Institution: University of Sussex		
Unit of Assessment: 10 – Mathematical Sciences		
Title of case study: Improving processes for generating flood risk assessments, used by insurance and other sectors		
Period when the underpinning research was undertaken: 15 May 2013 – 31 Dec 2020		
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:**
Omar Lakkis	Reader	2004 – present
Period when the claimed impact occurred: 1 Aug 2013 – 31 Jul 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Mathematics research at Sussex has significantly improved the operations of Ambiental, a UK company that provides computational flood risk assessments. Specifically, the results have halved the amount of time the company needs to produce an assessment for clients. This doubling of productivity has enabled Ambiental to launch new products and expand its market share, now reaching 50% of the UK flood insurance market. It has also grown its business overseas, with new customers in [text removed for publication]. [Text removed for publication].

2. Underpinning research

The research project was prompted by a conversation between Lakkis and Ambiental [text removed for publication] in 2013. Ambiental supplies flood maps, data sets, catastrophe models, flood forecasting products and environmental reports to clients including insurers, reinsurers, brokers, governments internationally as well as non-government organisations, commercial clients and strategic partners. However, the company was facing instabilities in [text removed for publication].

Lakkis's research focused on developing an extension of the shallow water equations to model rivers and floods with precipitation, recharge and infiltration, while also deriving a stable computer method to be used in Ambiental's code. The shallow water equations, also known as Saint-Venant's equations, use fundamental physical conservation laws, such as the conservation of mass, momentum and energy, to simulate and predict how fluids move over the Earth's surface. Discretised, i.e. converted into computer code, these equations form the core of software used to simulate floods and assess their risk in a given area of the world. Kinetic schemes are one way of discretising shallow water equations.

Unless conducted carefully by respecting mathematical and physical principles, the discretisation of shallow water equations can easily be unstable in so-called shock scenarios, e.g. large amounts of extra water added to a system, say from heavy rainfall or a sudden burst. The numerical instability of code means the equations as such produce [text removed for publication] that only postprocessing by highly skilled practitioners can understand and discard, leading to time and labour consumption.

The research by Lakkis and his team solved this fundamental problem. The stability of simulations is of paramount importance when running Monte Carlo methods to model stochastic shallow water equations, when the rainfall is given as a random term [3.3]. This is crucial to estimating statistical variables in the form of flood maps that are then used to package products for Ambiental's customers. Since unstable runs require human intervention and thus associated costs and times, Ambiental would benefit from reduced costs and delivery times if able to eliminate these instabilities from its code [5.1].

To improve Ambiental's code, Lakkis discretised the shallow water equations by applying a delicate computational technique called [text removed for publication] by using kinetic schemes. Kinetic schemes derive from a concept called kinetic equations where the water flow is viewed as the average of huge numbers of microscopic particles, and this allows the model to account for other features of the flow, such as friction caused by contact between particles and walls and when the added water mixes.

When the microscopic kinetic equations are averaged, the original (macroscopic) shallow water equations are recovered. Discretising the kinetic equations, which are linear, is easier but the code would be much more expensive to run; by averaging such discretisation, an efficient code is obtained that has built-in up-winding. This allows computer code to solve the equations accurately and in a stable manner. Details are found in [3.1], where Lakkis et al. justify the addition of rainfall and ground infiltration in such discretisation. [Text removed for publication], a one-dimensional open source proof-of-concept code is available at [3.2].

Tests showed that using the model gave very similar results to data from a real-world flume experiment [3.1].

3. References to the research

[3.1] M. Ersoy O. Lakkis P. Townsend (2021) A Saint-Venant Model for Overland Flows with Precipitation and Recharge Mathematical and Computational Applications 26 no. 1 pp. 1-27. Published 29 December 2020: https://www.mdpi.com/2297-8747/26/1/1

[3.2] M. Besson O. Lakkis P. Townsend (2013) Finite volume code 1D Saint Venant https://sourceforge.net/projects/finitevolumecode1dsaintvenant/

[3.3] P. Townsend O. Lakkis (2018) A Multilevel Approach to Simulation of a Stochastic Shallow-Water with Rainfall System AGU Fall Meeting Abstracts, 2018AGUFMNG21A0802T http://adsabs.harvard.edu/abs/2018AGUFMNG21A0802T

Research funding

[3.4] O. Lakkis and P. Townsend (2013 – 2017) EPSRC CASE award with Ambiental Technical Solutions Ltd. “Computational stochastic shallow water equations for flood risk assessment” £76,276 (from EPSRC) + £22,883 (from Ambiental)

[3.5] M. Dashti, O.Lakkis, C. Makridakis, V. Styles (2015 – 2020) EU Marie Sklodowska-Curie International Training Network “Mod Comp Shock - Modelling and Computing Shocks and Interfaces” £600,872

[3.6] O. Lakkis and M. Besson (2013) Erasmus support for intern M. Besson and HEIF “Computational flood risk assessment” £6,200

4. Details of the impact

The work under Lakkis's leadership featured in this case study – though inspired by initial discussions with Ambiental's staff – was carried out independently of Ambiental and without sight of the problematic [text removed for publication] code. Nevertheless, it was natural that, once Lakkis produced and openly circulated his findings, they would be relevant and potentially very useful for the company, which proved to be the case. To maximise the impact, an intern student, working under Lakkis, was tasked with integrating those components identified and derived from the existing research [3.2] into the specific [text removed for publication] commercial code. A PhD student of Lakkis, working part-time for Ambiental, further improved the code and worked with Lakkis on the mathematical justification of these improvements.

Lakkis identified a problem with the way the shallow water equations were implemented and then they ran on real-world scenarios such as periods of heavy rain or sudden addition of water (non-conservative regime). Lakkis's team saw that by modifying the underlying kinetic equations (a topic Ambiental's developers were unfamiliar with) to cover the non-conservative equations, there was a possibility of importing stable kinetic schemes (previously only tried for conservative regimes of shallow water) to model the non-conservative scenarios.

In 2014, Ambiental developers integrated the method established by Lakkis in the form of [text removed for publication] fluxes via kinetic averaging as described in section 5.6 of [3.1] within the company's code. The main import of these novel fluxes is extra stability, and thus robustness, for each single simulation of a flow. Since these simulations could be run hundreds of thousands, or even millions, of times in Monte Carlo runs, this robustness is crucial to reduce, or even eliminate, human intervention in the form of postprocessing of runs and the development of multilevel Monte Carlo methods [3.3].

According to [text removed for publication], the results of the academic work "impacted the whole process". Previously, filtering out the unstable mathematical simulations from the company's flood predictions was a time-consuming manual task. It's "actually the single longest process in building flood maps," [text removed for publication] [5.1].

After integrating Lakkis's findings into the [text removed for publication] code, the company [text removed for publication] the amount of time and resources needed to root out instabilities.

[Text removed for publication].

The work of Lakkis and his team has thus benefitted Ambiental's commercial operations via computational and quantitative products, comprising:

(a) The delivery of FloodMap products is significantly lower effort since 2013 – given the considerable reduction in required re-runs. "Bearing in mind that we run 100's of thousands of simulations to create a national model – even a reduction of a small percentage of unstable simulations can have a significant uplift in efficiency". [5.1]

(b) The developed FloodCat processes, which "are still in use today – and will help with future product builds". [5.3]

The impact and growth enabled Ambiental to expand its business; it now works with 50% of the UK insurance market, as well as administrations at various levels in [text removed for publication] [5.1].

[Text removed for publication].

As a commitment to further knowledge exchange and benefit from this collaboration, [text removed for publication], the lead software developer of [text removed for publication] at Ambiental since 2008, will join Lakkis's research team in 2021 for an EPSRC-funded PhD in collaboration with Ambiental, to learn and specialise further numerical and computational techniques to flood-risk modelling.

5. Sources to corroborate the impact

[5.1] Interview with [text removed for publication] Ambiental (23 December 2020) [signed transcript submitted as PDF; [text removed for publication]]

[5.2] [text removed for publication].

[5.3] Letter from Ambiental Risk Analytics, RHDHV (15 December 2020) [PDF]