WATER SUPPLY RESILIENCE IN THE UK

WORKSHOP REPORT


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Summary

A workshop was organised by Systems-NET to explore the potential for systems engineering to help address today's key challenges for ensuring a resilient and sustainable water supply.

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Purpose

Water Supply Resilience in the UK is one of the Grand Challenges faced by our society today and is a challenge likely to become more significant in the future. In the UK water is abstracted from two types of freshwater sources: ground water and surface water. Ground water refers to water under the earth surface such as aquifers. Surface water is the water that comes from rivers and reservoirs either natural or manmade. Some water resources in the UK are already under stress and there are no additional water resources for water abstraction [1], i.e. in the UK the northern regions have abundant water whilst the south and east experience frequent draughts especially during the summer, paradoxically the demand for water in poor water regions is higher than in rich water regions as the population density is higher there [2]. Projections of climate change indicate an increase of temperature and decrease of rainfall over the summer months in the next decades potentially increasing the stresses on water availability [3]. Climate change, protection of the environment, population growth and changing demand all have an impact on water availability. Systems-NET organised this workshop with the view of encouraging discussions and exchange of ideas between academia and industry and where appropriate to explore opportunities for the systems engineering community to participate.

Workshop

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 presentations from participants from industry; Yorkshire Water, Severn Trent Water and Castleton Consulting Ltd (also appendix A). After each presentation there was a questions and answers session to discuss the main points. The third part of the workshop was a plenary discussion to suggest ideas for future work and collaboration.

Research Presentations

The presentations from the academic research community were:

- Systems Engineering and the Grand Challenges for Water Supply Resilience in the UK- Dr Gema Styles (Co-ordinator of Systems-NET), Advanced VR Research Centre
- Water Demand and Supply Management for the Residential Sector Using Integrated Resource Planning (IRP) Principles- Despoina Manouseli (Ph.D. Student- LU)
- DANSE-Design for Adaptability and Evolution in Systems of Systems- Antara Bhatt (Research Assistant at Advanced VR Research Centre-LU)
- Assessing the Sensitivity of Historic Micro-Component Household Water Use to Climatic Drivers. PhD Thesis.- Professor Rob Wilby (Hydroclimatic Modelling)
- Novel Sensors to provide more Resilience, Water Treatment and Supply- Professor Andrew Wheatley (Head of Water Engineering Group School of Civil and Building Engineering)
- Water - Energy Nexus: Challenges and Opportunities in England and Wales - Naomi Kelly (Ph.D. Student)
- Resilience and Innovation across Complex Systems- Dr Donna Champion (Senior Lecturer in Information Systems)
- Online Modelling and Prediction in Water Distribution Systems- Dr John Brooke (Strategic Research and Software Development)
- Safe and Sure: Towards a New Paradigm for urban Water Management - Dr Guangtao Fu (Senior Lecturer in Environmental and Water Engineering)
- Architecting Resilience as a System of Systems - Professor Roy Kalawsky (Director of the Advanced VR Research Centre)

The research being addressed by the academics attending the workshop were mainly concerned with household water demand, modelling systems, management of water resources, and development of sensors for several applications. Specific research topics included:

Water demand in the future

- Innovative methods to manage growing water demand and education campaigns to influence domestic demand. Use of micro-component analysis (method to disaggregate household water use into end uses like bathroom, kitchen etc.) to forecast demand.

a) Water distribution and infrastructure

- Using architecture modelling and simulation to explore more resilient and robust water systems; Water companies can use architecture patterns to model more resilient and robust systems

b) Management of water resources
   - Improving management of water resources using collaboration across a wide range of stakeholders. Water-energy nexus. Impact of fracking on water resources
   - Developing socio-business understanding of the critical relationships needed in order to value water
   - Use of Anglian Water Golden 100 data to explore the climate sensitivity of historic micro-component water use and determine the differential impact of weather/non weather variables on household micro-component water use.
   - Identify risks to water quality during treatment and supply, and new emergent risks. Research on a non-invasive flow and turbidity meter.
   - Development of intelligent sensors to monitor water quality. Acoustic leak detection.
   - Intelligent decision support tools for human workforce controlling water networks based on sensors information
   - Developing a new paradigm for Safe and Sure urban water management in the UK in response to emerging challenges and global uncertainties. Creation of a quantitative assessment framework with tools and approaches for threat mitigation, adaptation options and strategies.

Industrial Presentations

The presentations from the industrial participants were:

- Industrial Grand Challenges- Peter Coddington (Network Asset Planning Manager at Yorkshire Water)
- The 2030 Vision - Matt Lovell (Asset Strategy Manager, Severn Trent Water)

- Changing our Relationship with Water- Jon Kendall (Castleton Consulting Ltd)

The main concerns highlighted in the industrial presentations were:

  - To deliver a more resilient network, as current clean and waste water networks are unlikely to meet the future needs of society. Old assets are difficult to locate, assess and monitor i.e. cast iron pipes are damaged by frost and become brittle.
  - Challenges related to the level of service i.e. risk-based approach to compliance, new measure to manage flooding, droughts, interruptions to supply, and contamination of water by hazardous substances.
  - Environmental challenges for sustainable abstraction and reducing carbon footprint as it impacts climate change.
  - Financial challenges that allow water companies to present to customers affordable bills and remain competitive.

Discussion

Water supply resilience in the UK can be understood as a complex system that depends on many other systems ranging from climate change, rainfall distribution, water resources, abstraction licences, water companies, distribution networks, water demand, etc. In order to understand the complexities involved it will be necessary to develop a comprehensive model so that in depth studies can be taken. Representing this entire complex system in a model with all the interlinking factors would be an ambitious task, however it would have the potential to show the interactions within all the parts and facilitate analysis. Such analysis is necessary to envision solutions in a holistic manner. This is not an easy task as some of the constituent parts of such a system are complex systems themselves i.e., the actual network of pipes and infrastructure to deliver water.

Complex systems have three characteristics in common with other systems; ability for self-organisation, adaptability and emergent behaviour [4]. In order to facilitate the emergence of a 'water system' that self-organises and adapts to new environmental conditions, economic constraints and population demand, it is necessary to maintain a better collaboration between the researchers and the industry to provide cost effective and viable solutions. Research groups need to take into account the main issues and priorities that trouble the industry to be able to contribute in solving them. Systems-NET organised this workshop with the aim of promoting communication and transfer of knowledge to make water supply resilience an achievable goal.

Conclusions/Recommendations

In the workshop presentations the necessity to manage/ influence/ control not only the growing demands of water, but also water resources and infrastructure was emphasized repeatedly. All the presentations in the workshop contained elements to spark new ideas and platforms for collaboration; one of the topics discussed was using architecture modelling and simulation to explore more resilient and robust water systems, for example work already being carried out at the University of Manchester and in a separate project at Loughborough University, aims to support engineering actions with monitoring information and computation data about the state of the system. Another novel idea was presented by Castleton Consulting , who showed an example of crowd sourcing where people contribute to the gathering of data using mobile phones, for example in the case of reporting radiation levels around the Fukushima area after the disaster of 2011.

According to the Environment Agency solving the challenge of Water Supply Resilience in the UK requires urgent action in key areas i.e. infrastructure, water demand, water distribution, and management of water resources. The Environment Agency has proposed to tackle some of the challenges for future water availability though the following measures [1]:

1. More efficient regulation for water abstraction as the UK population grows
2. Improving interconnectivity between water resources
3. Trading of licenses between water companies
4. Creating new water resources

From the industrial presentations it is clear that modernising infrastructure for clean water and maintaining waste water networks are both a high priority; many current network assets are difficult to locate, condition assess, monitor and replace. It was discussed that at present some 60% of the cast iron networks need replacement, and although they are a historic legacy, they have become prompt to failure in recent years due to the harsh winter weather. However, the cost of replacement is very high.

To solve the challenges of modernising infrastructure and maintaining waste water networks, we need an interdisciplinary approach involving experts from water supply companies, systems engineers, climate experts, and key users (domestic, industry and agriculture). By treating the resilience of water as a system of systems it should be possible to begin to address the more challenging aspects of ensuring water supply into the future. For example, an integral line of attack should include actions such as mapping the current resources, surveying the current condition, analysing the problem areas, and understanding the nexus within all the stakeholders like geographical and economic implications. Strengthening the links between several elements from the academic research and industry could make an important contribution to solving these challenges. For example the development of monitoring sensors has been successfully employed to survey leaks in water pipes.

There was extremely strong support to build on this workshop from all the participants as well as interest in the industrial challenges and ideas to tackle them through research. It was agreed to organise a follow-on workshop with the participation of a wider audience especially with participation of other stakeholders such as water companies, manufacturing industries, energy sector, farmers, and environmentalists.

The follow-up Systems-NET workshop will take place during November 2014 'Resilience of Water Networks in UK', if possible this will be arranged at one of the water company sites to be agreed with the participants.

List of Participants

Matt	Lovell	Severn Trent Water
Donna	Champion	Loughborough University
Jon	Kendall	Castleton Consulting Ltd
Peter	Coddington	Yorkshire Water (Network Asset Planning Manager)
Gema	Styles	Loughborough University
John	Brooke	University of Manchester
Antara	Bhatt	Loughborough University
Guangtao	Fu	University of Exeter
Roy	Kalawsky	Loughborough University
Andrew	Wheatley	School of Civil and Building Engineering Loughborough University
Darren	Cadman	Loughborough University
Robert	Wilby	Loughborough University
Naomi	Kelly	Loughborough University - SBE
DESPOINA	MANOUSELI	Loughborough University
Demetrios	Joannou	Loughborough University

References

[1] The case for change – current and future water availability. The Environment Agency. 2011, Report GEHO1111BVEP-E-E

[2] Future Water - The Government's strategy for England. Defra 2008

[3] UK Climate Projections (UKCP09)

[4] L.A.N. Amaral and J.M.Ottino, Complex Networks, Augmenting the framework for the study of complex systems, Eur. Phys. J B 38,147-162 (2004)

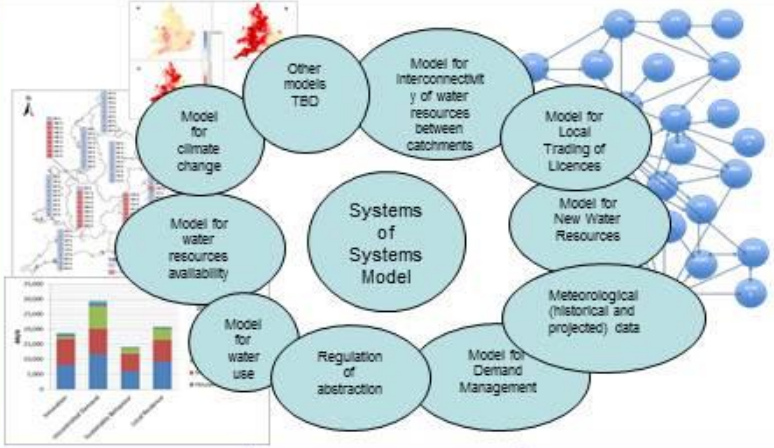
Appendix A

Systems Engineering and The Grand Challenges for Water Supply Resilience in the UK

Problem Statement:
A report-analysis published by the Environment Agency in 2011 called 'The Case for Change – current and future water availability' and which was reviewed in 2013 concluded that; water resources are already under pressure, there is uncertainty regarding future water availability, and that (under several climate projection scenarios) by the year 2050 there will be less water available than today, with many catchments across Wales, south west and northern England experiencing significant unmet demand. Over the longer term climate change could have a bigger impact on water availability than population growth and changing demands, and although demand management has an important role to play in improving water availability in the future, demand management alone will not fix the problem.

Assessing the problem for Water Supply Resilience

Water Supply Resilience is a Complex System:
Number of components? Geography, environment, climate, water resources, seasons, demand, population growth, regulatory
How components interact with each other? Licences-Water resource, Geography-Water availability, Water demand-population growth, public perceptions
System behaviour? Abstraction of water is regulated but availability of water depends on rainfall, measures to reduce water consumption are implemented but population increases. Climate models predict draughts but the frequency of floods increase.
Rules change over time? Water availability has seasonal and climate dependence, legislations change to protect the environment, charging for water, population growth varies across the UK.
Geographical Context? Stresses on water availability vary across river basin districts and catchment areas in the UK.
Socio-economic Context? Water consumption responds to demand scenarios, such as uncontrolled demand scenario or sustainable behaviour



Government	People	Water Companies
Industry and Commercial sectors	Developers, owners and managers of land	Environment Agency
Ofwat	Water Saving Group WSG	UKCP09 Climate Projections
Energy Saving Trust	Waterwise	Defra

Funding Body: EPSRC

Solutions Sought
- More efficient regulations for water abstraction as population grows
- Interconnectivity between water resources
- Trading of licenses between companies
- New water resources

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

Water Demand and Supply Management for the Residential Sector Using Integrated Resource Planning (IRP) Principles

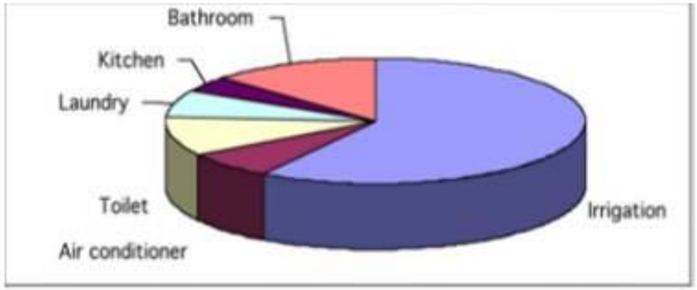
Problem Statement: Projected extreme weather events, rapid demographic and lifestyle changes call for innovative methods to manage growing water demand. Aim for all UK water utilities is to achieve balance between supply and demand, and to examine in parallel both demand and supply options. Defra's strategy aims at reducing residential water consumption from 150 to 130 l /c per day until 2030.

Aims & Objectives:

1. Analysis of factors that influence domestic water demand in the region (including weather variables).
2. Domestic water demand forecasting as a result of a business as usual scenario and alternative demand management policies (and source substitution options) scenarios using end-use analysis,
3. Assessment of the customers' Willingness to Conserve and exploration of the link between conservation attitudes and observed end use water consumption.
4. Determination of the potable water savings attributed to water demand management initiatives.

Research Details:
End-use or micro-component analysis is a method according to which water demand is disaggregated into end uses such as bathroom tap, toilet, irrigation and dishwashers. Thus, it enables accurate demand forecasting and the determination of water conservation potential of the set of options being considered. It is a highly recommended method in the context of IRP.

End-Use analysis of residential water demand



Funding Body: Loughborough University

Collaboration: Water company

Anticipated Impact:
Validation of real water savings that originate from demand management initiatives provides evidence to encourage the application of such schemes. The data obtained through end-use analysis will be useful for understanding the factors influencing domestic demand. Thus they will assist in improving future demand projections. The water company will be able to target Water Demand Management awareness and education campaigns in an effective manner so that maximum water savings can be achieved.

Key Contact: Despina Manouseli
D.MANOUSELI@LBORO.AC.UK

Systems-NET

EPSRC Pioneering research and skills

Loughborough University

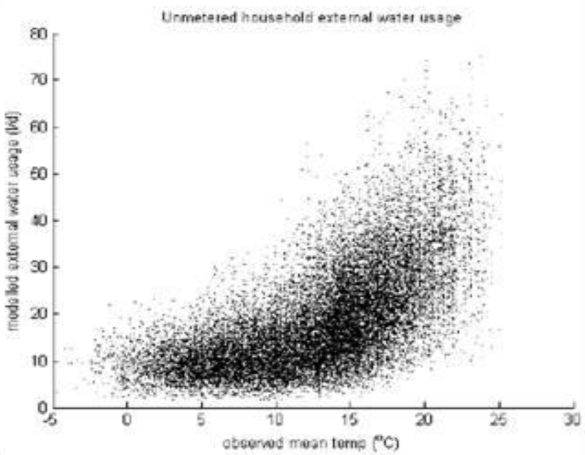
Research: Assessing the sensitivity of historic micro-component household water use to climatic drivers. PhD Thesis.

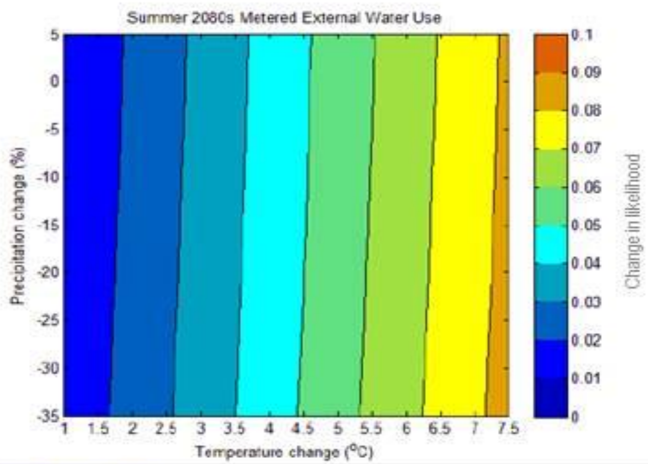
Problem Statement: The 2012 Climate Change Risk Assessment identified water security as one of the most significant threats facing the UK. It is now recognized that household water demand could be one 'low regret' measures amongst a raft of strategies intended to balance water supply and demand in the face of large uncertainties about climate and non-climate pressures.

Aims & Objectives: (1) To use the Anglian Water Services Ltd 'Golden 100' data set to explore the climate sensitivity of historic micro-component water use. (2) To develop transferrable protocols for error trapping, formatting and mining relationships from large, complex water industry data sets. (3) To determine the differential impact of weather/non-weather variables on household micro-component water use (frequency and amounts).

Research Details:

- Assessed sensitivity to T, P, SMD, sun; and socio-economic indicators
- Built (logistic) regression models of water use
- Assessed potential changes to micro-comps given UKCP09





Change in likelihood of summer external water-use in unmetered households' by the 2080s.

Funding Body: **EPSRC Adaptation and Resilience to a Changing Climate Coordination Network (ARCC CN)**

Collaboration: Anglian Water Services Ltd

Example impacts: (1) Creation of a 'clean' data base of customer micro-component water use, and more robust estimates of per capita consumption across the sampled household types. (2) Deeper understanding of links between household water use and weather. (3) Evidence that that the observed reduction in demand following the introduction of a hosepipe ban in 2012 was largely explained by the subsequent cool, wet summer.

Key Contacts: Rob Wilby, Department of Geography; Jo Parker, WS Atkins. PhD thesis: https://dspace.lboro.ac.uk/2134/14939

Systems-NET

EPSRC Pioneering research and skills

Loughborough University
Advanced VR Research Centre

Architecting Resilience as a System of Systems

Problem Statement: The quality of the environment and availability of natural resources are intrinsically linked to the infrastructure we build and rely upon today. The interdependence and inter-connectedness mean that a holistic view is even more important for future sustainability and resilience.

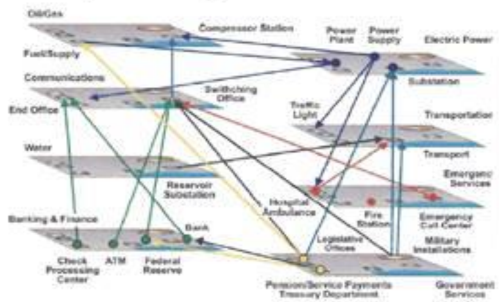
Aims & Objectives:

- Create an executable systems architecture allowing analysis of emergent behaviour
- Create an systems architecture for a resilient water supply network
- Produce a systems model in order to optimize and select alternative system architectures
- Provide a system modeling environment that facilitates architecture evolution
- Create system architecture patterns for re-use by key stake holders

Research Details:
Executable architectures are the building blocks of next generation modelling and simulation. They enable complex inter-relationships between coupled systems to be explored. Advanced model based systems engineering tools are being developed to facilitate the analysis of systems of systems(SoS). Interactive visual analytics enables projections to be made against the behaviour of the coupled system models. Verification and validation of these executable architectures is being undertaken against real-world examples.

Modelling & Simulation: The simulation environment for these system architecture patterns will allow:

- Evaluating candidate architectures against a set of SoS constraints
- Exploring alternate architecture patterns
- Analyse emergent behaviours of the SoS



Funding Body: EU FP7 €12m, DANSE

Collaboration: IAI, IBM, EADS, Thales, CARMEQ, INRIA, ALES, Sodius

Application & Impact: Water supply companies facing the challenge of changing the architecture of their systems can use architecture modelling and simulation to explore more resilient and robust systems.

- Creation of state of the art systems modeling and simulation environment with deployable tool-net
- Creation of systems architecture for water management
- Next generation IBM modeling tools
- Application of interactive visual analytics

Key Contact: Roy S. Kalawsky, 635678, r.s.kalawsky@lboro.ac.uk, School: Electronic, Electrical & Systems Engineering

Research: Novel sensors to provide more resilience, water treatment and supply the Water Group, School of Civil and Building Engineering

Problem Statement:

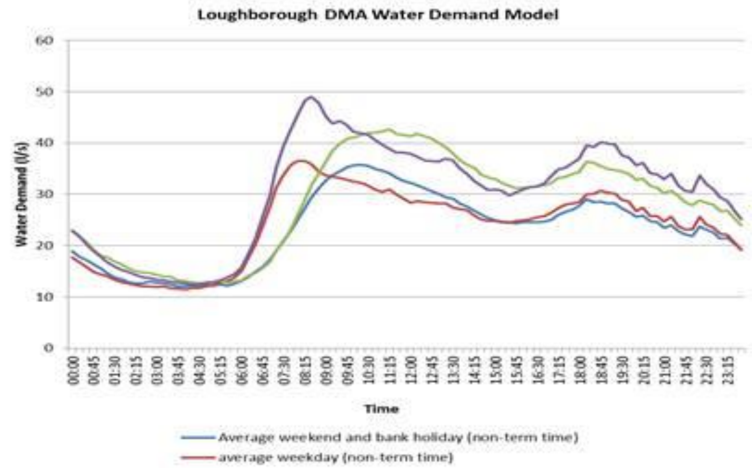
Identify risks to water quality during treatment and supply , identifying newly emergent risks.

Aims & Objectives:

- Measuring water quality on-line.
- Identifying physical, chemical and biochemical changes during treatment and delivery.
- Developing new more reliable sensor technologies for water quality monitoring.
- Integrate sensors into models to suit the complexity of treatment and supply systems.

Research Details: Project Titles

- Research on a non-invasive flow and turbidity meter, Eng Doc 2013-2017, sponsored - Dynamic Flow Technologies Severn Trent and Wessex Water.
- Non-invasive off-gas analysis for remote control of infrastructure for off-grid communities, EPSRC led by Nottingham 2012-2015.
- Development of intelligent, integrated sensors, i.e. flow conductivity, turbidity and UV to monitor water quality. Eng Doc graduated 2011, sponsor - Myriad Vision/Severn Trent.
- Acoustic leak detection, using changes in magnitude and frequency shifts in distribution.
- Potential application of fluorescence (lazer, UV, microwave) for non-invasive carbon analysis. RA with Cranfield, EPSRC.



Funding Bodies: Research Councils and Industry

Collaboration: Nottingham, Cranfield, West of England, SWIG, UKWIR, Water Utilities and Consulting Engineers

Anticipated Impact:

- Online monitoring of water quality risks.
- Identifying, monitoring newly emergent risks during treatment and distribution.
- Developing non-invasive sensors.
- Integrated self validating sensors.
- Models of flow perturbations and their effects on water quality.

Key Contact: Andrew Wheatley & Richard Blanchard.
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Online modelling and prediction in water distribution systems

John M. Brooke

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

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

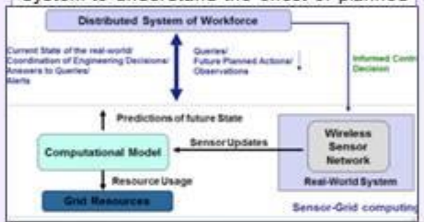

Figure 1: shows the three conceptual components of thisl system. requirements.

Research Details

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 visualization 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.

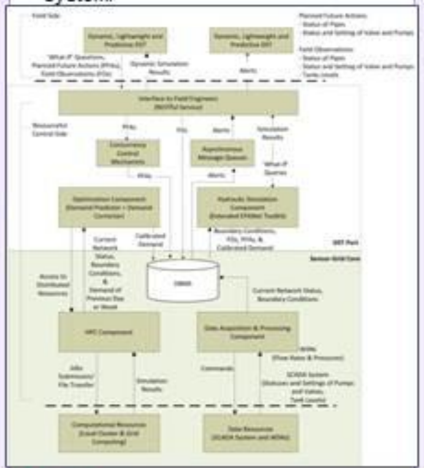

Figure 2: Complete architecture of the system

Expected impact

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.

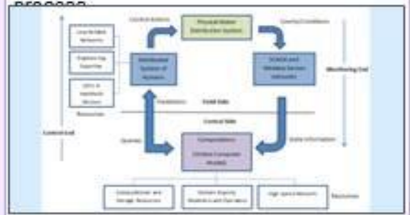

Figure 3: improved decision making process will bring the following benefits.

- 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.

Collaborators

Preparatory work based on data supplied by Yorkshire Water, United Utilities, Thames Water.

Current collaboration with Water Reseach Centre on behalf of a consortium of UK water companies backed by a KTP funded by the TSB.

Funding for basic research from PhD and MSc projects.

Figure 4: part of the current user inteface 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.

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UNIVERSITY OF EXETER Centre for Water Systems

EPSRC Pioneering research and skills

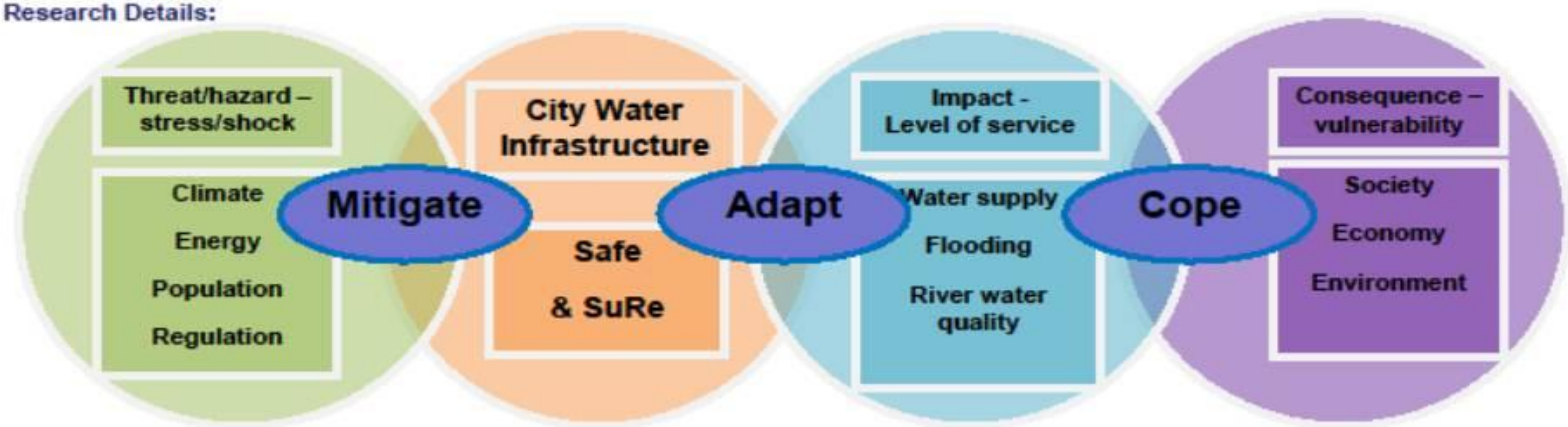
Safe & SuRe Water

Research: Safe & SuRe: towards a new paradigm for urban water management

Problem Statement: The water sector in the UK has been very successful by many measures, however, all this has been achieved using a 19th century approach based on unlimited resources, unrestrained demand and a stable climate. A new paradigm is needed for urban water management.

Aim: To develop a new *paradigm* for '**Safe & SuRe**' urban water management in the UK in response to emerging challenges and global uncertainties.

Research Details:



Anticipated Impact:
- Development of a Safe & SuRe water vision for British cities
- 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

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

Funding Body: EPSRC , March 2013 - Feb 2018

Key Contact: Guangtao Fu, g.fu@exeter.ac.uk, Centre for Water Systems, College of Engineering, Mathematics and Physical Sciences, University of Exeter

Systems-NET EPSRC Pioneering research and skills YorkshireWater

Industrial Grand Challenges

Problem Statement(s):
The clean and waste water networks are a legacy and an inheritance of times gone. Still surprisingly resilient they are coming under increasing pressure to meet the demands of today.

Extreme weather patterns, continuing population growth and the resultant expansion of built environments, a long lived asset base and restrictive economic environments mean that we need to think differently about how we manage and develop the networks to meet the future needs of society.

Buried assets are difficult to locate, condition assess and monitor. They are also costly to upgrade. Of all the assets owned by a water company they are the most important as they directly impact upon the customer when they fail.

Known barriers/constraints:

Willingness and ability of our customers to pay

Regulatory regime and drivers – at home and in Europe

Lack of investment and R&D in the water industry

The assets are not easily accessible, visible and are poorly understood

Aims & Objectives:

Understand what collaborative approaches could be taken to deliver a more resilient network i.e. removing surface water from sewers

What research activities are ongoing in other fields that may have relevance to the water industry i.e. new modeling and predictive techniques and technologies

Grand Challenges:
Removing surface water from sewers

Understanding and accurately predicting our network performance

Providing a water network that can accommodate the extreme weather patterns without failure i.e. remove Cast Iron from the network

Key Contact: Peter Coddington (Yorkshire Water)
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Systems-NET

Severn Trent Water: The 2030 Vision

What are the challenges facing the water industry?

- Levels of service
  - Risk based approach to compliance
  - New measures – interruption to supply/ priority hazardous substances
  - Flooding / drought
- Environmental
  - Sustainable abstraction
  - Reducing carbon footprint
- Financial
  - Affordable bills
  - Competition

Potable Water 2030

- Climate variability
  - Sustainable abstraction
  - Water re-use for domestic properties
  - Leakage-tackling the root causes
- Dependable Service
  - Interruptions of supply
  - Flexibility of the grid - water trading
  - Real time monitoring and control of network
- Towards 100% compliance
  - Intake management to avoid challenges/risks
  - Advance oxidation processes/ novel adsorbents
  - Real time quality management

Waste Water 2030

- Resource recovery
  - Tighter consents
    - Advance treatment and recovery for PO4
    - Biogas generation – CHP and gas-to-grid
- Climate variability
  - Dealing with storm water
    - Catchment –based flood attenuation
    - Real time monitoring and control network
    - Proactive management of blockages
- Risk based design
  - Asset condition monitoring / modelling
    - Intelligent assets / management information

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