Institution: Swansea University
Unit of Assessment: 17 - Geography, Environmental Studies and Archaeology
Title of case study: Improved post-wildfire hazard assessment and risk reduction policy and practice

1. Summary of the impact

Wildfires can reduce the wettability of soil (i.e. increase their water repellency), accelerating runoff and erosion that in turn can cause flooding, landslides and aquifer contamination. Our research has revealed a link between fire severity and soil wettability that has led to substantial changes in the policy for mandatory post-fire assessments by the United States Forest Service (USFS). Implemented in 2011, these changes have resulted in improved land-rehabilitation practice in the USA. Moreover, this practice is being increasingly applied elsewhere, including Canada, Australia and parts of Europe, all of which now include specific consideration of soil wettability following severe fires and are underpinned by the methodology we developed. Based on these assessments, landscape-rehabilitation is applied at high-risk areas following wildfires, to limit the threats to life, property, infrastructure and ecosystem quality arising from excessive runoff and erosion. In the USA, for example, ~1.3 million hectares of burned land have been assessed in 2012 using the new post-fire assessment guidelines.

2. Underpinning research

Context: Wildfires burn 300–600 million hectares (~3%) of the global land surface each year. A decrease in soil wettability, caused by a heat-induced release of hydrophobic substances from organic matter during burning, together with reduced vegetation cover, can increase subsequent runoff and erosion, slow vegetation recovery, damage infrastructure (via debris flows and flooding), and reduce water quality (via increased sediment and nutrient delivery to streams and reservoirs). To mitigate these effects, hillslope rehabilitation treatments are commonly applied in high-risk areas. These are identified following specific post-fire assessment policy and procedures such those published by US land management agencies [C1–C4, C7]. A growing body of scientific research underpins both post-fire assessments and the choice of mitigation treatments applied.

Our research: Building on a foundation of research at Swansea, the effects of severe wildfire on soil wettability, hillslope runoff and erosion processes were investigated in Australia in Sydney's main water-supply catchment (supplying 4.5 million people), which was affected by severe wildfires that burned between December 2000 and January 2001. This work started in March 2001 and was funded by a Swansea-led NERC Urgency grant (Mar. 02–Feb. 04) [G1]; led by R. **Shakesby** (then Senior Lecturer, now Reader at Swansea); Named Investigators S. **Doerr** (then PDRO, now Prof. at Swansea), W. **Blake** (then PDRO at Swansea, moved to Univ. of Plymouth in 2004). Collaborators were P. Wallbrink (Senior Scientist, CSIRO, Canberra, Australia), C. Chafer (Senior Spatial Analyst, Sydney Catchment Authority, Australia) and the late G. Humphreys (then Associate Prof., Sydney Univ., Australia).

The fieldwork in Sydney's water-supply catchment continued until 2006, supported by a NERC Advanced Fellowship to S. Doerr (Nov. 03–Nov. 08) [G2]. For sub-catchments affected by different fire severities, the work involved firstly comparing satellite-derived with ground-assessed fire severity, and then determining the relationships of observed fire intensities with (i) soil wettability and (ii) the magnitude and longevity of any subsequent accelerated runoff, soil erosion, and water-supply catchment contamination risk. We then used these data to develop a generally applicable methodology for assessing soil-hydrological behaviour changes and thus accelerated erosion and flooding risk. These findings were disseminated in R1 and R2.

Building on this work, and also supported by the NERC Advanced Fellowship [G2], we conducted research in eastern Spain with A. Cerdà (Prof. at Valencia Univ. in 06–07), evaluating the effects of severe fire on soil wettability, the evolution of ash and tree-needle debris covering the ground in the post-fire period, and the resulting runoff and erosion responses [R3].

Subsequently, we filled a major remaining knowledge gap by quantifying natural 'background' water repellency levels in long-unburned terrain. Thus, a comprehensive range of fire-prone forest and soil types were tested in the northwestern USA in collaboration with S. Woods (Associate Prof. at Univ. of Montana) and D. Martin (Senior Researcher at the US Geological Survey, Boulder CO) [R4].

The key outcomes of our work on post-fire risk assessment and rehabilitation are: (i) revealing the contribution of soil water repellency to post-fire hydrological processes under different fire severities [R1, R3]; (ii) showing that the severity of soil water repellency is related to vegetation type, fire severity and time since burning [R1, R4]; and (iii) the production of a methodology for linking water repellency to fire severity [R1, R2]. An evaluation of the main findings set in an international context and methodological recommendations aimed specifically at land managers, was published in 2009 [R2].

3. References to the research

Journal impact factor (JIF), journal rank and article citations from WoS and Google Scholar as of 24 Oct. 2013 are given as indicators of research quality.

[R1] **Doerr SH, Shakesby RA** *et al*. 2006. Effects of differing wildfire severities on soil wettability and implications for hydrological response. *J. Hydrol*. 319: 295–311. *doi:10.1016/j.jhydrol.2005.06.038* (Times cited: WOS 95, Google 127; JIF: 2.66; rank 4 of 78 in the field of Water Resources)

[R2] **Doerr SH, Shakesby RA**, MacDonald LH. 2009. Soil water repellency: a key factor in post-fire erosion. In: Cerdà A, Robichaud PR, eds. *Fire Effects on Soils and Restoration Strategies*. Enfield, NH: Science Publishers: 198–223. (Peer-reviewed book chapter, Times cited: Google 31)

[R3] Cerdà A, **Doerr SH**. 2008. The effect of ash and needle cover on surface runoff and erosion in the immediate post-fire period. *Catena* 74: 256–263. *doi: 10.1016/j.catena.2008. 03.010* (Times cited: WOS 54, Google 91; JIF: 1.89; WOS rank 9 of 33 in Soil Science)

[R4] **Doerr SH** *et al.* 2009. 'Natural background' soil water repellency in conifer forests of the north-western USA: its prediction and relationship to wildfire occurrence. *J. Hydrol*. 371: 12–21. *doi: 10.1016/j.jhydrol.2009.03.011* (Times cited: WOS 18; Google 29; JIF: 2.66; rank 4 of 78 in the field of Water Resources)

A citation analysis (Web of Science, WoS, 24 Oct. 2013) using the terms *water repellency* AND *fire severity* for the last ten years, reveals that our landmark paper [R1] remains by far the most cited in this field, and publications by the Swansea team (**Doerr** and **Shakesby,** including R1) represent 6 of the 10 most highly cited papers on this topic (excluding general review papers and work in which water repellency presence was not quantified but instead only assumed to be present based on burned area inferred from satellite data).

Main funding sources:

[G1] NERC (£89,013): '*Erosional consequences of different fire intensities of fire-induced water repellency in the Sydney forest fires region'* (NER/A/S/2002/00143). Project funded under the 'NERC Urgency Scheme' 2002–2004. PI: R. **Shakesby** (then Senior Lecturer); Named Investigators S. **Doerr** (then PDRO), W. Blake (then PDRO). Collaborators were P. Wallbrink (Senior Scientist, CSIRO, Canberra, Australia), C. Chafer (Senior Spatial Analyst, Sydney Catchment Authority, Australia) and the late G. Humphreys (then Associate Prof., Sydney Univ., Australia).

[G2] NERC (£292,588): '*Hydrophobic behaviour of soils: origin, control and environmental impacts'*. (NER/J/S/2002/00662). 2003–2008; Advanced Fellowship awarded to S. **Doerr**.

4. Details of the impact

Our research has directly influenced policy and practice by (a) identifying the need for fire-severity assessment to prevent post-fire hydrological damage, and (b) providing a methodology for soil-wettability assessment in relation to fire severity, which land managers use to determine post-fire mitigation needs.

Impact in the USA: The value of our research is recognised by US land-management authorities, who are global leaders in the implementation of post-fire evaluation and rehabilitation protocols. Around 3 million hectares of land burns annually in the USA. Most of these fires affect federal land, which is subject to formal burned-area emergency assessments led by the US Forest Service (USFS)[1] to determine if critical 'values' (i.e. life, property, infrastructures) are at imminent post-fire risk. Proven rehabilitation methods (e.g. erosion barriers, mulch or wetting agent applications that reduce runoff and erosion) are then applied to manage unacceptable risks to life and infrastructures. The federal budget for this is not capped (e.g. >$60 million spent in 2012).

The direct link we established between the degree of soil water repellency and burn severity [R1] has prompted material changes in USFS post-fire assessment policy and procedure. "*The work by Doerr et al. (2006) allows managers to make inferences about post-fire soil water repellency and infiltration from burn severity designations. Thus, larger areas of burned landscape can now be assessed more accurately for their post-fire hydrologic condition and predicted hydrologic response, and management decisions concerning treatments, access, or water impoundments made*" [C1]. Our research outcomes were first integrated into USFS post-fire research and management practice via USFS publications in 2008 and 2010 [C2-C4]. A formal revision of the US Forest Service Manual [C5], which is their primary manual on land management policy and procedure, was made in 2011. Our work, cited in the aforementioned USFS publications [C2-4], directly led to the revision of Section 2520 of [C5]: Watershed Protection and Section 2523: Burned-Area Emergency Assessment, which address post-fire site-specific assessment. Since the revisions, it is mandatory for Burned Area Emergency Response (BAER) teams to assess soil water repellency in relation to burn severity specifically because of its proven role in promoting extreme runoff and erosion events. The assessment follows our methodology [R1, R2].

Approximately 300 active USFS BAER specialists, who are typically divided into teams of 12 core and 80 standby members, carry out post-fire assessment and apply these new procedures. They assess every fire >100 hectares affecting federal land. Assessments are often also carried out on private land in collaboration with relevant commercial or private landowners. If a fire is small with minimal risk, 1 or 2 days are sufficient to complete the assessment, but large fires may require 7 to 10 days. The additional water-repellency assessment procedures developed at Swansea represent *c.* 25% of the post-fire assessment effort. They have been applied following all major US 2012 and 2013 wildfires – in 2012, for example, 109 fires covering ~1.3 million hectares in total were assessed using the new procedures [C1]. The resulting post-fire rehabilitation treatment costs were *c*. $80 million, compared with estimated damage costs of $1,298 million had the assessments and treatments not been applied. Risk categories used in the post-fire assessment (and number of fires relevant to one or more risk category) were: Life (59), Property (83), Water Quality (35), Threaten and Endanger Species (20), and Soil Productivity (93) [C1].

Impact elsewhere: The revised USFS assessment procedures have been adopted in many other parts of the world, including Australia, Canada, Portugal, Spain, and Greece. For example, in Australia with its fire-prone Eucalypt forests, the 2003 Canberra wildfires caused water contamination resulting in the shutdown of water supply from one of the main catchments. This event contributed to Australian water-supply managers in forested regions (e.g. Sydney, Melbourne, Canberra; combined population: 9 million) adopting US response-guideline procedures [C6]. Following catastrophic fires near Melbourne in 2009 that killed 173 people, USFS personnel assisted with post-fire assessment, implementing the revised post-fire assessment guidelines and

[1] *The USFS is responsible for 93 million ha of land. This represents 1/3rd of the total forested land area and 1/9th of the total land area of the USA.*

also trained 50 Australian forestry staff [C1]. Subsequently, Australian Burned Area Assessment Teams (BAATs) applied these in the January 2013 fires in New South Wales [C6].

The impact of our research is also traceable through Australian policy changes following a key scientific summary document [C7], published by the eWater Cooperative Research centre (Australia's leading water-resource advisory group). This has led to demonstrable changes to the Sydney Catchment Authority policy regarding assessment and management high-risk areas following fire [C8], based on the 2010 Audit of the Sydney Drinking Water Catchment [C9]. The current and unseasonally early fires near Sydney (as of 24 Oct. 2013) have also affected Sydney's water supply catchment area and are likely to require post-fire assessments once extinguished.

Sources to corroborate the impact

C1. Testimonial letter (on file) provided by the Senior Research Engineer who has been the lead researcher quantifying the effectiveness of post-fire rehabilitation treatments; USFS Forest Service, Moscow, Idaho.

C2. New Procedures for Sampling Infiltration to Assess Post-fire Soil Water Repellency, Forest Service, Rocky Mountain Research Station, Research Note RN0-33 (2008). (http://www.treesearch.fs.fed.us/pubs/29326; accessed 22.10.2013) (*Doerr et al. 2006* [R1] *is referred to on page 4*)

C3. Post-fire Treatment Effectiveness for Hillslope Stabilization, Forest Service, Rocky Mountain Research Station General Technical Report GTR- 240 (2010). (http://www.treesearch.fs.fed.us/pubs/35691; accessed 22.10.2013) (*Our underpinning research* [R1, R2, R3] *is cited on pages 2, 3, 4 and 7*)

C4. US Forest Service Manual (FSM series 2000). This was updated in 2011 in response to an interim directive (http://www.fs.fed.us/im/directives/dughtml/fsm.html; accessed 22.10.2013). Chapter 2520 covers watershed protection and section 2523.1 Burned-Area Emergency Assessment.

C5. Field Guide for Mapping Post-fire Soil Burn Severity, Forest Service, Rocky Mountain Research Station General Technical Report GTR- 243 (2010). (http://www.fs.fed.us/rm/pubs/rmrs_gtr243.pdf; accessed 22.10.2013) (*Doerr et al. 2006* [R1] *is referred to on page 4*)

C6. Testimonial letter (on file) provided by the Senior Spatial Analyst responsible for wildfire severity erosion risk assessments at the Sydney Catchment Authority.

C7. Chafer, C.J. 2007. Wildfire, catchment health and water quality: a review of knowledge derived from research undertaken in Sydney's Water Supply Catchments 2002–2007. eWater (Evolving Water Management CRC), (http://www.ewater.com.au/bushfire/NewBushFire.woa/wa/listDownloads; accessed 22.10.13). (*Doerr et al. 2006* [R1] *is referred to on page 4 for two critical findings*)

C8. Sydney Catchment Authority 2012. Water Quality Management Framework 2012-2017. (http://www.sca.nsw.gov.au/__data/assets/pdf_file/0016/36412/Water-Quality-Management-Framework-2012-2017.pdf; accessed 22.10.2013)

C9. State of New South Wales and Department of Environment, Climate Change and Water NSW, 2010. 2010 Audit of the Sydney Drinking Water Catchment. The NSW Government links [C7] to section 42 of the Sydney Water Catchment Management Act 1998. (http://www.environment.nsw.gov.au/water/sdwc2010.htm; accessed 22.10.2013)

Users who have provided factual statements and can corroborate the impact:

C10. USA: Senior Research Engineer, USDA Forest Service, for verification of claims of impacts on post-fire assessment policy in the USA.

C11. Australia: Senior Spatial Analyst, Sydney Catchment Authority, for verification of claims of impacts on post-fire assessment procedures in Australia.