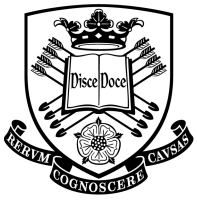


The
University
Of
Sheffield.

CCWI 2017

15th International Conference on Computing and Control for the Water Industry

Sheffield, UK
5th - 7th September 2017

Dear Delegate

Welcome to the conference booklet for the 15th Computing and Control for the Water Industry Conference 2017, 'Intelligent Water Systems'.

The infrastructure that provides our water services has never been more important, or facing greater challenges, whether from climate change, population growth or the ageing, deteriorating infrastructure itself. It is vital that we develop new and innovative ways to understand and manage these complex systems now and for the future such that we can continue to provide the water services that are the foundation for society, to ensure public health and wellbeing, to underpin economies and to protect and enhance the natural environment

There is currently great opportunity for the development and application of computing and control technologies for the water sector, from sensors to data communication, to simulation and analytics, to decision support and intervention. We are at a critical time in the innovation cycle so it is more vital than ever that we bridge from theory to practice and make a positive change in direction for the future. These challenges and opportunities span across a range of economic and development scales internationally.

The theme of this CCWI conference is Intelligent Water Systems, with the following aims:

- To facilitate continued co-operation of academic institutions and industry
- To examine the current state-of-the-art in computing and control techniques applicable to the water industry
- To provide a forum for discussions and the dissemination of ideas on applied computing and control for the water industry, with particular emphasis on;
    1. Provider's perspective - Recent developments in research;
    2. User's Perspective - Users' experience of latest techniques;
    3. Future needs - current and future planning and operational requirements.

Papers to be presented cover the following themes:

- Advances in sensors, instrumentation and communications technologies
- Big Data and IoT applications
- Data driven and soft computing analytics and visualisation
- Systems modelling, optimisation and decision support
- Real time monitoring, modelling, control and uncertainties
- Water quality modelling, including sediment and pollutant transport
- Water and wastewater treatment modelling, optimisation and control
- Demand forecasting, leakage and energy management
- Asset management and performance modelling
- Sustainable urban water management, including stormwater management and integration of water within smart blue-green cities
- Flood modelling and management
- Security, reliability and resilience
- Social and economic aspects of the water management

This booklet provides the abstracts for all the papers to be presented at the conference, with the full papers available online, open access at ccwi2017.figshare.com. Also include here are information of the keynote speakers, overview and full programmes, and other general and practical information.

We wish you a highly enjoyable and informative conference.

Joby Boxall, Vanessa Speight, Sally Jones, Richard Collins and Steve Mounce

(on behalf of the local committee)

Acknowledgements

The organising committee would like to thank all the people on who have helped prepare and run CCWI 2017. Particularly the valuable assistance provided by the international scientific committee.

CCWI 2017 Sponsors

Sponsors

We would like to express our gratitude to our generous conference sponsors.

ATi have kindly agreed to sponsor the conference gala meal.

EMS are the sponsors of the drinks reception at Kelham Island.

Metasphere and **RTC4Water** are additional conference sponsors. Come and visit their stands in the central exhibition space through the duration of the CCWI 2017.

Affiliates

Local Organising Committee

Name	Affiliation	Country
Joby Boxall	University of Sheffield	UK
Richard Collins	University of Sheffield	UK
Stewart Husband	University of Sheffield	UK
Sally Jones	University of Sheffield	UK
Steve Mounce	University of Sheffield	UK
Mark Smith	RPS Water	UK
Vanessa Speight	University of Sheffield	UK
Simon Tait	University of Sheffield	UK
Kieran Williams	Environmental Monitoring Solutions	UK

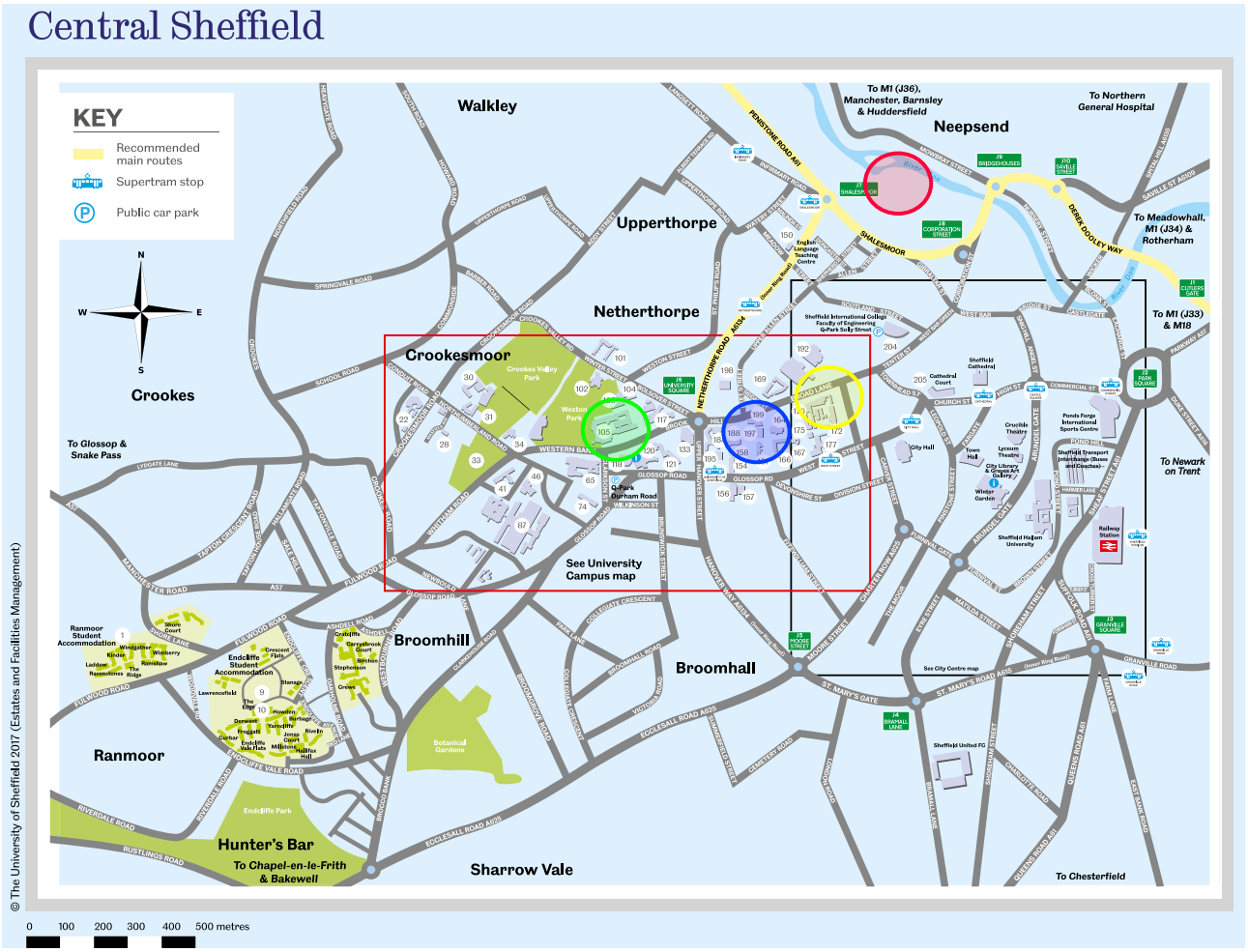
Scientific Committee

Name	Affiliation	Country
Helena Alegre	National Laboratory for Civil Engineering LNEC	Portugal
Andy Blackhall	Dwr Cymru Welsh Water	UK
Mirjam Blokker	Watercycle Research Institute KWR	The Netherlands
Dominic Boccelli	University of Cincinnati	USA
Bruno Brunone	University of Perugia	Italy
Steven Buchberger	University of Cincinnati	USA
Didia Covas	Instituto Superior Técnico	Portugal
Maria da Conceição Cunha	University of Coimbra	Portugal
Ana Deletic	Monash University	Australia
Yves Filion	Queen's University	Canada
Marco Franchini	University of Ferrara	Italy
Orazio Giustolisi	Bari University	Italy
Zoran Kapelan	University of Exeter	UK
Shuming Liu	Tsinghua University	China
Dirk Muschalla	Graz University of Technology	Austria
Avi Ostfeld	Technion	Israel
Olivier Piller	Irstea	France
Dusan Prodanovic	University of Belgrade	Serbia
Raido Puust	Tallinn University of Technology	Estonia
Wolfgang Rauch	University Innsbruck	Austria
Colin Rimmer	Atkins	UK
Juan Saldarriaga	Universidad de los Andes	Colombia
Dragan Savic	Exeter University	UK
Manfred Schutze	Ifak Magdeburg (current chair of IWA Joint Committee on Urban Drainage)	Germany
Ivan Stoianov	Imperial College London	UK
Bogumil Ulanicki	De Montfort University, UK	UK
Kobus van Zyl	University of Cape Town, Republic of South Africa	Republic of South Africa
Jan Vreeburg	Watercycle Research Institute KWR, The Netherlands	The Netherlands
Zheng Yi Wu	Bentley, USA	USA

The Venue: The Diamond

The Diamond is situated at **32 Leavygreave Rd, Sheffield, S3 7RD**. The contact telephone number for The Diamond Reception is +44 (0) 114 222 9134.

The Diamond accommodates undergraduate teaching for the Faculty of Engineering within specialist teaching laboratories, lecture theatres and flexible teaching rooms over six floors. The building also provides substantial mixed-use, student-led learning and teaching spaces. The nineteen laboratories in the building provide specialised engineering facilities to offer an excellent practical experience for students. These include a clean room, a virtual and augmented reality laboratory and a workshop. Dedicated teaching staff deliver exciting teaching to support students' development into graduate engineers.



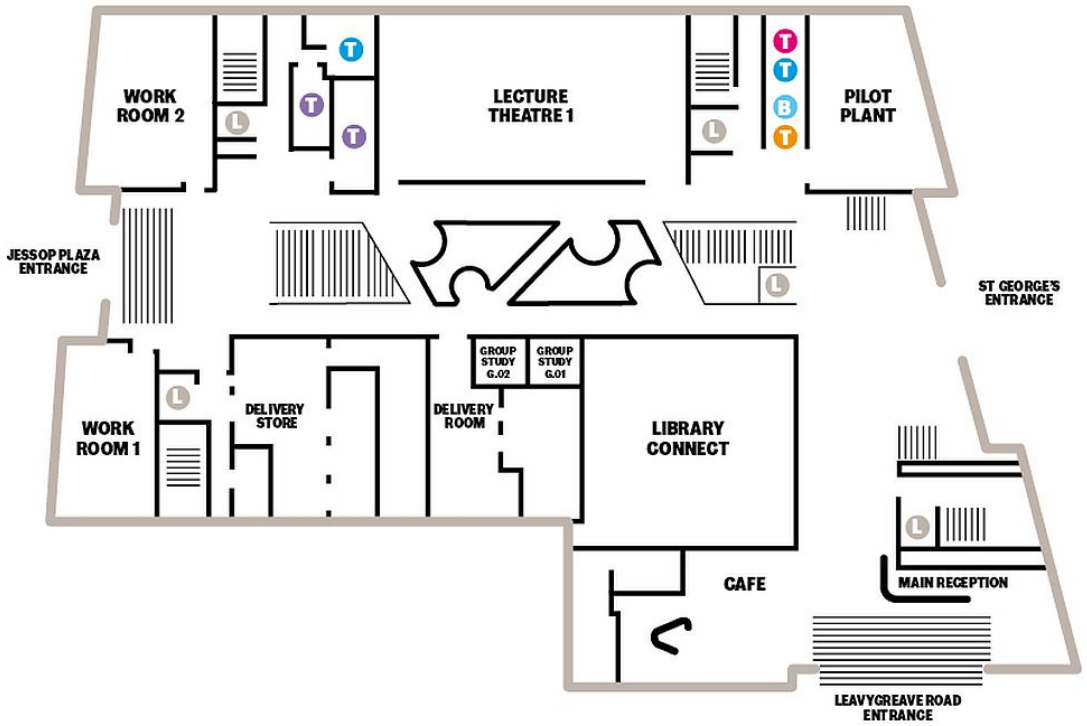
Location of **The Diamond** is highlighted by the Blue circle, No. 197. Lab Tours will be from the **Pam Liversidge Building** highlighted by the Yellow Circle. Conference drinks will be held at the **Kelham Island Museum**, highlighted by the Red Circle. The conference meal will be held at **Firth Court** highlighted by the Green Circle. Additional maps and directions can be found at `https://www.sheffield.ac.uk/ccwi/2017/venue`

Breakout and Meeting Rooms

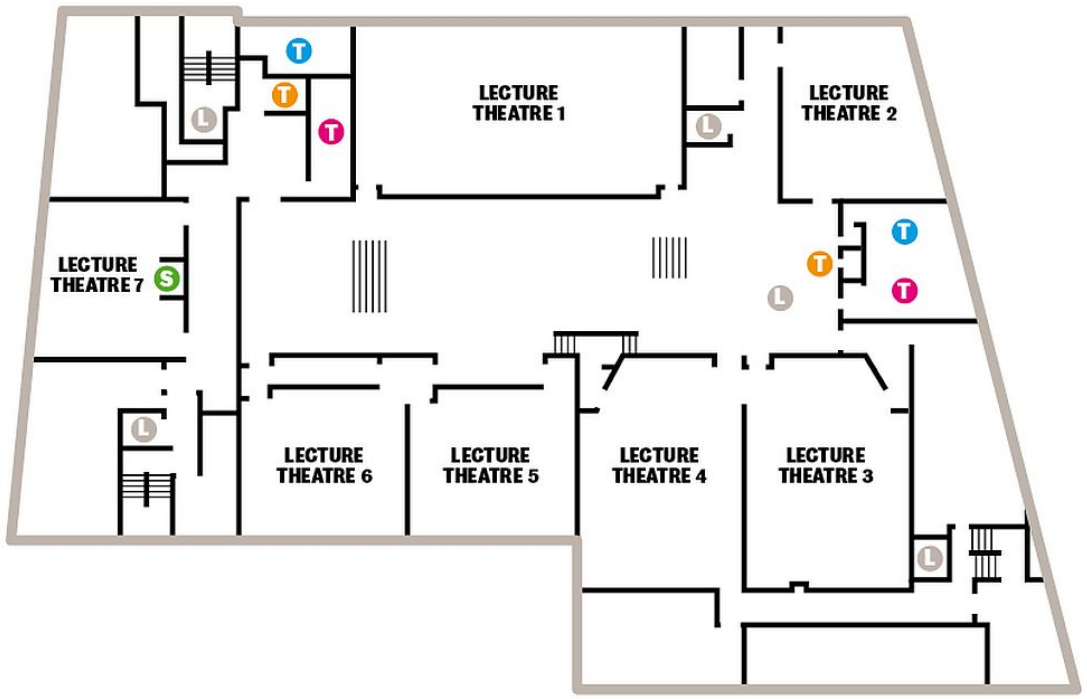
Workrooms 1 & 2 (see plan below) are available throughout the conference for breakout space and as a place to sit down for lunch. There are also lots of available informal seating (including the Diamond cafe) on the Ground and First Floor. If you require a private meeting room, this can easily be provided in The Diamond building, contact the conference reception desk to book a space.

Internet

There is a wireless network throughout The Diamond building. Wireless access should be accessible via the EDUROAM network or via the 'guest' network. The access code for the guest network is available at the conference reception desk.



The layout of the ground floor of The Diamond, Workrooms 1 & 2 are available as breakout space throughout the conference.



The layout of the basement of The Diamond. The conference welcome, keynote speeches and conference close will be in Lecture Theatre 1. The conference registration desk will be located in the center of the Basement Atrium

Guidelines for Platform Presentations

Length of Presentations

Each presentation should be 20 minutes in length including questions. Suggested timings are 15 minute presentation and 5 minutes for questions.

Session Chairpersons Please refer to the conference programme for name of your session's Chairperson. Please meet your Chairperson in your session room at least 15 minutes prior to the start of your session. Please provide your sessions chair with suitable short (50 words) biography so that they may introduce you properly, particularly highlighting if you are a student.

Presentation Upload

If you are intending to use a PowerPoint or other electronic presentation, it should be uploaded onto the computer in the allocated room prior to your session, at the latest in the break immediately prior to your session. It is strongly encouraged for you to bring your presentation on a number of formats and you are discouraged from using your own laptop. Platform presentations will not be recorded and the electronic presentations will not be stored or distributed by conference organisers at end of the conference.

Audio Visual Information

The use of PowerPoint or PDF presentations is strongly encouraged and the following equipment will be provided in all meeting rooms:

- Data / Video Projector
- A computer to which your presentation will be uploaded.
- Screen
- Lectern and lapel microphone

No other equipment will be provided unless agreed to by the Organising Committee. Please send a request immediately if there is something you require.

Keynote Speakers

Walter Grayman is an independent consulting engineer in Oakland, California, with over 45 years of experience in the areas of water supply and water resources with emphasis on infrastructure, modelling, water quality, GIS and risk/security issues. He holds a Ph.D. and M.S. from the Massachusetts Institute of Technology and a B.S. degree from Carnegie Mellon University; all in civil engineering with a speciality in water resources. He is a registered professional engineer in Ohio and active at the national level in the American Society of Civil Engineers (Environmental and Water Resources Institute) and American Water Works Association. Dr. Grayman has over 150 publications including co-editor of the ASCE/EWRI book Toward a Sustainable Water Future: Visions for 2050, co-author of the AWWA book Modelling Water Quality in Drinking Water Distribution Systems, and contributing author for McGraw-Hill and Wiley Handbooks on Water Distribution Systems and Water Supply Systems Security. He was the 2013 ASCE Julian Hinds Award recipient and has received best paper awards from ASCE and AWWA for his work in modelling water quality in distribution systems and water storage tanks.

Maria da Conceição Cunha is a Professor at the University of Coimbra, in Portugal. She holds a Diploma in Civil Engineering from the University of Coimbra (UC), an MSc in Hydraulics and Water Resources from the University of Lisbon, and a PhD in Natural Applied Sciences from the Catholic University of Louvain, in Belgium. She has been a Visiting Fellow at Princeton University (1997/98), an Invited Professor at the École Polytechnique Fédérale de Lausanne – EPFL (2002/09) and was awarded with a Distinguished Visiting Fellowship of the Royal Academy of Engineering (UK) last May. Her main research focus is the application of optimisation techniques to the design and proactive risk management of natural and built environment systems. She has been the president of the Portuguese Water Resources Association (2014/16), and currently acts as coordinator of the PhD Program in Environmental Engineering at the UC, member of the National Water Council (advisory board of the government for water and environment policies), member of the Environmental Council of the Navigator Company (paper industry), and member of the Council of the Administration of the Hydrographic Central Region. She has coordinated or participated in 35 research projects funded by the Portuguese Science and Technology Foundation, the European Union and other institutions. Her research gave rise to around 300 publications on the planning and management of different water systems, including over 70 papers in international peer-reviewed journals and a book about groundwater management published by an international publisher.

Simon Parsons, Director of Strategic Customer Service Planning – Scottish Water. Having joined Scottish Water in April 2012 as Chief Scientist, I am now Director of Strategic Customer Service Planning, leading teams in regulation, water and waste water services, strategic review, science and innovation. It's my responsibility to ensure customer needs and expectations are built into our strategies and plans for the future, ensuring we continue to deliver the very best service for all. Before joining Scottish Water I spent 17 years working in academia and research. This invaluable background allows me to provide a different perspective, challenging text book assumptions, pushing teams to go that extra mile and taking Scottish Water to new heights. With a passion for protecting public health I want Scottish Water to make sure the highest standards are maintained. And it's also our responsibility to protect Scotland's precious environment. These are exciting times for Scottish Water as we work towards becoming even more resilient and I'm proud to be at the heart of the innovative work we're doing across Scotland.

I have a BSc and PhD in Chemistry from Leicester University, I'm a Fellow of the Royal Society of Chemistry and I sit on the board of UK Water Industry Research (UKWIR). I hold a visiting chair at Cranfield University and was awarded the Royal Society of Chemistry's prestigious Sustainable Water Award for 2014 for advancing the understanding of natural organic matter in water treatment and for the development of treatment processes to improve water quality and sustainability.

CCWI 2017 Overview

TUESDAY 5TH SEPTEMBER

	LT3	LT4	LT5
08:00 - 09:00	REGISTRATION AND REFRESHMENTS		
09:00 - 09:15	WELCOME LT1		
09:15 - 10:00	Key note address LT1 ***A Whirlwind Historical Tour of the Wonderful World of Water Distribution Systems Analysis - Walter Grayman***		
10:00 - 10:20			
10:20 - 11:20	Demand forecasting, leakage and energy management ***Leakage***	Advances in sensors, instrumentation and communications technologies ***Sensing***	Water quality modellling, including sediment and pollutant transport ***Water quality***
11:20 - 11:40	REFRESHMENTS		
11:40 - 12:40	Demand forecasting, leakage and energy management 2 ***Demands and energy***	Systems modelling, optimisation and decision support ***Modelling and optimisation***	Water quality modellling, including sediment and pollutant transport 2 ***Water quality***
12:40 - 13:40	LUNCH		
13:40 - 15:00	Demand forecasting, leakage and energy management 3 ***Leakage***	Systems modelling, optimisation and decision support 2 ***Modelling***	Sustainable urban water management, including stormwater management and integration of water within smart blue-green cities ***Urban Drainage***
15:00 - 15:20	REFRESHMENTS		
15:20 - 16:40	Demand forecasting, leakage and energy management 4 Transients and leakage	Systems modelling, optimisation and decision support 3 ***Modelling***	Asset management and performance modelling ***Assets and performance***
17:00 - 18:45	LAB TOURS		
18:30 Drinks Reception at Kelham Island. Coaches will depart after lab tours 18:00, 18:15, 18:30, 18:45 Return coaches from 20:30.			

WEDNESDAY 6TH SEPTEMBER

08:30 - 09:00	REFRESHMENTS (AND DAY REGISTRATION)		
09:00 - 09:45	Key note address LT1 ***Trends and opportunities in water management - Maria da Conceição Cunha***		
09:45 - 10:00			
10:00 - 11:00	Real time monitoring, modelling, control and uncertainties ***Real time***	Demand forecasting, leakage and energy management 5 ***Demand forecasting***	Water quality modellling, including sediment and pollutant transport 3 ***Water quality***
11:00 - 11:20	REFRESHMENTS		
11:20 - 12:40	Real time monitoring, modelling, control and uncertainties 2 ***Pumps and valves***	Demand forecasting, leakage and energy management 6 ***Demands and metering***	Water quality modellling, including sediment and pollutant transport 4 ***Discolouration***
12:40 - 13:40	LUNCH		
13:40 - 15:00	Systems modelling, optimisation and decision support 4 ***Optimisation***	Asset management and performance modelling 2 ***Asset performance***	Data driven and soft computing analytics and visualisation ***Machine learning***
15:00 - 15:20	REFRESHMENTS		
15:20 - 16:40	Systems modelling, optimisation and decision support 5 ***Modelling***	Flood modelling and management ***Flood modelling and management***	Data driven and soft computing analytics and visualisation 2 ***Data driven analytics***
19:00 Conference dinner in Firth Hall.			

THURSDAY 7TH SEPTEMBER

08:30 - 09:00	REFRESHMENTS (AND DAY REGISTRATION)		
09:00 - 09:45	Key note address LT1 ***Building Blocks For A Resilient Water And Wastewater Service - Simon Parsons***		
09:45 - 10:00			
10:00 - 11:00	Water and wastewater treatment modelling, optimisation and control ***Treatment***	Demand forecasting, leakage and energy management 7 ***Leakage***	Security, reliability and resilience ***Resilience***
11:00 - 11:20	REFRESHMENTS		
11:20 - 12:40	Systems modelling, optimisation and decision support 6 ***Modelling***	Demand forecasting, leakage and energy management 8 ***Energy***	Advances in sensors, instrumentation and communications technologies 2 ***Sensing***
12:40 - 12:50	REFRESHMENTS		
12:50 - 13:10	Conference close LT1		
13:10 - 14:00	LUNCH		

Evening Events

All events are included in the registration fee and have a “smart, casual” dress code.

Tuesday Evening

Tea, Coffee Networking and Optional Lab tours

Between 17:00 and 18:45 on Tuesday tea, coffee and refreshments will be served in the Pam Liversidge building for a relaxed networking session. There will also be an opportunity to visit the water labs in the Civil and Structural Department at the University of Sheffield. Technicians from Yorkshire Water will also be attending to demonstrate their ‘Calm Networks’ training facility and to talk about their success in educating their operatives to prevent transients in distributions systems.

Evening Drinks Reception

The CCWI 17 Welcome Drinks Reception, sponsored by EMS, will be held at Kelham Island Museum.

The museum is steeped in Sheffield’s industrial history and stands on a man made island which is over 900 years old. It is home to one of only three Bessemer Converters left in the world and of course, the ever popular and historic River Don Engine, the most powerful working steam engine remaining in Europe, which will be run over the course of the evening.

Complimentary drinks and canapes will be served in the museum, delegates will be able to enjoy the history of Sheffield’s industrial revolution and explore at their leisure.

Delegates will then be free to move on to pubs or restaurants of their choice. The Kelham Island Museum is surrounded by local pubs who serve a whole host of real ales, which are not to be missed. For those who wish to eat, the Museum is a short ride to the City Centre.

Drinks Reception Address: Kelham Island Museum, Alma Street, Sheffield, S3 8RY.

Coaches to the evening drinks reception will leave from outside the Pam Liversidge building at **18:00**, **18:15**, **18:30**, **18:45**.

Coaches will return from Kelham Island from **20:30**.

Wednesday Evening

Conference Gala Meal

The CCWI 17 Conference Dinner, sponsored by ATi, will be held at Firth Hall, University of Sheffield.

Firth Hall is named after Sheffield steel manufacturer Mark Firth who played a key role in the University of Sheffield's early development. The building originally housed the University's Arts, Science and Medicine departments.

The building was opened by King Edward VII and Queen Alexandra in 1905, the same year that the University of Sheffield was granted its royal charter and officially came into being.

This stunning venue is located on Western Bank close to the bars/night life on West Street.

Delegates will be served a complimentary three course meal & drinks in the impressive Firth Hall, with the option of exploring what Sheffield's night life has to offer following the dinner.

Conference Dinner Address: Firth Court, Western Bank, Sheffield, S10 2TN.

TUESDAY 5TH SEPTEMBER (MORNING)

	LT3	LT4	LT5
08:00 - 09:00	**REGISTRATION AND REFRESHMENTS**		
09:00 - 09:15	**WELCOME LT1**		
09:15 - 10:00	**Key note address LT1** *A Whirlwind Historical Tour of the Wonderful World of Water Distribution Systems Analysis - Walter Grayman*		
10:00 - 10:20			
10:20 - 11:20	**Demand forecasting, leakage and energy management** ***Leakage*** **Session Chair – Kobus van Zyl**	**Advances in sensors, instrumentation and communications technologies** ***Sensing*** **Session Chair - Joost Van Summeren**	**Water quality modellling, including sediment and pollutant transport** ***Water quality*** **Session Chair - Walter Grayman**
	Data Setup for Water Distribution System Supervision **Pérez, R.**, Grau, S., Jiménez, V., Martínez, X., Tomas, R.	The Role of SMART Water Quality Monitors on the Path to SMART Water Networks **Strahand, M.**	Reduction in Infection Risk by Automated Rapid Detection of Faecal Contamination of Drinking Water Distribution Systems **Blokker, E.J.M.**, Smeets, P.W.M.H.
	Model Calibration for Leak Localisation, a Real Application Sanz, G., Meseguer, J., **Pérez, R.**	SAFEWATER – Application and Results of Innovative Tools for the Detection and Mitigation of CBRN- related Contamination Events in Drinking Water Supply Systems **Bernard, T.**, Rosenberg, A., Lucas, H., Rieder, A., Moßgraber, J., Deuerlein, J., Brill, E., Boudergui, K., Ilver, D., Ulitzur, N., Madar, A.E.	Infection Delay Time Analysis for Enhancing Water Networks Vulnerabilities to Contamination Intrusions **Lifshitz, R.,** Ostfeld, A.
	Leakage Modelling: High Leakage Exponents Due To Friction Effects **Heckmann, K.**, Sievers, J.	Identifiability analysis for pressure sensors positioning Puleo, V., Tarantino, S., **Freni, G.**, La Loggia, G.	Two-Point Constraint Control of Water Quality in Distribution Networks **Maheshwari, A.,** Abokifa, A.A., Gudi, R.D., Biswas, P.
11:20 - 11:40	**REFRESHMENTS**		
11:40 - 12:40	**Demand forecasting, leakage and energy management 2** ***Demands and energy*** **Session Chair - Juan Saldarriaga**	**Systems modelling, optimisation and decision support** ***Modelling and optimisation*** **Session Chair - Zheng Wu**	**Water quality modellling, including sediment and pollutant transport 2** ***Water quality*** **Session Chair - Stewart Husband**
	Exploring how Pipe-Level Energy Metrics Relate to Hydraulic Parameters using Multivariate Analysis **Hashemi, S.**, Filion, Y.R., Speight, V.L.	Dynamic Scenario Selection in Optimal Design Problems and Evolutionary Optimization with Uncertain System Knowledge **Sankary, N.**, Ostfeld, A.	Online Water Quality Monitoring based on Pattern Analysis **Page, R.M.**, Waldmann, D., Gahr, A.
	Influence of Pressure, Temperature and Humidity on Water Consumption **Suchacek, T.,** Tuhovcak, L., Rucka, J.	Spectral Propagation of Parameter Uncertainties in Water Distribution Networks **Braun, M.**, Piller, O., Deuerlein, J., Mortazavi, I.	Water Network Characterisation Based on Mass Balance with Regards to Discolouration Risk using High Frequency Turbidity Monitoring **Starczewska, D.**, Gaffney, J., Boult, S.
	A Comparison of Short-Term Water Demand Forecasting Models Pacchin, E., Gagliardi, F., **Alvisi, S.**, Franchini, M.	The EPANET Challenge **Ostfeld, A.**	
12:40 - 13:40	**LUNCH**		

TUESDAY 5TH SEPTEMBER (AFTERNOON & EVENING)

	LT3	LT4	LT5
13:40 - 15:00	**Demand forecasting, leakage and energy management 3** ***Leakage*** **Session Chair – Alan Lambert**	**Systems modelling, optimisation and decision support 2** ***Modelling*** **Session Chair – Luigi Berardi**	**Sustainable urban water management, including stormwater management and integration of water within smart blue-green cities** ***Urban Drainage*** **Session Chair - Simon Tait**
	Optimal Control for Water Loss from Water Distribution System: A Case Study of Beijing **Xu, Q.**, Liu, K., Zhao, S., Cao, N., Qiang, Z., Ben, W.	Why are Line Search Methods Needed for Hydraulic DDM and PDM Solvers? **Piller, O**., Elhay, S., Deuerlein, J., Simpson, A.	Evaluating Classification Algorithms for Improved Wastewater System Calibration **Younis, M.C.**, Keedwell, E., Savic, D., Raine, A.
	A Theory for Realistic Modeling of Leakage and Intrusion Flows Through Leak Openings in Pipes **Van Zyl, J.E.**, Lambert, A., Collins, R.	A Rehabilitation Decision-Making Approach for WDNs Based on Extended Period Simulations Darvini, G., **Ruzza, V.**, Salandin, P.	Prediction of CSO Chamber Water Levels Using Rainfall Forecasts **Rosin, T.,** Romano, M., Woodward, K., Keedwell, E., Kapelan, Z.
	Pressure: Leak Flow Rates using FAVAD: an Improved Fast-Track Practitioner's Approach **Lambert, A.**, Fantozzi, M., Shepherd, M.	WDNs calibration using k-means algorithm for pipes clustering and a hybrid model for optimization Freitas, R., **Brentan, B.M.**, Lima, G.M., Luvizotto Jr. E.	Smart Rainwater Management Systems Powered by the Internet of Things: A UK Case Study Rezaei, H., **Melville-Shreeve, P.,** Butler, D.
	Investigating Statistical Process Control and Geostatistical Techniques for Approximate Leak/Burst Event Location **Boatwright, S**., Romano, M., Mounce, S., Woodward, K., Boxall, J.B.	Optimising valve placement and pressure control for multi-feed sectors in water supply networks using outer approximation Pecci, F., **Stoianov, I.**	Effects of Manning Coefficients and Absolute Roughness on the Optimized Designs of Urban Drainage Networks Duque, N., **Montes, C.R.**, Zambrano, J.B., Saldarriaga, J.V.
15:00 - 15:20	**REFRESHMENTS**		
15:20 - 16:40	**Demand forecasting, leakage and energy management 4** **Transients and leakage** **Session Chair - Martin Lambert**	**Systems modelling, optimisation and decision support 3** ***Modelling*** **Session Chair - Maria da Conceição Cunha**	**Asset management and performance modelling** ***Assets and performance*** **Session Chair - Peter Van Thienen**
	Probabilistic Modelling of Transient Propagation in Water Distribution Systems **Collins, R.**	A Dynamic Model for Smart Water Distribution Networks **Kaltenbacher, S.**, Steffelbauer, D.B., Cattani, M., Horn, M., Fuchs-Hanusch, D., Römer, K.,	Agent-Based Modeling as a Decision Support Tool for Water Conservation Planning Tourigny, A., **Filion, Y.R.**
	Cumulative Pressure Induced Stress for Characterising Pressure Transients and Variability in Water Supply Networks **Stoianov, I.**, Hoskins, A.	On the Solvability of the Pressure Driven Hydraulic Steady-State Equations Considering Feedback-Control Devices **Deuerlein, J.**, Piller, O., Parisini, F., Simpson, A., Elhay, S.	Understanding the Range of Influence of Moderate-Sized and Short-Duration Transients in Water Distribution Systems Stephens, M., **Marchi, A.,** Gong, J., Lambert, M., Leonard, M., Simpson, A.
	Pipe Leak Diagnostic Using Empirical Mode Decomposition (EMD) and Automatic Selection of the Intrinsic Mode Function (IMF) Yusop, H.M., **Ghazali, M.F.**, Yusof, M.F.M., Remli, M.A.P.	Hydraulic Reliability analysis of a Real Network with Remotely Real-time Controlled Pressure Control Valves Laucelli, D.B., **Berardi, L.**, Simone, A., Raspati, G., Ugarelli, R.M., Giustolisi, O.	Modelling Capitol Costs of Sewer System Assets Cabral, M., Pinheiro, A., Loueriro, D., **Covas, D.**
	Application of Least Squares Support Vector Machines and Acoustic Measurements for Leak Flow Rate Prediction Butterfield, J.D., Meruane, V., **Collins, R.**, Meyers, G., Beck, S.B.M.		Management-Indicators Consulting System for Potable Water Utilities **Hansen Rodríguez, M.P.**, Rodríguez Varela, J.M., Laurel Varela, Y., Fernández García, H., Martínez Ocampo, G., Antúnez Leyva, E., Gómez Lugo, L.
17:00 – 18:45	**Networking and Lab Tours in the Pam Liversidge Building**		
18:30 Drinks Reception at Kelham Island. Coaches will depart after lab tours 18:00, 18:15, 18:30, 18:45 Return coaches from 20:30.			

WEDNESDAY 6TH SEPTEMBER (MORNING)

	LT3	LT4	LT5
08:30 - 09:00	**REFRESHMENTS (AND DAY REGISTRATION)**		
09:00 - 09:45	**Key note address LT1** *Trends and opportunities in water management - Maria da Conceição Cunha*		
09:45 - 10:00			
10:00 - 11:00	**Real time monitoring, modelling, control and uncertainties** ***Real time*** **Session Chair - Ramon Perez**	**Demand forecasting, leakage and energy management 5** ***Demand forecasting*** **Session Chair - Yves Filion**	**Water quality modellling, including sediment and pollutant transport 3** ***Water quality*** **Session Chair - Vanessa Speight**
	An Integrated State Estimation Approach to Enhance the On-line Monitoring Capabilities of Water Distribution Systems **Díaz, S.**, González, J., Mínguez, R.	A Model Pre-processing Approach for Improving Calibration-based Leakage Detection using a Genetic Algorithm **Sophocleous, S**., Savic, D., Kapelan, Z., Shen, Y., Sage, P.	Optimal Positioning of Water Quality Sensors in Water Distribution Networks: Comparison of Numerical and Experimental Results Piazza, S., Sambito, M., Feo, R., **Freni, G.**, Puleo, V.
	A Real Time System for Detecting Events in Water Networks **Meeus, S.**, Marshallsay, D.	A Perspective on Reducing Uncertainties in Water Distribution Networks Management Using Clusters **Lifshitz, R.**, Ostfeld, A.	Can a Valve Closure Transient Cause Mobilisation of Adhered Particles? **Weston, S.**, Collins, R., Boxall, J.B.
	Extracting Temporal Patterns for Contamination Event Detection in a Large Water Distribution System **Cheifetz, N.**, Kraiem, S., Mandel, P., Féliers, C., Heim, V.	A Python Tool for Generating Synthetic Demand Scenarios **Santopietro, S.**, Granata, F., Tricarico, C., de Marinis, G., Gargano, R.	Inline Mobile Water Quality Sensors Deployed for Contamination Intrusion Localization **Sankary, N.**, Ostfeld, A.
11:00 - 11:20	**REFRESHMENTS**		
11:20 - 12:40	**Real time monitoring, modelling, control and uncertainties 2** ***Pumps and valves*** **Session Chair - Bogumil Ulanicki**	**Demand forecasting, leakage and energy management 6** ***Demands and metering*** **Session Chair - Olivier Piller**	**Water quality modellling, including sediment and pollutant transport 4** ***Discolouration*** **Session Chair - Mirjam Blokker**
	Unsteady Flow Modelling of RTC in Water Distribution Networks **Creaco, E.**, Campisano, A., Franchini, M., Modica, C.	Identifying Relationships between Weather Variables and Domestic Water Consumption using Smart Metering **Xenochristou, M.**, Kapelan, Z., Hutton, C., Hofman, J.	Using Hydraulic Models and Real Time Monitoring to Provide Resilience for Birmingham **Rimmer, C.**
	Real-time whole-cost optimization of water production and distribution **Sunela, M.I.,** Puust, R.	Analysis of shower water use and temperature at a South African University campus Botha, B.E., **Jacobs, H.E.**, Biggs, B., Ilemobade, A.A.	Discolouration Risk Management and Chlorine Wall Decay **Sunny, I.**, Husband, S., Moore, G., Drake, N., Mckenzie, K., Boxall, J.B.
	Mechanical reliability analysis of a real network to support the design of Isolation Valve System Laucelli, D.B., **Berardi, L.**, Simone, A., Raspati, G., Ugarelli, R.M., Giustolisi, O.	Leak Detection in a DMA, a Real Application of Flow Modelling Jiménez, V., Grau, S., **Pérez, R.,**	Application of Water Distribution Models in Mains Cleaning- A Case study **Mansoor, M.A.M.**, Bleakley, E., Yan, J., Vairavamoorthy, K.
	Self-tuning Pump Operation Mode for Fluid Storages to Increase Energy Efficiency **Hieninger, T.,** Schmidt-Vollus, R.	End-Use Estimates of Water Demand Within Certain Residential Categories in the City of Johannesburg Jacobs, H., **Llemobade, A.A.**, Botha, B.E.	Rusby Wood a Smart Network for Sustainable Discolouration Risk Reduction **Cook, D.**, Husband, S.
12:40 - 13:40	**LUNCH**		

WEDNESDAY 6TH SEPTEMBER (AFTERNOON & EVENING)

	LT3	LT4	LT5
13:40 - 15:00	**Systems modelling, optimisation and decision support 4** ***Optimisation*** **Session Chair - Marco Franchini**	**Asset management and performance modelling 2** ***Asset performance*** **Session Chair - Heinz Jacobs**	**Data driven and soft computing analytics and visualisation** ***Machine learning*** **Session Chair - Michele Romano**
	Operational interventions in WDS to improve water quality: a comparison of multi-objective optimization formulations **Quntiliani, C.,** Marquez-Calvo, O., Alfonso, L., Di Cristo, C., Leopardi, A., de Marinis, G.	Urban Water Infrastructure Asset Management Plan: A Practical Approach Ferreira, B., **Carriço, N.J.G.**	Pattern Recognition in Residential End Uses of Water Using Artificial Neural Networks and Other Machine-Learning Techniques **Carranza, J.C.I.**, Morales, R.D., Sánchez, J.A.
	Pumping Cost Optimization in Looped Water Networks with Storage Capacity through the Searching of the Setpoint Curve León-Celi, C.F., **Iglesias-Rey, P.**, Martinez-Solano, F.J., Savic, D., Vamvakeridou-Lyroudia, L.S.	Continuous Robotic Inspection of Pipes for Data Rich Asset Management **Van Thienen, P.,** Maks, M., Yntema, D., Janssens, J.P., Bergmans, B., Diemel, R., Helgers, M., Horst, P., Trietsch, E.	Automatic Detection of Sewer Faults Using Continuous CCTV Footage **Myrans, J.,** Kapelan, Z., Everson, R.
	Costs Functions Proficiency over the Urban Drainage Networks Optimal Design Duque, N., Aguilar, A., **Saldarriaga, J.**	A Fast Method to Identify the Criticality of Individual Components in Water Supply Networks **Meijer, D.**, Clemens, F.	Applying Deep Learning with Extended Kalman Filter and Genetic Algorithm Optimization for Water Distribution Data Driven Modeling **Wu, Z.Y.**, Rahman, A., Li, Q.
	Comparison between Optimal and Real Design in Water Distribution Systems (WDS). Effect of Population Growth during the Project Lifespan. Posada, A., Bohórquez, J., Robles, J., **Saldarriaga, J.**	Fault Detection and Diagnosis for Pressure Control Valves in Water Supply Networks **Changklom, J.**, Stoianov, I.	
15:00 - 15:20	**REFRESHMENTS**		
15:20 - 16:40	**Systems modelling, optimisation and decision support 5** ***Modelling*** **Session Chair - Avi Ostfeld**	**Flood modelling and management** ***Flood modelling and management*** **Session Chair - Kieran Williams**	**Data driven and soft computing analytics and visualisation 2** ***Data driven analytics*** **Session Chair - Shuming Liu**
	Fractality in Water Distribution Systems **Diao, K.**, Butler, D., Ulanicki, B.	A 3D Web Gis Interactive Visualisation System For Animated Floods **Khoury, M.**, Gibson, Chen, A.S., Savic, D., Vamvakeridou-Lyroudia, L.S., Djordjevic, S.	Clustering-Based Burst Detection using Multiple Pressure Sensors in District Metering Areas **Wu, Y.**, Liu, S.
	Segments Identification in Water Distribution Systems by Using Network Topological Matrices **Mahmoud, H.**, Kapelan, Z., Savic, D.	Optimising a Fuzzy Logic Real-Time Control System for Sewer Flooding Reduction using a Genetic Algorithm **Shepherd, W.**, Mounce, S., Ostojin, S., Abdel-Aal, M., Schellart, A., Skipworth, P., Tait, S.	Online Burst Detection in Water Networks with an Ensemble of Flow Prediction Models **Adachi, S.,** Takahashi, S., Takemoto, T.
	Comparison of Different Controllers for Equitable Water Supply in Water Networks Anjana, G.R., **Mohan Kumar, M.S.,** Amrutur, B.	Optimal Location and Sizing of Stormwater Storage Units: Case Study in Bogota **Zeferino, J.A.**, Cunha, M., Simões, N.E., Saldarriaga, J.G.	Online Advanced Uncertain Reasoning Architecture with Binomial Event Discriminator system for novelty detection in smart water networks **Mounce, S.**, Fargus, A., Weeks, M., Young, J., Ejimbe, D., Goya, E., Holburn, M., Jackson, T., Boxall, J.B.
	An Improved Simulated Annealing Algorithm for Solving Complex Water Distribution Networks **Cunha, M.**, Marques, J.	Analysis and Simulation of Drainage Capacity of Urban Pipe Network **Gomes, R.**, Vellando, P., Sousa, J., Sá Marques, J., Muranho, J.	Data-driven Approach to Short-Term Forecasting of Turbidity in a Trunk Main Network **Meyers, G.,** Kapelan, Z., Keedwell, E.
19:00 Conference dinner in Firth Hall.			

THURSDAY 7TH SEPTEMBER

	LT3	LT4	LT5
08:30 - 09:00	**REFRESHMENTS (AND DAY REGISTRATION)**		
09:00 - 09:45	**Key note address LT1** *Building Blocks For A Resilient Water And Wastewater Service - Simon Parsons*		
09:45 - 10:00			
10:00 - 11:00	**Water and wastewater treatment modelling, optimisation and control** ***Treatment*** **Session Chair - Will Shepherd**	**Demand forecasting, leakage and energy management 7** ***Leakage*** **Session Chair - Joby Boxall**	**Security, reliability and resilience** ***Resilience*** **Session Chair - Dominic Boccelli**
	Integrated Treatment Plant and Distribution Network Models To Predict The Drinking Water Quality From Source To Tap **Heinsbroek, A.R.**, Wolthek, N.B.A., Wuestman, R.	Water Advisory Demand Evaluation and Resource Toolkit Paluszczyszyn, D., Illya, S., Goodyer, E., **Kubrycht, T.**	Water Distribution System Recovery Strategies Considering Economic Consequences from Business Loss **Lee, S.**, Shin, S., Judi, D., McPherson, T., Burian, S.
	Multimechanism Fouling Model for Micro and Ultrafiltration Membranes for Wastewater Treatment Janus, T., **Ulanicki, B.**	Tactical Leakage Targeting, A Modelling and Control System to Aid Efficient Leakage Strategies **Rogerson, S.**	A new Index System for Intermittent Water Supply **Loubser, C.**, Jacobs, H.E.
		A Multivariate Geospatial Data-Driven Approach to Descriptive Modelling of Burst Behaviour in a Small Island Context **Mackey, T.**, Mounce, S., Boxall, J.B., Cashman, A.	Augmented Resilience of Water Distribution Systems following Severe Abnormal Events Piller, O., **Sedehizade, F.**, Bernard, T., Braun, M., Cheifetz, N., Deuerlein, J., Wagner, M., Lapébie, E., Trick, I., Weber, J.-M., Werey, C.
11:00 - 11:20	**REFRESHMENTS**		
11:20 - 12:40	**Systems modelling, optimisation and decision support 6** ***Modelling*** **Session Chair - Zoran Kapelan**	**Demand forecasting, leakage and energy management 8** ***Energy*** **Session Chair - Didia Covas**	**Advances in sensors, instrumentation and communications technologies 2** ***Sensing*** **Session Chair - Ivan Stoianov**
	A Particle Filter Model for Online Demand Estimation of Non-Geographical Distributed Demand Pattern Networks Do, C.N., Simpson, **A., Deuerlein, J., Piller, O.**	An Energy Evaluation of Common Hydraulic Thresholds in Water Mains **Hashemi, S.**, Filion, Y.R., Speight, V.L.	One-Class SVM - Leak Detection In Water Distribution Systems **Cody, R.**, Narasimhan, S., Tolson, B.
	Multi-object approach for WSN Partitioning in the framework of Pressure Driven Analysis Creaco, E., **Di Nardo, A.**, Di Natale, M., Giudicianni, C., Santonastaso, G.E.	Assessment of Alternatives for Energy Efficiency Improvement using a Hydraulic Simulation Model **Santos-Tellez, R.U.**, Rodriguez-Varela, J.M., Silvestre, J.M., Tzatchkov, V.G.	Valve Status Verification and Sensor Error Detection via Causal Inference from Sensor Data Vries, D., **van Summeren, J.**
	Adaptation of Physarum Polycephalum Evolution for Least-Cost Design of Water Distribution Networks Skulovich, O., **Ostfeld, A.**	New test-rig for micro hydropower turbomachines **Delgado, J.**, Ferreira, J.P., Covas, D., Avellan, F.	Feasibility Study on Water Temperature and Pressure Sensing Based on Wireless Passive SAW Technology Tang, Z, **Wu, W.**, Gao, J.
	Case Study: Improvements to a Real-Time Network Modelling Framework Masud Rana, S.M., Oliveira, P.J., Qin, T., **Boccelli, D.L.**	Water and Energy Efficiency in Bulk Water Systems **Monteiro, L.**, Mamade, A., Figueiredo, D., Alves, R., Póvoa, P., Covas, D.	Design of an Observational Study for Investigating the Impact of Pressure Transients on Pipe Failures in Water Supply Networks **Rezaei, H.**, Stoianov, I.
12:40 - 12:50	**REFRESHMENTS**		
12:50 - 13:10	**Conference close LT1**		
13:10 - 14:00	**LUNCH**		

Abstracts

You will find the abstracts for the conference presentations in the next section. The abstracts are organised by theme, in each theme the papers are presented in the order they appear in the conference programme. Additionally you will find an author index at the end of this document to help find abstracts.

The full papers are available on the FigShare site ccwi2017.figshare.com.

Demand forecasting, leakage and energy management

Data Setup for Water Distribution System Supervision

Ramon Pérez[1], Sergi Grau[2], Víctor Jiménez[1], Xavier Martínez[3], Ricard Tomàs[2]

[1] SAC-UPC, Rambla Sant Nebridi 10, Terrassa 08222, Catalunya.

[2] Aigües de Manresa, Plaça de la Plana de l'Om, 08241 Manresa, Catalunya.

[3] Fundació CTM Centre Tecnològic Plaça de la Ciència, 2 08243 Manresa, Catalunya.

[1]ramon.perezr@upc.edu

The availability of on-line data coming from the water distribution systems (WDS) allows the monitoring of such critical infrastructures. Nevertheless the huge amount of data that come to the control centre implies an enormous processing challenge [4]. The use of data avoids any physical theory and relies on statistical correlations and inferences. Nevertheless the previous efforts in modelling the networks encourage the companies to fusion information coming from both sources. Models help validating data and data update these models. This paper presents the first stage of an ongoing project focused in the integration of data and models. Data are collected, harmonised and validated using the models so that they will be used in following stages of the project for the supervision of the WDS (water balance and quality). A tool is being developed in R where the different modules will be integrated.

Keywords: Data Management; Calibration; Sensor Validation.

A Theory for Realistic Modelling of Leakage and Intrusion Flows Through Leak Openings in Pipes

Van Zyl JE[1], Lambert A[2], Collins R[3]

[1] Department of Civil Engineering, University of Cape Town, South Africa

[2] Water Loss Research & Analysis Ltd, United Kingdom, LL30 1SL.

[3] Department of Civil and Structural Engineering, University of Sheffield, UK

[1]kobus.vanzyl@uct.ac.za

The hydraulics of leakage and intrusion flows through leak openings in pipes is complicated by variations in the leak areas due to changes in pressure. This study presents a theoretical framework for the analysis of both leakage and intrusion flows through real leaks in pipes. A linear area-pressure relationship is assumed. The leakage exponent of a given leak opening is shown to generally not be constant with variations in pressure, and to approach infinity when the leakage number approaches a value of minus one. Significant modelling errors may result if an exponent used in the power equation used beyond its calibration pressure range, or at high exponent values.

Keywords: Leakage Modelling; FAVAD; N1.

Leakage Modelling: High Leakage Exponents Due to Friction Effects

Heckmann, Klaus[1], Sievers, Jürgen[2]

[1,2] GRS gGmbH, Cologne, Germany

[1]klaus.heckmann@grs.de

The relationship between pressure and leakage in water distribution systems has been in the focus of several studies. A common description of the pressure-leakage response is a power equation, or a combination of two different powers like in the fixed and variable area discharge (FAVAD) concept. From a theoretical perspective the exponent can be understood as the result of variable leak opening under pressure and the water flow through the leak channel, which may have different behaviour for specific applications. Thus, these theoretical considerations may explain leakage exponents in the range of 0.5 to 1.5 for turbulent flow. This is known to be contradicted by values from field studies, which measure occasionally higher leakage powers. The understanding of this behaviour of leaks is still challenging.

In other fields, namely in process industry and nuclear technology, the behaviour of leaks in pipes is also modelled. A relevant ingredient for the leakage-pressure relationship of a crack-like leak in such an installation is the individual flow resistance of a leak. The modelling of such flow resistance, partly due to friction, is the outcome of decades of studies and evaluations of experiments. In the paper, these friction modelling aspects are applied to leaks in water distribution systems. It is shown that the consideration of frictional resistance of leaks can explain leakage exponents higher than 1.5.

Keywords: Leakage Exponent; Leakage; Friction.

Exploring How Pipe-Level Energy Metrics Relate to Hydraulic Parameters Using Multivariate Analaysis

Saeed Hashemi [1], Yves R. Filion[2], Vanessa L. Speight[3]

[1] Water Design Specialist, CH2M Hill

Toronto, Ontario (Canada)

[2] Department of Civil Engineering, Queen's University

Kingston, Ontario, (Canada)

[3] University of Sheffield, Sheffield, (UK)

[1] saeed.hashemi@ch2m.com, [2] yves.filion@civil.queensu.ca, [3] v.speight@sheffield.ac.uk

PCA in this study builds upon a correlation matrix of 11 hydraulic parameters including pipe hydraulic data and pipe-level energy metrics by using Eigen values and Eigen vectors to compress the high-dimensional space of the data into a two-dimensional space. This makes the visualization of the data possible, including all hydraulic parameters simultaneously. The graphical presentation of the hydraulic parameters (mono-plots) and the data set (bi-plots) help which parameters can lead into inefficiency in pipes in the whole dataset.

The results show that the metric energy lost to friction in a pipe along with average unit headloss, average flow rate and proximity to major components have a high influence in distinguishing poorly performing pipes from the others. Average pressure and the metric for energy needed by the user for each pipe tend to track closely, despite a lower statistical importance than previous parameters. Diameter and pipe roughness tend to stand alone with poor representations on the two principal component axes.

Keywords: Energy Efficiency; Principal Components Analysis; Water Distribution Systems.

Influence of Pressure, Temperature and Humidity on Water Consumption

Tomas Suchacek[1], Ladislav Tuhovcak[2], Jan Rucka[3]

[1,2,3] Brno University of Technology, Faculty of Civil Engineering, Institute of Municipal Water Management, Zizkova 17, 602 00 Brno, Czech republic

[1]*suchacek.t@fce.vutbr.cz*

The article deals with the optimization of pressure conditions in public water supply systems. By reducing the pressure in the water supply system, the reduce of the direct losses of water from the supply system will be reliably achieved, on the other hand there is also a slight decrease in water consumption in the connected properties. Consumption is possible to divide into two parts that are pressure and non-pressure dependent consumption. The quantification of the impact of a pressure reduction in the water supply system is not trivial. In order to achieve the optimal pressure conditions in the water supply system, it is necessary to consider what pressure should be achieved in the outcome so as to achieve an economic optimum while maintaining the basic limiting conditions, i.e. the adherence to the required pressure conditions in the water supply system at the connection point. These tasks are typically solved using simulation software tools, e.g. on the basis of EPANET. However, there is still a lack of much relevant information to enter into this analysis and subsequent decision making. Within the present study, a long-term experiment was carried out, where a very precise measurement of pressures and flows in the internal water supply of the administrative building was carried out. Different water pressures were set at the inlet point of the internal water supply of the building at fourteen-day time intervals, and the volumes of consumed water were measured at the same time. The obtained data were statistically evaluated. The dependency between the decrease respectively the increase of the pressure in the internal water supply and the water consumption was monitored. The article offers very interesting results.

Keywords: Water Consumption; Pressure; Dependency.

A Comparison of Short-Term Water Demand Forecasting Models

E. Pacchin, F. Gagliardi, S. Alvisi1, M. Franchini

Department of Engineering, University of Ferrara, Via Saragat 1, 44122 Ferrara, Italy

[1]*stefano.alvisi @unife.it*

In this paper a comparison among six short-term water demand forecasting models is presented. The models differ in terms of forecasting technique, type of prevision (deterministic or probabilistic) and data requirement for calibration. In particular, the compared models are: an Artificial Neural Network based model, a model based on periodic patterns, both requiring a calibration over a year of historically observed water demands, two models that take into account the periodic behaviours using observed data only on a restricted time window preceding the time of forecast, a probabilistic model based on Markov chain and a Naïve model. All the models are evaluated applying them to seven real-life case studies, consisting in two-year time series of hourly water demands observed in districts/networks with a number of users variable from 120000 to 300. The comparison shows that all the models provide similar and medium-high forecasting accuracy for each case study but the models based on the moving-window technique are more robust and their performances do not worse moving from the calibration to the validation period as for all the other models considered..

Keywords: Water Demand; Forecasting; Moving Window.

Optimal Control for Water Loss from Water Distribution Network: A Case Study of Beijing

Qiang Xu[1], Kuo Liu[2], Shunping Zhao[3], Nan Cao[4], Zhimin Qiang[5], Weiwei Ben[6]

[1, 5, 6] Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Shuang-qing Road 18, Beijing, 100085

[2, 3, 4] Beijing Waterworks Group, Xuanwumenxi Street 121, Beijing, 100031

[1]*qiangxu@rcees.ac.cn*

Water loss control is a key issue for most water supply companies all over the world because of freshwater scarcity and ever-rising water demand. Beijing is one of the cities facing severe water scarcity, so water loss control has been emphasized during the past decades. However, due to the huge size of the water distribution network, there is a great need to optimize the water loss control strategies. The water distribution network of Beijing has been planned to be partitioned into over 700 DMAs. Assessment of the DMAs' water loss conditions and prediction of the achievements of different water loss control measures are critical to manage these DMAs. The goal of this paper is to develop a mathematical model to reveal how low the water loss of a DMA could go, so as to optimize the water loss control strategies. 36 DMAs were selected as study areas and data of the lowest minimal nigh flow (LMNF) and DMA characters (including pipe material, pipe length, number of properties, pipe age, and water pressure) were collected. The relationship between LMNF and DMA characters was established using multi-variant regression method. The model fit the data with R^2=0.8. The model was then compared to the commonly used water loss indicator UARL and its sensitivity to the input variables was analyzed. Finally, the model was applied by Beijing Waterworks Group to optimize its water loss control strategies.

Keywords: Optimal Water Loss Control; Water Distribution Network; Lowest Minimal Night Flow (*LMNF*) model.

Model Calibration for Leak Localization, a Real Application

Gerard Sanz [1], Jordi Meseguer [2], Ramon Pérez [3]

[1,3] SAC-UPC, Rambla Sant Nebridi 10, Terrassa 08222, Catalunya.

[2] Cetaqua, Water Technology Center

[3] *ramon.perez@upc.edu*

The localization of leaks in Water Distribution Networks has a major relevance in terms of environmental and economic efficiency. This localization is generally carried on in situ by human operators using time consuming methods like acoustic loggers. Nevertheless, the automated aid provided to the operators is continuously increasing thanks to the exhaustive use of models. Models that have to be calibrated and updated in order to provide proper help and an improvement in the leak search. This paper presents an experience of leak localization using steady state models combined with a demand calibration algorithm. The calibration produces a notable improvement of the localization accuracy and signals changes in the network configuration. Results presented are based on real data and a real leak provoked for the test.

Keywords: Leak Localization; Calibration; Water Networks; Demands; Pressure Measurements.

Pressure: Leak Flow Rates Using FAVAD: An Improved Fast-Track Practitioner's Approach

Allan Lambert [1], Marco Fantozzi [2], Mark Shepherd [3]

[1] Water Loss Research and Analysis Ltd, Llanrhos, LL30 1SL United Kingdom

[2] Studio Marco Fantozzi, Via Forcella 29, 25064, Gussago (BS) Italy

[3] JOAT Consulting, 24 Alexander Park Road, Westmead, KZN 3610, South Africa

[1]*allanlambert@live.co.uk*

The FAVAD concept, for realistic modelling of leakage and intrusion flows through leak openings in pipes in water supply systems, allows for variations in the area of leaks resulting from changes in pressure. The hydraulic theory and equations recently published by van Zyl et al are clearly appropriate for detailed application and understanding of laboratory tests on pipe samples. However, if the concept is to be widely applied to improve the reliability of current methods for assessing hourly, daily and annual leakage in thousands of distribution zones, many having complex pressure management, fast-track approaches for practitioners based on the full FAVAD concept are needed. The paper describes several such fast-track approaches which should improve the reliability of current methods of assessing leakage from night flows in distribution Zones, and expand their application to low pressure and intermittent supply systems with customer storage tanks.

Keywords: FAVAD; Pressure; Leakage.

Investigating a Spatially Constrained Geostatistical Technique for Approximate Leak/Burst Event Location

Shaun Boatwright[1, 2,*], Michele Romano[2], Stephen Mounce[1], Kevin Woodward[2], Joby Boxall[1]

[1] Pennine Water Group, Department of Civil and Structural Engineering, University of Sheffield, Sheffield, S1 3JD, UK

[2] United Utilities, Lingley Mere Business Park, Warrington, WA5 3LP, UK

[*] *shaun.boatwright@uuplc.co.uk*

Responding quickly to leaks and bursts in water distribution systems can provide a number of benefits to water companies. Therefore, methods which allow a water company to determine the approximate location of leaks and bursts in a timely manner are desirable. This paper presents 10 examples of a spatially constrained inverse-distance weighted interpolation technique for determining the approximate location of a new leak or burst which has been tested using pressure data collected during a number of bursts simulated by opening fire hydrants in a real water distribution system. The results of the examples indicate that the SCIDW technique can reduce the proportion of the DMA which needs to be searched but that there are a number of factors, which have been identified as a result of these examples, which affect the leak/burst localisation performance which are not currently accounted for by the methodology.

Keywords: Leak/burst Localisation; Inverse-Distance Weighted Interpolation; Spatial Constraint.

Probabilistic Modelling of Transient Propagation in Water Distribution Systems

Richard Collins[1]

[1] Civil and Structural Engineering Department, University of Sheffield,

r.p.collins@sheffield.ac.uk

It is known that large hydraulic transients have the potential to cause significant damage to pipeline systems. In addition, the repeated application of these transient pressures has been hypothesised as a potential cause of fatigue failure in WDS. It has also been shown that transients can have impacts on water quality, either through contaminant ingress or by sloughing off biofilms. System operators and managers often ignore transient effects as they underestimate their severity and believe that the character of complex systems reduces their impact. However, literature suggests that the opposite may sometimes be true. The current state of WDS is largely unknown, due to their huge spatial extent and to the large part they are buried. This means that the task of accurately modelling their hydraulic behaviour is extremely difficult, even more so with the increased information requirements for an accurate dynamic model.

Uncertainty represents such variability in data and is ubiquitous because of our incomplete knowledge of either the underlying physics or inevitable measurement errors. Hence in order to fully understand any simulation results, and to subsequently get the best representation of the true reality of the system, it is imperative to incorporate uncertainty from the beginning of the simulations, and not as an afterthought. This paper explores the development of a robust modelling methodology to probabilistically predict the propagation of hydraulic transients in a water distribution system.

Keywords: Transients, Dynamic Modelling, Probabilistic Methods

Transients and Variability in Water Supply Networks

Ivan Stoianov[1], Asher Hoskins[2]

[1] Imperial College London, Department of Civil and Environmental Engineering, (InfraSense Labs), London SW7 2BU, UK

[2] Inflowmatix Ltd, 1 Venture Road, Southampton Science Park, SO16 7NP, UK

[1]*ivan.stoianov@imperial.ac.uk*

In this paper, we introduce and apply novel metrics to quantitatively characterise and account for the broad spectrum of pressure cycles, variations and transient events that continuously occur in operational systems. The Cumulative Pressure Induced Stress (CPIS^{TM}), which builds upon advances in fracture mechanics and fatigue induced failures, includes all pressure cycles irrespective of their amplitude and frequency within a moving 24-hour time window. Pressure is continuously sampled at 128S/s. Embedded signal processing algorithms combined with cycle counting methods allow for CPIS^{TM} to reduce a spectrum of varying pressure variations into a set of stress reversals. In this way, quantitative metrics for characterising the cumulative pressure induced stress and individual transient events are continuously available to network operators within a risk-based "pipe stress" warning system. The described metrics and methods and their implementation enable utilities to prioritise interventions and repairs (early asset stress warning) in order to maintain steady-state ("calm") hydraulic conditions, and assess the long-term impact of the dynamic hydraulic behaviour on assets failures (pipes, pumps, control valves, air valves, surge vessels etc).

Keywords: Pressure Transients; Characterisation.

Pipe Leak Diagnostic using Empirical Mode Decomposition (EMD) and Automatic Selection of the Intrinsic Mode Function (IMF)

Hanafi.M.Yusop [1(a)],M.F.Ghazali[1] [(b)],M.F.M.Yusof [1(c)] ,M.A.PiRemli[1(d)]

[1]Advanced Structural Integrity of Vibration Research (ASIVR),

Faculty of Mechanical Engineering ,University Malaysia Pahang'

26600 Pekan ,Pahang ,Malaysia.

m.hanafiyusop@yahoo.com.my [(a)], fairusham@ump.edu.my [(b)], fadhlan@ump.edu.my [(c)]*

aminuddin_pr@yahoo.com [(d)]

In a recent study, the analysis of pressure transient signals could be seen as an accurate and low-cost method for leak and feature detection in water distribution systems. Transient phenomena occur due to sudden changes in the fluid's propagation in pipelines system caused by rapid pressure and flow fluctuation due to events such as closing and opening valves rapidly or through pump failure. In this paper, it is to apply the Hilbert-Huang transform (HHT) as a method to analyse the pressure transient signal. The HHT is a way to decompose a signal into intrinsic mode functions (IMF). However, this method has the difficulty in selecting the suitable IMF for the next data post-processing method which is Hilbert Transform (HT). The current paper presents the implementation of an integrated kurtosis-based algorithm for a z-filter technique (I-kaz) to kurtosis ratio (I-kaz-Kurtosis), for this allows automatic selection of the IMF that should be used. This technique is demonstrated on a 57.90-meter medium high-density polyethylene (MDPE) pipe installed with a single artificial leak. The analysis results using the I-kaz-kurtosis ratio revealed that the method can be used as an automatic selection of the IMF although the noise level ratio of the signal is lower. Despite this, the I-kaz-kurtosis ratio method is recommended as a means to implement an automatic selection technique of the IMF for HHT analysis.

Keywords: Leak Detection; Pressure Transient; I-kaz; Hilbert Huang Transform (HHT).

Application of Least Squares Support Vector Machines and Acoustic Measurements of Leak Flow Rate Prediction

Joseph D. Butterfield[1], Vivianna Meruane[2], Richard P. Collins[3], Gregory Meyers[4], and Stephen B.M. Beck[1]

[1] Department of Mechanical Engineering, University of Sheffield, Sheffield, South Yorkshire, S10 3JD, UK

[2] Department of Mechanical Engineering, Universidad de Chile, Beaucheff 851, Santiago, Chile

[3] Department of Civil and Structural Engineering, University of Sheffield, Sheffield, South Yorkshire, S10 3JD, UK

[4] College of Engineering, Mathematics and Physical Sciences, University of Exeter, North Park Road, Exeter, EX4 4QF, UK

[1] *jbutterfield1@sheffield.ac.uk*

Leakage from water distribution pipes represent a huge issue worldwide with economic. Leaks are normally found by placing sensors either side of the leak recording the leaks acoustic emission as it discharges the leak hole. As the leak noise is intrinsic to the leak, it contains information which could provide information about the leak, including the leak flow rate. Any tool which can accurately determine the leak's flow rate could be used by water industry practitioners in order to prioritise leakage repair activities by repairing the higher leak flow rates first. This will result in economic savings through reduced water lost and better allocation of company resources. This paper demonstrates a small element of research undertaken at the University of Sheffield in collaboration with several UK water companies. The aim of the research is to develop a tool in order to predict leak flow rate using acoustic emission sensors. The research uses Least Squares-Support Vector Machines in order to predict leak flow rate in MDPE pipe using high quality data from a unique experimental pipe rig. The results demonstrate that there is sufficient information within the leak's acoustic emission signal in order to predict leak flow rate. Therefore the research represented in this paper presents a tool which can be used by water industry practioners to prioritise leak repair.

Keywords: Leakage; Pipeline; Acoustic Emission.

A Model Pre-Processing Approach for Improving Calibration-Based Leakage Detection Using a Genetic Algorithm

S. Sophocleous[1], D. Savic[2], Z. Kapelan[3], Y. Shen[4], P. Sage[5]

[1,2,3]Centre for Water Systems, University of Exeter, North Park Road, Exeter, EX4 4QJ, UK

[4]Severn Trent Water Ltd, Stratford Road, Longbridge, Warwick, CV34 6QW, UK

[5]WITSConsult Ltd, Milton Rough, Acton Bridge, Northwich, CW8 2RF, UK

[1]ss694@exeter.ac.uk

The paper presents a systematic approach for narrowing down the search for leaks and unknown closed valves in the water distribution network. The developed approach is applied on a real system and a calibration problem is solved for the ultimate purpose of detecting existing background leakage hotspots. A Genetic Algorithm is used to solve the optimization problem searching for calibration parameter values, while minimizing the differences between observations and model outputs. The optimisation problem is coded in two ways, a scenario-based framework where the maximum number of leaks and closed valves in the network is specified and non scenario-based framework. The leak detection methodology takes advantage of the new pre-processing method to reduce the search space size for the optimisation problems to only significant parameters that contribute to the fitness and hydraulic changes of the model. Artificial calibration data are generated by means of hydraulic modelling employed to mimic planned hydrant discharges during a low demand period. The staged approach demonstrates that the search for location and range of flows for unknown leaks can be reduced to only a small part of the network components. This appears to provide additional benefits towards calibrations problem complexity reduction and reduced time in finding leaks.

Keywords: Hydraulic Models; Leakage Detection; Calibration; Optimisation.

A Perspective on Reducing Uncertainties in Water Distribution Network Operation Using Clusters

Lifshitz Ron [1], Ostfeld Avi[2]

[1,2] Faculty of Civil and Environmental Engineering, Technion – Israel Institute of Technology, Haifa 32000, Israel.

[1]1lifshitz.ron@tx.technion.ac.il

[2]ostfeld@tx.technion.ac.il

In water distribution system operation problems, a solution is often, if not always, valid for a small variety of forecasted scenarios. The number of unknown variables, such as consumer consumptions, pipe smoothness, leaks or infections makes the forecasting of the conditions in which the network operates almost impossible. On the other end, most of the solution procedures take use of deterministic models such as water and energy balance or demand patterns – and even stochastic models cannot predict the conditions for which the problem in hand is defined. This procedure of using exact solution models for inexact problems is reconsidered while a methodology of using clusters in water distribution systems is demonstrated on selected regions, utilizing simple examples as an effective tool for bridging the gap.

Keywords: Water Distribution Systems; Uncertainty; Cluster.

A Python Tool for Generating Synthetic Demand Scenarios

Simone Santopietro[1], Francesco Granata[2], Carla Tricarico[3],
Giovanni de Marinis[4], Rudy Gargano[5]
[1,2,3,4,5] Università di Cassino e del Lazio Meridionale
Via G. Di Biasio 43, 03043 Cassino - Italy
[1]s.santopietro@unicas.it

Demand modelling has a great impact on the outcome of hydraulic simulations of water distribution systems. Its stochastic nature has to be considered in order to obtain more reliable results. A stochastic approach, based on a mixed probability distribution, able to model residential water demand has been implemented in Python. This distribution considers both the event of null and not null water demand and allows to estimate the statistical parameters, solely on the number of supplied users and on the related average demand pattern. This approach is well suited to be used in hydraulic simulation workflows (e.g. using the EPANET toolkit) and a Python implementation could encourage a more refined demand characterization also in non-scientific environments.

Keywords: Demand Modelling; Stochastic Approach; Python.

Identifying Relationships Between Weather Variables and Domestic Water Consumption Using Smart Metering

Maria Xenochristou[1], Zoran Kapelan[2], Chris Hutton[3], Jan Hofman[4]

[1,2] Centre for Water Systems, University of Exeter, North Park Rd., Harrison Building, Exeter EX4 4GF, U.K.

[3] Wessex Water, Claverton Down Road, BA2 7WW Bath, U.K.

[4] Water Innovation and Research Centre, University of Bath, BA2 7AY Bath Avon, U.K.

[1] *mx220@exeter.ac.uk*

Satisfying the water supply-demand balance is a major problem of modern societies due to water scarcity, which is expected to be amplified by changes in the climate. In order to fulfil future demands, accurate predictions of water consumption are essential. This paper investigates the relationship between water consumption and air temperature, using a combination of smart demand metering data, household characteristics, and socio-economic data. Results indicate that the correlation between water consumption and temperature increases during working days, evenings, as well as during the summer and spring. In addition, a positive correlation was identified for households that are metered, have bigger gardens, and medium occupancy, as well as residents with higher socio-economic status and high seasonal variations in water consumption.

Keywords: Water Demand; Smart Meters; Weather.

Analysis of Shower Water Use and Temperature at a South African University Campus

BE Botha[1], HE Jacobs[2], B Biggs[3] and AA Ilemobade[4]

[1,2] Department of Civil Engineering, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa

[3] JG Afrika, 14 Central Square, Pinelands, 7430, Cape Town, South Africa

[4]School of Civil and Environmental Engineering, University of the Witwatersrand, Private Bag 3, WITS, 2050, South Africa

[2]hejacobs@sun.ac.za

Earlier research has underlined that household end-uses form building blocks of the residential water demand pattern. Numerous end-use studies have been presented in the past, but none have reported on shower end-uses at Universities in South Africa. This research focuses on shower water use, as part of the first detailed end use field study conducted in South Africa. An extensive desktop study was conducted regarding South African end-uses, focusing on shower use. Shower flow rate was physically measured under different conditions, while actual shower duration for the same showers was derived from water temperatures recorded over two periods of 5 days each, at 1 min frequency. The changes in temperature were used to estimate actual shower duration and event start times. The total shower event volume was stochastically determined by using Monte Carlo analysis. The average shower duration of the 759 shower events identified as part of this study was 9 min and 33 sec, with a flow rate of 8.7 L/min. The average shower event volume was 83 L/event.

Keywords: Water Use; Shower; Temperature.

Leak Detection in a DMA, a Real Application of Flow Modelling

Víctor Jiménez[1], Sergi Grau[2], Ramon Perez[1]

[1] SAC-UPC, Rambla Sant Nebridi 10, Terrassa 08222, Catalunya.

[3] Aigües de Manresa, Plaça de la Plana de l'Om, 08241 Manresa, Catalunya

[1] *ramon.perez@upc.edu*

This paper presents a versatile methodology to calculate parameters that characterise the demand of a DMA. This parameters are used for the leak modelling so that a predictive model is built and trained with historical data and used to detect on-line new leaks so that the repair time can be reduced applying proper leak localisation techniques. This methodology has been programmed using R where the modelling packages available provide assortment of predictive models easily to implement. It has been integrated in a Data analysis tool in order to utilise the great amount of information coming continuously from the WDN. Once the methodology and the tool are described the results applied to a real DMA are presented. This work has been carried out by the fundació CTM Centre Tecnològic (CTM) collaborating with Research Center for Supervision, Safety and Automatic Control (CS2AC) within a research project of Aigües de Manresa.

Keywords: Data Management; Leak Localisation; Demand Modelling.

Categories in the City of Johannesburg

H Jacobs[1], AA Ilemobade[2], BE Botha[1]

[1] Department of Civil Eng., Stellenbosch University. Private Bag X1, Matieland, 7602, South Africa

[2] School of Civil and Environmental Eng., University of the Witwatersrand, Johannesburg. Private Bag 3, WITS, 2050, South Africa

[2]*adesola.ilemobade@wits.ac.za*

Increasing drought in many South African communities is driving the need to accurately estimate the end-uses of water within different categories of water users and as a consequence, to realistically determine by how much water use can be reduced. In some water catchments, the accurate estimation of different end-uses is urgently needed given the recent limitations put in place to curtail water. This study, which is part of a larger study commissioned by Johannesburg Water, provides theoretical estimates, using REUM, for end-uses of water for several middle-income homes in a study area served by Johannesburg Water. For indoor end-use, 1, 2, 3 and 4 people per household were modelled and for outdoor end-use, specifically garden irrigation, two cases were modelled i.e. plot sizes of 500m² (15% irrigated area) and 1500m² (35% irrigated area).

For indoor end-use, parameters that are noted to be quite variable include: shower event volume (shower flow rate and duration); shower- and bath frequency; washing machine event frequency and toilet flush frequency. The results validate earlier reports i.e. that the largest 4 end-uses (i.e. toilet, bath-shower and washing machine) contribute 81.5% to total indoor water use, with the shower being the most notable indoor end-use. Outdoor water use for the 1500m² plot (35% irrigated area) is notably higher in summer (i.e. December to February), when rainfall is prevalent, than indoor use. This large water requirement is explained by the difference between the evaporation rate and rainfall in the summer months. On the other hand, for the 500m² plot (15% irrigated area), the garden irrigation requirement is notably less than indoor end-use, irrespective of household size. At this stage of the project, it is apparent that Water Demand Management measures should target the identified notable indoor end-uses (i.e. toilet, shower, bath and washing machine) for relatively smaller properties. For larger properties however, the focus should be on reducing garden irrigation.

Keywords: Indoor, outdoor, end-use

Water Advisory Demand Evaluation and Resource Toolkit

Daniel Paluszczyszyn[1], Sunday Illya[2], Eric Goodyer[3], and Tomasz Kubrycht[4]

[1,2,3,4] De Montfort University, The Gateway, Leicester, LE1 9BH, U.K.

[1] *paluszcol@dmu.ac.uk*

The purpose of this feasibility study is to determine if the application of computational intelligence can be used to analyse the apparently unrelated data sources (social media, grid usage, traffic/transportation and weather) to produce credible predictions for water demand. For this purpose the artificial neural networks were employed to demonstrate on datasets localised to Leicester city in United Kingdom that viable predictions can be obtained with use of data derived from the expanding Internet-of-Things ecosystem. The outcomes from the initial study are promising as the water demand can be predicted with accuracy of 0.346 m3 in terms of root mean square error.

Keywords: Demand; Prediction, Computational Intelligence.

Tactical Leakage Targeting a Modelling and Control System to Aid Efficient Leakage Strategies

Sarah Rogerson[1]

[1]Artesia Consulting Ltd, Unit 2, Badminton Court, Yate, Bristol, BS37 5HZ

[1]*sarah@artesia-consulting.co.uk*

Water companies are under increasing pressure to drive down their level of leakage. Furthermore companies are seeking to be more efficient in the way they manage and reduce leakage levels. We present a preliminary investigations into a new approach to leakage targeting at a district metered area (DMA) level. The approach enables modelling of leakage at component level: growth rates of leaks, leak sizes and leak run times. These components allow a bottom-up approach of defining the natural rate of rise (NRR) and allocation of resource within a network to provide an efficient approach for leakage targeting.

Keywords: Leakage Targeting; Leak Break Out; Leak Growth.

A Multivariate Geospatial Data-driven Approach to Descriptive Modelling of Burst Behaviour in a Small Island Context

T. Mackey[1], S. Mounce[2], J. Boxall[2], A. Cashman[1]

[1] Centre for Resource Management and Environmental Studies, University of the West Indies, Cave Hill Campus, Barbados

[2] Pennine Water Group, Department of Civil and Structural Engineering, University of Sheffield, Sheffield, United Kingdom

[1]tara.mackey@mycavehill.uwi.edu

The efficient management of water resources in the Caribbean is challenging for several reasons: weak institutional and regulatory frameworks, limited financial and technical resources, ageing pipe assets, average unaccounted-for water along with leakage rates that are approximately 50%, and limited data resources. This paper presented a methodology that used geographic information systems (GIS) to geo-spatially model 8 factors that contribute to pipe bursts (i.e. material, diameter, length, installation era, pressure, connection density, soil type, and rainfall) and incorporated these factors as input variables for data-mining using Self Organising Maps (SOM). SOMs is a data-driven technique used to explore complex multi-dimensional data even though data may be sparse or limited. The combination of GIS and SOMs allowed for the efficient use of available data and promoted knowledge discovery. Key findings revealed that pipe bursts in Barbados are mainly driven by pressure, clay soils, high rainfall, pipe age, and small pipe diameters. Although there were data limitations, results showed that this methodology can allow utilities, especially in small island states, to narrow their focus on susceptible areas of the pipeline, reduce futile efforts, maximise resources, and implement a technical tool that may be used before making any major investment decision.

Keywords: Pipe Bursts; Data-driven Modelling; Leakage.

An Evaluation of Common Hydraulic Factors Thresholds in Water Mains

Saeed Hashemi [1], Yves R. Filion[2], Vanessa L. Speight[3]

[1] Water Design Specialist, CH2M Hill

Toronto, Ontario (Canada)

[2] Department of Civil Engineering, Queen's University

Kingston, Ontario, (Canada)

[3] University of Sheffield, Sheffield, (UK)

[1] saeed.hashemi@ch2m.com, [2] yves.filion@civil.queensu.ca, [3] v.speight@sheffield.ac.uk

This study uses a regression-based modelling approach using an ensemble of 20,000 water mains compiled for 17 North American networks to understand the relationships between pipe factors (pipe flow rate, unit headloss, proximity to major components, average pressure, and diameter) and energy efficiency/energy loss performance metrics. The regression analysis aims to predict efficiency values in pipes based upon common-practice values of average pressure and unit headloss to better understand the energy performance associated with those thresholds.

The results of regression analysis show that commonly considered pressure ranges (30-50 m) correspond to good values of the energy needed by user (ENU) metric, with pressure deficient pipes by definition having lower, non-ideal ENU values. For unit headoss, common thresholds that would trigger pipe replacement (3 m/km in transmission mains, 10 m/km in distribution mains) correspond to net energy efficiency (NEE) of 74.9 and 74.6 percent, respectively, for the ensemble of water mains analyzed. These pipes represent the poorest performers and while there are not many such pipes within the ensemble, as NEE of 74.6 corresponds to the 7th percentile, there is a need for tools and analyses like these to help water utilities identify the pipes with the greatest energy impact from across their water distribution systems.

Keywords: Correlation and Regression Analyses; Pipe-level Energy Metrics; Unit Headloss.

Assessment of Alternatives for Energy Efficiency Improvement Using a Hydraulic Simulation Model

Rodrigo Ulises Santos-Tellez[1], José Manuel Rodríguez-Varela[2], Juan Maldonado Silvestre[3], Velitchko G. Tzatchkov[4]

[1,2,3,4] Urban Hydraulics Department, Mexican Institute of Water Technology, Jiutepec, Mor. CP 62550, México

[1] rodrigo_santos@tlaloc.imta.mx, [2]manuel_rodriguez@tlaloc.imta.mx, [3]jmaldon@tlaloc.imta.mx, [4]velitchk@tlaloc.imta.mx

Many water utilities that provide water, drainage and sanitation services in Mexico encounter several problems performing these duties. They face insufficient funds, frequent changes of administrative and qualified technical personnel, as well as distribution-network aging. This situation, along with high water losses in transmission pipelines and distribution networks, illegal service connections, and intermittent water supply have led to a large portion of the water utilities having to deal with a low willingness from the users to pay for the service provided. Pumping and water treatment make up most of the high electricity costs generated from the provision of water supply services.

This paper presents the results of an energy efficiency study, using a hydraulic simulation model as a starting point in which various energy-consumption optimization scenarios were considered. Priority was placed on existing infrastructure use, the assessment of alternatives for pumping equipment operation, the addition of complimentary equipment with its corresponding capital and running costs as well as its repercussions on the service provided to end-users and finally their impact on the total running costs for the water utility.

In general form, the analyzed sources of supply produce an average of 437 L/s, with an energy consumption of 920 kW/h. Based on the hydraulic simulation, it is possible to take 5 pumping sites out of operation from the Pump Stations G.O. 1 and 2 which implies a reduction of 121.7 kW/h and as such, considering the rate at the moment of this study which is $1.025 kW/h, yields an annual savings of $55,000.00 USD, representing a 24% decrease in the total energy consumed by the distribution network.

Keywords: Energy Saving; Water Utilities, Water Pumping and Treatment.

New Test-rig for Micro Hydropower Turbomachines

João Delgado[1,2,3], João P. Ferreira[2] Dídia I.C. Covas[2], François Avellan[3]

[2] CERIS, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal

[3] Laboratory for Hydraulic Machines, École Polytechnique Fédérale de Lausanne, Avenue de Cour 33 Bis CH-1007 Lausanne, Switzerland

[1]*joao.borga.delgado@tecnico.ulisboa.pt, joao.delgado@epfl.ch*

Energy recovery in water supply systems has been pointed as an interesting opportunity. The available powers for recovery are usually small and, therefore, there is the need to develop cost-effective solutions. Pumps running as turbines are pointed as a prospective solution for this purpose. However, there are still some challenges to address, namely the prediction of turbine mode performance. For this purpose, a new test-rig was assembled to test different pumps in turbine mode. This paper shows the details of the developed experimental facility, data acquisition and control system. Preliminary experimental results are presented for the efficiency hillchart, as well as the influence of backpressure in the pressure fluctuations downstream the pump. The development of this test-rig aims at collecting reliable data for developing formulations to accurately predict the pump as turbine performance.

Keywords: Pumps Running as Turbines; Experimental Facility; Efficiency Measurement.

Water and Energy Efficiency in Bulk Water Systems

Laura Monteiro[1], Aisha Mamade[2], David Figueiredo[3], Rita Alves[4], Pedro Póvoa[5], Dídia Covas[6]

[1,2,6] CERIS, Instituto Superior Técnico, Lisbon, Portugal

[3,4] Research, Development and Innovation Unit, Águas do Tejo Atlântico, Lisbon, Portugal

[5] Asset Management Unit, Águas do Tejo Atlântico, Lisbon, Portugal

[1] *laura.monteiro@tecnico.ulisboa.pt*

Water losses and energy efficiency in supply systems is an actual concern for utilities. While the methodologies for water losses and energy efficiency assessment have been developed, their application in bulk water supply systems is limited. This paper provides data on water losses levels and energy efficiency performance of three Portuguese bulk water supply systems that can be benchmarked with similar systems worldwide. In addition, it points out major uncertainties in water balances calculation in such systems and identifies constraints in applying the methodology. The usefulness of computing the energy balance for efficiency assessment in bulk supply systems is demonstrated.

Keywords: Water Balance; Energy Balance; Bulk Water Systems.

Water quality modellling, including sediment and pollutant transport

Reduction of Infection Risk by Automated Rapid Detection of Faecal Contamination of Drinking Water Distribution Systems

E.J.M. Blokker[1], P.W.M.H. Smeets[2]

[1,2] KWR Watercycle Research Institute, Groningenhaven 7, Nieuwegein, the Netherlands

[1]*mirjam.blokker@kwrwater.nl*

Water companies may perform a quantitative microbial risk assessment to verify that the produced water is safe to drink. However, in the drinking water distribution system (DWDS) a faecal contamination may occur when the integrity of the system is broken. Therefore a similar verification of water safety during distribution is desirable, however challenging due to the complexity and extent of the network. Currently verification consists of regulatory 100 ml samples for E.coli and enterococci analyses at the consumer tap. The drawbacks are that not all contaminations are detected and analysis results take 24 to 48 hours, before action can be taken.

Automated analysers that take a sample and analyse it on location within a few hours are now available and can act as online sensors for faecal contamination. This allows a much faster response when a contamination is detected. In this study a hydraulic model was run with many contamination scenario's and sensor networks to quantify the resulting exposure of consumes to pathogens. The resulting infection risk was then determined with a previously developed QMRA model for distribution systems. It was shown that a boil water notice within hours instead of days can significantly reduce the infection risk. Next to reducing infection risk, these automated analysers can help to better assess infection risk levels and enable more flexibility in network maintenance.

Keywords: Faecal Contamination; Infection Risk; Sensoring.

Infection Delay Time Analysis for Enhancing Water Networks Vulnerabilities to Contamination Intrusions

Lifshitz Ron[1], Ostfeld Avi[2]

[1,2] Faculty of Civil and Environmental Engineering, Technion – Israel Institute of Technology, Haifa 32000, Israel.

[1]*lifshitz.ron@tx.technion.ac.il*

[2]*ostfeld@tx.technion.ac.il*

In water distribution systems, the prediction of infection spread along the system's components is critical both for minimizing impact on the system population and for real-time response. Delaying the overall spread of an infection from a single or from multiple infection sources can be a very useful tool for handling such contamination scenarios. In this study, a new parameter for Infection Delay Time (IDT) is presented and the methodology utilizing it is presented on simple and complex networks, along with highlighting the IDT advantages and applications for system’s design and operation.

Keywords: Analysis; Contamination; Infection Delay Time.

Two-Point Constraint Control of Water Quality in Distribution Networks

Abhilasha Mhaeshwari[1], Ahmed A. Abokifa[2], Ravindra D. Gudi[3] , Pratim Biswas[4]

[1,3] Chemical Engineering Department, Indian Institute of Technology Bombay, Powai, Mumbai - 400076, India

[2,4] Department of Energy, Environmental and Chemical Engineering, Washington University in St.Louis, St. Louis, USA

[3]*ravigudi@che.iitb.ac.in*

Providing potable drinking water, with sufficient free residual chlorine to prevent microbial regrowth and contaminant by-product formation, is of utmost importance for municipal authorities. This work aims towards water quality control as it transports through water distribution networks. Presence of excessive chlorine (used as disinfectant worldwide) in water causes the generation of carcinogenic disinfectant by-products such as Tri-halo methane (THMs). On the other hand, lower chlorine levels in water results in microbial contamination. Hence, this leads to a two-point constraint control problem of maintaining free residual chlorine levels under the upper and lower bounds by suitably optimizing the disinfectant dosage at booster stations. However, transport delay and complex interrelations present amongst the nodes in large water distribution network, makes it difficult to design a global feedback control system. Therefore, in this work we have proposed to decentralize the system by clustering demand nodes of the network based on concentration sensitivity matrix analysis. Further, input-output pairs for decentralized controllers were mapped with the knowledge of interactions between manipulating and control variables using partial correlation analysis. We also considered the results of partial correlation analysis to generate communication links which will be implemented for higher level co-ordinated decentralized control to account for dynamic, non-negligible interactions as disturbances to local control units. The proposed three step clustering-mapping strategy and mathematical formulation for two point control by optimized dosage is successfully verified for the steady state case on a prototype distribution example network.

Keywords: Water Disinfection; Optimal Chlorine Dosage; Decentralized Control.

Online Water-Quality Monitoring based on Pattern Analysis

Rebecca M. Page[1,1], Daniel Waldmann[1], Achim Gahr[2]

[1,2] Endress+Hauser (Schweiz) AG, Kägenstrasse 2, 4153 Reinach, Switzerland

[3] Endress+Hauser Conducta GmbH+Co. KG, Dieselstrasse 24, 70839 Gerlingen, Germany

[1]rebecca.page@ch.endress.com

To date, drinking water quality monitoring frequently relies on a threshold-based approach coupled with occasional manual sampling for reference analysis and as evidence for legal requirements concerning the water quality. However, the increased availability of online measurements provides a good basis for an adaptive approach to high-resolution monitoring of water quality. In this case study, patterns in water quality of limestone springs were identified using multivariate analysis and artificial neural networks. Self-organizing maps were used to calculate system states based on six online parameters (spring discharge, turbidity, pH, el. conductivity and spectral absorption at 254 nm). A non-linear Sammon projection highlighted the relationship between the different system states, rendering a basis for the quantification of change occurring during the observation period in December 2015 - January 2016. The multivariate approach highlighted different phases during an event based on the relative location in a scatter plot and on the xy distance between two system states based on consecutive measurements. As this approach does not require the definition of thresholds and considers actual changes in system state, it is applicable to complex systems and adaptive management strategies.

Keywords: Drinking Water Quality; Online Early Warning System; Multivariate Pattern Analysis.

Water Network Characterisation With Regards to Discolouration Risk Using High Frequency Turbidity Monitoring

Dagmara Starczewska[1], John Gaffney[2], Stephen Boult[3]

[1,2,3] School of Earth and Environmental Sciences, The University of Manchester, Manchester, M13 9PL, UK

[1]*dagmara.starczewska@manchester.ac.uk*

Water companies are currently facing the challenge to continue the supply of high quality drinking water while at the same time trying to meet ever increasing regulatory standards. Despite a high standard of water quality monitoring at both water treatment plants and major supply mains, many water companies continue to use customers as water quality monitors in their distribution networks. This paper presents the assessment of particulate transport in water distribution systems over short and long-duration monitoring (years) by the application of the latest technology for continuous and remote monitoring of turbidity. Turbidity was monitored at 15 minute resolution at 2 sites in a District Meter Area (DMA) with historical evidence of discolouration problems. Monitoring at this resolution demonstrates its necessity to determine whether and when there is a discolouration problem and how it responds to remediation. Also, demonstrated is the utility of calculating high resolution mass flux from turbidity as an aid to predicting discolouration. Multi-year monitoring at a single site in the DMA has given a unique insight into discolouration processes and the impact of remediation.

Keywords: Turbidity; Discolouration; Field Measurements.

Optimal Positioning of Sensors in Water Distribution Networks: Comparison of Numerical and Experimental Results

Stefania Piazza[1], Mariacrocetta Sambito[1], Roberto Feo[1], Gabriele Freni[1], Valeria Puleo[2]

[1] School of Engineering and Architecture, University of Enna "Kore", Cittadella Universitaria, 94100 Enna, Italy.

[2] Department of Civil, Environmental, Aeronautic and Chemical Engineering, University of Palermo, Viale delle Scienze, Ed. 8, 90100 Palermo, Italy.

[1]mariacrocetta.sambito@unikore.it; Tel.: +39-0935-536439

The present work aims to investigate water quality deterioration in water distribution systems. In water distribution networks, the resource could lose its potability and chemical characteristics due to deliberate or accidental contamination, potentially connected with combination of pipe breaches and low pressure. To promptly detect the event of contamination is essential implement a chemical monitoring network inside the water supply and to achieve the optimum positioning of the probes, to reduce the cost of the instrumentation and maintenance obtaining, at the same time, a reliable monitoring of the system. To this aim, optimization techniques are widely applied returning the optimal positioning of sensors following the maximisation (or minimisation) of multiple objective functions. The approach is obviously affected by the approximations that are typical of numerical and modelling approaches. An experimental confirmation of the optimised setup is usually impractical (for the extension of the analysed networks) or impossible (due to the fact that analysed networks are often in use).

In the present study, a numerical optimisation approach was compared with the results of an experimental campaign. The optimization problem is formulated in accordance with literature state-of-the-art ([1], [2] among others), using genetic algorithm NSGA-II coupled with a hydraulic simulator. The results were tested and verified using a looped laboratory distribution network, equipped with a real-time monitoring water quality system, which allows to control how chemical parameters change in continues.

Keywords: Water Quality; Optimal Positioning of Sensors; Water Distribution Networks.

Can a Valve Closure Transient Cause Mobilisation of Adhered Particles?

Sally Weston[1], Rich Collins[2], and Joby Boxall[2]

[1 2] Department of Civil and Structural Engineering, Sir Frederick Mappin Building, University of Sheffield, S1 3JD, UK.

[1] *sljones1@sheffield.ac.uk*

Dynamic forces induced by hydraulic transients are traditionally associated with structural consequences, however attention should also be given to water quality implications. Conceptually the dynamic forces due to hydraulic transients could mobilise adhered particles and release hazardous material into the bulk water, potentially causing public health and economic problems. This paper presents a set of controlled and systematic experiments that conclusively prove, for the first time, the ability of valve closure transients to mobilise an adhered particle where steady state conditions cannot. This is a significant finding as there is a net decrease in flow, hence pseudo steady state shear stresses, yet the dynamic forces are greater than the initial conditions. Future work will aim to deepen this new understanding of the impact of transients on water quality in Drinking Water Distribution Systems.

Keywords: Transients; Water Quality; Mobilisation.

Inline Mobile Water Quality Sensors Deployed for Contamination Intrusion Localization

Nathan Sankary[1], Avi Ostfeld[2]

[1,2] Technion – Israel Institute of Technology, Faculty of Civil and Environmental Engineering, Haifa, Israel, 32000

[1]*nesankar@mtu.edu*

The intrusion of an unknown substance in to a water distribution system can dramatically disrupt the ability to deliver sufficient quantities of clean water. Although prompt detection can be considered the most important matter to protect the public from ingestion of unknown substances, it is equally critical that a managing authority locate the intrusion, and return the network to standard operation. This study investigates the use of previously studied inline mobile water quality sensors in an "on-demand" fashion to localize potential contamination intrusion locations. This study employs mobile sensors to traverse through water distribution system pipes along paths that provide the most new information about potential source location contamination statuses. Using network connectivity, upstream regions of nodes traversed by the mobile sensors are deemed either a feasible or infeasible intrusion region based on the contamination status determined by the mobile sensor. Successively, mobile sensors are input until the region of potential intrusion is smaller than a defined threshold number of network nodes. Results of the mobile sensors employed for contamination intrusion localization are compared to the fixed sensor information. This study represents a preliminary investigation of a simple heuristic method to best deploy mobile water quality sensors for contamination event localization.

Keywords: Water Distribution Systems; Mobile Sensors; Contamination Response.

Using Hydraulic Models and Real Time Monitoring to Provide Resilience for Birmingham

Colin Rimmer

Atkins / Severn Trent Water Chadwick House, Birchwood Park,

Warrington, WA3 6AE.

colin.rimmer@atkinsglobal.com

The Birmingham Resilience Project aims to deliver a new water supply for customers in Birmingham. The new water source will allow the Elan Valley Aqueduct to be shut down for extended periods so that maintenance on the 100-year-old asset can be completed. The new source will also provide backup during an emergency event. In addition to the new water supply the existing Severn Trent Strategic Grid is required to transfer at least 55 Ml/d into the Birmingham distribution network.

This paper describes the modelling techniques used to successfully increase the flow on key sections of Severn Trent's Strategic Grid System. The monitoring installed at key locations ensured that there was no disruption of supply for customers and any potential discolouration events were avoided.

Keywords: Systems Modelling; Real Time Monitoring; Decision Support; Discolouration Risk.

Discolouration Risk Management and Chlorine Wall Decay

Iftekhar Sunny[1], Stewart Husband[1], Graeme Moore[2], Nick Drake[2], Kevan Mckenzie[2], Joby Boxall[1]

[1]Pennine Water Group, Department of Civil and Structural Engineering, University of Sheffield, S1 3JD, Sheffield (UK)

Scottish Water, Juniper House, Heriot Watt Research Park, EH14 4AP, Edinburgh (UK)

[1]izsunny1@sheffield.ac.uk

This paper explores the concept that periodic imposed excess shear stress events to manage discolouration risk in trunk mains can also impact on the chlorine wall decay by changing the properties of the accumulated pipe wall material. By implementing a series of varying magnitude shear stress events in multiple trunk main demonstrated that significant material was mobilised, thereby cleaning the mains and reducing discolouration risk. Measured chlorine data also suggests that repeated shear stress intervention also reduced the chlorine wall decay relative to a control network and the larger the intervention greater the benefit. Calibrated first order chlorine decay simulations in EPANET supported this finding. The modelling results further show that the wall decay has a dominant influence on this change even for these large diameter pipes. The significance of these findings is to evidence the additional value of regular hydraulics based cleaning interventions for large diameter mains delivering service improvement in terms of both discolouration risk and persistence of chlorine residual.

Keywords: Discolouration Risk, Shear Stress, Chlorine Decay.

Application of Water Distribution Models in Mains Cleaning – A Case Study

M.A.M. Mansoor[1], E.Bleakley[2], J. Yan[3], and K. Vairavamoorthy[4]

[1,2,3] Jacobs 2 Colmore Square, Birmingham B4 6BN

[4] IWMI, 127Sunil Mawatha, Battaramulla, Colombo, Sri Lanka

[1] *mohamed.mansoor@Jacobs.com*

As part of addressing a potential water quality problem in the water distribution network and to meet Drinking Water Inspectorate (DWI targets, Jacobs was commissioned to design mains cleaning solutions for large supply area of a major water utility in the UK.

The main purpose of the project was to remove the biofilms and sediments in the pipe while making sure the network does not experience discolorations. In this project only the preferred material (Plastic, Asbestos Cement, and Ductile Iron) mains were cleaned using two different approaches, namely robust flushing and air scouring. This paper is only concerned with the robust flushing aspect, where mains are cleaned by generating sufficient shear stress.

The Prediction of Discolouration in Distribution Systems (PODDS) methodology is used in the flushing design [1]. The main challenge in the design was to clean the mains while maintain the levels of service to the customer and preventing discolouration upstream and maintaining a calm network so that valve operations carried out in the field do not cause pressure surges and isolations in the network. Potential issues faced during the hydraulic design of flushing are highlighted through a case study.

Keywords: Mains Cleaning, PODDS, Hydraulic Design.

Rusby Wood a Smart Network for Sustainable Discolouration Risk Reduction.

Dr. Dominic Cook[1], Dr. Stewart Husband[2]

[1]Yorkshire Water Services, Western Way, Halifax Road, Bradford, BD6 2SZ, UK

[2]Department of Civil & Structural Engineering, University of Sheffield, S1 3JD, UK

[1]Dominic.cook@yorkshirewater.co.uk

Managing discolouration customer contacts has never been more important to UK Water Companies, with the Economic Regulator setting strict water quality customer contact targets, imposing large financial penalties if they are exceeded without providing additional funding to facilitate necessary network investment.

19% of discolouration customer contacts can be directly associated with the mobilisation of discolouration material from the trunk main distribution system, but these pipes due to their criticality of supply and size are extremely expensive to clean.

This paper presents a practical example demonstrating that with the addition of relatively inexpensive automated flow control, metering and instrumentation, a water supply system can be configured to automatically re condition itself. Five trunk main sections will sequentially run a maximum flow between service reservoirs before returning to normal operating flows. This produces a safety headroom between normal operating flow and the maximum hydraulically available flow this dramatically reduces discolouration risk should an un planned high flow event occur on the network.

The system is designed to ‘self check’ whereby sending and receiving reservoir levels and flow pressure and turbidity at strategic points are within set parameters before the reconditioning occurs.

In addition, if abnormal flows, pressures or turbidity levels are detected at any time on one of the trunk main sections, the inlet valve on the appropriate receiving reservoir will automatically close. This prevents discoloured water from entering the reservoir allowing the operator time to repair and flush the affected main.

Keywords: Discolouration; Mains Conditioning; DOMS.

Systems modelling, optimisation and decision support

Dynamic Scenario Selection in Optimal Design Problems and Evolutionary Optimization with Uncertain System Knowledge

Nathan Sankary[1], Avi Ostfeld[2]

[1,2] Technion – Israel Institute of Technology, Faculty of Civil and Environmental Engineering, Haifa, Israel, 32000

[1]*nesankar@mtu.edu*

The design of water resource management and control systems have provided a promising space for evolutionary algorithms. In many cases a system for managing a water resource requires a large degree of planning and design before implementation and many stake holders perceive different objectives with different importance. Multiobjective evolutionary algorithms inherently provide a tool that can best satisfy the desires of many stakeholders (many objectives) through computation of a non-dominated solution set. However, the performance of an optimal solution provided by a multiobjective evolutionary algorithm is likely to deteriorate during real-world implementation if design conditions of the optimization framework are not identical to those imposed on the system in practice. This paper focuses on evaluating a scenario based multiobjective evolutionary algorithm for real-world design problems in which the environment where a system will operate is dynamic, and uncertain. A previously developed genetic algorithm termed the “RNSGA-II” used for water distribution system design is augmented to incorporate robust objectives and simple Monte Carlo sampling to solve the classic water quality sensor placement problem. This study aims to further develop an understanding of scenario based optimization methods for optimizing solutions to perform well in the face of uncertainty.

Keywords: Multiobjective Optimization; Robust Optimization; Min-max Optimization; Evolutionary Algorithms.

Spectral Propagation of Parameter Uncertainties in Water Distribution Networks

Mathias Braun[1], Olivier Piller[1], Jochen Deuerlein[2], Iraj Mortazavi[3]

[1] Irstea, UR ETBX, Dept. of Water, 33610 Cestas, France

[2] 3S Consult GmbH, Albtalstrasse 13, 76137 Karlsruhe, Germany

[3] CNAM, EA-7340-M2N Modélisation Mathématique et Numérique, 75003 Paris, France

[1]*mathias.braun@irstea.fr*

The hydraulic state of a water distribution network is governed by a large number of uncertain parameters. These parameters may be given by uncertain consumer demand, valves states, the value of pipe diameters or the roughness of the pipes. In practice, the influence of parameter variations is important in the decision-making process of water utilities, which emphasizes the need for proper quantification of the resulting uncertainties in head and flow. The central step in uncertainty quantification is the propagation of uncertainties through the system. In the past, the influence of parameter uncertainties on the system state has been studied using perturbation methods, stochastic collocation and interval state estimation. This paper presents the results of an alternative spectral approach that has been examined as part of the French-German research project ResiWater. The generalized Polynomial Chaos Expansion is applied to a small looped water distribution network with multiple uncertain input parameters using a non-intrusive projection method. These results are compared to the Monte Carlo simulation as representative of stochastic collocation methods. It is demonstrated that the Polynomial Chaos Expansion is capable to capture a high order of non-linear effects like the Monte Carlo simulation for a considerably lower computational effort.

Keywords: Water Distribution Networks; Polynomial Chaos Expansion; Uncertainty Propagation.

The EPANET challenge

Avi Oftfeld[1]

[1] Faculty of Civil and Environmental Engineering, Technion – IIT, Haifa 32000, Israel

[1] *ostfeld@technion.ac.il*

One would rarely find anyone in the water distribution systems community that is not aware of EPANET [1]. From the early nineties, when EPANET was first introduced by the EPA, EPANET made a revolution in the water distribution systems research as well as at the practical engineering community. With numerous studies (303,000 EPANET hits on Google as of March 2, 2017) including evolutionary computational models, water quality applications, real time operation, and much more. Nothing in this professional world would have been looked alike without EPANET. As the official development of EPANET through EPA ceased, different initiatives imitated such as the Open Water Analytics [2] and recently the Center for Infrastructure Modeling and Management [3]. The water distribution systems community is now faced with a big challenge on how the future of EPANET should look like. This is a foremost challenge which goes far beyond the technical issues of a new graphical user interface (GUI) that involves technical fixes, or a more convenient framework to work with EPANET. This paper and talk will cover the author view on where EPANET should evolve from here. There should be very careful thinking on where this huge EPANET ship should sale.

Keywords: EPANET.

Why are Line Search Methods Needed for Hydraulic DDM and PDM Solvers?

Olivier Piller[1], Sylvan Elhay[2], Jochen Deuerlein[3,4], and Angus Simpson[4]

[1] Irstea, UR ETBX, Bordeaux regional centre, Cestas F-33612, France

[2] School of Computer Science, University of Adelaide, SA 5005, Australia

[3] 3S Consult GmbH, Albtalstrasse 13, 76137 Karlsruhe, Germany

[4] School of Civil, Environmental and Mining Engineering, University of Adelaide, Adelaide SA 5005, Australia

[1]*olivier.piller@irstea.fr*

It is common that non-convergence problems occur for simulations under normal or abnormal operations. Among the main causes, there are the use of sublinear functions for calculation of the hydraulic steady-state, some derivative issues and an ill-conditioned iteration matrix in the solution method. The objective of this paper is to specify non-convergence cases for existing hydraulic software solutions. The damped Newton solution together with regularization techniques are proposed for ensuring global convergence, whatever the initial solution. Failures of convergence are shown to exist even on small case studies.

Keywords: Steady State Modelling; Convergence; Inexact Line Search Method.

A Rehabilitation Decision-Making Approach for WDNs Based on Extended Period Simulations

Giovanna Darvini[1], Valentina Ruzza[2], Paolo Salandin[2]

[1] DICEA, Università Politecnica delle Marche, via Brecce Bianche, Ancona, Italy

[2,3] DICEA, Università di Padova, via Loredan, Padova, Italy

[1]g.darvini@univpm.it

The paper addresses the relevant topic of the rehabilitation in water distribution networks (WDNs). The degradation due to ageing of the networks reduces their mechanical and hydraulic characteristics, making the pipes subject to malfunctions and failures as well as to the increase of the leakage amount. To ensure a proper service in term of quantity and quality of the water delivered to users, a suitable maintenance program must be implemented, but the associated costs are relevant, and the interventions must be planned on the basis of both technical and economic constraints. This subject is here tackled by a Monte Carlo (MC) approach, considering both the hydraulic and mechanical deterioration processes of pipes affected also by leakage, as usual in the real world. Within the MC iterations, first a probabilistic model simulates the chain of repair and failure conditions, and then the performances of the each WDN configuration is evaluated by use of an efficient pressure-driven hydraulic algorithm. The analysis of the synthetic Anytown network leads to some unexpected results in terms of pipe replacement prioritizing, and due to a different leakage percentage affecting the network, the order of priority in the pipe maintenance program may result substantially modified.

Keywords: Water Distribution System Rehabilitation; Leakage; Pipe Prioritizing.

WDNs Calibration Using k-means Algorithm for Pipes Clustering and a Hybrid Model for Optimization

Rodrigo Freitas[1], Bruno Melo Brentan[2], Gustavo Meirelles Lima[3], Edevar Luvizotto Junior[4]

[1,2,3,4] Laboratory of Computational Hydraulics,

University of Campinas, Campinas - SP, Brazil.

[1]rodrigo-freitas@hotmail.com.br, [2]brunocivil08@gmail.com, [3]limameirelles@gmail.com,

[4]edevar@fec.unicamp.br.

The modelling of Water Distribution Networks (WDNs) is an important issue for an efficient operation of water systems. The hydraulic simulations are used to establish the optimal conditions for pumps and valves, helping stakeholders to manage the systems. A reliable model should guarantee the minimal uncertain becoming the simulations the most real as possible. The calibration processes is used to reduce the uncertainties associated to pipe roughness and nodal demand, pipe status or leakage flow. Due to the high degrees of freedom surrounding this process, the improvement of available information of the hydraulic state of the network and the reduction of parameters to be calibrated can conduct for more reliable calibrated model. In this sense, this work present a hybrid calibration method, consisting in three stages defined as grouping pipes with k-means algorithms, pressure estimation with artificial neural networks (ANN) and an optimization process using particle swarm optimization (PSO) algorithms. A comparison between the classical approaches for roughness calibration is presented, reinforcing the improvement of the calibration process through the uncertain reduction.

Keywords: Water Distribution Networks; Roughness Calibration; k-means; ANN; Particle Swarm Optimization.

A Dynamic Model for Smart Water Distribution Networks

Stefan Kaltenbacher[1], David B. Steffelbauer[2], Marco Cattani[3], Martin Horn[1], Daniela Fuchs-Hanusch[2] and Kay Römer[3]

[1]Institute of Automation and Control, Inffeldgasse 21B/I

[2]Institute of Urban Water Management, Stremayrgasse 10/I

[3]Institute of Technical Informatics, Inffeldgasse 16/I

Graz University of Technology

[1]s.kaltenbacher, [2]david.steffelbauer, [3]m.cattani, [1]martin.horn, [2]fuchs-hanusch, [3]roemer@tugraz.at

While background leakages accounting for substantial water losses in supply networks remain undetectable, human reaction to even visible pipe bursts is insufficiently slow. We lose precious time in which not only water losses but severe damage to the surrounding infrastructure could be prevented. These leakages can often be identified only during the minimum night flow and so repair work is delayed by days, causing intermittent water supply and outages. Increasing costs and the importance to ensure supply security require further measures.

Therefore, the application of holistic algorithms controlling proportional valves and pumps allows to act instantaneously on failures by isolating affected pipe sections and by reducing the pressure in that region. With the target to apply classical control theory and yet avoid too complex formulations, this paper presents a dynamic model using no more parameters than a typical, steady-state EPANET model. By means of a sophisticated network description, we modify the rigid water column theory in terms of pressure-driven demands. Other than traditional methods, this approach enables nodal consumptions to dynamically change inner system states such as pressure or flow values. Within this method, the nodal elevation undergoes proper treatment in the model equations and further ensures that pressure values will not become negative as one may have experienced in EPANET.

Keywords: Hydraulic Network Modeling; Flow Dynamics; Water Distribution Control Systems.

On the Solvability of the Pressure Driven Hydraulic Steady-State Equations Considering Feedback-Control Devices

Jochen Deuerlein[1,4], Olivier Piller[2], Fabrizio Parisini[3], Angus R. Simpson[4] , Sylvan Elhay[5]

[1,3] 3S Consult GmbH, Albtalstrasse 13, 76137 Karlsruhe, Germany

[2] Irstea, UR ETBX, Bordeaux Régional centre, Cestas F-33612, France

[4] School of Civil, Environmental and Mining Engineering, University of Adelaide, Adelaide SA 5005, Australia

[5] School of Computer Science, University of Adelaide, SA 5005, Australia

[1]*deuerlein@3sconsult.de*

Water supply networks (WSNs) represent an important part of urban technical infrastructure. Recently, the resilience of water distribution networks facing different physical and cyber threats has gained increasing attention. In order to improve the operation of complex water distribution systems under both, extreme and normal hydraulic conditions, mathematical simulation models are indispensable tools for engineers, network planners, network operators and decision makers. Especially, in the case of extremely disruptive events that might be caused by natural hazards or deliberate malevolent attacks by humans, the proper operation of the system for maintaining the supply of drinking water to at least parts of the population is a very challenging task. Resilient behaviour can be reached only by adaptive system operation including isolation of parts of the network and control of pressure and flows in the system. For that purpose, different kinds of control devices are used that may be remotely controlled or which are operated in the field. Existing hydraulic simulation software often fails to calculate reliable results for systems under control and pressure insufficiency. A mathematical framework for the simulation of the steady-state flow in reticulation water supply networks with special consideration of feedback control devices and pressure dependent demands is proposed in this paper. The well-known content model is extended by the content of pressure dependent outflows. The nonlinear consumption functions in combination with linear inequality constraints (box constraints) replace the constant demands of demand driven analysis. It is shown that the range of solvable problems in combination with flow control devices is enlarged by the relaxation of fixed demands.

Keywords: Pressure Driven Modelling; Control Valve; Convex Optimization.

Hydraulic Reliability Analysis of a Real Network with Remotely Real-Time Controlled Pressure Control Valves

Daniele B. Laucelli[1], Luigi Berardi[1], Antonietta Simone[1], Gema Raspati[2], Rita Maria Ugarelli[3], Orazio Giustolisi[1]

[1]Technical University of Bari, Via E. Orabona 4, Bari, Italy

[2]SINTEF Building and Infrastructure, Richard Birkelands vei 3, Trondheim, Norway

[3]SINTEF Building and Infrastructure, Forskningsveien 3b, NO-0314, Oslo, Norway

[1]*luigi.berardi@poliba.it*

The paper considers a real water distribution network, where current pressure control strategies exploit classical pressure control valves (PCVs). A previous study identified alternative pressure control strategies exploiting remote real time controlled pressure control valves (RRTC PCVs) together with existing classic ones, aimed at reducing background leakages. The proposed analysis relates to the hydraulic reliability of the system accounting for RRTC PCVs compared to the classic PCVs (already installed). The analysis also assumes fire protection requirements, statistical increase of customer demands and the increase of pipes deterioration (background leakages and pipe roughness). The hydraulic reliability analysis is part of the Management module of the WDNetXL system and is based on advanced hydraulic modelling, including pressure-dependent water demand components (e.g., background leakages), classic PCV and RRTC-PCVs as well as any hydraulic control device (pumps, directional valves) that might change WDN topology during the simulation.

Keywords: Water Distribution Network; Pressure Ccontrol; Hydraulic Reliability.

Optimising Valve Placement and Pressure Control for Multi-feed Sectors in Water Supply Networks Using Outer Approximation

Filippo Pecci[1], Ivan Stoianov[2]

[1,2] Dept. of Civil and Environmental Engineering, Imperial College London, London, UK,

[2]ivan.stoianov@imperial.ac.uk

In this paper, we investigate the problem of optimising both the location and control settings of pressure reducing valves in multi-feed sectors in water supply networks. A simplification of the problem formulation is presented with respect to previously published research by reducing the degree of nonlinearity of optimisation constraints. The resulting optimisation problem is a nonconvex mixed integer nonlinear program. We then apply an outer approximation algorithm for the generation of good quality solutions of the considered design-for-control problem. We evaluate the presented method on a large-scale operational water supply network in the UK.

Keywords: Pressure Management; Multi-feed Sectors; Valve Placement; Optimisation.

Operational Interventions in WDS to Improve Water Quality: a Comparison of Multi-Objective Optimization Formulations

Claudia Quintiliani[1], Oscar Marquez-Calvo[2], Leonardo Alfonso[3], Cristiana Di Cristo[4], Angelo Leopardi[5], Giovanni de Marinis[6]

[1, 4, 5, 6] University of Cassino and Southern Lazio, Cassino (Italy)

[2, 3] UNESCO-IHE Institute for Water Education, Delft (The Netherlands)

[1]c.quintiliani@unicas.it

Managing water quality in drinking water distribution systems is very important to guarantee consumers' health. Disinfection is used to reduce the risk of pathogenic contamination or microbial species proliferation. Chlorine is a disinfection substance that is traditionally used due to its effectiveness and low cost. However, the use of chlorine has related disinfection by-products, some of which can have carcinogenic effects on human health (e.g., trihalomethanes, THMs). In this context, the objective of this paper is to compare different multi-objective optimization problem formulations to improve the operational interventions of WDSs, in order to reduce the formation of THMs in the network. The analysis of two case studies shows that operating valves is more convenient than operating hydrants and pumps in most of the proposed formulations.

Keywords: Optimization; Drinking Water Quality; Operational Interventions.

Pumping Cost Optimization in Looped Water Networks with Storage Capacity through the Searching of the Setpoint Curve

Christian-F. León-Celi[1], Pedro Iglesias-Rey[2], F. Javier Martinez-Solano[3], D. A. Savic[4], L. S. Vamvakeridou-Lyroudia[5]

[1,2,3] Department of hydraulic and environment. Politécnica de Valencia University, Valencia, 46022, Spain

[4,5] Centre for Water Systems. University of Exeter. North Park Road Exeter EX4 4QF UK

[2]Pedro Iglesias-Rey (piglesia@upv.es)

The pumping cost optimization still being a priority to minimize the operating costs in a water network due to the high cost of energy. In that context before to optimize the operation of installed pumps, it is required to find out the optimal operational points of each pump station independently of its associated features of flow rate and pumping head that are limited and limit the optimal solution. Thus, the aim of this work is to find the minimum energy curve (i.e. flow rate and pumping head) with the minimum cost that should be follow by each pump station to keep the minimum nodal pressure required by the network within a specific storage range in the tanks. This concept is known as setpoint curve. The objective function to be minimized considers the pumping cost with a diary structure of the energy fare, the water treatment costs and penalty costs related to the nodal pressure and the storage capacity of the network. To carry out the optimization the Differential Evolution algorithm has been applied. The proposed methodology has been tested in the water network D-town BWN II which has five pumping stations and seven tanks. Results show the maximum savings that it is possible to achieve in pump stations and gives important information to select a suitable pumping system that fit with the optimal operation of the network.

Keywords: Water; Optimization; Pump.

Costs Functions Proficiency over the Urban Drainage Networks Optimal Design

Natalia Duque[1], Andrés Aguilar[2], Juan Saldarriaga[3]

[1,3] Water Supply and Sewers Systems Research Center (CIACUA), Department of Civil and Environmental Engineering, Universidad de Los Andes, Bogotá, Colombia.

[2] Department of Civil and Environmental Engineering, Universidad de Los Andes, Bogotá, Colombia.

[3]*jsaldarr@uniandes.edu.co*

The urban drainage networks optimal design objective function must represent accurately the real construction costs of these systems. This design problem involves two sub problems which require a specific cost function. For the layout selection problem, a cost function in terms of the flow rate and direction is needed, since there is no information about the diameter, depth, and slope of the pipes. A good estimation of the layout cost function is needed to find the minimum-cost urban drainage network design. The optimal hydraulic design of the network requires the best layout selection. In this paper some cost functions are tested using the urban drainage network optimal design methodology proposed by Duque N. et al. (2015) [1], on part of a real network located in Bogota, Colombia. Afterwards, a sensitivity analysis is performed to determine the effect of each cost function over the layout selection and hydraulic design of the network. Moreover, this analysis aims to evaluate the cost functions proficiency and robustness, when changing parameters such as the filling ratio and the pipes material.

Keywords: Urban Drainage Networks; Optimization, Layout; Cost Function.

Comparison between Optimal and Real Design in Water Distribution Systems (WDS). Effect of Population Growth during the Project Lifespan.

, Alejandra Posada[1], Jessica Bohórquez[2], Juliana Robles[3], Juan Saldarriaga[4]

[1,2,3,4] Water Supply and Sewers Systems Research Center (CIACUA), Department of Civil and Environmental Engineering, Universidad de Los Andes, Bogotá, Colombia.

[4]*jsaldarr@uniandes.edu.co*

Urban processes affect Water Distribution Systems (WDS) and cause unsatisfactory operation, which violates the minimum pressure limit. For this reason, stablishing a valid rehabilitation criteria based on previous studies is necessary. In this paper a methodology to verify the results obtained by Specific Power and Resilience Index criteria is presented. The results obtained for six study cases in Colombia were analyzed in terms of costs, parameters and number of changes showing a reduction in costs and a reduced number of changes in the algorithm based on the second index.

Keywords: WDS Rehabilitation; Optimum design; Population Growth.

Fractality in Water Distribution Networks

Kegong Diao[1], David Butler[2], Bogumil Ulanicki[3]

[1,3] De Montfort University, The Gateway, Leicester LE1 9BH

[2] University of Exeter, North Park Road, Exeter EX4 4QF

[1]kegong.diao@dmu.ac.uk

Fractals have been identified as a common feature of many natural and artificial systems that exhibit similar patterning at different scales. Understanding fractals is a critical aspect of decoding complex systems, as the pattern of such large systems can be revealed by identifying only a small part of the system. Furthermore, identify existing features of such systems can start at the large scale with the fewest details of the system under scrutiny before doing a more detailed analysis at finer scales. Such a process provides an efficient and reliable way of analysing and managing information of big data systems.

This study revealed the fractality in water distribution networks (WDNs) based on research on fractals in complex networks. Specifically, we explored the existence of fractal patterns in six real world WDNs of different complexities (e.g. from a network with only 21 pipes to a network with 2465 pipes). The box-covering algorithm has been applied, which is the most widely used method to distinguish between fractal or non-fractal networks. The WDNs are first mapped into undirected graphs. Next, the method partitions the nodes into boxes of size l_B, i.e. the maximal distance between nodes within each box is at most $l_B - 1$. By varying the box sizes, different minimum numbers of boxes N_B required to cover the entire network can be identified. A network is fractal if the regression line for $\log(N_B)$ and $\log(l_B)$ is linear.

The results demonstrate the existence of fractal patterns in all case study WDNs, as linear regression lines with coefficient of determination over 0.95 ($R^2 > 0.95$) are obtained in all analyses. As further verification, the self-similarity on multiscales is revealed, i.e. the similarity in patterns of component criticality. Based on the fractal patterns, a systematic method is also developed for more efficient identification of critical pipes in WDNs, e.g. reducing the computational load by 61% in the case study.

Keywords: Complexity; Criticality; Fractality; Water Distribution Networks.

Segments Identification in Water Distribution Systems by Using Network Topological Matrices

Herman Mahmoud[1], Zoran Kapelan[2], Dragan Savic[3]

[1,2,3] Centre for Water Systems, College of Engineering, Mathematics, and Physical Sciences, University of Exeter, North Park Rd., Harrison Building, Exeter EX4 4GF, U.K.

[1]haam201@exeter.ac.uk

In this paper, a methodology is proposed to identify network segments (i.e., sets of pipes and nodes) that belong to an individual valve or a set of valves. The methodology is developed based on the basic network topological matrices (i.e., node-link connectivity matrix, valves topological matrix). In comparison to other existing methods, the proposed methodology has able to identify all segments for a given water distribution system (WDS) in a single network run without introducing pseudo valves, pipes and auxiliary valve matrix or performing hydraulic analysis. The results show that the approach is capable of identifying both regular segment valves association and unintentionally isolated segments in accurate and efficient manner. Due to its generic nature and relative simplicity, the methodology has the ability to create network segments in automated way from network input data, e.g., by reading and automatically processing the relevant data the EPANET2.0 input file. The integration of the proposed segmentation method with a hydraulic solver (such as one used in EPANET 2.0), therefore, lends itself naturally to tackling practical problems, such as determining strategic and optimal location for isolation and PRV valves, WDS reliability, and response approaches to network failure events.

Keywords: Network Segmentation; Isolation; Segments; Unintentional Segments.

Comparison Of Different Controllers For Equitable Water Supply In Water Networks

G R Anjana[1], M S Mohan Kumar[2] and Bharadwaj Amrutur[3]

[1] Department of Civil Engineering

[2] Department of Civil Engg., IFCWS, ICWaR, Robert Bosch Centre for Cyber Physical Systems

[3] Department of Electrical Communication Engineering and Robert Bosch Centre for Cyber Physical Systems,

Indian Institute of Science, Bangalore, India

[*[1]anjanagr@civil.iisc.ernet.in]*

Equitable distribution of water among consumers is one of the most important agenda for many water authorities around the world. Many methods have been listed in literature for equitable distribution of water. In recent years, different automatic controller based approaches were also introduced for flow control in water systems. In this work, a comparative study is carried out among Dynamic Inversion based PID (DI-PID), Model Predictive Control (MPC) and EnKF based PID controllers for flow control application in real time for a water distribution network- Bangalore inflow water distribution system. It was observed that the DI-PID and EnKF based PID controllers are better than other controllers for equitable distribution of water in a mega city like Bangalore

Keywords: Water Distribution Systems; Equitable Water Supply; Controllers.

An Improved Simulated Annealing Algorithm for Solving Complex Water Distribution Networks

Maria Cunha[1], João Marques[2]

[1,2] MARE – Marine and Environmental Sciences Centre, Department of Civil Engineering, University of Coimbra, Coimbra, Portugal

[2]*jmarques@dec.uc.pt*

Optimising the design of water distribution networks (WDNs) is a well-known problem that has been studied by numerous researchers. This work proposes a heuristic based on simulated annealing and improved by using concepts from the cross-entropy method. The proposed optimization approach is presented and used in two case studies of different complexity. The results show not only a fall in the computational effort of the new approach relative to simulated annealing but also include a comparison with other heuristic results from the literature, used to solve the same problems.

Keywords: Water Distribution Networks; Simulated Annealing; Cross-entropy.

Online Demand Estimation of Geographical and Non-Geographical Distributed Demand Pattern in Water Distribution Networks

Nhu Cuong Do[1], Angus R. Simpson[2], Jochen W. Deurelein[3], Olivier Piller[4]

[1,2] School of Civil, Environmental and Mining Engineering, University of Adelaide, Adelaide SA 5005, Australia.

[3] 3S Consult GmbH, Karlsruhe, Germany

[4] Irstea, UR ETBX, Department of Waters, France, Bordeaux

[1]nhu.do@adelaide.edu.au

The issue of demand calibration and estimation under uncertainty is known to be an exceptionally difficult problem in water distribution system modelling. In the context of real-time event modelling, the stochastic behaviour of the water demands and non-geographical distribution of the demand patterns makes it even more complicated.

This paper considers a predictor – corrector approach, implemented by a particle filter model, for solving the problem of demand multiplier factor estimation. A demand forecasting model is used to predict the water demand multiplier factors. The EPANET hydraulic solver is applied to simulate the hydraulic behaviour of a water network. Real time observations are integrated via a formulation of the particle filter model to correct the demand predictions.

A water distribution network of realistic size with two configurations of demand patterns (geographically distributed demand patterns and non-geographically distributed demand patterns) are used to evaluate the particle filter model. Results show that the model is able to provide good estimation of the demand multiplier factors in a near real-time context if the measurement errors are small. Large measurement errors may result in inaccurate estimates of the demand values.

Keywords: Particle Filtering, Real Time Demand Estimation, Water Distribution Systems, Calibration..

Multi-Object Approach for WSN Partitioning in the Framework of Pressure Driven Analysis

Creaco E.[1], Di Nardo A.[2,3], Di Natale M.[2,3], Giudicianni C.[2], Santonastaso G.F.[2,3]

[1] Dipartimento di Ingegneria Civile e Architettura, Università di Pavia, Via Ferrata 3, 27100 Pavia, Italy

[2] Dipartimento di Ingegneria Civile Design Edilizia e Ambiente, Università degli Studi della Campania 'L. Vanvitelli', via Roma 9, Aversa, 81031, Italy

[3]Action Group CTRL+SWAN of the European Innovation Partnership on Water, EU

[2]*armando.dinardo@unina2.it*

This paper proposes a novel methodology for WSN (water supply network) partitioning, made up of two serial steps and aimed at investigating leakage reduction benefits as a dual-use value of water network partitioning (WNP). Step 1 makes use of a spectral clustering algorithm to define the optimal layout of the districts, exploiting the properties of the connectivity matrix and giving a mathematical elegance to the arduous problem of optimal cluster definition. Taking the partitioning results of step 1 as granted, Step 2 deals with closure of isolation valves and installation of flow meters in the boundary pipes between either district. In the context of Step 2, a bi-objective optimization, aimed at maximizing the daily water volume supplied to the WSN users and at minimizing the leakage, is performed, in which network behavior is tested in PDA (pressure driven analysis). The applicability of the methodology is shown in a real case study.

Keywords: Spectral Clustering; Pressure Driven Model; Water Leakage.

Adaptation of *Physarum polycephalum* Evolution for Least-Cost Design of Water Distribution Network

Olya Skulovich[1], Avi Ostfeld[2]

[1,2] Faculty of Civil and Environmental Engineering, Technion - IIT, Haifa 32000, Israel

[2]*Corresoponding author: ostfeld@tx.technion.ac.il*

This study presents a physarum polycephalum-inspired mathematical model for the solution of the problem of least cost design of water distribution systems. We propose modifications of the classical physarum polycephalum mathematical model to adjust it for water distribution system optimization. The methodology was tested on two small-scale benchmark examples: two-loop and Hanoi networks. In the both cases, the obtained results are 10-11% above the known optimal solution, however, the number of iterations required to achieve them are exceptionally small. The proposed approach should be further tested for its applicability to the larger networks. Altogether, the method can serve as a good and easily obtainable first approximation for the least cost water distribution system design.

Keywords: Physarum Optimization; Water Distribution Systems; Least Cost Design.

Case Study: Improvements to a Real-Time Network Modelling Framework

S. M. Masud Rana[1], Paulo José Oliveira[2], Tian Qin[3], Dominic L. Boccelli[4]

[1,2,3,4] Department of Chemical and Environmental Engineering

University of Cincinnati, Cincinnati, OH, 45221-0012

[1]ranasd@mail.uc.edu, [2]oliveipa@mail.uc.edu, [3]qintn@mail.uc.edu, [4]dominic.boccelli@uc.edu

Short-term water demand forecasts are valuable for distribution system operators controlling the production, storage and delivery of drinking water. In certain problems, such as real-time pump scheduling, the cycle of data acquisition, model computation, and decision-making is time-sensitive, and requires an automatic procedure to handle the transfer of information between data source(s), forecasting model(s), and the operator. Recent development of a composite demand-hydraulic model integrates a demand time series model with a hydraulic network model to estimate and forecast demands using measurements typically available to water utilities. The application to a real-world network model with approximately 12,000 demand nodes and six flow measurements resulted in good representation of the observed flow rates. However, the performance of the demand-hydraulic algorithm, and subsequent analysis, has demonstrated limitations in two aspects of the demand estimation and forecasting framework: the temporal representation of the estimated demands, and the clustering approach needed to reduce the scale of the parameter estimation problem. The current research will present preliminary results associated with data-driven approaches for representing the temporal demands and application of alternative clustering algorithms to improve the overall demand estimation process.

Keywords: Real-time Modeling; Time Series; Clustering.

Real time monitoring, modelling, control and uncertainties

An Integrated State Estimation Approach to Enhance the On-line Monitoring Capabilities of Water Distribution Systems

Sarai Díaz[1], Javier González[2], Roberto Mínguez[3]

[1,2] Department of Civil Engineering, University of Castilla-La Mancha, Avda. Camilo José Cela, s/n, 13071 Ciudad Real, Spain

[2,3] Hidralab Ingeniería y Desarrollos, S.L., Hydraulics Laboratory, University of Castilla-La Mancha, Avda. Pedriza-Camino Moledores s/n, 13071 Ciudad Real, Spain

[1]*Sarai.Diaz@uclm.es*

State estimation techniques have been widely discussed in academia in the context of water distribution systems, but there are few real-life applications. The aim of this paper is to show the potential advantages of systematically implementing state estimation techniques for on-line monitoring water distribution systems. With this purpose, two state estimation-based methodologies are here applied to C-Town case study: (1) calibration via multi-period state estimation, in order to adjust model parameters based on state estimation results over time, and (2) topological state estimation, in order to identify changes in the statuses of pumps and valves. Results show that state estimation techniques are a good alternative to adapt the paradigm of water distribution networks analysis to the reality of telemetry systems.

Keywords: ICT; Calibration; Topological Analysis.

A Real Time System for Detecting Events in Water Networks

Shana Meeus[1], Dene Marshallsay[2]

[1,2]Artesia Consulting Ltd, Unit 2, Badminton Court, Yate, Bristol, BS37 5HZ

[1]*shana@artesia-consulting.co.uk*

Water distribution networks will need to evolve to meet the future challenges of population growth, climate change, aging infrastructure and ever increasing customer expectations. Part of this evolution will be the use of smarter systems to manage the network based on advanced data analytics. This paper presents a new system for automatically detecting abnormal events that occur in water networks and automatically reporting alarms back to the operators. The system makes use of existing flow data, without the need for new hardware or changes to the logging frequency of flow data. The paper presents the development of the system and examples from a case study with Dŵr Cymru Welsh Water.

Keywords: Water Leaks; Pipe Bursts; Event Detection.

Extracting Temporal Patterns for Contamination Event Detection in a Large Water Distribution System

Nicolas Cheifetz[1], Selma Kraiem[1], Pierre Mandel[1], Cédric Féliers[1], Véronique Heim[2]

[1] Veolia Eau d'Ile de France, Le Vermont, 28, Boulevard de Pesaro, Nanterre F-92751, France

[2] Syndicat des Eaux d'Ile de France (SEDIF), 120 Boulevard Saint-Germain, Paris F-75006, France

[1]*nicolas.cheifetz@veolia.com*

Monitoring water quality in a drinking Water Distribution Network (WDN) is typically based on several sensors that are deployed on different locations of the WDN. Each sensor measures one or multiple signals, and the real challenge resides in detecting significant contaminations by analyzing these water quality signals. In practice, some detection methods may fail due to a specific design to certain forms of contaminants as well as a generic formulation with model-free algorithms. Both cases might trigger false alarms or produce no detection when a contamination occurs. Moreover the problem is hardly addressed when the underlying hydraulic regime changes over time causing fluctuations in the detection statistics. Such variation can dramatically decrease the detection performance or result to misleading analysis. Events like source shifting or tank filling are normal situations and can occur frequently depending on the operating conditions. This paper aims to deal with the variability of the contamination events under various operational conditions in water networks. The procedure is fully data-driven and leads to the extraction of meaningful temporal patterns using various data analysis techniques. This methodology can be used as a preprocessing stage to improve the performance of any algorithm to detect contaminations. The proposed approach is illustrated on a large real-world network in France and a qualitative interpretation is given to highlight a better understanding of the hydraulic regimes over time.

Keywords: Water Distribution System; Early Warning Detection System; Sequential Pattern Mining.

Unsteady Flow Modelling of RTC in Water Distribution Networks

Creaco E.[1], Campisano A.[2], Franchini M.[3], Modica C.[4]

[1] Dipartimento di Ingegneria Civile ed Architettura, University of Pavia, Via Ferrata 3, 27100 Pavia – Italy

[2,4] Dipartimento di Ingegneria Civile ed Architettura, University of Catania, Viale Andrea Doria 6, 95125 Catania – Italy

[3] Dipartimento di Ingegneria, University of Ferrara, Via Saragat 1, 44122 Ferrara – Italy

[1]*creaco@unipv.it*

This paper describes the use of the unsteady flow modelling (UFM) for the simulation of remote Real Time Control (RTC) of pressure in water distribution networks (WDNs). The developed model combines UFM with specific simulation modules for generation of pulsed nodal demands and dynamic adjustment of pressure control valves. The results of the application to a skeletonized WDN show that UFM provides a sound description of the amplitude of the pressure head variations at the controlled node. Further calculations prove the RTC algorithm to be stable in the presence of measurement errors on the monitored variables.

Keywords: Pressure; Real Time Control; Unsteady Flow.

Real-time Whole-cost Optimization of Water Production and Distribution

Markus I. Sunela[1], Raido Puust[2]

[1] Fluidit Ltd., Åkerlundinkatu 11 A, 33100 Tampere, Finland

[2] Tallinn University of Technology, Ehitajate tee 5, 12616 Tallinn, Estonia

[1]*markus.sunela@fluidit.fi*

Optimizing water production and distribution in near real-time can result in significant savings in energy and chemical costs. This paper presents a novel, generic optimization framework, based on a single-solution meta-heuristic optimization algorithm called modified hybrid discrete dynamically dimensioned search (MHD-DDS). The optimization framework finds optimal settings for all stations in the network and optimal frequencies for all variable-speed driven pumps (VSP) for the 24 hours following the optimization run start. Tampere water supply system was used as a large-scale case-study, and the optimization was able to reduce production and distribution costs by almost 20 % while ensuring better quality of service (QoS) than before.

Keywords: Pump Scheduling; Real-time; Case-study**.**

Mechanical Reliability Analysis of a Real Network to Support the Design of Isolation Valve System

Luigi Berardi[1], Daniele B. Laucelli[1], Antonietta Simone[1], Gema Raspati[2], Rita Maria Ugarelli[3], Orazio Giustolisi[1]

[1]Technical University of Bari, Via E. Orabona 4, Bari, Italy

[2]SINTEF Building and Infrastructure, Richard Birkelands vei 3, Trondheim, Norway

[3]SINTEF Building and Infrastructure, Forskningsveien 3b, NO-0314, Oslo, Norway

[1]*luigi.berardi@poliba.it*

The Isolation Valve System (IVS) allows to detach some portions of water distribution networks (WDN) to perform planned (e.g. maintenance) or unplanned (e.g. failures) works. Isolating WDN segments causes pressure reduction and possible insufficient water supply conditions; the larger the number of valves (and segments) the larger the reliability of the system in face of segment isolation scenario. This contribution introduces some reliability indicators ranging from single node and time step up to the entire WDN, based on the explicit pressure-driven hydraulic simulation of the system under each segment isolation scenario over an operating cycle. Such mechanical reliability indicators are used to support the selection among optimal alternative IVS design solution obtained by minimizing the number of valves and the length of segments. The strategy is demonstrated on the real WDN serving the municipality of Oppegård (Norway).

Keywords: Water Distribution Network; Isolation Valve System; Mechanical Reliability.

Self-tuning Pump Operation Mode for Fluid Storages to Increase Energy Efficiency

Thomas Hieninger (M.Sc.), Prof. Dr.-Ing. Ronald Schmidt-Vollus
Nuremberg Campus of Technology, Fuerther Straße 264b, D-90429 Nuremberg
Nuremberg Institute of Technology, Kesslerplatz 12, D-90489 Nuremberg
thomas.hieninger@th-nuernberg.de

This contribution deals with a self-tuning strategy for centrifugal pumps running fluid storages to decrease energy demand. The results are based on a MATLAB/Simulink model of a pump system, which is explained and verified. To analyse the energy demand and time for filling processes and to examine the applicability of the self-tuning strategy three possible systems and different filling strategies are regarded. Based on the most efficient strategy a self-tuning program was developed. For this program, convenient starting conditions and target values for constant or variable outflow are described. Thus, this optimisation strategy can be used as an on-line tuning program, which is simple to implement in running pump storage systems. The tuning strategy is tested with a genetic algorithm and a Nelder-Mead algorithm. Finally, a self-tuning program for fixed time operation mode is shown.

Keywords: Self-tuning; Pump Operation; Energy Efficiency.

Advances in sensors, instrumentation and communications technologies

The Role of SMART Water Quality Monitors on the Path to Smart Water Networks

Michael Strahand[1]

[1] Analytical Technology, Technology House, Gatehead Business Park, OL3 5DE

Self managing, self cleaning potable water distribution networks are within reach. Key to achieving this goal will be the deployment of thousands of water quality monitors. This paper will look at available technologies and the issues associated with obtaining, validating and contextualising the information.

Keywords: Water Quality Distribution.

SAFEWATER – Application and Results of Innovative Tools for the Detection and Mitigation of CBRN- related Contamination Events in Drinking Water Supply Systems

Thomas Bernard,[1] Aharon Rosenberg[2], Helena Lucas[3], Adrian Rieder[4], Jürgen Moßgraber[1], Jochen Deuerlein[5], Eyal Brill[6], Karim Boudergui[7], Dag Ilver[8], Nirit Ulitzur[9], Anna Elinge Madar[10]

[1]Fraunhofer IOSB, Karlsruhe, Germany;

[2]Hagihon Ltd., Jerusalem, Israel

[3]Aguas do Algarve SA, Faro, Portugal

[4]Wasserversorgung Zürich, Zürich, Switzerland

[5]3S Consult GmbH, Karlsruhe, Germany

[6]Decision Makers Ltd., Shoam, Israel

[7]CEA-LIST, Gif-sur-Yvette, France

[8]ACREO AB, Kista, Sweden

[9]BioMonitech Ltd., Qiryat Tivon, Israel

[10]ARTTIC, Paris, France

[1]thomas.bernard@iosb.fraunhofer.de

The security of drinking water is increasingly recognized as a major challenge for municipalities and water utilities. The safety and or security of drinking water can be threatened by natural disasters, accidents or malevolent attacks. The European FP7 project SAFEWATER (10/2013 - 12/2016) developed a comprehensive event detection and event management solution for drinking water security management and mitigation against major deliberate, accidental or natural CBRN related contaminations. The aim of this paper is to present the main results of the SAFEWATER project with a focus on (1) new sensors for detection of chemical, biological and radiological threats, (2) Event Detection System and (3) results of real-life user-case scenarios which have been investigated at three water utilities.

Keywords: Drinking Water Networks; CBRN Sensors; Real-time Event Detection.

Identifiability Analysis for Pressure Sensors Positioning

Valeria Puleo[1], Silvia Tarantino[2], Gabriele Freni[3], Goffredo La Loggia[4]

[1,2,4] Department of Civil, Environmental, Aeronautic, and Chemical Engineering, University of Palermo, Viale delle Scienze, Ed. 8, 90100 Palermo, Italy.

[3] School of Engineering and Architecture, University of Enna “Kore”, Cittadella Universitaria, 94100 Enna, Italy

[1]*valeria.puleo@unipa.it*

The identifiability analysis is investigated as sampling design method aimed to the leakage detection in looped water distribution networks. The preliminary ranking of the candidate nodes for the pressure sensors positioning is performed by running several hydraulic simulations and calculating sensitivity functions. The reduced subset of nodes and their sensitivities are then used to perform the identifiability analysis by calculating the collinearity index which provides the maximum number of sensors and their location into the network. The index selects the nodes according to their sensitivities to several leakages scenarios, simulated in EPANET by changing the emitter coefficient of the leakages function both with a One-At-Time and Monte Carlo approach. The collinearity index also identifies the subset of the pressure monitoring nodes with the lowest correlation (redundancy) between the measurements. The method is applied to the benchmark network Apulian.

Keywords: Leakages; Identifiability; Sensor Positioning.

One-Class SVM – Leak Detection in Water Distribution Systems

Roya Cody[1], Sriram Narasimhan[2], Bryan Tolson[2]

[1] PhD candidate, [2]Associate Professor, Civil and Environmental Engineering, University of Waterloo, Waterloo, Ontario, Canada, N2L 3G1

[1]rcody@uwaterloo.ca

Acoustic leak detection in water distributions systems has been reviewed and validated for decades in various laboratory and field settings. However, the existing systems rely heavily on detailed knowledge of the pipe system, an assumption of ideal conditions, as well as direct access to infrastructure pipelines. This paper presents an experimental investigation that addresses the need of minimally invasive water distribution monitoring in cold climates. Monitoring in cold climates is achieved with a permanent dry barrel hydrant mounted passive sensor system. The sensor system sits within the water column while still being accessible via the hydrant. Lab tests utilize a retrofitted hydrant and pipe system. Experiments show the effectiveness of using fire hydrant mounted sensors in leak detection. Acoustic signals due to simulated leaks are measured, and a one-class support vector machine (OCSVM) classification methodology is applied. Results showed that a simulated leak can be detected with a 97% classification accuracy.

Keywords: One Class SVM; Water Distribution System; Dry Barrel Fire Hydrant Mounted Sensor.

Valve Status Verification and Sensor Error Detection via Causal Inference from Sensor

Dirk Vries[1,*], Joost van Summeren[1]

[1]KWR Watercycle Research Institute, Groningenhaven 7, 3433PE Nieuwegein, The Netherlands

[*]*dirk.vries@kwrwater.nl*

Recent developments in (near) real-time sensor applications have the potential to provide operators and managers with useful information on drinking water distribution supply and need of its maintenance. A systematic methodology based on causal inference from observational data is proposed to increase knowledge of water supply distribution systems equipped with sensor networks. This methodology can be used to help identify deviations from expected operation of water supply and sensor infrastructure, using only observational data. We outline the first steps of two distinct procedures that use data from a sensor network, to infer a map of a causal dependence structure. These procedures are applied to scenario studies where an unexpected change in operation occurs, i.e. a valve status is different and a sensor bias is introduced. A draft outline of future steps is given that could improve and validate the methodology.

Keywords: Graph Modelling; Sensor Networks; Causal Inference.

Feasibility Study on Water Temperature and Pressure Sensing based on Wireless Passive SAW Technology

Zhaozhao Tang[1], Wenyan Wu[2], Jinliang Gao[3]

[1] Faculty of Arts and Creative Technologies, Staffordshire University,
Stoke on Trent, ST4 2DE, United Kingdom

[2] School of Engineering and the Built Environment, Birmingham City University,
Birmingham, B4 7XG, United Kingdom

[3] School of Municipal and Environmental Engineering, Harbin Institute of Technology,
Harbin, 150090, P. R. China

[2]*wenyan.wu@bcu.ac.uk*

The conventional methods in monitoring water distribution system require batteries as power supply for sensor nodes. These methods are unreliable because the risk of damaging batteries is high especially in harsh environment. Wireless passive surface acoustic wave (SAW) sensors do not need direct power supply like batteries for the sensor nodes. In this research, a feasibility study on water temperature and pressure sensing by using wireless passive SAW technology was undertaken. A wireless passive SAW temperature and pressure delay line sensor was adapted in a designed framework which can simulate water temperature and pressure changes in the pipeline. The experimental results show that wireless passive SAW sensor worked properly in this designed framework. There is only slight attenuation on response signals in the framework compared to the open-air environment. The related phase delays of the response signals depend linearly on the temperature (pressure) when the pressure (temperature) keeps constant, which meet the theoretical analysis of the sensor node design.

Keywords: SAW Sensor; Water Distribution Network; Pressure.

Design of an Observational Study for Investigating the Impact of Pressure Transients on Pipe Failures in Water Supply Networks

Hossein Rezaei[1], Ivan Stoianov[2]

[1,2] InfraSense Labs, Department of Civil and Environmental Engineering,
Imperial College London, SW7 2AZ, United Kingdom

[1]h.rezaei12@imperial.ac.uk, [2]ivan.stoianov@imperial.ac.uk

A system-wide investigation into the impact of quasi-steady and unsteady state pressure variations on the structural degradation and ultimate failure of pipes is critical for prioritising operational and capital expenditures. Such investigations rely upon an optimally designed observational study and the availability of metrics, which accurately capture the physical phenomena. The objective of this paper is to explore advances in causal inference and statistical methods in order to develop a sampling survey methodology that is required to differentiate the impact of pressure variations and transients, and other causal factors on pipe deterioration and failures.

Keywords: Observational Study; High-Resolution Pressure Logging; Pressure Transients.

Asset management and performance modelling

Agent-based Modeling as a Decision Support Tool for Water Conservation Planning

Tourigny A[1], Filion Y[2]

[1,2] Queen's University Department of Civil Engineering, Kingston ON, K7L 3N9, Canada

[1]*a.tourigny@queensu.ca*

The paper presents a simulation approach to model water conservation campaigns by coupling agent-based and hydraulic models. The approach is unique as it incorporates modeling the communication strategies that can be used to promote water reduction measures. An illustrative case study is developed where households, represented as agents, are targeted through a mail-in and social media campaign that prompts them to consider adopting rain barrels. The water demands before and after the rain barrel campaign are evaluated through the EPANET2.0 hydraulic network solver in order to calculate the change in energy use stemming from the measures. The study found that 1.51 ML of water a day could be saved through the campaign however it would take 18 years to reach the adoption target using the proposed communication strategy.

Keywords: Decision Support; Water Distribution; Energy Reduction.

Understanding the Range of Influence of Moderate-Sized and Short-Duration Transients in Water Distribution Systems

Mark Stephens[1], Angela Marchi[2], Jinzhe Gong[2], Martin Lambert[2], Michael Leonard[2], Angus Simpson[2]

[1] South Australian Water Corporation, Victoria Square, Adelaide, SA 5000, Australia

[2] The University of Adelaide, North Terrace, Adelaide, SA 5005, Australia

[1]mark.stephens@sawater.com.au

While extreme pressure transients are widely understood, moderate and frequent transients are not frequently studied. This paper reports on field results from the Central Business District (CBD) of Adelaide, South Australia, which show that moderate transients are caused by regular and semi-regular events. The results are analysed to assess the range of influence (and impact) of these events and are also compared to the results from transient hydraulic models. The use of the model predictions, with relative adjustment for measured damping, can be used to estimate the number of events that could be detected based on the number of time-synchronised high frequency loggers and their location.

Keywords: Transient Impact; Field Data; Pipe Water Networks.

Modelling Wastewater System Cost Infrastructures

Marta Cabral[1], Alexandre Pinheiro[1], Dália Loureiro[2], Dídia Covas[1]

[1] CERIS, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal

[2] National Civil Engineering Laboratory, Lisbon, Portugal

[1]marta.f.cabral@tecnico.ulisboa.pt

The aim of this paper is the establishment of cost functions for the various assets of sewer systems, namely gravity and raising pipes, drainage and storm water pipes, service connections and pumping stations. Costs are defined as a function of the main physical characteristics of the assets, such as, pipe material and nominal diameter (for pipes and service connections) and flow rate, pump head and pump power (for pumping stations). A five-step methodology was followed: 1) data collection, processing and analysis, 2) present cost value calculation, 3) asset characterization and key parameters identification, 4) cost functions and prediction band estimation, and 5) cost functions validation. Cost and infrastructure data for construction contracts of wastewater systems managed by different Portuguese water and wastewater utilities were analysed. Cost functions were estimated based on multiple linear regression analysis.

Keywords: Cost Functions; Wastewater Systems; Multiple Linear Regressions.

Management-Indicators Consulting System for Potable Water Utilities

Martha Patricia Hansen R. [1], José Manuel Rodríguez V. [2], Yenni Laurel V. [3], Horacio Fernández G. [4], Gema Alín Martínez O.[5], Edgar Antúnez L.[6], Luis Gómez L.[7]

[1,2,3,5,6,7] Instituto Mexicano de Tecnología del Agua (IMTA), Paseo Cuauhnáhuac 8532, Col. Progreso, Jiutepec, Morelos, 62550, México (https://www.gob.mx/imta)

[4] Universidad Tecnológica Emiliano Zapata (UTEZ), Av. Universidad Tecnológica 1, Palo Escrito, Emiliano Zapata, Morelos, 62765, México (http://www.utez.edu.mx/)

[1]phansen@tlaloc.imta.mx

The service-quality performance that a water utility offers any city can be measured according to the efficiency and effectiveness with which it provides water, gathers it and treats it once it becomes wastewater. Other important aspects are, user satisfaction, the continuous provision of water with quality and quantity, knowledge of the elements that make up the infrastructure, having a reliable users' register; knowledge of production and delivery of water to consumers, use of all treatment units' full capacity. Not to mention, attention to users' complaints in a reasonable time and timely payment for the service as well as the repayment of operation costs, maintenance and administration.

This is why it is important to create a system of indicators that permits the evaluation of the evolution of the development and modernization process of water utilities for potable water, sewerage and treatment, set goals to be reached, and contribute to the transparency of national information.

The Mexican Water Technology Institute (IMTA, 2017), created an indicator program for the management of water utilities (PIGOO, based on its initials in Spanish) which have gone up from 50 to 189 since 2005 to 2016, they provide service to 49% of the population in Mexico. At the same time, the number of management indicators has gone from 12 to 29. Information is available for the 245 participating organisms on the web site, http://www.pigoo.gob.mx/, which has an option for consulting a mobile app for the Android operating system.

The battery of 29 management indicators permits the measurement of the performance and efficiency of potable water systems in technical-operative, commercial and financial aspects. Ideally, performance indicators for water utilities would be linked to an objective or a strategy that the same entity sets. These are calculated through data gathered from annual reports of variables such as water volume produced, number of employees, total revenue and costs, occurrence of leaks, complaints etc.

The website has, among other things, the possibility of comparing these indicators, geographic consulting, and search filters for different demographic and geographic ranges of value for different management-performance indicators. This work presents the diverse topics and options that the program offers as well as the analysis of its results.

Keywords: Performance Indicators; Water Operating Systems; PIGOO; México.

Urban Water Infrastructure Asset Management Plan: A Practical Application

Bruno Ferreira[1], Nelson J. G. Carriço[1,2]

[1] Barreiro School of Technology, Polytechnic Institute of Setubal, Rua Américo da Silva Marinho, 2839-001 Lavradio, Portugal

[2]*nelson.carrico@estbarreiro.ips.pt*

In this paper, an application of the Portuguese infrastructure asset management methodology to a case study was presented. The IAM plan should have three distinct planning levels: strategic, tactical and operational. Each one of these levels follows a five-step structured sequence: (i) definition of objectives, assessment criteria, metrics and targets; (ii) diagnosis; (iii) plan elaboration; (iv) plan implementation; (v) plan monitoring and review. The paper focus, mainly in steps (i) to (iii) and to the tactical level of planning. Th IAM methodology was applied to a sixty-year-old water supply system (WSS) located in Lisbon's metropolitan area, Portugal. The strategic plan was elaborated by the municipality for the period 2015-2035 and has three strategic objectives. Based on these objectives eight strategies were outlined. Considering the strategic plan four tactical objectives were defined and for each of these objectives, assessment criteria were defined and adapted to system’s reality. Metrics were defined for each of the previously established assessment criteria, allowing constant and accurate evaluation of each objective. As a result, twelve metrics were established based on three different dimensions (i.e., cost, risk and performance). The metrics were calculated and evaluated based on the defined reference values to diagnose the WSS. The WSS present a low IVI, a high unmetered consumption, high level of service connection failure and high operation costs due WSS aging and degradation. Four intervention alternatives were established and evaluated. Each alternative was evaluated by multicriteria decision analysis method, based on the performance, risk and cost assessment results. Results obtained are discussed and the main conclusions are presented.

Keywords: Infrastructure Asset Management; Performance; Planning; Urban Water Infrastructures.

Continuous Robotic Inspection of Pipes for Data Rich Asset Management

Peter van Thienen[1,a,b], Maurits Maks[2,a], Doekle Yntema[3,a], Jean-Paul Janssens[4,b], Bart Bergmans[5,b], Roel Diemel[6,b], Michel Helgers[7,b], Peter Horst[8,b], Eelco Trietsch[9,b]

[1,2,4] KWR Watercycle Research Institute, Nieuwegein, The Netherlands

[2,3] Wetsus, Leeuwarden, The Netherlands

[5] Evides, Rotterdam, The Netherlands

[6] Brabant Water, 's Hertogenbosch, The Netherlands

[7] Dunea, Zoetermeer, The Netherlands

[8] PWN, Velserbroek, The Netherlands

[9] Vitens, Zwolle, The Netherlands

[a] Ariel project team

[b] AIR project team

[1]*peter.van.thienen@kwrwater.nl*

An aging network in combination with stricter stakeholder requirements force the Dutch drinking water sector to improve the asset management of their water transport and distribution networks. Autonomous inspection robots (AIRs) provide a means to obtain knowledge on the condition of more pipes against lower cost, resulting in more focused rehabilitations and replacements, reduction of water loss through leakage, and a better knowledge and understanding of the system. In this paper, we describe the concept, a first prototype, and further steps that are currently being taken towards the development and application of this tool.

Keywords: Pipe Inspection; Condition Assessment; Robotics.

A Fast Method to Identify the Criticality of Individual Components in Water Supply Networks

Didrik Meijer[1], Francois Clemens[1,2]

[1] Deltares, P.O. Box 177, 2600 MH Delft, The Netherlands

[2] Delft University of Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands and Deltares, P.O. Box 177, 2600 MH Delft, The Netherlands

[1]Didrik.meijer@deltares.nl

For the management of piped infrastructure (e.g. water supply networks, gas distribution systems) strategies are required to program the maintenance activities (e.g. repairs, replacement). In general, these activities are based on risk management that combines the probability and consequences of failure. In this paper a method is proposed to quickly identify the most critical elements in a network with respect to malfunctioning of a system as a whole. As opposed to methods applied so far, this method does not rely on iterative hydraulic calculations but takes the structure of the network as a starting point and is based on Graph theory.

First the theory of the method is presented, secondly the first results are presented based on a water supply network and the outcomes are compared with traditional methods applied so far. Finally, the results are discussed and conclusions are formulated.

Keywords: Asset Management; Criticality; Water Supply Networks.

Fault Detection and Diagnosis for Pressure Control Valves in Water Supply Networks

Jiramate Changklom[1], Ivan Stoianov[2]

[1,2] Department of Civil and Environmental Engineering, Imperial College London (InfraSense Labs)

[1] *j.changklom13@imperial.ac.uk*

The control of water supply networks is becoming more advanced and complex, and it is therefore increasingly important to continuously monitor and optimise the performance of automatic control valves. This paper investigates a method for early fault detection and diagnosis (FDD) of pressure control valves in water supply networks. Potential faults are categorised, and different process variables and residuals are defined from continuous measurements and model-based simulations of the operation of a diaphragm actuated globe valve in order to detect a fault and diagnose its likely cause. We generate and utilise experimental data from controlled laboratory conditions and an operational network together with numerically simulated data to validate the performance of the proposed FDD method.

Keywords: Pressure Control Valves; Fault Detection; Fault Diagnosis.

Data driven and soft computing analytics and visualisation

Pattern Recognition in Residential End Uses of Water Using Artificial Neural Networks and Other Machine-Learning Techniques

Juan Carlos Ibáñez Carranza[1], Roberto Díaz Morales[2], Jose Antonio Sánchez[3]

[1] Canal de Isabel II. Santa Engracia, 125. 28003 Madrid (Spain)

[2] Treelogic. Parque Tecnológico de Asturias, parcela 30, 33428 Llanera, Asturias (Spain)

[1]jci@canaldeisabelsegunda.es [2]roberto.diaz@treelogic.com [3]joseantonio.sanchez@treelogic.com

Machine-Learning and other Artificial Intelligence techniques have nowadays many practical applications in engineering, science or everyday life. In the water industry, there is also a broad scope of potential applications. In this paper, it will be presented a system developed by Canal de Isabel II to identify residential use of water in its different appliances, based on records from precision water meters equipped with pulse emitters. Developed models are based on Support Vector Machines, and Artificial Neural Network paradigms. Training data sets for the models have been extracted from a sample of about 300 residential users in the Region of Madrid (Spain), monitored since 2008. In this time, more than 35 million of water use events have been registered and about 15 million hours of water consumption monitored.

Machine-Learning techniques have proved to be an accurate and suitable method for automate this task that otherwise should require a huge number of man-hours of processing by operators.

Keywords: Water End Use; Residential Water Use; Artificial Neural Networks; Support Vector Machines; Machine Learning.

Automatic Detection of Sewer Faults Using Continuous CCTV Footage

Joshua Myrans[1], Zoran Kapelan[1], Richard Everson[1]

[1] University of Exeter, Harrison Building, North Park Road, Exeter, Devon, UK

jm494@exeter.ac.uk

The work presented in the paper demonstrates the automatic detection of faults in sewers using CCTV footage. Specifically, it develops the fault detection methodology for application to a continuous video sequence, implementing a new ‘Smoothing’ stage. This new stage implements a Hidden Markov Model and Windowing technique, able to incorporate information from an entire CCTV segment to improve the frame by frame identification. The modified methodology was tested and demonstrated on footage taken from real world surveys in the UK. The results obtained, demonstrate that the extended methodology has improved performance with up to an 8% increase in accuracy and up to 5% increase in area under the ROC curve. Given the ability to produce predictions comparable to those of surveyors, the methodology shows promise for future application in industry.

Keywords: Automatic; Fault Detection; Hidden Markov Model.

Applying Deep Learning With Extended Kalman Filter and Genetic Algorithm Optimization for Water Distribution Data-Driven Modeling

Zheng Yi Wu[3], Atiqur Rahman[2] and Qiao Li[1]

[1]Bentley Systems, Incorporated, Watertown, CT, USA

[2]College of William & Mary, Williamsburg, VA, USA

[3]Denver University, Denver, Colorado, USA

[1]zheng.wu@bentley.com

Data-driven analysis has recently emerged as an important task for smart water management as large amount of various data collected via smart meters, sensors and data loggers. Among the methods developed for data-driven modeling, deep neural network (DNN) is proved as the competitive and generic approach to solve many challenging problems, including but not limited to voice recognition, natural language processing, image classification etc. Deep belief network (DBN) is one of the DNNs and widely used for data analysis. This paper extended authors' previous research in applying DBN model with the genetic algorithm to integrate with the Extended Kalman Filter (EKF). It results in a comprehensive and generic approach, by which the genetic algorithm is employed to optimize the configuration of the DBN and the EKF is applied to assimilate the newly available data with the trained DBN model so that the model can be updated whenever new data becomes available. The proposed method has been tested in the case studies of different domains, including but not limited to water distribution systems. The results show that the deep learning method integrated with EKF has resulted in good performance.

Keywords: Deep Learning; Data-Driven Analysis, Predictive Modeling; Optimization; Smart Water Systems.

Clustering-Based Burst Detection Using Multiple Pressure Sensors in District Metering Areas

Yipeng Wu[1], Shuming Liu[2]

[1,2] School of Environment, Tsinghua University, 100084, Beijing, China

[2]*shumingliu@tsinghua.edu.cn*

Bursts in water distribution systems (WDS) can cause water loss, service interruptions and other negative effects. However, it is challengeable for worldwide water utilities to timely be aware of bursts. This paper presents a novel burst detection approach using data from multiple pressure sensors in district metering areas (DMA). Differing from most data-driven methods that employ prediction models, this method utilizes a clustering algorithm to detect burst-induced data. Owing to the use of cosine distance in clustering analysis, temporal varying correlation between data from diffierent sensors is exploited, making the method only requires one day's worth of data to implement. When applied to a DMA with three pressure sensors, the method successfully detected some real and simulated bursts over a period of two months.

Keywords: Burst Detection; Cosine Distance; Clustering.

Online Burst Detection in Water Networks With an Ensemble of Flow Prediction Models

Shingo Adachi[1], Shinsuke Takahashi[2], Takeshi Takemoto[3]

[1, 2] Research & Development Group, Hitachi, Ltd.

292 Yoshida-cho, Totsuka-ku, Yokoyama-shi, Kanagawa, 244–0817, Japan

[3] Service and Platform Systems Business Unit, Hitachi, Ltd.

5-2-1 Omika-cho, Hitachi-shi, Ibaraki, 319–1293, Japan

[1]shingo.adachi.fc@hitachi.com

Pipe bursts in water distribution networks have to be dealt with quickly so as to prevent secondary accidents and expansion of supply suspension. Online burst detection methods have been actively studied from within the framework that an anomaly is detected by assessing the deviation of actual sensor readings from the corresponding predictions. However, these methods might fail or take too long to detect a gradually developing burst because their predictions are based on sensor readings from recent periods that would be immediately affected by the burst. In this study, we adopt an ensemble of flow prediction models to detect both step-shaped and gradually developing bursts earlier. One prediction model using recent flow readings has a smaller prediction range, which enables earlier detection of step-shaped bursts, while another model using only the older flow readings can robustly detect gradually developing bursts. The proposed method forms an ensemble of the models with different usages of flow readings and takes advantage of the strengths of each so that it can detect bursts of various development rates earlier. As a case study, the proposed method was applied to a set of synthetic data of a DMA with 20m^3/h inflow on average. It was found that half of the randomly generated gradually developing bursts were detected around when the development of the burst flow slowed down. It was also demonstrated that adopting the ensemble models actually reduced the amount of time it took to detect gradually developing bursts. A future task is the evaluation of the proposed method utilized for a real burst event.

Keywords: Anomaly detection; Leakage; Prediction Model.

Online Advanced Uncertain Reasoning Architecture with Binomial Event Discriminator System for Novelty Detection in Smart Water Networks

S. R. Mounce[1], A. Fargus[2], M. Weeks[2], J. Young[2], D. Ejimbe[3], E. Goya[3], M. Holburn[4], T. Jackson[2], and J. B. Boxall[1]

[1] Department of Civil and Structural Engineering, University of Sheffield, Sheffield, S1 3JD, UK

[2] Cybula Ltd, Computer Science Building, Deramore Lane, York. YO10 5GH, UK

[3] Thames Water, The Power House -Reading STW, Island Rd, Reading, Berkshire, RG2 0RP, UK

[4] Solvd, 2 Faraday Court, Rankine Road, Basingstoke, Hampshire RG24 8PF

[1]*s.r.mounce@sheffield.ac.uk*

Minimising the loss of treated water from water supply systems due to bursts is an ongoing issue for water service providers around the world. Sensor technology and the ‘big data’ they generate combined with machine learning based analytics are providing an opportunity for automated event detection. AURA-Alert has been developed as an online (Software as a Service) system which automates the training data selection (by selecting data with acceptable Match Strength and with regular retraining). The addition of a Binomial Event Discriminator service can produce alerts based on windows of thresholded match distances. A pilot deployment on over 200 live data streams in the cloud has been deployed as part of the SmartWater4Europe project. Examples of analysis for real events are presented. For a historic subset of eight data streams over a three month period up to 58% of bursts were detected (depending on window used for evaluation). It is concluded that the system is an effective and viable tool for novelty detection for water network time series data with potential for wider applicability. Key strengths include lack of per site configuration, data-driven self-learning (from periods of normality), real-time, high scalability and full automation of model retraining.

Keywords: Smart Water Networks; Neural Networks; Data Driven; Burst Detection; Online.

Data-driven Approach to Short-Term Forecasting of Turbidity in a Trunk Main Network

Gregory Meyers[1], Zoran Kapelan[2], Edward Keedwell[3]

[1,2,3]Centre for Water Systems, University of Exeter, Exeter, EX4 4QJ, UK

[1]*gmm206@exeter.ac.uk*

Water discolouration is an increasingly important and expensive issue due stricter regulatory demands and ageing Water Distribution Systems (WDSs) in the UK and abroad. This paper presents a turbidity forecasting methodology capable of aiding operational staff and enabling proactive management strategies. The methodology presented here does not require a hydraulic or water quality network model that can be expensive to build and maintain. The methodology is tested and verified on a real UK trunk main network with observed turbidity measurement data. Results obtained show that the classification based forecasts of turbidity can reliably detect if discolouration material is mobilised up to 5 hours ahead. The methodology could be used as an early warning system to enable a range of proactive management strategies as an alternative to regular trunk mains cleaning.

Keywords: Discolouration; Machine Learning; Random Forrest.

Sustainable urban water management

Evaluating Classification Algorithms for Improved Wastewater System Calibration

Mohammed Chachan Younis[1], Edward Keedwell[2], Dragan Savic[3], Anthony Raine[4]

[1,2] Department of computer Science [3] Centre for Water Systems, College of Engineering, Physics and Mathematics, University of Exeter

[4] BSc (Hons) C.WEM MCIWEM. Pell Frischmann

[1] *mcy201@exeter.ac.uk*

Hydraulic models provide an approximate model of rainfall collection (storm), wastewater collection (foul), and combined (both rainfall and wastewater collections) network performance, capturing the large scale element of the system, but such systems require calibration with real world data to achieve reliable and accurate results. However, many factors surrounding real-world network and catchment characteristics are unknown and can influence the hydraulic performance of the network. Consequently, calibrating wastewater models to accurately reflect real-world conditions is a time consuming and complex process. This paper employs a two stage urban runoff forecasting approach with a combination of image classification techniques and modelling using InfoWorks ICM. The image classification section consists of the automated processing of the satellite image as an aid to modelling wastewater in the urban environment by classifying the land-cover as pervious and impervious segments of water from rainfall events. By classifying such areas with an urban catchment, and by using the Wallingford PR Equation across all tests of Area 1 (roads), 2 (roofs) and 3 (permeable area), we explore the potential for a partially automated network system calibration process of a wastewater network.

Keywords: Urban Drainage, InfoWorks ICM, Image Classification.

Prediction Of CSO Chamber Water Levels Using Rainfall Forecasts

T. Rosin[1, 2,*], M. Romano[2], K. Woodward[2], E. Keedwell[1], Z. Kapelan[1]

[1] Centre for Water Systems, College of Engineering, Mathematics and Physical Sciences, University of Exeter, UK, EX4 4QJ

[2] United Utilities Plc, Lingley Mere Business Park, Warrington, UK, WA5 3LP

**tr319@exeter.ac.uk*

CSOs are a major source of pollution, spilling untreated wastewater directly into water bodies and/or the environment. This paper describes an investigation of the use of rainfall forecasts when predicting water level in a Combined Sewer Overflow (CSO) chamber. A prediction model based on a multi-layer feed-forward Artificial Neural Network (ANN) with a sliding time-window of inputs was developed to model the relationship between contributing rainfall and water level within a CSO chamber and predict the occurrence of spills. Three versions of the aforementioned prediction model were developed and compared: 1) without using forecast rainfall data, 2) with perfect rainfall forecasts (i.e. forecasts assuming perfect knowledge of historical rainfall into the future) and 3) with real rainfall forecasts. These models were tested on a CSO located in the Wirral area of the United Utilities network and were all able to successfully predict CSO spills 2 hours ahead. Use of forecast radar rainfall data, generated by the Met Office, was shown to demonstrably improve the accuracy of the ANN predictions and increase the prediction range of the model. Unsurprisingly, this accuracy was further improved when using perfect rainfall forecast data, due to errors inherent in real forecasts. It is envisioned that ANN models could be beneficially used by water utilities for near real-time modelling of water level in CSO chambers and generate alerts for upcoming spills events. The use of forecast data increases the detection time of CSO discharges, potentially enabling water utilities to take appropriate and timely action to address potential issues before the customers and environment are adversely effected.

Keywords: Artificial Neural Network; Combined Sewer Overflow; Radar Rainfall Nowcasts.

Smart Rainwater Management Systems Powered by the Internet of Things: a UK Case Study

Hossein Rezaei[1], Peter Melville-Shreeve[2], David Butler[3]

[1,2] Over the Air Analytics Limited, Innovation Centre, Rennes Drive, Exeter

[3] Centre for Water Systems, College of Eng. Maths and Physical Sciences, University of Exeter

[1]hossein.r@ota-analytics.com

Climate change is projected to significantly alter existing rainfall patterns. Traditional water and wastewater assets are unlikely to be able to respond to such events, particularly when factoring in increasing population growth. Novel source control and non-potable use strategies are required to limit the impacts of extreme events on water resources.

A novel, smart Rainwater Management System (RMS) was developed by Over the Air Analytics Ltd. building on research conducted at University of Exeter. The technology sees the commercial application of emerging Internet of Things (IoT) protocols and communication platforms to manage rainwater at source to mitigate flooding and provide alternative water resources in urban settings. With new technologies in data gathering, communications, power management, and associated software, IoT systems can enable real-time management of water sector assets. In addition, the reducing cost of such technologies is enabling their deployment in a widening set of technical niches. In this paper, results from a trial with the Future Cities Catapult (London) are presented including high resolution data acquisition and analysis of an innovative smart RMS. Over a 4-month trial period, at a residential property, the smart RMS successfully attenuated the rainfall from several storm events, whilst enabling rainwater reuse for non-potable applications (i.e. WC flushing). Despite some gaps in the data, due to power and connectivity disruptions, the system showed a high degree of reliability, with little downtime. The study concludes that the use of IoT in RMS shows potential to increase the flexibility and resilience of water and wastewater assets by adapting to the challenges of climate changes in an affordable, reliable and scalable system.

Keywords: Internet of Things; Smart Rainwater Harvesting; Smart Rainwater Management Systems.

Effects of Manning Coefficients and Absolute Roughness on the Optimized Designs of Urban Drainage Networks

Natalia Duque V.[1], Carlos Montes R.[2], Juan Zambrano B.[3], Juan Saldarriaga V.[4]

[1,2,4] Water Supply and Sewers Systems Research Center (CIACUA), Department of Civil and Environmental Engineering, Universidad de Los Andes, Bogotá, Colombia.

[3] Department of Civil and Environmental Engineering, Universidad de Los Andes, Bogotá, Colombia.

[3]n.duque634@uniandes.edu.co

Urban drainage networks are designed according to a series of regulations and methodologies that seek for an adequate operation of the system while transporting the urban wastewater and runoff. The design methodologies are founded in empirical or physically based flow resistance equations, such as Manning's and Darcy-Weisbach's equation, respectively. This work presents a statistical analysis over the costs obtained using the mentioned equations, considering different scenarios and materials. Furthermore, a comparison of the total construction costs was made to determine which methodology is the most appropriate for an urban drainage optimal design. The numerical examples were performed over two urban drainage networks with different topographical characteristics.

Keywords: Urban Drainage Networks; Optimization; Darcy-Weisbach; Manning.

Flood modelling and management

A 3D Web GIS Interactive Visualisation System for Animated Floods

Khoury[1], Gibson[2], Chen[3], Savic[4], Vamvakeridou-Lyroudia[5], Djordjevic[6]

[1,2,3,4,5,6] Centre for Water Systems - University of Exeter, EX4 4QF, Devon (United Kingdom)

[1]m.khoury@exeter.ac.uk

We present an interactive 3D WebGIS visualisation system that can show animated 3D floods, terrain, and buildings from a web browser. The system is entirely written in Javascript and using optimised WebGL technology based on the open source Three.js library. It can be used to view and deform terrain and flood surfaces in real-time, provided the modelling data are supplied in standard image formats. Although, in the examples presented below, the .png pictures expressing flood depth were produced via the CADDIES-2D modelling and simulation framework, the system can work online in real-time with any kind of flood modelling tool, as long as it provide 32 bits encoded images in a reasonable time frame. The system can show real-time 3D flood animations and seems to be simple and flexible enough to be used in future multi-player online serious games centred on flood.

Keywords: Flood Animation 3D-Visualisation.

Optimising a Fuzzy Logic Real-Time Control System for Sewer Flooding Reduction using a Genetic Algorithm

W. Shepherd[1], S. R. Mounce[1], S. Ostojin[2], M. Abdel-Aal[1], A. Schellart[1], P. Skipworth[2] and S. Tait[1]

[1] Pennine Water Group, Department of Civil and Structural Engineering, University of Sheffield, Sheffield, S1 3JD, UK

[2] Environmental Monitoring Solution, Unit 7, President Buildings, Savile Street East, Sheffield, S4 7UQ, UK

[1]w.shepherd@sheffield.ac.uk

CENTAUR aims to provide an innovative, cost effective, local autonomous data driven in-sewer flow control system whose operation will reduce urban flood risk. The system comprises of a specially designed flow control device and a wireless local water level monitoring and control system. A data driven algorithm has been developed that is able to analyse the water level data and issue instructions to the flow control device to reduce flood risk at the downstream flooding location. This Fuzzy Logic control algorithm has been linked to a SWMM model to allow virtual testing to take place and provide the basis for a Genetic Algorithm to optimise the Fuzzy Logic membership functions. Methods for generating the initial starting membership functions for input to the Genetic Algorithm have also been investigated. Results confirm that the best Genetic Algorithm optimised Fuzzy Logic controllers reduce flood volume by up to 25% depending on the timestep at which the algorithm is run and the membership function initialisation method.

Keywords: Real Time Control; Sewer Flooding; Genetic Algorithm; Fuzzy Logic.

Optimal Location and Sizing of Stormwater Storage Units: Case Study in Bogotá

João A. Zeferino[1], Maria C. Cunha[2], Nuno E. Simões[3], Juan G. Saldarriaga[4]

[1,2,3] MARE, Department of Civil Engineering, University of Coimbra Polo II, 3030-788, Coimbra, Portugal

[4] CIACUA, Aqueduct and Sewage Research Center, Department of Civil and Environmental Engineering, University of Los Andes, Bogotá, Colombia

[1]*zeferino@dec.uc.pt*

Flooding in urban areas may result in costly damage, and affect population safety and the proper functioning of cities. Controlling and managing urban stormwater involves adapting the urban drainage network to reduce peak runoff and prevent flooding impacts. This work presents an optimization model to find the best solution for implementing rainwater storage units (SUs). The optimization model was used to determine the optimal location and size of the SUs and their outflow orifice sizes, in order to minimize SU construction, maintenance and flood damage costs. Flood damage costs were assessed based on the depth of urban floodwater and the type of buildings. EPA-SWMM was used to simulate the hydrologic and hydraulic behavior of the drainage system and a simulated annealing algorithm was implemented to solve the optimization model. The developed methodology was tested on a case study inspired by a real urban area located in Bogotá, Colombia.

Keywords: Rainwater Storage Unit; Optimization; Simulated Annealing.

Analysis and Simulation of Drainage Capacity of Urban Pipe Network

Gomes, R.[1,6], Vellando, P. [2,7], Sousa, J.[3,6], Sá Marques, J.[4,6], Muranho, J.[5,6]

[1] Polytechnic Institute of Leiria, School of Technology and Management (Portugal)

[2] University of A Coruna, School of Civil Engineering, (Espanha)

[3] Polytechnic Institute of Coimbra, Department of Civil Engineering (Portugal)

[4] University of Coimbra, Department of Civil Engineering, Coimbra (Portugal)

[5] University of Beira Interior, Department of Computer Science, Covilhã (Portugal)

[6] MARE - Marine and Environmental Sciences Centre, Faculdade de Ciências e Tecnologia, Coimbra (Portugal)

[7] CITEEC - Centro de Innovación Tecnolóxica en Edificación e Enxeñería Civil, University of A Coruna (Espanha)

[1] Corresponding author: ricardo.gomes@ipleiria.pt

Nowadays the urban drainage networks performance is affect by the rapid development of urbanization, the infrastructure degradation and the climate changes. Thus, when high intensity precipitation occurs, instead of infiltrating in the soil, the rainwater causes an increase in the surface runoff which rapidly accumulates at the lowest points of the urban catchment, causing floods. The floods have a particular importance in urban areas, because affect the economic activities, the environment and the residents' lives; however, any intervention for floods control will always have high costs. Once it is technically/economically infeasible to design a storm water system which will never cause floods (the cost would be prohibitive), the best practices involves establishing a compromise between the cost and an acceptable risk of flooding to be considered in the design. It is within this framework that hydrology-hydraulic models have been used worldwide as a tool to support the planning, analysis, and design of storm water systems.

In the last decades the urban area of Leiria (Portugal) has spread quickly and the impervious surfaces increased significantly, mostly because of the type of pavements used (asphalt and Portuguese cobblestone) and the area occupied by buildings. One of the major problems is related to the recurrent floods in Leiria's downtown during periods of higher rainfall intensity. The urban area benefits from a large drainage network, but in some zones it has low performance, due to the degradation of the infrastructure and the successive located interventions occurred in the last decades (for network expansion and rehabilitation works). To minimize the flooding impacts in Leiria's downtown, the municipality intends to build an underground pipeline (a length of 1.5 kilometres, with a 2.0 metres diameter and 0.2% slope) to convey the runoff by gravity from Leiria's downtown to the river. This paper presents an integrated study of the urban catchment and the drainage network capacity using the Storm Water Management Model (SWMM). This study includes the analysis of the solution for different rainfall intensities (corresponding to different return periods) to assess its performance and, when required, suggests additional recommendations.

Keywords: SWMM; Urban Catchment; Urban Drainage Networks.

Water and wastewater treatment modelling, optimisation and control

Integrated Treatment Plant and Distribution Network Models to Predict the Drinking Water Quality from Source to Tap

A.R. Heinsbroek[1], N.B.A. Wolthek[2], R. Wuestman[3]

[1,2,3] Vitens NV, PO Box 1205, 8001 BE Zwolle, Netherlands

[1] *abel.heinsbroek@vitens.nl*

An accurate and real-time prediction of the water quantity and quality inside drinking water treatment plants is paramount to a more efficient and stable operation and can be utilized to proactively inform customers about changes in the delivered water quality. Although multiple attempts have been done to create real-time simulations of complete treatment plants, up until now the influence of residence time inside the pipes and treatment processes was ignored. In groundwater treatment, however, due to often long transport pipes between the well fields and the plant, the residence time is of significant influence. Therefore, a new modelling approach linking hydraulic simulations using EPANET with chemical calculations using PHREEQC was developed and validated for the small-scale groundwater treatment plant of Hoenderloo. By connecting the model of the treatment plant to a model of its distribution network a real time prediction of the delivered water quality, tracing packages of water all the way from the source wells to the customer tap, can be made.

Keywords: Drinking Water Treatment; Water Quality Modeling; Distribution Networks.

Multimechanism Fouling Model for Micro and Ultrafiltration Membranes for Wastewater Treatment

Tomasz Janus[1] and Bogumil Ulanicki[2]

[1] Independent Researcher

[2] Water Software Systems, De Montfort University, LE1 9BH, Leicester, United Kingdom

[1] *tomasz.k.janus@gmail.com*

Fouling is a term describing progressive reduction of membrane permeability during filtration of solutes and suspensions. The problem with fouling lies in its complexity and our lack of understanding of the science behind it. In wastewater treatment applications the problem is addition-ally magnified by polydispersity of wastewater suspensions. For these reasons fouling models in wastewater treatment applications are usually black-box or grey-box. Theoretical/classical fouling models are available but are applied predominantly to monodisperse suspensions where one fouling mechanism dominates and hence, only one classical fouling equation suffices to describe the filtration process. In wastewater applications we need to solve several equations simultaneously in order to be able to predict different stages of the filtration process. This paper presents such a model which combines three classical fouling mechanisms: blocking, constriction and cake growth. The paper shows successful calibration results but also indicates parameter identifiability issues.

Keywords: Fouling; Microfiltration; Mechanistic Model.

Security, reliability and resilience

Consequences from Business Loss

Seungyub Lee[1], Sangmin Shin[1], Dave Judi[2], Timothy McPherson[2], Steven Burian[1]

[1] Dept. of Civil and Environmental Engineering, University of Utah, Salt Lake City, UT

[2] Pacific Northwest National Laboratory, Richland, WA

seungyub.lee@utah.edu

Water distribution systems (WDSs) recovery methods have been assessed primarily using hydraulic deficit. However, hydraulic deficit does not reflect all performance goals needed to effectively guide resilience strategies. In this paper, a new approach is presented to measure resilience based on the idea of economic consequence loss in businesses due to WDS failure. Economic consequence loss of industry, classified by the NAICS code, are defined by relating GDP value added and water usage. Three different resilience objectives were investigated using a hypothetical water network: (1) identification of pipe criticality; (2) defining recovery strategies for different failure scenarios; and (3) development of recovery pathways by considering system resilience. Hydraulic analysis was performed using pressure driven analysis based on EPANET2.0. Results of pipe criticality proved high hydraulic deficit not always translated to high economic productivity loss. Also, the proposed system resilience quantification measure effectively serves as a guide for recovery pathways more resilient than other measures tested. In conclusion, considering both hydraulic resilience and economic consequence provides a more effective approach toward enhancing overall system resilience.

Keyword: Economic Consequence; Resilience; Recovery Strategies.

A New Index System for Intermittent Water Supply

C Loubser[1], HE Jacobs[2]

[1,2] Department of Civil Engineering, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa

[1]*carloloubser@sun.ac.za*

Intermittent water supply is a worldwide phenomenon, that adversely impacts water availability, water quality, human health, reticulation network operation, maintenance, service life as well as water demand. A need was identified to develop an index designed to categorise, classify and better understand intermittent water supply in all its forms. Research to date has addressed the prevalence, causes, impacts, water quality, health problems, water demand and operational problems associated with intermittent water supply. Despite the available body of research, an index has not been developed to quantify the extent of intermittent supply in any given supply system, or part thereof. A study was conducted on the experience of intermittent water supply and lessons learnt throughout the world, with the specific aim of developing an index comprising all relevant parameters. The study included an extensive literature review and detail analyses of causes, impacts and magnitudes associated with intermittent water supply. As part of this research, all the relevant parameters are being identified and incorporated to conceptually develop a generic index for intermittent water supply. It was found that intermittent water supply is often complicated by other factors leading to ephemeral periods of non-supply, especially in developing countries. Parameters that were available in quasi real-time, such as reservoir levels, flow rates and water pressure, were considered useful in view of future application to control and manage distribution systems so as to prevent areas of intermittent supply. With the index fully developed it will become possible to compare intermittent water supply in a global context, get an understanding of the causes, classify severity and potential impacts of intermittent water supply, better plan remedial action, and increase reticulation network resilience.

Keywords: Intermittent Water Supply.

Augmented Resilience of Water Distribution Systems Following Severe Abnormal Events

Olivier Piller[1], Fereshte Sedehizade[2], Thomas Bernard[3], Mathias Braun[1], Nicolas Cheifetz[4], Jochen Deuerlein[5], Martin Wagner[6], Emmanuel Lapébie[7], Iris Trick[8], Jean-Marc Weber[9], and Caty Werey[10]

[1] Irstea, UR ETBX, Dept. of Water, F-33612 Cestas, France

[2] Berliner Wasserbetriebe, Neue Jüdenstraße 1, D-10179 Berlin, Germany

[3] Fraunhofer Institute IOSB, Fraunhoferstrasse 1, D-76131 Karlsruhe, Germany

[4] Veolia Eau d'Ile de France, Le Vermont, 28, Boulevard de Pesaro,
F- 92751 Nanterre, France

[5] 3S Consult GmbH, Albtalstrasse 13, D-76137 Karlsruhe, Germany

[6] TZW: DVGW-Technologiezentrum Wasser, Außenstelle Dresden, Wasserwerkstr. 2, D-01326 Dresden, Germany

[7] CEA, DAM, F-46500 Gramat, France

[8] Fraunhofer Institute for Interfacial Engineering and Biotechnology
Nobelstr. 12, D-70569 Stuttgart, Germany

9 Service de l'eau de l'Eurométropole Strasbourg, 1 Parc de l'Etoile,
F-67076 Strasbourg, France

[10] ENGEES GESTE and ICUBE F-67070 Strasbourg, France

[1]*olivier.piller@Irstea.fr*

The detection of faults and the capacity to return quickly to a normal state after failures and interruption of services are essential for water utilities. The ResiWater project aims to improve the following three aspects for better network security and enhanced resilience: prevention, surveillance and response of water distribution systems facing the major threats. In this paper, we present the ResiWater project main results after two years. A focus is made on the resilience framework and the development of high-performance sensors for fast detection of water quality deterioration or system breakdown.

Keywords: Secure Sensor Networks; Robust Simulation Models; Resilience Assessment.

Contributing Authors