Water quality impacts after wildfires: how can we anticipate risks?

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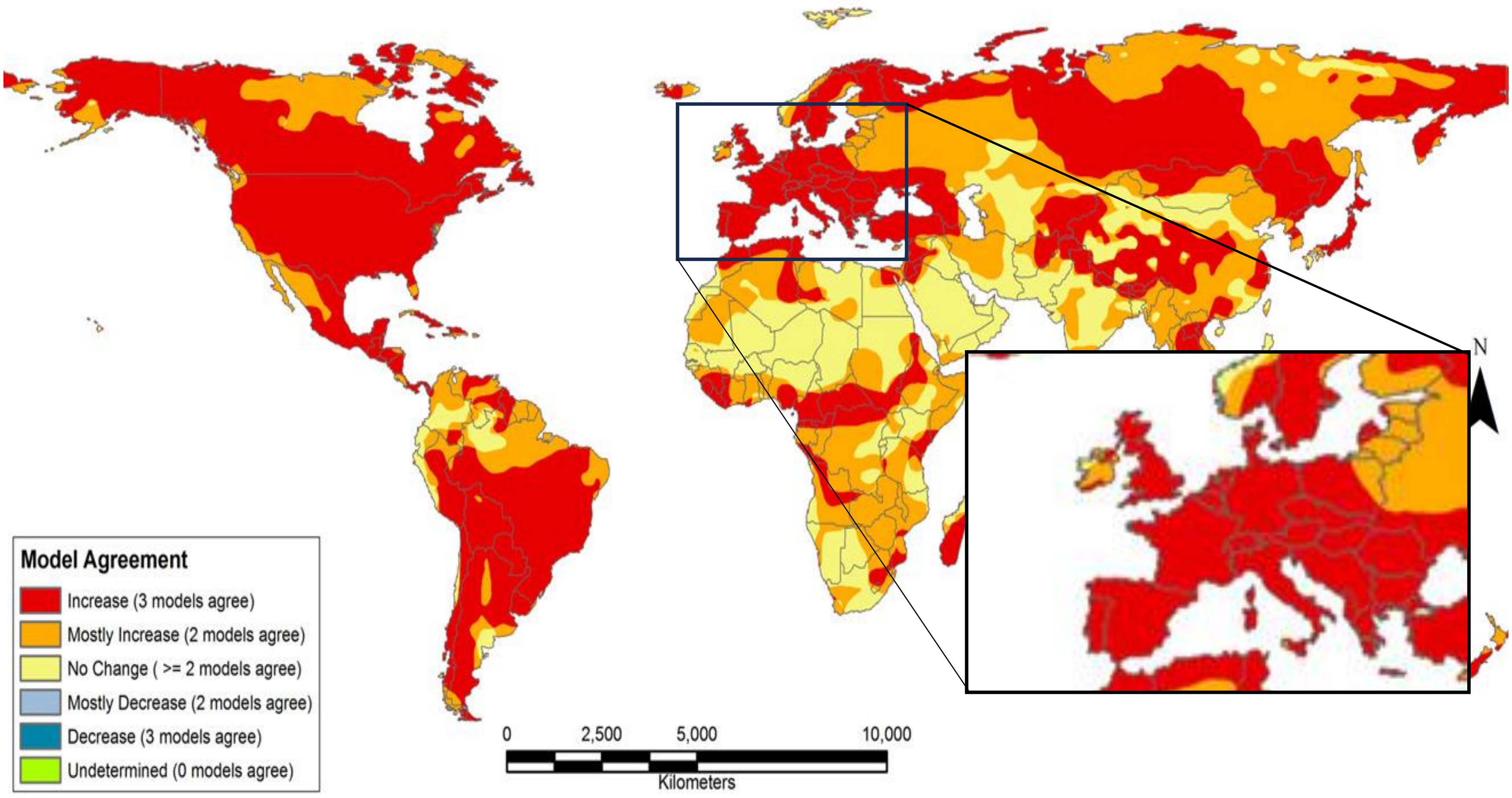
Global wildfire

- Fires have affected world's land surface for >400 Mill. years
- Now burn ~4.6 Mill km^2 of the land surface p.a. (~ 200 x size of Wales)
- Currently ~4% of Earth's vegetated land surface
- UK Fire Rescue Services attend over 70,000 vegetation fires per year
- Global area burned declined ~20% in last two decades (Andela et al. 2017)
- Many areas show increased fire risk

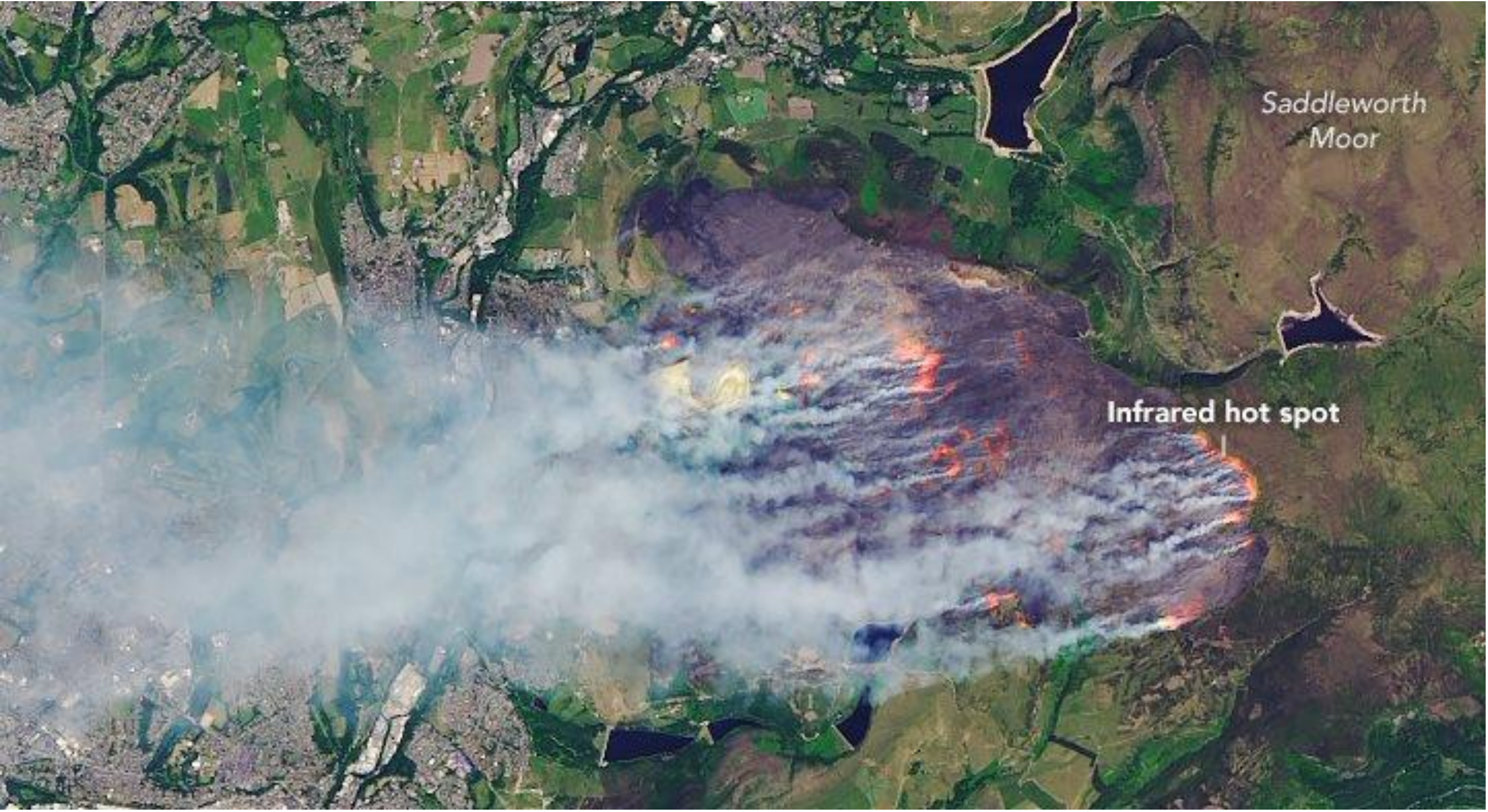
Global wildfire: increase in fire weather severity



Composite Cumulative Severity Rating anomaly map for the IPCC A2 scenario for 2014-2050 (Flannigan et al. 2013)

2018 Saddleworth Moor fire

- Ignited June 2018, major national incident
- Army activated to support fire suppression
- ~1000 hectares wildfire in rural urban interface
- Only 5 English wildfires of similar size since 2009 (Forestry Commission, 2019)



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Risks are not over once flames are out:

- enhanced runoff and erosion

Wildfires:

- Reduces soil protection by vegetation
- Break up soil aggregates
- Increase soil water repellency →
- Reduce porosity and infiltration
- Reduce soil resistance to detachment and transport

Example of major post-wildfire flooding and mass movements

Montecito debris flow after Thomas Fire, California
Jan. 2018 – 23 deaths

Wildfire and water resources: the problem

- Fire-prone or fire-managed ecosystems (forests, grass- and peatlands) provide ~60% of the water supply for the world's 100 largest cities and ~60% for the UK population

- Reservoirs highly vulnerable in fire season as water levels are often already low

Green Wattle Creek, Australia, 2020

- Burned the largest urban supply reservoir in Australia
- Compromised the provision of fresh water to ~85 % of the population of Greater Sydney

2018 Saddleworth Moor fire

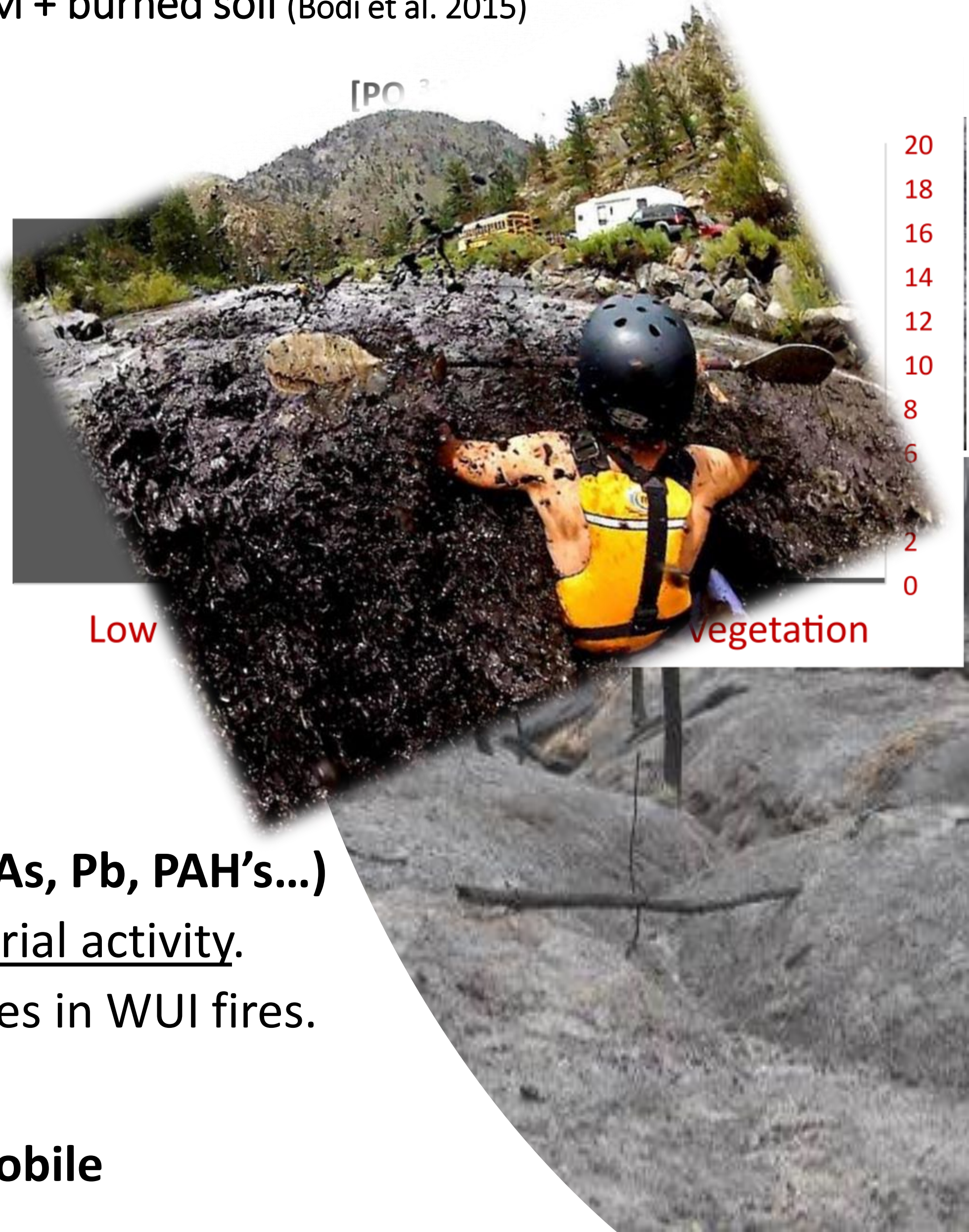
Risks are not over once flames are out:

- enhanced runoff and erosion

ASH?

A new material after wildfires: ASH

Ash = mineral ash + charred OM + burned soil (Bodi et al. 2015)



- **Produced in large quantities:**
  - Up to 10 cm thick layers
  - Ash loads >190 t ha^{-1} (USA).
- **Rich in nutrients:**
  - 4 t of P available for release to a single waterbody (Australia).
- **Can include and release pollutants (Fe, As, Pb, PAH's…)**
  - Heavily polluted areas due to <u>industrial activity</u>.
  - Contaminants from burned structures in WUI fires.
- **Low density and cohesion and highly mobile**

3. Burn severity and water contamination risk

Ash loads after the 2018 Saddleworth Moor fire:

Extreme severity (burned into peat): 33,700 kg/ha

High severity (surface only burned): 2,300 kg/ha

Total content

Total Analysis		$PO_4^{\equiv}$	Al	Si	Ca	Pb	Na	Mg	P	Mn	Fe	Ni	Cu	Zn	As	Cd	Hg
ASH		(mg·Kg^{-1})													(µg·Kg^{-1})		
AUSTRALIAN	Eucalypt	1490	7000	2079	177000	35.0	5043	9900	486.2	510	4300	16.0	21.0	144	1574	173	2.82
CANADIAN	Boreal	18205	1320	1782	163000	24.0	3113	12000	5941	830	979	15.0	29.0	144	463	222	3.34
SPANISH	Pine	5830	32800	2255	133000	59.0	1123	5500	1902	320	30600	32.0	30.0	172	9666	258	14.6
UK - Wales	Heathland	8265	2805	1595	11800	112.0	663	2700	2697	1430	7100	16.0	50.0	181	4352	1133	21.5
URIA	Heathland	7555	10000	2376	29400	35.0	3563	6400	2465	1000	8600	22.0	40.0	101	4446	181	8.18
USA	Chaparral	16695	22600	2068	215000	38.0	4603	22000	5448	710	19100	99.0	52.0	112	2366	209	48.2
Saddlew	EXTREME Grey	3950	7500	880	20300	25.0	553	980	1289	42.0	5600	13.0	11.0	35.0	2441	413	7.71
Saddlew	EXTREM RED	5695	15600	979	13300	30.0	803	1400	1858	27.0	11500	21.0	14.0	45.0	4347	573	12.7
Saddlew	HIGH SEVERITY	9270	1936	2090	18100	70.0	1213	4100	3025	910	2890	26.0	59.0	150	713	802	42.9
BL		0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0

Some examples of water quality challenges

- **Turbidity** (suspended solids): reduces treatability
- **Dissolved organic carbon:** requires optimisation of coagulants to remove higher organic fractions from the water
- **Metals:** chromium, arsenic, lead, mercury and copper may need to be removed
- **Nutrients:** phosphorus promotes cyanobacteria growth, which produce cyanotoxins, as well as taste and odour compounds
- **Toxic organic compounds** e.g. polycyclic aromatic hydrocarbons or, potentially, persistent free radicals, are long-lived and tend to bioaccumulate

Example: Denver, USA, 1996 and 2002

- $32 million direct costs for restoring ecosystem services and managing drinking water treatment
- Main issue: suspended sediment

Example: Canberra, Australia, 2003

- **$38 million** direct costs managing **drinking water treatment**
- Main issues: increases in **turbidity, Fe, Mn, P, N** for over 12 months.
- **Water unfit for direct use and forced water restrictions**

Huff. Post

Example: Fort McMurray, Canada, 2016

- >$1 million increases in drinking water treatment costs
- Advice to public to boil water lasted up to 12 weeks

dnoticias.pt

MADEIRA PAÍS MUNDO DESPORTO 5 SENTIDOS CASOS DO DIA BOA VI

Enxurradas obrigam município de Ansião a interromper captação de água

PORTUGAL / 08 JUL 2017 / 17:45 H.

O município de Ansião interrompeu a captação de água para abastecimento público devido às enxurradas dos últimos dias, que transportaram cinzas dos incêndios que afectaram o Pinhal Interior, disse hoje à agência Lusa o

Example: Pedrógão, Portugal, 2017

Main issue: water restrictions due to ash in surface waters

Forest Service WEPP Interfaces

WEPP:Road 2411 runs YTD	**WEPP:Road Batch** 268 runs, 22026 segments YTD
ERMiT 8458 runs YTD	**ERMiT batch (download)** 82 runs YTD
Disturbed WEPP 1307 runs YTD	**Disturbed WEPP batch (download)** 17 runs YTD
FuME (Fuel Management) 175 runs YTD	**Rock:Clime**
Tahoe Basin Sediment Model 13 runs YTD	**Lake Tahoe WEPP Watershed GIS Interface**
WEPPcloud	**WEPPcloud Postfire Erosion Prediction (PEP)**
QWEPP	**Peak Flow Calculator**

Units: ○ metric ◉ U.S. customary [ ] personality (a to z)

Other WEPP Resources
[FS WEPP hints and requirements | Send FS WEPP developers your comments on these Interfaces]
[FS WEPP privacy disclaimer]

Pete Robichaud, USDA Forest Service RMRS Air, Water, and Aquatics Environments, Moscow, Idaho
These interfaces funded in part by

WEPPcloud-PEP (Post-fire Erosion Prediction) technology – with ash

- Based on the **Water Erosion Prediction Project model (WEPP)**.
- **Physically based runoff-erosion model developed** by the USDA.
- **Routinely used by federal agencies** for the **evaluation of natural resources issues** throughout the **USA and in over 15 countries**.
- We added the **capability to predict ash transport and potential contamination risk**.
- It is capable of predicting water contamination risks for **real and simulated fires**.

Fire and water
Predicting and mitigating water pollution risk from wildfire ash

NERC SCIENCE OF THE ENVIRONMENT

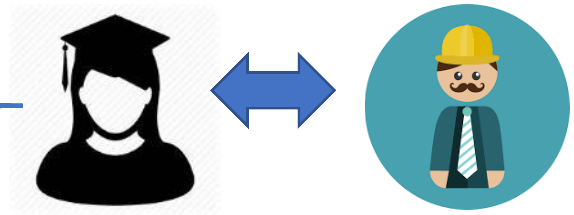
UK Natural Environment Research Council (NERC)

Discovery Science project (£677 k)

Forest Service U.S. Department of Agriculture

Swansea University Prifysgol Abertawe

The University of Melbourne



Dŵr Cymru Welsh Water

Cyfoeth Naturiol Cymru Natural Resources Wales

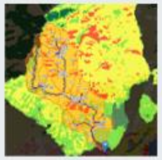
Forestry Commission

South Wales Fire and Rescue Service

Brecon Beacons Our National Park

WEPPcloud-PEP (Post-fire Erosion Prediction) technology – with ash (WATAR)

- Online, open-access end-user interface
- **Calibrated and validated for runoff and erosion for regions in US**
- **Now available for Europe and for Australia** (experimental)



WEPPcloud-(Un)Disturbed for United States

The WEPPcloud-Disturbed allows users to upload a burn severity map and predict erosion based on fire severity. Optionally, the user can forgo uploading a burn severity map to model unburned conditions. It uses SSURGO to create 7778 soils and NLCD to parameterize landuse for unburned conditions. For fire and treatment conditions soils and managements are procedurally generated and parameterized from the disturbed database based on soil texture and landuse. This allowing forests, shrubs, and grass to be burned based on landuse. The parameterization is intended to provide meaningful comparisons between unburned, burned, and treatment conditions. In the long-term disturbed is envisioned to replace the WEPPcloud-PEP interface.
This interface also incorporates the Wildfire Ash Transport And Risk estimation tool (WATAR).

Start Disturbed Run

1244 projects and 73,279 hillslopes (69,547 WATAR hillslopes) ran since January 1, 2021

WEPPcloud-EU

WEPPcloud for Europe.

Managements are assigned based on ESDAC landuses. Soils are built from ESDAC and EU-SoilHydroGrids data. U.S. climate stations are selected based on E-OBS monthly precip and temperatures.

The PeP interfaces provide post fire erosion modeling and ash transport modeling. Parameterizes soils based on burn severity and soil texture using Disturbed WEPP soil files. The PeP interface incorporates the Wildfire Ash Transport And Risk estimation tool (WATAR).

Start EU WEPPcloudi-Disturbed Run

69 EU projects and 4,019 hillslopes ran since January 1, 2021

85 EU PeP/WATAR projects and 4,890 hillslopes (4,635 WATAR hillslopes) ran since January 1, 2021

WEPPcloud-AU

WEPPcloud for Australia.

Managements are assigned based on Land Use of Australia 2010-11. Soils are built from ASRIS soil data. U.S. climate stations are selected based on AGDC monthly precip and temperatures.

The PeP interfaces provide post fire erosion modeling and ash transport modeling. Soils based on burn severity and soil texture using Disturbed WEPP soil files. The PeP interface incorporates the Wildfire Ash Transport And Risk estimation tool (WATAR).

Start AU WEPPcloud Run (Experimental)

AU WEPPcloud-PeP w/ WATAR

118 AU projects and 6,816 hillslopes ran since January 1, 2021

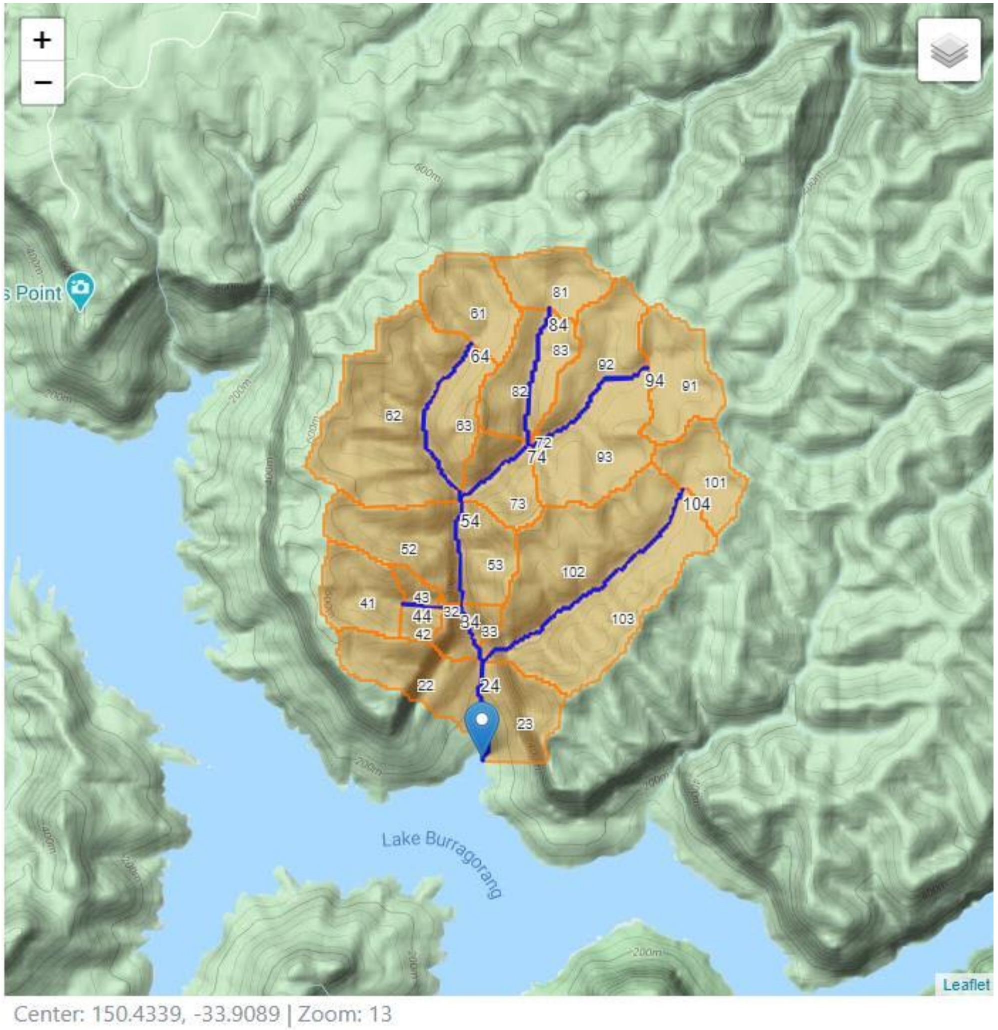
138 AU PeP/WATAR projects and 7,937 hillslopes (7,523 WATAR hillslopes) ran since January 1, 2021

https://wepp.cloud/

WEPPcloud-WATAR: Predicting impacts to water quality from a real fire

Existing on-line databases to delineate and characterize channels and sub-catchments with:

- Topographic info: DEM (30 m)
- Land use and management (unburned)
- Soil properties
- Climate information



Required inputs:

- Soil Burn Severity map
- Ash depth/load map
- Ash chemical composition (optional)

WEPPcloud-PEP: Anticipating risks to water quality using a simulated fire

Crowden simulated fire (Greater Manchester, UK)


Saddleworth Moor fire declared major incident as residents evacuated

Army on standby as huge blaze forces residents in Stalybridge to leave their homes

Wildfires sweep across moors outside Manchester - in pictures

- Catchment contributing a **major fresh-water reservoir** supplying Manchester
- Past heavy **industrial activity** in the area
- **Concern over water pollution risk**

Crowden simulated fire (Greater Manchester, UK)

Fire Name	Crowden		
Fire Date (month/day)	4-Aug		
Burn Class	**Area**	**Ash load**	
	ha	**T/ha**	**T**
Unburned	450	N/A	N/A
Low Severity	440	2.3	1012
Moderate Severity	510	2.3	1173
HighSeverity	14	36	504

INPUT DATA FOR WATER QUALITY AND HYDRODYNAMIC MODELS?

Return Period Results

Ash and potential pollutants transport recurrence intervals

Probability	Recurrence Interval	Ash delivery by water	Runoff	Peak Discharge	Sediment yield	PO4≡	Al	Si	Ca
%	years	tonne	mm	m^3/s	tonne	kg	kg	kg	kg
Worst case scenario		2689				22245.8	8010.2	5010.2	49779.7
3.4	20	1300	64	170	2200	11950.6	2621.8	2694.2	23571.5
10.3	10	1200	61	150	2000	11031.3	2420.2	2486.9	21758.3
20.7	5	1100	56	130	1900	10112.0	2218.5	2279.7	19945.1
41.4	2.5	880	42	110	1500	8089.6	1774.8	1823.7	15956.1

Crowden simulated fire (Greater Manchester, UK)

Ash, sediment and potential pollutants concentration recurrence intervals

Reservoir capacity (gross)	Current volume (gross)
million litres	million litres
6700	2934.60

Probability %	Recurrence Interval years	Ash delivery by water g/L	Sediment yield g/L
Worst case scenario		0.92	-
3.4	20	0.48	0.75
10.3	10	0.44	0.68
20.7	5	0.37	0.65
41.4	2.5	0.32	0.51

CONCENTRATION IN RESERVOIRS

DOES NOT ACCOUNT FOR HYDRODYNAMICS AND REDISTRIBUTION TO CALCULATE CONCENTRATIONS

Probability %	Recurrence Interval years	$PO_4^{\equiv}$ mg/L	Al mg/L	Si mg/L	Ca mg/L	Pb µg/L
Worst case scenario		7.6	7.7	1.7	17.0	56.4
3.4	20	4.1	5.9	0.9	8.0	30.7
10.3	10	3.8	5.8	0.8	7.4	28.4
20.7	5	3.4	5.8	0.8	6.8	26.0
41.4	2.5	2.8	5.6	0.6	5.4	20.8
	Current concentration	0.0	5.0	0.0	0.0	0.0

Model outputs: Probability of exceeding guideline values

Ash, sediment and potential pollutants concentration recurrence intervals

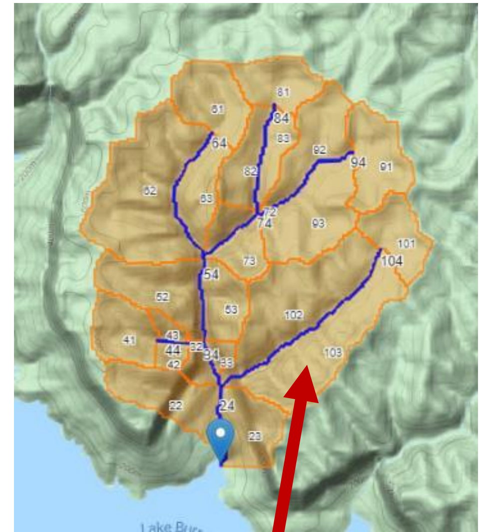
Reservoir capacity (gross)	Current volume (gross)
million litres	million litres
6700	2934.60

PROBABILITY OF EXCEEDING GUIDELINE VALUES

Recurrence interval for selected pollutant

Element	Current concentration	Target concentration	Probability	Return period
	µg/L	µg/L	%	years
Pb	10	15	**11.5**	**20**

Model outputs: Locating erosion and contaminant hotspots



PRIORITIZING HOTSPOT AREAS

Average Annual Summary for Subcatchments for Years 1-30

TopazID	Runoff	Lateral Flow	Baseflow	Soil Loss	Sediment Deposition	Sediment Yield	Ash by Water
	mm	mm	mm	kg/ha	kg/ha		
22	0.43	0.09	330	140	0		
23	2	2.1	340	350	52		
31	2.6	0.063	370	380	0		
32	0.69	0.13	330	130	0		

Thanks for your attention!