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Water at the Centre of Environmental Issues – Research at the UCD Dooge Centre for Water Resources Research

Zeinab Bedri
Technological University Dublin, zeinab.bedri@tudublin.ie

Eva M. Mockler
University College Dublin

Michael Bruen
University College Dublin

See next page for additional authors

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Water at the Centre of Environmental Issues – Research at the UCD Dooge Centre for Water Resources Research

Bedri, Z., Mockler, E. M., Bruen, M.*,Zhao, Y., Purcell, P.J., Al Saji, M., Corkery, A., Doherty, L., Dzakpasu,M., Martins, J., Quinn, A, Rymszewicz, A. & Willuwet, L.

[1]UCD Dooge Centre for Water Resources Research, Dublin, Ireland
(*Corresponding author: E-mail: Michael.bruen@ucd. ie)

Abstract
Since 1988, the UCD Dooge Centre for Water Resources Research has been conducting research in a wide range of water topics including hydraulics, hydrology, coastal dynamics and wastewater with an emphasis on multi-disciplinary collaboration. This paper presents an overview of this research, both past and present, and provides an outlook to the future research directions of the Centre.

Keywords
Water resources, research, hydrology, catchment management, coastal modelling, climate change

1. INTRODUCTION

Irish researchers have contributed substantially to international research in the area of hydrology and both Jim Dooge, UCC and UCD and Eamonn Nash, National University of Ireland, Galway (NUIG) follow in the footsteps of men such as Mulvaney and Kelly. Their combined legacy has provided the basis for ongoing research into the many modern issues related to water.. The UCD Dooge Centre for Water Resources Research (CWRR), named in memory of Jim Dooge, aims to continue this tradition, to improve knowledge in the area of water resources to inform environmental managers, policy makers and the broader research community.

The CWRR has a well-established tradition of research in water engineering including hydrologic and hydraulic studies, water quality modelling and environmental impact assessment, water and wastewater treatment science and technology and water pollution control. Over eight million euro of funding has been secured in recent years, through sponsored and contract research projects and with clients in both the public and private sector. These research projects have contributed to the postgraduate education of over a hundred students over the past 25 years.

The main focus of the CWRR's research to date has been related to;

(a) Use of GIS and decision support systems in water resources engineering,

(b) Study of aquatic chemistry,

(c) Unit processes in water and sewage treatment,

(d) Flood forecasting and management,

(e) Estuary hydrodynamics and water quality,

(f) Theoretical and numerical analysis on the behaviour of classical unit hydrograph and flood routing methods,

(g) Hydraulic resistance in natural streams,

(h) Conveyance and sediment transport in floodplain flows,

(i) Catchment hydrological and pollution modelling

(j) Performance of constructed wetlands and other novel techniques for wastewater treatment.

2. BACKGROUND

The UCD Dooge Centre for Water Resources Research (CWRR) was formally opened in 1988 by the then Minister for the Environment, Mr. Padraig Flynn, T. D. under the direction of Dr. Phillip O' Kane. He was then succeeded by the late Mr. Aodh Dowley in 1990 who later became Head of the Civil Engineering Department at

the time. Prof. Michael Bruen has been the director of the Centre since June, 1996.
Hydrological modelling has been one of the first research activities within the Centre. Of the early hydrological studies was a research project on the spatial variability of land surface processes (SLAPS I and SLAPS II) under the EPOCH programme of the European Union. Another research project studying the role of soil moisture in climate modelling was funded by the European Economic Community (EEC) programme (see Dooge and Bruen, 1997). Other studies at the time focused heavily on the improvement of flood estimation and analysis (see for examples Dooge and Bruen, 1989, 1997; Bruen and Dooge, 1992).
The CWRR has carried out hydrodynamic and water quality coastal modelling since 1990. Simulations using numerical models, at first based on the finite difference method, were considerably enhanced by the purchase of two Digital Equipment Corporation (DEC) Alpha workstations, which were the state-of-the-art computation equipment at the time. This facilitated much improved simulation speeds for the computationally demanding coastal modelling experiments. Among the first coastal modelling studies of the CWRR were a nutrient and pathogen model of Dublin Bay as part of a multi-disciplinary study (Dowley and Qiang, 1991) and a number of applied studies of Dublin Bay related to coastal water quality issues (Dowley and Qiang, 1992; Dowley and Hussey, 1995).The development, improvement, and application of decision support tools have also been core to the research within the CWRR. The tools have proved to be of great support to policy-makers and have been widely applied in Environmental impact assessments and design decisions (see Rogers and Bruen, 1999, 2000; Rogers et al., 1999). Ireland’s first water related decision support system was developed there by J Y Zhang, Dowley and Bruen.

3. RESEARCH ACTIVITIES

Water is an essential requirement for life, for food and for development and in recent times has formed the basis of a number of key EU directives (WFD, Floods Directive etc.) that are shaping the direction of environmental research both in Ireland and in Europe. Climate change is an added influence which is expected to impact heavily on the water resources both in Ireland and elsewhere. These environmental and policy factors have driven the research at the CWRR, as detailed below.

3.1 Hydrological and catchment water quality

Dooge (2005), advocated a methodology of careful simplification through which modellers can aim to derive a better understanding of dominant processes. Modelling and data analysis at catchment scale has followed this principal in the investigation of both flooding and water quality processes across Ireland.

3.1.1 Hydrological Modelling

There is an emphasis in the CWRR on comparative hydrology, with modelling investigations typically including several catchments and model structures. A wide range of complexity of models have been explored and compared, from black-box, conceptual, fully physically based distributed catchment modelling (Dooge et al., 1999; Nasr et al., 2007; Taskinen and Bruen, 2007). Statistical analyses of hydrological processes have also been undertaken (Taskinen et al., 2008). Sensitivity analysis of hydrological models and parameters has been investigated for several models, as an important aspect of model evaluation (Mockler and Bruen, 2013; O'Loughlin et al., 2013). The use of radar data with hydrological modelling has been investigated for flood forecasting and warning in Irish catchments (Bruen, 2000, 2012; Desta et al., 2012).

3.1.3 Catchment water quality modelling

Water quality modelling has gained prominence in recent years due to the need to apply state of the art advancements in science to address environmental issues, and to support water policies such as the Water Framework Directive (WFD). Funding and research in this area has been driven by the dominant national issues, with a focus on nutrients, pathogens and sediment. As with hydrological modelling investigations, a broad range of catchment scale water quality modelling has been employed and compared in the CWRR, including both well established and “home-grown” models.
Due to strong coding experience of researchers in the Centre, water quality components of existing models have been edited and tested with other model components to assess performance Igbal and Bruen (2014) and ultimately improve the understanding of hydrological processes through modelling. New models have also been developed including a physically based phosphorus modelling component for distributed modelling (Nasr et al., 2005) and comparison of this model with other established models (Nasr et al., 2007). Recent modelling developments have included a fuzzy national phosphorus export model (Nasr and Bruen, 2013).
Driven by the EU Bathing Water Quality Directive 2006/7/EC ,the Smart Coasts Project employed a catchment model (MIKE11) to simulate the transport of Escherichia coli (E. coli) and Intestinal Enterococci (IE) from an agricultural catchment to the Irish sea (Bedri et al., 2014). The model has been calibrated at a sub-catchment level to predict faecal contamination from human sources (e.g. septic tanks) using measurements of the Human

Gene Marker (HF183f), and results highlight the need to upgrade domestic waste water systems within the catchment to avoid human health risk in bathing water areas during high rainfall events.

The CWRR, as a part of the SILTFLUX project, is carrying out the first comprehensive assessment of the magnitude and dynamics of fine sediment transport and resultant sediment ecological impacts in selected Irish rivers. This work, funded by the Irish EPA is driven by WFD requirements for the improvement of water quality status. The main objective of the ongoing work is to increase knowledge and understanding of silt fluxes in rivers to help set appropriate standards for suspended or deposited sediment which would reflect nature of sediment transport, ecological response and specifics of Irish catchments. The research combines high resolution continuous monitoring of study catchments and a range of modelling approaches, and aims to produce a nationally applicable sediment yield prediction tool.
Additional on-going research includes investigation of the impact of forest operations on water quality in rivers and streams (recently completed HYDROFOR project funded by the Irish EPA).

3.2 Decision Making and the Environment
A key goal for the CWRR is to transform and communicate modelling results and research findings to useful information for policy makers and environmental managers. Systems analysis and decision support systems for environmental management have been central to the Centre's research. These include the application of the ELECTRE III model (Martin and Bruen, 1998; Rogers and Bruen, 1999, 2000) to a number of design problems. The WINCOMS project (Bruen, 2008) identified new approaches for public participation using decision support systems for the implementation of the WFD. These projects have influenced many subsequent scientific studies in the Centre to specifically address the challenge of communicating and disseminating the research findings in meaningful ways, including interactive websites with real-time forecasts e.g. Smart Coasts, (Bedri et al., 2014), policy documents, e.g. related to road runoff (Desta et al., 2007) and management tools (Pathways Project).

3.2.1 Integrated Catchment Management
Geographical Information Systems (GIS) have been considered as invaluable tools for catchment modelling and management for many years in the CWRR (Gismalla and Bruen, 1996; Zhang et al., 1996). Advancements of GIS data and computing power have allowed scientists to explore catchments in new ways, by combining information from many disciplines to develop conceptual understanding of catchments processes (Bruen, 2009). Researchers at the CWRR, as a part of the *Pathways* Project, have developed the suite of Catchment Management Support Tools (CMST), combining GIS and water quality models to support catchment management in Ireland. The tools are applicable at national scale, and were informed by previous and on-going national and international studies, along with the field data collected in the four *Pathways* study catchments (Mockler et al., 2013). Compared to previous studies, which were based on a fixed number of catchments, the models that are the basis of these national tools face the challenge of being nationally applicable operational models that aim to support the WFD objectives.

3.3 Coastal Studies
"Modelling the water quality of the Dublin region will continue to be a fruitful topic of research at the CWRR for many years to come and we trust that this work will provide useful practical assistance to decision makers." (Dowley and Qiang, 1991)

These were the final concluding remarks of the report describing the first hydrodynamic and water quality model developed at the UCD Dooge Centre for Water Resources Research completed as part of a multi-disciplinary project led by the Environmental Research Unit (ERU) of Trinity College Dublin, Ireland. The described work entailed development and application of two-dimensional finite difference (Dowley and Qiang, 1991) hydrodynamic and water quality models of Dublin Bay to simulate the transport and fate of pathogens and nutrients discharged from a wastewater treatment plant, and their effects on the recreational water quality at close-by beaches. The acquisition of two DEC Alpha workstations at the time, reduced computation time to manageable time scalesand made scenario development feasible.. They also facilitated subsequent improvements to the model numerical scheme (Hussey, 1996) which significantly enhanced the simulation speed.
The second generation of hydrodynamic and water quality models at CWRR took advantage of advances in un-structured mesh theories for numerical modelling. Consequently, the Dublin Bay hydrodynamic and water quality model was reconstructed using a two-dimensional finite-element model under the INTERREG IIIA programme which was a joint research venture between the University of Wales, UK and UCD. The work aimed to improve the understanding of the transport of sewage discharges into Dublin Bay and their fate under varying environmental conditions (see Bedri et al., 2011) in order to help achieve and maintain the bathing water quality standards set by the EU Bathing Water Directive and 2006/7/EC (EC, 2006) . A comparative study of the two-

dimensional finite difference and finite element hydrodynamic models of Dublin Bay highlighted the computation superiority and flexibility of the finite-element model over the finite-difference one.The finite element modelling efforts were further extended to include a three-dimensional models of Dublin Bay to simulate the effect of thermal discharges from a power plant and their effects on the mixing and transport of wastewater (Bedri et al., 2013) in estuarine waters. In a study comparing two-dimensional and three-dimensional coastal models, Bedri et al. (2011) highlighted the merits and importance of three-dimensional models in simulating the hydrodynamics and pollutant transport in stratified flow environments.

These hydrodynamic and water quality models of Dublin Bay have played a major role in assisting policy-makers over the years. These include consultations and model simulations to provide an environmental impact assessment during the design of a causeway across a tidal lagoon in Dublin Bay, and an assessment of discharge strategies for extension works of sewage treatment plants, and future projections of sewage discharges (Dowley and Bedri, 2004; Dowley and Hussey, 1995; Dowley and Qiang, 1992).

However, the last decade has witnessed key changes to the EU environmental policies which call for improved methodological approaches to achieve higher water quality standards required by these EU policies. This made it necessary to adopt more holistic approaches to the evaluation of pressures on the coastal system. Therefore under the funding of INTERREG IVA, the CWRR has embarked on a research project that develops a real-time water quality forecasting system that comprises an integrated catchment- 3D coastal water quality model to simulate flow and contaminants from a catchment to coastal waters (see Bedri et al., 2014).

3.4 Water Issues in the Manmade Environment

Climate change, urbanisation, and population growth are three main stressors on our environment. The CWRR has earlier on recognised the need to study these environmental stresses and their effects on the urban society and has conducted research in the following key areas:

3.4.1 Climate change impacts

The frequency and severity of extreme weather events, such as extreme rainfall, flooding and drought have been the focus of many research projects within the CWRR. The TELFLOOD project funded by the EU-FP4 was one of the first large-scale projects to be researched within the CWRR and it studied methods for improving flood forecasting lead times using rainfall forecasts from high-resolution regional atmospheric models for steep catchments near urban areas (Bruen, 2000). Subsequently, an initiative by the Irish Office of Public Works (OPW) to update flood estimation methods in Ireland, has prompted the CWRR to conduct a series of research projects to review the methods of flood estimation in use by Irish local authorities (O'Sullivan, et al. 2012a), and to investigate approaches for improving flood estimation in catchments and compound river channels. These studies included the development of a revised Muskingum routing approach for compound channels (O'Sullivan, et al. 2012b) in addition to numerous investigations on the interactions and energy transfer between the main channel and floodplain sections of a compound channel using one-dimensional, two-dimensional and three-dimensional models (see Ahilan et al., 2012; Conway et al., 2012). An on-going research project at the Centre includes trend analysis of precipitation records to investigate the influence of climate on catchment hydrology.

Furthermore, as part of the UR-Flood project (under the 2nd ERA Net CRUE research initiative), a study was undertaken to explore the role of public perception in flood risk management (Bradford et al., 2012). The study utilised extensive quantitative (survey questionnaires) and qualitative research (focus groups and structured interviews) to identify obstacles and barriers in flood and communication strategies in Ireland (O'Sullivan et al., 2012c). The work highlighted the importance of public communication and risk perception in the development of flood management plans.

Although the prediction and analysis of flooding has been the focus of many research institutes including CWRR, the occurrence of other climate change effects such as droughts/low flow regimes have also been investigated at the Centre. A previous study funded by the Irish EPA, has analysed low flow regime in Irish rivers and examined the climate change indicators in order to produce improved estimated for low flow indices in Irish rivers for water quantity and quality management. The study applied various statistical techniques employed in trend analysis and time series predictions and concluded that while there is an overall increase in the low-flow index, data in some hydrometric stations showed a significant decreasing trend strongly associated with a decreasing trend in total summer rainfall (Nasr and Bruen, under review). Moreover, a current study is in progress to review the state-of-the art in warning systems for extreme events and natural disasters. The reviewed disasters include extreme precipitation, droughts, extreme temperatures (heat and cold waves), inland and coastal flooding, landslides and debris flows, ecosystem function and dynamic shifts, and many others. The work will interview various national and international agencies with responsibility for disaster warning and management and report on their capabilities and data availability. It is envisaged that this work will contribute to decision making in relation to a national disaster warning infrastructure, regardless of the managerial context in which it is deployed. It will describe in detail the warning possibilities and their technical requirements for a wide range of natural and environmental disasters related to climate change. It will also demonstrate the huge overlap in data requirements involved and identify the synergies and value that can be achieved with a coordinated approach.

3.1.2 Wastewater treatment

The development of novel approaches for the improvement of wastewater treatment has been one of the key research activities within the CWRR.

The wastewater treatment group has focused on the development of the novel constructed wetland (CW) technology aimed to achieve high treatment efficiency, therefore, promoting CW from a polishing wastewater treatment facility into a major treatment process in small and middle scale wastewater treatment facilities in practice. A number of physical and numerical modelling studies were conducted to develop and optimise operational strategies of CW for high strength wastewater treatment efficiency. The investigations include operational methodologies such as "tidal flow" strategy (Zhao et al., 2004a; Sun et al., 2006, Hu et al., 2014a,b), effluent recirculation in constructed wetlands (Zhao et al., 2011b) , "Anti-sized" constructed wetland (Zhao et al., 2004b; Sun et al., 2007; Hua et al., 2013) and step-feeding methods (Hu et al., 2012b) in addition to numerical modelling tools such as STELLA for modelling pollutants behaviour in CW system (see Kumar et al., 2011a,b). In a recent work, Zhao et al., 2013 developed an integrated constructed wetland as a multi-function system that serves as a wastewater treatment system while preserving the aesthetic appearance of a landscape.

Nutrient (Nitrogen and Phosphorus) removal in constructed wetlands has been extensively studied within the CWRR. Biological process of nitrification and denitrification, CANON process for Nitrogen removal has been well investigated and this has provided good showcase of robust N removal in CW system (Hu et al., 2012a). Significant Phosphorus removal has been achieved in the alum sludge-based CW system, which is the first of its kind worldwide (Babatunde and Zhao, 2009). In addition, several strategies of Phosphorus recovery from the used/saturated alum sludge have been explored (Zhao et al., 2011a). Other studies for Phosphorus removal/immobilization include: adsorption of Phosphorus by alum sludge (Yang et al., 2006; Razali et al., 2007; Babatunde et al., 2009; Babatunde and Zhao, 2010), reject water treatment via alum sludge filtration (Yang et al., 2009) and pesticide removal via waterworks residual (Hu et al., 2011).

Sludge management/treatment represents up to 60% of the cost incurred by water and wastewater treatment processes. Therefore a number of studies were conducted to improve conditioning and dewatering, the most important processes in sludge management. The studies investigated the use of dual polymers (Ma et al., 2007), skelton builder addition (Zhao, 2006) and non-polymer conditioning (Tony et al., 2008, 2011) to achieve better dewatering of alum sludge. Also the possibility of recycling and re-using alum sludge for co-conditioning wastewater sludge (Yang et al., 2007), development of alum sludge-based CW system (Zhao et al., 2009a), a method for Phosphorus control in lake sediments (Wang et al., 2013) as well as the use of dewatered alum sludge in the construction sector have been investigated.

Furthermore, a research is underway to investigate methods to recover energy from wastewater treatment. The study explores methodologies of incorporating microbial fuel cell (MFC) technology into constructed wetlands for combined purposes of nutrient removal and the production of electricity (Doherty and Zhao, 2014).

3.1.3 Waste management

Waste management has been widely recognised as one of the most problematic areas of Irish environmental management. With the rate of waste generation continuing to increase and existing waste disposal sites reaching the end of their useful lifetimes, waste management is increasingly becoming a matter of urgency (Purcell and Magette, 2009). In response to the need to address waste management issues, a study was conducted at the Centre to understand and characterise waste generation patterns arising from demographic changes and development within the Dublin region. The work created a geographical information system (GIS) model of biodegradable municipal waste generation to provide waste estimates which can aid waste planning and policy decisions (Purcell and Magette, 2009). Also the study conducted questionnaires to residential and commercial sectors to investigate relative to waste generation, waste management behaviour, attitudes, and future concerns (Purcell and Magette, 2011) with the aim of implementing targeted intervention strategies to optimise waste diversion from landfills.

3.1.4 Road run-off

Highway runoff has been identified as a significant source of contaminants that adversely impact on the receiving aquatic environment and therefore has been the focus of a number of research studies within the CWRR. In a study funded by the Irish EPA, Desta et al. (2007) investigate the quality of highway runoff from four sites from two motorways outside Dublin by taking water quality samples during storm events and analysing them for heavy metals, some specified PAH's, among other pollutants and detected significant levels of heavy metals in the water samples taken. Also Purcell et al. (2012) conducted a study to assess the environmental impacts of the construction activity of a motorway on the water quality and their potential effects on the aquatic life. As part of the study, a real-time water quality station was installed o provide a continuous data stream for monitoring purposes and mitigation measures were taken to reduce the impact of the construction on the aquatic environment. The study reports the success of these mitigation measures.

Reclaimed asphalt (RA) is a valuable natural resource that is not currently used to its full potential. Before the widespread use of the material can be encouraged, the potential for RA to adversely affect its environment must be assessed. To this end, and with a particular focus on the aqueous environment, a combination of leaching tests, larger-scale tests using a rainfall simulator and computer modelling are currently underway in the CWRR (Quinn et al., 2012).

3.1.5 Urban water systems

Population growth, urbanisation and climate change represent significant pressures on urban water resources, requiring water managers to consider a wider array of management options that account for economic, social and environmental factors. As part of a research study in the Centre, a Dynamic Urban Water Simulation Model (DUWSiM) was developed to link urban water balance concepts, with the land use dynamics model (MOLAND) and the climate model LARS-WG to assist in the long-term planning of urban water supply and water demand by analysing the effects of urbanisation scenarios and climate changes on the urban water cycle. The model DUWSiM has been tested using data from Dublin, and results show that the model was able to satisfactorily predict water demand and stormwater runoff (Willuweit and O'Sullivan, 2013).

4. LABORATORY ACTIVITIES SUPPORTING RESEARCH

The laboratory facilities support most of the experimental research studies at the Centre allow researchers to actively engage in data collection and analysis. The facilities at the CWRR include laboratories for Hydraulics, Water & Effluents, and Unit Treatment Processes. The laboratory has the infrastructure and capacity to undertake water quality analysis for a large number of water quality determinands including BOD, COD, TOC and nutrients (N and P), turbidity, suspended solids, alkalinity, hardness, and chlorine.

5. SUMMARY AND OUTLOOK

There is an increasing realisation of the centrality of water issues in the natural and constructed environment and of its role in life, food, risk, natural hazards and the transport and attenuation of pollution. Fulfilling an increasing need for multi-disciplinary research to address complex challenges depends on our understanding of and ability to model the complex interactions with water. The research at the UCD Dooge Centre for Water Resources Research will continue to contribute to these tasks.

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Disclaimer

The work presented herein provides a short overview of the history of research activities at the CWRR, and while it has aimed to include most studies conducted in the Centre some studies may not have featured in the overview. Any such omission is unintentional.

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