Institution: Swansea University

Unit of Assessment: 14

Title of case study: Enabling international land managers to mitigate water-contamination risks from wildfires

Period when the underpinning research was undertaken: April 2009 – December 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:
Stefan Doerr	Professor	1998 - present
Cristina Santin	Associate Professor	2013 - present
Jonay Neris	Research Officer	2015 - present

Period when the claimed impact occurred: 1 January 2014 - 31 December 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

Wildfires pose a serious but largely unquantified threat to water supplies and aquatic ecosystems when contaminant-enriched ash is eroded and transported by water into rivers and reservoirs. In collaboration with water industries and land managers, Swansea University (SU) researchers have developed (i) a conceptual risk assessment and mitigation framework, (ii) an end-user online modelling tool and (iii) an effective hillslope stabilisation method, that enable contamination risk to be quantified and effective mitigation measures to be implemented. These methods and tools have led to reduced water contamination and treatment costs, as well as to the enhanced resilience to wildfire impacts of fire-prone landscapes in Europe and Australia.

2. Underpinning research

Wildfires burn ~4% of the Earth's vegetated surface annually. Their ashes are rich in pollutants and highly susceptible to erosion and transport by water, posing a serious threat to water quality. Major wildfire events have led to drinking-water restrictions, affecting large metropolitan areas and creating substantial costs (e.g., Belfast: GBP3,000,000; Canberra: GBP23,000,000; Denver: GBP21,000,000). Fire-prone catchments provide water for 60% of the world's 100 largest cities and for 70% of the UK's population. In the UK alone, annual water industry losses from wildfires are estimated at GBP16,000,000 [**R6**]. However, knowledge on how to quantify and mitigate water-contamination risks from wildfires remained largely non-existent until we began our research.

Since 2009, Doerr's group at Swansea University (SU) has focussed on identifying and mitigating water-contamination risks from wildfire ash in direct collaboration with scientists, fire services, land managers and water suppliers in the UK, Australia, Portugal, Spain and the USA. This involved the following five strands of **underpinning research and resulting advances [Ras]:**

- **Ra-A**: Quantification of wildfire ash production, ash contaminant content, its transport behaviour in water, and impacts on water quality [**R1-R3**].
- **Ra-B**: Development of a satellite data-based methodology involving a new spectral index (Normalised Wildfire Ash Index) that allows the amount of ash and its spatial distribution across the landscape to be quantified as function of fire severity [**R3**].
- **Ra-C**: An evaluation of which hillslope mitigation methods are most effective in reducing water erosion and ash transport to water bodies [**R4**].
- **Ra-D**: A conceptual and globally applicable decision-support framework for predicting and mitigating water-contamination risk before, during and following wildfires [**R5**].
- **Ra-E**: A new model (the first of its kind) that enables quantifying the potential flux of contaminants into water bodies following actual or potential future wildfires [**R6**]. This has been incorporated into an online end-user modeling tool with customized interfaces for Europe, Australia and the USA (*WEPPcloud-WATAR: **W**ater **E**rosion **P**rediction **P**roject cloud model - **W**ildfire **A**sh **T**ransport **A**nd **R**isk estimation tool*) [**R6**].

During our initial research with Melbourne University [**G1**] on the impacts of Australia's deadliest wildfires ('Black Saturday' 2009; 173 fatalities) we quantified the ubiquitous thick ash and analysed its chemical properties. We found ash loads of 8kg/m^2 with substantial enrichment in water-soluble organic carbon and heavy metals compared to the underlying soil [**R1**] (**Ra-A**).

Its significance for water quality led to **Doerr & Santin** being funded in 2013 by Water New South Wales (WNSW operate the state's water supply systems [**G2**]), to identify the water-contamination risk following a severe fire near Sydney. Ash and its contaminants were quantified using field sampling in areas affected by different fire severities. In collaboration with WNSW we developed our new satellite-data based method for upscaling this for the entire area burned, enabling the maximum water contamination potential from this fire to be quantified [**R2,R3**] (**Ra-A & B)**. In 2015, supported by **Neris'** MSCA Fellowship [**G3**] and the land-management body Cabildo de Tenerife, Spain, we also began to develop and test hillslope treatments for mitigating post-fire erosion, including quantifying their efficacy on steep hillslopes after wildfire. Applying a thin layer of natural needle or wood chip mulch was found to be much more effective and of equal cost to the installation of the commonly used erosion barriers [**R4**] (**Ra-C**).

Further UK and international collaboration with academic and end-user partners [**G5**], enabled us to build on these advances and develop (i) a decision support framework that considers all relevant steps in quantifing and mitigating contamination risk before, during and after fire events [**R5**] (**Ra-D**) and (ii) the *WEPPcloud-WATAR* end-user model, the only erosion model that allows ash movement from hillslopes to channels and associated water contamination risk to be estimated [**R6**] (**Ra-E**). It has terrain, soil and climate data already built in for Europe, Australia and the USA, and requires only ash loads, contaminant contents and fire severity to be added. This model allowed us to provide United Utilities (UK) and WNSW with contamination risk and mitigation benefit assessments following major fires in their water supply catchments.

3. References to the research (Swansea University authors in **bold,** all publications are peer reviewed, with 5 published in Q1 journals (JCR2019) and work supported by funding from NERC, The Leverhulme Trust, Water New South Wales, Horizon2020, WEFO, Melbourne Water).

[R1] **Santin C., Doerr S.H., Shakesby R.A., Bryant R.,** Sheridan G.J., Lane P.N.J., Smith H., Bell T.L. (2012) Carbon forms and sequestration potential within ash deposits from forest fires: new insights from the 2009 'Black Saturday' fires, Australia. *European Journal of Forest Research* 131:1245-1253. (Q1 journal) https://doi.org/10.1007/s10342-012-0595-8

[R2] **Santin C., Doerr S.H.**, Chafer C. (2015) Quantity, composition and water contamination potential of ash produced under different wildfire severities. *Environmental Research* 142: 297-308. (Q1 journal) https://doi.org/10.1016/j.envres.2015.06.041

[R3] Chafer C., **Santin C., Doerr S.H.** (2016) Modelling and quantifying the spatial distribution of post-wildfire ash loads. *International Journal of Wildland Fire* 25: 249-255. (Q1 journal) https://doi.org/10.1071/WF15074

[R4] **Neris J., Doerr S.H.**, Notario J.S., Arbelo C.D., Rodríguez-Rodríguez A. (2017) Effectiveness of polyacrylamide, and wood shred and pine needle mulches as post-fire hillslope stabilization treatments in soils with contrasting water repellency. *Forests* 8: 247. (Q1 journal) https://doi.org/10.3390/f8070247

[R5] Nunes J.P., **Doerr S.H.**, Sheridan G., **Neris J., Santin C.**, Emelko M.B., Silins U., Robichaud P.R., Elliot W.J., Keizer J. (2018) Assessing water contamination risk following vegetation fires: Challenges, opportunities and a framework for progress. *Hydrological Processes* 32: 687-694. (Q1 journal, within top 20 most read papers in this journal in year since publication.) https://doi.org/10.1002/hyp.11434

[R6] **Doerr S.H.**, **Neris J.,** Elliot W.J., Robichaud P.R., Lew R., **Santin C.,** Sheridan G. (2019) Incorporating water contamination risk from wildfire ash into the decision-making process: A new online tool for researchers and end-users. *American Geosciences Union Fall Meeting*, San Francisco, USA, paper 611668. https://agu.confex.com/agu/fm19/meetingapp.cgi/ Paper/611668

Grants funding the research:

[G1] **Doerr S.H.** (PI), Shakesby R (CoI) (April 2009-Sept 2010) 'The catastrophic Victoria wildfires: impact of extreme burn severity on the soil system' [NE/H00131X1]. NERC Urgency Grant, GBP52,835.

[G2] **Doerr S.H.** (PI) (2013) 'Water contamination risk from bushfire ash'. Water New South Wales, Australia, [GGR795] GBP14,000.

[G3] **Doerr S.H.** (PI), **Neris J.** (Marie Skłodowska-Curie Fellowship holder) (Aug 2015-Dec 2017) 'When the smoke clears: predicting and preventing catastrophic erosion and flooding after wildfires in volcanic terrains' [655993], EC H2020-EU.1.3.2. Nurturing excellence by means of cross-border and cross-sector mobility, GBP181,143.

[G4] **Doerr S.H.** (PI and Fellowship holder) (Sept 2016-Feb 2018) 'Predicting and mitigating hydrological risks from fire' [RF-2016-456/2]. The Leverhulme Trust - Research Fellowship, GBP49,631.

[G5] **Doerr S.H.** (PI), **Santin C.** (CoI) (Mar 2018-Mar 2021) 'Fire and Water; predicting and mitigating water pollution risk from wildfire ash' [NE/R011125/1]. NERC Standard Grant, GBP550,396.

[G6] **Doerr S.H.** (PI), **Santin C.** (Fellowship holder) (Jan 2017-Dec 2019) 'Good fire, bad fire: optimizing prescribed burning for sustainable carbon capture and water quality maintenance' [663830], EC H2020, Ser Cyrmu Fellowship, GBP184,768.

4. Details of the impact

Our diverse body of pioneering research produced over a number of years had a both broad and deep **direct impact on the assessment and management of environmental risks from wildfire.** It specifically improved post-fire diagnostics, land management and drinking-water provision in Australia and Europe, with associated environmental and economic benefits.

Water services in Australia:

- WNSW, who supply greater Sydney (>6,000,000 people) commissioned us to quantify ash loads, ash characteristics and predict water contamination potential (**Ra-A**&**B**, [R2-R3]) after a severe fire in their Balmoral catchment in 2013. A key finding was that the contamination potential of arsenic and boron, which were pollutants of concern after previous fires, was relatively low. Phosphorous was a more significant threat, but possible to deal with using the existing water treatment infrastructure. As **a direct impact** of our report to WNSW, "*no costly modifications to existing water treatment capabilities were required*" [**C1**, Water Quality Scientist, WNSW].

- The unprecedentedly extensive 2019/2020 Australian wildfires resulted in most of Greater Sydney's main domestic water supply catchments being burned. **Ra-B,D**&**E** allowed us to provide WNSW with (i) ash distribution loads, (ii) expected contaminant concentrations in ash, (iii) a risk analysis of ash and contaminant movement for potential rainfall scenarios, and (iv) the location of 'hotspots' where landscape characteristics and thick ash layers cause high erosion risk. These **outputs directly guided** mitigation measures, such as the installation of fabric curtains across the lake that capture sediment, modifications in the water extraction depth at the dam and location of erosion mitigation barriers on critical hillslope erosion 'hotspots' [**C1, C2**].

"In this way, the work of Prof. Doerr and his team improved confidence in our assessment of ongoing water quality risks, which was used to inform capacity planning by our major water treatment customer." [**C1**, Water Quality Scientist, WNSW].

A large rainfall event in March 2020 eroded most of the ash from the hillslopes (as predicted by our model), causing large sediment plumes in the reservoir, yet the mitigation measures enabled WNSW to continue supplying safe drinking water to Sydney. *"The erosion risk mapping produced by Prof. Doerr's team was **used to guide the placement of erosion mitigation** installations. The WEPPcloud-WATAR capabilities represent a significant improvement from our existing fire impact risk assessment methodology implemented at the start of the 2019-2020 fire season. We have **adopted the methodologies developed by Prof. Doerr's team** this year into a revised water quality risk assessment process for future fire events"* [**C1**, Water Quality Scientist, WNSW].

- Following the catastrophic 2019/2020 wildfires, the Water Services Association of Australia (WSAA), who represent 20,000,000 urban water customers, adopted our decision-support framework for risk assessment and mitigation (**Ra-D**) in its entirety in their national industry guidelines providing a "*structured approach to identifying mitigating strategies and undertaking risk assessments*" [**C3**, pg 26; see Fig 7.2 for graphical representation of our framework, pg 27].

UK emergency services and water suppliers:
In 2018, England's largest wildfire on Saddleworth Moor led to evacuations and burned 1,800ha of water-supply catchments managed by United Utilities. The fire burned deep into peat soils high in metal contaminants, a legacy of emissions from surrounding industrial sites, raising concerns of potential water contamination. Our research findings ([R5], **Ra-D**) guided the UK Fire and Rescue Services in where to focus hosing to extinguish the fire, reducing peat loss and contaminant release from burning and erosion.

"*Work between Prof. Doerr's team, the Fire and Rescue Services and United Utilities has been a great example of how* ***insights gained from their research have had a direct impact*** *on minimising environmental damage and risk to water resources*" [**C4**, Tactical Adviser to the UK Fire and Rescue Services].

Using our method (**Ra-A**), we identified a substantial water contamination risk from (e.g.) lead, arsenic and mercury. Based on **Ra-C&D** [R4-6] we guided United Utilities to cover hillslopes adjacent to the reservoir with biodegradable netting which prevented ash and soil eroding into the reservoir. This was the first substantive on-site mitigation treatment for water-contamination risk following a UK wildfire.

"I am pleased to report that the mitigation treatments have been successful in reducing the risk of contaminating raw water prior to treatment. Not only does this reduce the reliance on the treatment process to remove contaminants, but it also assists in ensuring that there are sufficient water resources available for treatment and supply to customers." [**C5**, Integrated Catchment Strategy Manager, United Utilities].

We also provided United Utilities with water-contamination probabilities for future fire scenarios and mitigation recommendations based on our *WEPPcloud* model (**RaC-E**), [R4-R6, **C6**].

"Prof. Doerr's team has also provided risk assessments for two other catchments (Chew and Torside) using their model, which we deem as high risk in terms of future fire impacts. This has been very useful in enabling us to focus our wildfire risk and impact reduction measures of resource allocation. These can range from targeted vegetation treatments to reduce landscape-scale flammability and upgrading of filtration capabilities where necessary. …Therefore, by applying the recommendations of the research there is a cost avoidance that could be up to £1 million for every wildfire avoided." [**C5**, Integrated Catchment Strategy Manager, United Utilities].

Improved environmental management in Spain:
The Canary Islands' steep slopes are particularly vulnerable to post-fire erosion. In direct collaboration with *Cabildo de Tenerife* (Island Council of Tenerife), we evaluated the effectiveness of log barriers [R4], the traditionally-used hillslope erosion mitigation treatment (~GBP18,000,000 treatment costs between 2007 and 2017). Having determined their low efficacy, we developed alternative methods involving increased ground cover, which reduced soil and contaminant transport by 51-77% based on our monitoring of field plots (**Ra-D**, [R4]), but which were comparable in application cost (~GBP1200/ha). These findings **led to changes** in the post-fire erosion treatment guidelines for the Canary Islands [**C7**, **C8** pg 16, **C9** pg 14], which now incorporate the application of ground cover treatments using locally-obtained forest materials (wood-chip or pine-needle mulch) as recommended in R4. This treatment was adopted as standard practice on the islands and was applied after two fires in 2018 (391ha) and 2019 (9687ha) **[C7]**. Based on road repair costs alone following the 2009 post-fire erosion damage in the Canary Islands (~GBP7,100,000; GBP1900/ha) **[C7]**, the associated cost savings from avoided infrastructure repairs after the 2018 and 2019 fires can be estimated at GBP760,000 and GBP19,000,000 respectively.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[C1] Letter from the Water Quality Scientist responsible for Sydney's catchments at *Water New South Wales* (WNSW), Australia, summarising the nature and impact of the work carried out by Doerr and his team on water contamination risk assesment and mitigation in their catchments after the 2013 and 2019/20 fires. *Dated 17/12/2020. Provided as a PDF.*

[C2] Guardian World News article, 7.02.2020 quoting the CEO of *Water New South Wales* stating "*the organisation had sophisticated models that could predict what was coming into water storages*" which enabled mitigation planning. The models are not identified in this article, but we were the only group providing ash modelling outputs to WNSW, unequovically identifying us as the providers of these outputs (as also made explicit in C1).

[C3] Canning A, Ryan G, et al. (2020). National Good Practice Operational Guidelines for Bushfire Management for the Australian Water Industry, *Water Services Association of Australia* (WSAA); 39 pp. Our decision support framework (as described in [R6]) is incorporated verbatim on pages 26-28. We have no connection to the WSAA and had not been made aware of the incorporation of our model until its publication. *Provided as a PDF.*

[C4] Letter from the *Tactical Adviser to the UK Fire and Rescue Services* battling the Saddleworth Moor wildfires. It summarises the impact of the work carried out by Doerr and his team on the suppression of the fire and the subsequent mitigation of erosion and water contamination risk. *Dated 24/02/2020. Provided as a PDF.*

[C5] Letter from the Water Process Technical Manager of Quality & Scientific Services at *United Utilities*, UK on the nature and impact of the work carried out by Doerr and his team on water contamination risk assesment and mitigation in their catchments after the Saddleworth Moor wildfires of 2018. *Dated 15/12/2020. Provided as a PDF.*

[C6] Links to WEPPcloud user modelling tools: https://wepp.cloud/weppcloud/

[C7] Letter from the Head of the Technical Service for Planning and Forestry Projects of the Tenerife Island Council (Cabildo de Tenerife, Spain) on the formal implementation of, and the resulting cost savings from, the new post-fire erosion control measures developed by Doerr and his team. *Dated 22/02/2021. Provided as a PDF.*

[C8] Gobierno de Canarias. ORDEN - Nº: 243 / 2018 (in Spanish). In this official document, the Government of the Canary Islands specifies how post-fire mitigation was to be carried out on Tenerife after the 2018 fire by the company *GESPLAN*. Our undepinning work [R4] is directly referred to on page 16. *Dated 3/10/2018. Provided as a PDF.*

[C9] Gobierno de Canarias. ORDEN - Nº: 99/2020 (in Spanish). In this official document, the Government of the Canary Islands specifies how post-fire rehabilitation after the 2019 fire in Gran Canaria was to be conducted by the company *GESPLAN*. Our undepinning work [R4] is directly referred to on page 14. *Dated 30/04/2020. Provided as a PDF.*