

Institution: University of Exeter		
Unit of Assessment: UoA 12 Engineering		
Title of case study: CAFlood – rapid flood modelling software which has improved community resilience to flooding		
Period when the underpinning research was undertaken: 2010-2013		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Albert Chen	Associate Professor	2006-present
Dragan Savic	Professor	1994-present
Slobodan Djordjevic	Professor	2002-present
Michele Guidolin	Research Fellow	2010-2016
Bidur Ghimire	Research Fellow	2010-2013
Mike Gibson	Research Fellow	2011-present
Andrew Duncan	Research Fellow	2010-2017
Period when the claimed impact occurred: 2014-2020		
Is this case study continued from a case study submitted in 2014? N		
1. Summary of the impact		
<p>Tools, methods and solutions to address increased flooding risk are urgently needed with damage costs in the UK estimated at £1bn per annum. The software tool CAFlood allows accurate flood risk assessment to be carried out much more rapidly than conventional approaches. Adopted by national and international government organisations and industries, it has provided timely and high-resolution flood risk analysis, leading to impacts including:</p> <ul style="list-style-type: none"> • Safeguarding of people, properties and businesses in Torbay (UK), Taipei (Taiwan) and Naples (Italy) from over £78m of flood damage. • Benefits from commercial uptake in reinsurance companies (Munich Re and Swiss Re) flood risk assessment and Thames Water asset management. 		
2. Underpinning research		
<p>Since 2000, researchers at the Centre for Water Systems (CWS) at the University of Exeter have developed a strong portfolio of research on flood risk modelling and impact assessment through a number of EPSRC and EU funded projects.</p> <p>Flood related research by a led by multidisciplinary team Profs. Chen, Savic, and Djordjevic has been supported by EPSRC funding (EP/H015736/1, 2010–2013) to investigate a radically different approach to modelling flood dynamic behaviour over 2D terrain. The team investigated the use of cellular automata, an artificial intelligence methodology that implements general rules to determine interactions between cells in a local neighbourhood in a discrete manner, for flood propagation modelling. The project was co-funded by 14 private and public sector partners, including Thames Water, Yorkshire Water, United Utilities, Northumbrian Water, Halcrow, Wallingford Software, the Environment Agency and Torbay Council.</p> <p>As a result, the CAFlood software was created to simulate flood propagation over a terrain using cellular automata transition rules, rather than the solution of complex</p>		

hydraulic equations [3.1]. The use of cellular automata allows the computing algorithms to be highly parallelised and executed in a distributed computing environment, taking advantage of the processing capacity of modern graphical processing units. The model's applicability was validated with simulations of various flood types (e.g. pluvial [3.2], fluvial [3.3], and coastal [3.4]) and environments (e.g. rural floodplain [3.5], urban areas [3.6]). Because of its computing efficiency it can cope with a wide range of flooding scenarios, with high levels of complexity. The software delivers accurate and efficient simulations with comparable levels of precision to software based on traditional hydraulic models, but in 20-30% of the time [3.3; 3.6].

Relative to existing modelling tools, the high performance of CAFlood has enabled it to:

- (1) provide flood forecasting and early warning with longer lead-times based on real-time weather observation and prediction information - so that decision makers can better coordinate emergency response actions to protect citizens;
- (2) analyse flood risk for the same area with finer resolutions, or for a larger area with the same resolution – so that mitigation measures can be developed and implemented to reduce hazard impact; and
- (3) more effectively quantify the uncertainty caused by various factors by employing multiple simulations – so that long-term policy or strategic planning can be implemented to ensure adaptations are flexible and robust to cope with future climate change and socio-economic development scenarios.

A basic version of the CAFlood software has been provided as open source on the CWS website along with a user manual and key scientific publications.

3. References to the research

- 3.1. Ghimire, B., Chen, A.S., Guidolin M., Keedwell E.C., Djordjević S., Savić D.A.** (2013) Formulation of fast 2D urban pluvial flood model using cellular automata approach, *Journal of Hydroinformatics*, 15(3), 676-686. [doi:10.2166/hydro.2012.245](https://doi.org/10.2166/hydro.2012.245).
- 3.2. Wang, Y., Chen, A.S., Fu, G., Djordjević, S., Zhanga, C. and Savić, D.A.** (2018) An integrated framework for high-resolution urban flood modelling considering multiple information sources and urban features, *Environmental Modelling & Software*, 107, 85-95. doi.org/10.1016/j.envsoft.2018.06.010
- 3.3. Guidolin, M., Chen, A.S., Ghimire, B., Keedwell, E. C., Djordjević, S., Savić, D.A.,** (2016) A weighted cellular automata 2D inundation model for rapid flood analysis, *Environmental Modelling and Software*. 84, 378–394. [doi:10.1016/j.envsoft.2016.07.008](https://doi.org/10.1016/j.envsoft.2016.07.008).
- 3.4. Vamvakeridou-Lyroudia, L.S., Chen, A.S., Khoury, M., Gibson, M.J., Kostaridis, A., Stewart, D., Wood, M., Djordjevic, S., Savic, D.A.** (2020) Assessing and visualising hazard impacts to enhance the resilience to urban flooding. *Science of the Total Environment*. 707 (136078). [doi:10.1016/j.scitotenv.2019.136078](https://doi.org/10.1016/j.scitotenv.2019.136078).
- 3.5. Khoury M., Gibson M.J., Savic D.A., Chen A.S., Vamvakeridou-Lyroudia L.S., Langford H. and Wigley S.** (2018). A Serious Game designed to explore and understand the complexities of flood mitigation options in urban-rural catchments, *Water*, 10(12), 1885. [doi:10.3390/w10121885](https://doi.org/10.3390/w10121885).
- 3.6. Webber, J.L., Gibson, M.J., Chen, A.S., Savic, D.A., Fu, G., Butler, D.** (2018) Rapid assessment of surface-water flood-management options in urban catchments, *Urban Water Journal*. 15(3), 210-217. [doi:10.1080/1573062X.2018.1424212](https://doi.org/10.1080/1573062X.2018.1424212).

4. Details of the impact (indicative maximum 750 words)

CAFlood has been adopted by national and international industries and government organisations for fast flood risk assessment to develop protecting infrastructures, to establish flood forecasting and early-warning systems, and to create commercial services for strengthening flood resilience. The major impacts are outlined below.

Safeguarding of people, properties and businesses

- CAFlood has supported flood risk management planning in multiple cities. An **estimated 3,000 people have been protected and £78m potential damage has been prevented by £3.4m Torbay flood defence investment [5.1; 2018]**

In 2018, Torbay Council, as part of an EU Horizon 2020 project (EU-CIRCLE), adopted CAFlood for high-resolution flood risk assessment in Torquay, Paignton and Brixham. CAFlood was the only software capable of undertaking the full range of flood simulations within the required timescales. The analyses included evaluation of the effectiveness of various adaptation measures such as raising the existing flood wall or adding a secondary flood wall with different height options. **Figure 1** demonstrates one of the analysis outcomes using CAFlood in Paignton.



Figure 1

The results provided the evidence that flood damage could be reduced from £78m to £0.2m by installing the secondary flood wall, safeguarding more than 3,000 people in 700 residential households, 330 commercial properties and 165 hotels [5.1]. According to Torbay Council: “*This scheme was approved by the Environment Agency and the government has confirmed investment of £3.4m in the critical infrastructure to improve the community resilience against flooding*”.

- **200,000 households and over a million commuters benefited in Taipei City, Taiwan [5.2; 2019]**

Taipei City Government has been working with National Taiwan University (NTU) since 2019 to build a flood forecasting and early warning system to strengthen the city’s capability to respond to flooding events, where Typhoon Nari in 2001 claimed 30 lives, and resulted in an economic loss of over £200m [5.2]. NTU used CAFlood to inform an early warning system, which has transformed the Taipei emergency services approach to flood crisis management. Now over 200,000 households and over a million commuters in the Metropolitan Taipei Area are benefitting [5.2].

- **Strategies planned to protect citizens from flooding in Naples, Italy [5.3; 2019]**

The Italian government-funded Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC) Foundation adopted CAFlood to help the city of Naples develop adaptation strategies to reduce future flood impact and protect its 980,000 inhabitants. The work demonstrated the advantages of CAFlood over the CMCC’s existing system, saving 3 months and €12,000 for 30 simulations. [5.3].

Benefits arising from commercial uptake

Commercialisation of the software has led to benefits through licensing and improvements in risk analysis and premium estimation.

- **Flood risk assessment for a major global re-insurance industry [5.4; 2014-2016]**

CWS formed a research partnership with Munich Re, one of the world's largest reinsurance companies in 2014-2016 to customise the software to meet the needs of large-scale commercial applications in China and Australia without expensive hardware investment [5.4]. Munich Re stated that "*CAFlood made a significant contribution to the competitiveness of our business during this period*". The quantified benefits of CAFlood application by Munich Re are unavailable due to commercial confidentiality, however as an indication of scale, in 2019 AON reported the global economic losses caused by flooding were \$82bn, of which \$13bn was insured.

Swiss Re, another leading provider of reinsurance, collaborated with CWS in 2019 to explore the use of CAFlood and confirmed it will improve the resolution with 10 times faster computation in their modelling practice [5.5; 2020]. As a result, in August 2020 Swiss Re signed a Memorandum of Understanding with CWS to collaborate further on the development of CAFlood [5.5].

A US climate risk analytics company, risQ, acquired a CAFlood licence (for £33,000) to enable it to analyse climate risk for the US municipal market, enabling project and investment decisions such as the construction of schools, hospitals or roads [5.6].

- **Help for Thames Water in prioritising its maintenance strategy, contributing to a 60% reduction in properties impacted by water main bursts [5.7; 2015-2016]**

CAFlood was adopted by an SME, ICS Consulting, through a Knowledge Transfer Partnership (KTP) project with CWS in 2014-2017, to simulate flooding caused by water main bursts. As a result, in 2015-16 ICS secured a £100,000 contract with Thames Water (the UK's largest water company with 17m customers) to identify locations in London at risk of flooding from burst water mains [5.7]. The 120,000 pipe burst simulations took only a few weeks to complete using CAFlood; conventional hydraulic models would have taken months. From this information Thames Water prioritised areas of highest risk in a £247m maintenance programme that has helped drive a 60% reduction in properties affected by large bursts [5.7].

There was also a positive impact for ICS: a new product – inFRA - was created through the KTP with CAFlood as the core engine. . inFRA, has contributed to ICS's business growth - turnover with existing clients has increased by over £100,000 in the first year and consecutively led to a new £100,000 contract with Scottish Water [5.7]. inFRA and the Thames Water project was shortlisted for the Water Industry Achievement Awards in 2017 [5.7].

5. Sources to corroborate the impact

- 5.1. Confirmation by Torbay Council that CAFlood efficiently demonstrated reliable analyses to support their securing £3.4m government investment to protect 3,000 people and reduce £78m flood damage.
- 5.2. A statement from National Taiwan University that CAFlood has been adopted by Taipei City Government in flood forecasting system. CAFlood enables early warnings to be issued, so that citizens in identified hotspots can take measures to ensure safety and minimise disruption and damage.

- 5.3.** An acknowledgment by CMCC Foundation for the CAFlood's efficiency in flood risk assessment at municipality level in Naples to protect 980,000 inhabitants, in which CAFlood has saved CMCC 3 months and €12,000.
- 5.4.** A confirmation from Munich Re that CAFlood has been widely used in the company in large-scale flooding models covering thousands of events without requiring additional expensive computational infrastructure. Munich Re also used CAFlood to assess flash flood event hazards, to validate flood maps from other vendor and consulting companies, and to analyse the possible losses caused by flood catastrophes. CAFlood has strengthened the competitiveness of the business.
- 5.5.** A testimony from Swiss Re confirms CAFlood has improved the resolution of modelling with a ten-fold speed increase compared with their current solution. It also highlights how the business will benefit from CAFlood and the signed Memorandum of Understanding to build the partnership in CAFlood applications.
- 5.6.** A licencing agreement with risQ to implement CAFlood in the US market to support investment decision making.
- 5.7.** Statement from ICS Consulting Ltd and KTP report have confirmed that CAFlood has contributed to the completion of the major project with Thames Water to reduce 60% water main bursts and enabled the business's growth into new markets.