. Therefore, the information provided by the monitoring and computation of the state of the system must be relayed to a human workforce who implement the control. This workforce should be able to make queries to the system to understand the effect of planned

- The research plan has been developed around the architecture in Figure 2 below. This involves;
  - Development of machine learning algorithms to process sensor and SCADA data to drive the model.
  - Integration of engineer's reports and customer complaints.
  - Parallelisation and optimisation of the computational core.
  - User-friendly visualisation tools to display the information to operators, planners and field engineers.
  - Integration layer to enable third-party software to be included in the total system.



**Figure 1:** shows the three conceptual components of this system. requirements.

**Figure 2:** Complete architecture of the system

| Research Details   | Expected impact   | Collaborators  |
|--|---|--|
| <p>The research plan has been developed around the architecture in Figure 2 below. This involves;</p> <ul style="list-style-type: none"> <li>Development of machine learning algorithms to process sensor and SCADA data to drive the model.</li> <li>Integration of engineer's reports and customer complaints.</li> <li>Parallelisation and optimisation of the computational core.</li> <li>User-friendly visualisation tools to display the information to operators, planners and field engineers.</li> <li>Integration layer to enable third-party software to be included in the total system.</li> </ul> | <p>Figure 3 below shows the improved information flow in the engineering decision making process. Since water distribution networks will be managed by human actions for the foreseeable future, it is critical to involve the workforce in the whole process.</p> <p>Figure 3 below shows the improved information flow in the engineering decision making process. Since water distribution networks will be managed by human actions for the foreseeable future, it is critical to involve the workforce in the whole process.</p> | <p>Preparatory work based on data supplied by Yorkshire Water, United Utilities, Thames Water.</p> <p>Current collaboration with Water Research Centre on behalf of a consortium of UK water companies backed by a KTP funded by the TSB.</p> <p>Funding for basic research from PhD and MSc projects.</p> |

**Figure 3:** improved decision making process will bring the following benefits.

- Engineering decisions can be made based on the current state of the system.
- The system can be self-optimising, information about the effects of decisions can be stored and can be used to inform future practice.
- As algorithms and sensors improve the system can be updated without breaking the information interfaces that the engineers rely on.
- The uncertainty produced by lack of information about ageing assets buried underground can be reduced by learning about the behaviour of the assets online and upgrading the model of the network accordingly.

**Figure 4:** part of the current user interface for decision support tools based on information supplied by Yorkshire Water.

Information about the state of the system is provided by the architecture shown in Figure 2 and overlaid on a map of the area. The user interface has a series of panels to support modelling and decision making and these will tested in the working practices of the companies.

John Brooke, tel: 0161-275-6816  
[john.brooke@manchester.ac.uk](mailto:john.brooke@manchester.ac.uk)  
 School of Computer Science

## Research: Evaluating the resilience of critical infrastructure for emergency response to extreme flood events in Leicester City

**Problem Statement:** Leicester City is ranked 16<sup>th</sup> out of the 4,215 settlements assessed within England in the National Priority Ranking in terms of surface water flooding risks (Defra 2009). Fluvial flood risks are also considered high due to its geographical setting.

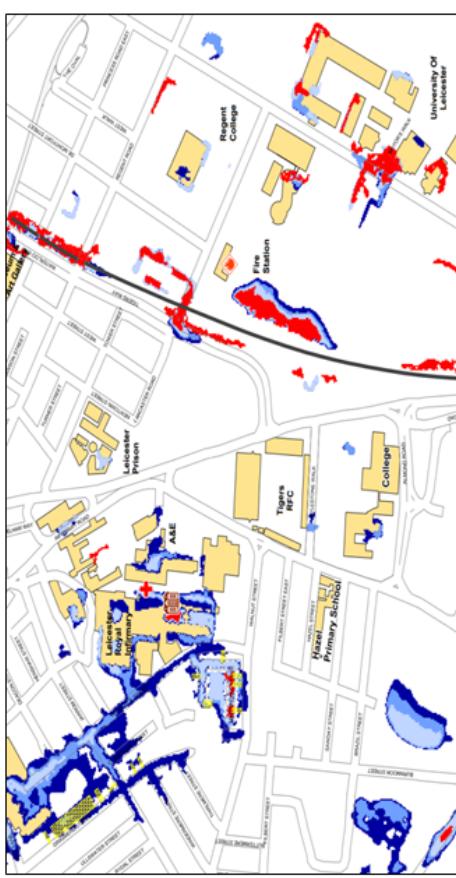
### Aims & Objectives:

The overarching aim is to evaluate the robustness of flood emergency planning and response in terms of its dependency on critical infrastructure. Research questions include:

- 1: What are the infrastructural "pinch points" in Leicester in terms of emergency response?
- 2: What are the impacts (isolated and networked) of failure to emergency response?
- 3: How to make the whole system of emergency planning and response resilient and robust?

### Research Details:

- Operational nodes and networks (e.g. command centre, emergency shelters, transport infrastructure, fire and rescue stations and hospital).
- Utility infrastructure (electricity grid and substation, telecommunication and water treatment).
- Vulnerability analysis
  - isolated impacts
  - cascading impacts
- Case study with Leicester Fire and Rescue Service



Vulnerability to flash water flooding – South Leicester

Funding Body: NERC ~£800000

Collaboration: LRF, LCC, LF&R, EA



### Anticipated Impact:

- An inventory of infrastructure nodes and networks that could be affected by extreme flooding
- A list of recommendations in the form of adaptation measures and contingency plans
- Generic recommendations to flood emergency response that can be readily adopted by decision makers beyond the Leicester City.

**Key Contact:** Dapeng Yu, 01509228191 [d.yu@lboro.ac.uk](mailto:d.yu@lboro.ac.uk)

Department of Geography  
University of Leicester

## Research:

**Problem Statement:**  
Lack of competent and qualified staff

### Aims & Objectives:

To design sustainable courses in WASH

- Ascertain learning needs
- Identify capacity gaps
- Produce curricula and learning / teaching materials

### Research Details:

- Focus group and semi-structured interviews
- Training courses



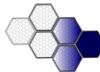
**Funding Body:** Varries DFID/ WSUP/ WSP

**Collaboration:** NGOs, Universities, Ministries

### Anticipated Impact:

- Reduced water related disease
- Improved living conditions
- Better dignity and equity

**Key Contact:** Brian Reed WEDC



## Research: Examination of household water demand determinants and exploration of the link between demand management programs and water conservation.

**Problem statement:** Projected extreme weather events, rapid demographic and lifestyle changes call for innovative methods to manage growing water demand. Aim for all UK water utilities is to achieve balance between supply and demand, and to examine in parallel both demand and supply options. Defra's strategy reduction from 150 to 130 l/c/d until 2030. Studies on the effectiveness of water conservation initiatives and on customers WTC are limited in the literature and even fewer contain actual savings measurements for households.

### Aims & Objectives:

1. Analysis of factors that influence domestic water demand in the region (including weather variables).
2. Assessment of the customers' Willingness to Conserve (WTC) and exploration of the link between conservation attitudes and observed water consumption.
3. Assessment of the effectiveness of water conservation programs and determination of the potable water savings attributed to them.

### Research Details:

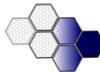
Statistical analysis will reveal the factors that affect water demand. Weather and Socio-demographic variables will also be used for the analysis.

Information/awareness campaigns, appliances retrofits, consumption metering, water-efficient devices, source substitution via rainwater tanks or other water conservation programs will be evaluated by observing the historic billing data of the participating households and comparing them with a control group's consumption data.

Personal interviews and at home observations will lead to the assessment of the customers' willingness to conserve water.

**Anticipated Impact:**  
The accuracy in measuring the effectiveness of water conservation initiatives has been the Achilles heel of urban water planning. The water companies will be more able to apply more effective conservation strategies and they will be better informed about their customers' attitudes towards urban water demand management.

**Key Contact:** Despina Manouseli, [d.manouseli@lboro.ac.uk](mailto:d.manouseli@lboro.ac.uk)  
School: Civil and Building Engineering-WEDC  
[https://www.linkedin.com/profile/view?id=200236510&trk=nav\\_responsive\\_tab\\_profile](https://www.linkedin.com/profile/view?id=200236510&trk=nav_responsive_tab_profile)



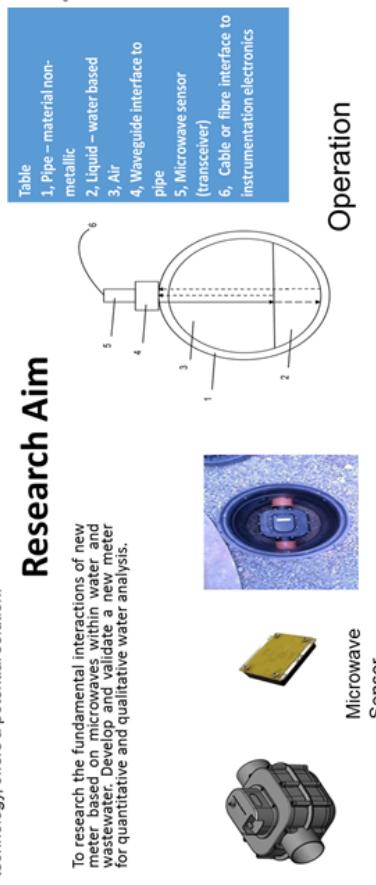
# Novel, non-intrusive microwave sensors for water analysis

## Problem Statement

Accurate flow and quality measurements are essential in the water industry mainly to ensure distribution system efficiency, correct Billing and proper resource management. At present non-intrusive flow measurement is undertaken by electromagnetic or laser Doppler measurements. These methods require either full pipes or clear fluid and wastewater flows are often measured at open channel levels. Thus this novel non-invasive wastewater meter capable of accurately measuring the smallest of flows in part filled sewer pipes, using microwave technology, offers a potential solution.

## Research Aim

To research the fundamental interactions of new meter based on microwaves within water and wastewater. Develop and validate a new meter for quantitative and qualitative water analysis.



## Research Details



### □ Preliminarily Results

Good correlations at typical flows for 110mm diameter pipe.

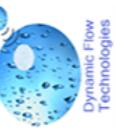
### □ Further Research

- Long term stability i.e. continuous running
- Different viscosity - contaminants
- Application of fundamental equations

### □ Anticipated Impact

- There are currently no non-invasive reliable flow measurements of wastewater in situ. The unit is expected to be cost effective enough to allow extensive use.
- Measuring quality can only be done by discrete samples at present.

Contact: Vasiliki Koutsopoulou, Andrew Wheatley & Koji Shiono



## Research Objectives

The main objectives include:

- Measure reflectance absorption characteristics with different pipe diameters and materials, its accuracy and precision.
- Predict the impact of solids deposition or corrosion (wetted perimeter) and surges on microwave signals.
- Understand the effect of pipe features; connections and geometry (bends, junctions) on microwave signals.
- Obtain MCERTS (Monitoring Certification Scheme) for the new meter.
- Contribute to the writing up of a new ISO Standard for flow measurement in partially full pipes.
- Investigate the sensitivity of microwave signals on compounds of special concern such as the plasticizers, pesticides and pharmaceuticals in clean water.
- Understand the effectiveness and range of potential applications of microwaves for water analysis.

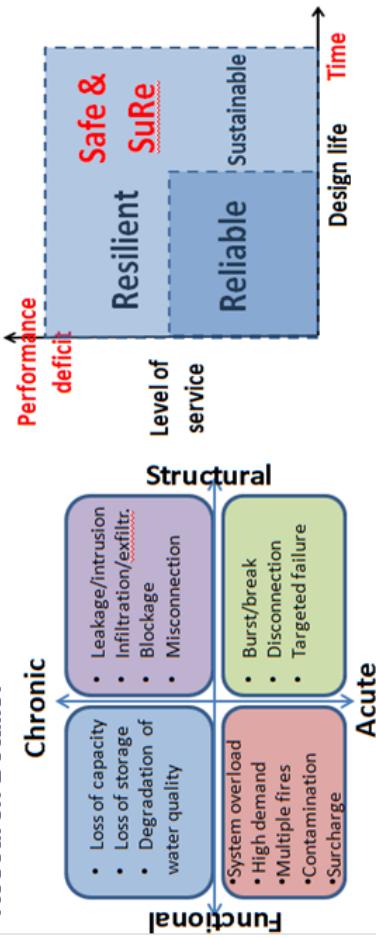
## Safe & SuRe: Global Resilience Analysis of Water Networks

**Problem Statement:** Urban water infrastructure was built using the Fail-Safe paradigm, consequently its performance under extreme threats is not well understood. There is a need to develop guidelines or standards for building resilience in water supply and urban drainage networks.

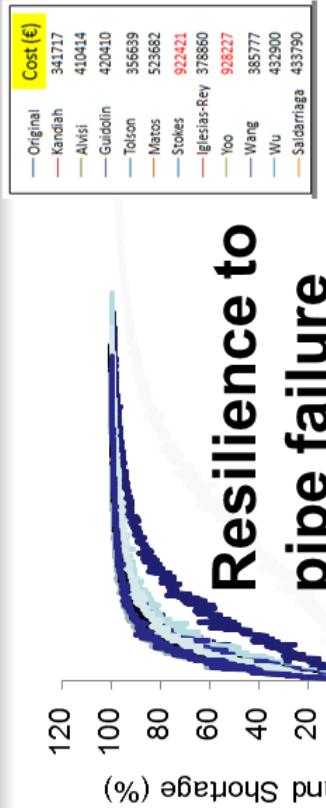
### Aims & Objectives:

- Safe & SuRe aims to develop a new paradigm for ‘Safe & SuRe’ urban water management in response to emerging challenges and global uncertainties. The specific objectives include:
- To develop a global resilience analysis framework to evaluate water network resilience to specific failures;
  - To evaluate different design strategies for improving system resilience;
  - To develop guidelines for building resilience in urban water networks.

### Research Details:



Resilience = min (failure: magnitude, duration)



Funding Body: EPSRC , March 2013 - Feb 2018

Collaboration: EA, WIF, ESKTN, CCW, ACO, B&V, Arup, Severn Trent, Northumbrian, Lund University

### Anticipated Impact:

- Creation of a new quantitative option assessment framework
- New approaches and tools for threat mitigation and adaptation options and strategies
- Guidelines for developing Safe & SuRe solutions for urban water management in practice
- Guidelines for moving towards a SuRe water community

**Key Contact:** Guangtao Fu, [g.fu@exeter.ac.uk](mailto:g.fu@exeter.ac.uk),  
Centre for Water Systems, University of Exeter

## Resilience and Innovation across the Water-Energy Nexus



### PhD Students

Naomi Kelly:

Water-Energy Nexus: Adaption  
strategies to manage water scarcity  
With Prof. Rob Wilby

### Valuing a Diminishing Resource: The Social Impact of Water

Project beginning Feb 2015

Sarah Ameen:  
Promoting Innovation through Water  
Policy  
Started October 2014.

Developing new tools and methods to evidence  
the social impact of living in water-stressed  
areas.

International seed corn grant will facilitate  
European collaboration