A Post-Fire Catchment Hazards Toolbox for assessing erosion and flooding risks after bushfire

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Key Points

- The Post-Fire Catchment Hazards Toolbox was developed and operationalized through a carefully designed collaboration between a team of forest hydrologists, government agency staff, and a team of data scientists specializing in engagement and technology for building decision support tools.
- Land managers can use the Toolbox to rapidly determine likely changes in catchment hazard after a bushfire or to assess the potential impacts from hypothetical fire scenarios, including planned burns.
- The development of the Toolbox outlines an approach to model development and research utilization that is designed to fast track the uptake of research and predictive models amongst government agencies.

Abstract

Intense rainfall following bushfires can trigger debris flows, flash floods, and major water quality contamination events in forested upland environments. Current climate trends are producing conditions that increase the frequency and magnitude of these hazardous events. At the same time, communities are expanding into steep, upland environments, leading to increased exposure to hazards. Catchment managers require a tool to anticipate changes in the likelihood of post-fire catchment hazards to prepare for, rapidly respond to, and mitigate potential risks. We have developed a scripted geoprocessing tool, based on the latest science and stakeholder engagement, to map the magnitude of post-fire hydrogeomorphic hazards along stream networks. The toolbox integrates into state forest management agencies' existing data management systems and consists of a module for each of the following three hazards: (1) debris flow, (2) flash flood, and (3) water quality. The debris flow module integrates a source area determination model, an initiation likelihood model, and a flow runout model to assign a likelihood to possible debris flows within a catchment. The flash flood module uses fire-induced soil modifications and catchment hydrological responses to determine the likelihood of a flash flood occurring within a catchment. The water quality module uses the Revised Universal Soil Loss Equation and debris flow likelihood to determine the water quality contamination potential over a burned area. The tool provides catchment managers with easy access to a fast runtime model that can cover large spatial scales to protect the range of environmental, economic, geomorphic, and recreational values in upland catchments. Our tool provides catchment managers with a means to overlap spatial hazard information with values to evaluate the risk posed by post-fire hydrogeomorphic events.

Keywords

post-fire hazard, debris flow, flash flood, water quality, engagement, mitigation, decision support tool

Introduction

Catchment hazards such as debris flows, flash floods, and extreme water quality impacts often increase in magnitude following bushfires (Moody et al, 2013). Potential impacts from these hazards include damage to critical infrastructure, disruptions to water supply, ecosystem degradation, and injury or even loss of life (Smith et al, 2011; Nyman et al, 2011). Current climate trends are producing conditions that will drive increases in the frequency and magnitude of post-fire catchment hazards (Nyman et al, 2019). At the same time, communities are expanding into steep, upland environments, leading to increased exposure. To mitigate the increase in risk, decision makers require tools that enhance their understanding of the likelihood and magnitude of these hazardous events occurring across a catchment.

In SE Australia, there is a large body of data and research that examine the factors contributing to the occurrence of post-fire hydrogeomorphic events, including catchment characteristics, burn severity, and rainfall (e.g., Keeble et al, 2024; Langhans et al 2016). Despite large investments in research and major advances in modelling capability, there has been little progress to date in the development of operation tools that reflect the best available science to be used by government agencies in the mitigation of and response to the hazards associated with post-fire hydrogeomorphic events.

The issue of translating research into practical outcomes is a common one across hydrological and ecological research disciplines (Hering 2018). There is generally a large lag between when new knowledge is generated and when that knowledge is incorporated into improved management practices. This gap stems from challenges with generalizing research beyond the experimental settings in which it was conducted, technological constraints for operationalizing complex models, data availability, and the degree of maturity amongst end-users in terms of ability to integrate new knowledge and tools into decision making processes.

In this project we outline an approach to model development and research utilization that is designed to fast track the uptake of research and predictive models amongst government agencies. The study is set in Victoria where there has been significant investment from government agencies into research on bushfire and catchment hydrology. The investment in research has been driven by the emerging threat of catchment events following bushfires, which appear to have been increasing in size and intensity in the last few decades. The research has been focused on three key threats that emerge because of bushfire impacts on catchment processes:

- Post-fire debris flows, which can impact on infrastructure, life, and property.
- Increased sediment delivery to waterways and deterioration in water quality.
- Increased peak flows from upland catchments, which can result in increased susceptibility to flash floods.

The research on these threats, led by researchers at the University of Melbourne (UoM), has been published widely in peer-reviewed journal articles and has been instrumental in generating the data and process understanding needed to inform the development of predictive models. One of the potential applications of this research in improving catchment management is in the implementation of a system for post-fire catchment risk assessment at the Department of Energy, Environment and Climate Action (DEECA). These assessments are routinely conducted by Rapid Risk Assessment Teams (RRATs) following major bushfire incidents. The assessments are completed on short timeframes by teams who are not catchment modelers, and this has important implication for how the research and models are packaged for the end-user. This paper described the process of collaboration, engagement, and technical model development that we undertook to consolidate our scientific understanding and produce a tool (Post-Fire Catchment Hazards toolbox) that is aligned with the objectives and capabilities of the RRATs.

METHODS

A collaborative model for research utilization and tool development

The Post-Fire Catchment Hazards toolbox was developed and operationalized through a carefully designed collaboration between a team of forest hydrologists, government agency staff, and a team of data scientists specializing in engagement and technology for building decision support tools. The collaborative process used to deliver this project is summarized in Figure 1. The roles of the different team can be summarized as follows:

- A team of forest hydrologists at the UoM led the model development by consolidating existing research and building the architecture and algorithms that are aligned with the operational needs amongst the end-users within the Bushfire RRATs.
- Data scientists at the Alluvium Group led the engagement with government agency staff to understand how the model would be used and then translating this into model specifications and code needed for embedding the tools into existing processes and data infrastructure at DEECA.
- DEECA staff provided coordination and technical input needed to operationalize the tools. Their ongoing input was critical in ensuring the specifications were clearly defined, that the tool was fit-for-purpose (i.e. for RRATs deployments) and that there was efficient integration into DEECA’s FME (Feature Manipulation Engine).

Post-fire catchment hazard assessment – background

A research team from the UoM has led the development of post-fire catchment models in SE Australia. Models have been developed from empirical data on post-fire rainfall-runoff relationships, erosion rates, post-fire debris flow occurrence and observations of water quality impacts after bushfire. The research from UoM was first operationalized following large bushfires in 2009, when teams of catchment hydrologist and GIS specialist from the US Forest Service were brought in to assist Victoria with undertaking post-fire rapid risk assessments (Figure 2). During their deployment to the Victorian bushfires, the teams from the US Forest Service were seeking input from existing research to help inform the catchment risk assessments. They needed information to understand how natural and built assets may be impacted by post-fire flooding and erosion. In response to this emerging need for information on bushfire impacts on catchments, UoM developed their first algorithms to assess post-fire catchment hazards (Sheridan et al, 2011). Simple rules-based algorithms for hazard assessment were developed for post-fire debris flows, flash floods, and water quality impacts. These algorithms were reflective of the state-of-knowledge at the time and were built with a level of complexity that was aligned with the needs of the post-fire risk assessment teams.

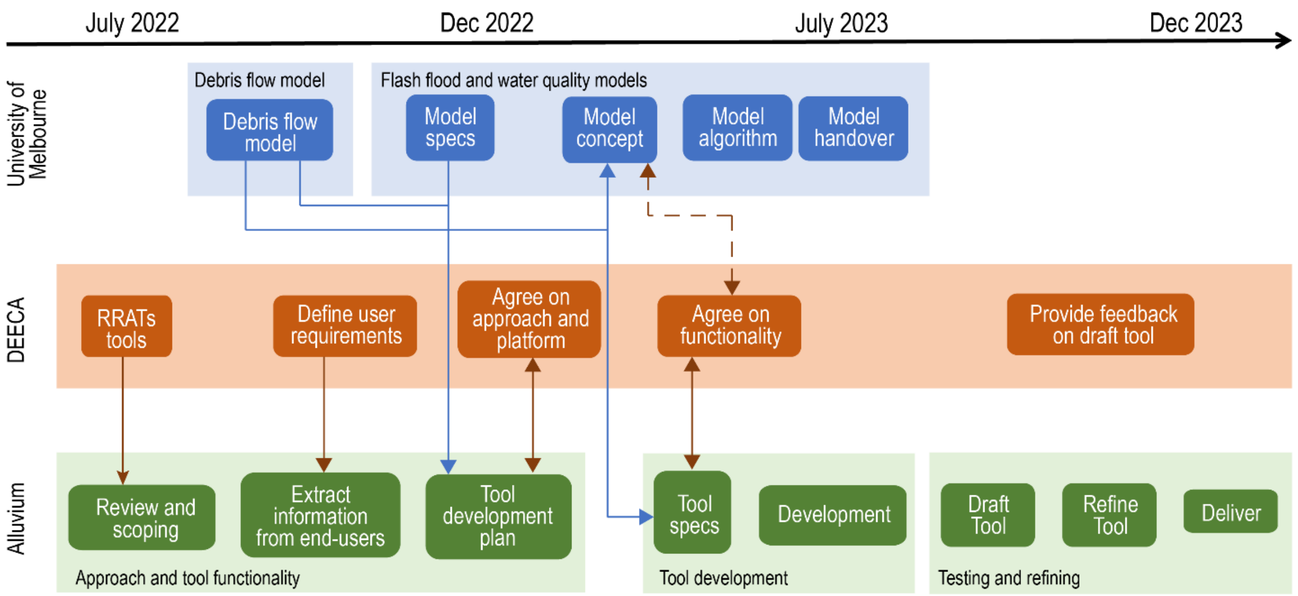

Figure 1. Workflow showing collaborations between the University of Melbourne, DEECA, and Alluvium to produce the Post-Fire Catchment Hazards Toolbox.

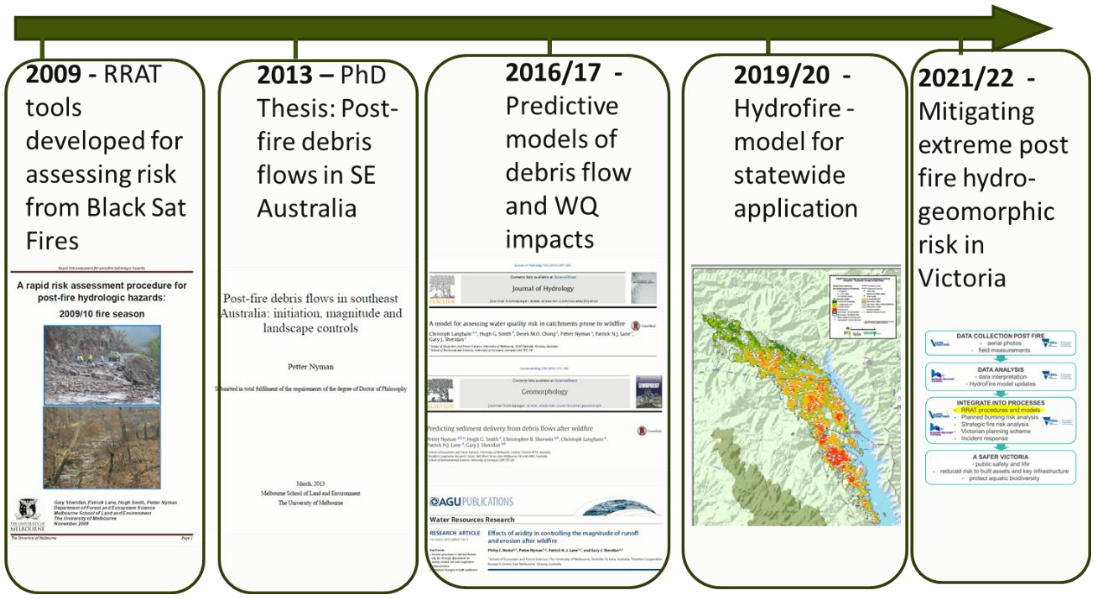

Figure 2. The history of research and model development for post-fire catchment hazard assessment.

About a decade later, the science on post-bushfire hydrology had advanced significantly, and the tools developed in 2009 where outdated with respect to the predictive capability that comes with better data and deeper understanding of bushfire impacts on catchment processes. Some of the key developments between 2010 and 2020 included:

- Completed PhD projects on post-fire debris flows (Nyman, 2013), the role of fire severity in generating variable post-fire erosion rates (Cawson 2012) and its interactions with landscape properties (Van der Sant, 2016).
- Process-based models that predicts erosion response from burned areas (Langhans et al 2016; Nyman et al 2015)
- New datasets that link fire severity and soil properties to changes in runoff ratio and peak flows (Van der Sant et al 2016; Noske et al 2016).

Recognizing the increasing importance of this science for making informed decisions on bushfire management and response, DEECA initiated a program of research utilization that aimed to update the catchment hazard assessment tools for the Bushfire RRATs. Researchers at UoM were therefore engaged by DEECA to consolidate their research and update their hazard assessment algorithms. The Alluvium Group was engaged concurrently, and tasked with translating the outputs from UoM into products that integrate efficiently with DEECA systems and the risk assessment processes that are implemented by the Bushfire RRATs.

Post-fire catchment hazard assessment – bringing science into practice

Data scientists at the Alluvium Group engaged with DEECA to determine the key design considerations that needed to be resolved to develop an operational tool. The information gained from this engagement was used to bridge the gap between model developers and end-users at DEECA. Discussions were held with end-users of the tool at DEECA and with the team overseeing the FME integration to determine tool specifications based on insights on the following themes:

- Skills and level of experience of the end-users in GIS and data management.
- Existing FMEs and software packages used at DEECA.
- The RRATs process and the method for incorporating hazard information into risk assessment and management issues.
- The inherent structure of the modelling from UoM and constraints and opportunities that this presents in terms of implementation.

A key high-level design criterion that emerged from these discussions was the need for efficient handling of data and minimizing the amount of geoprocessing required during the deployment of the RRATs to a fire event. The tool needed to run rapidly, such that information can be obtained for large burned areas (up several 1000s km^2) within days following a fire. The model had to be implemented with as much pre-processing of data and parameters as possible. Another design criterion was flexibility in how the users engage with the tool. There was a need to have the tool sitting as a geoprocessing software within the DEECAs FME, where a user could run the model without any familiarity with GIS or the functionality of the tool. There was also a need for the same tool to be developed into a standalone toolbox that could be run within an ArcGIS environment by users who are proficient with this type of software and as a redundancy if no online access to the FME is available.

In terms of the outputs of the tool, we worked with DEECA to understand how the information would feed into risk assessments. A key decision point was that the tool should not be built to incorporate information on the consequence of hazardous events in a burned catchment (Figure 3). That is, the tool focuses on predicting the hazard, not the risk. This meant the model development could focus on utilizing science to characterize the hazard irrespective of where assets (e.g. road infrastructure, threatened species, water supply reservoir) are located. This decision also meant the actual risk assessment is conducted by the Bushfire RRATs after having mapped the hazard using the tool. Clearly articulating where the tool outputs sit in the overall risk assessment framework was critical to ensure that resources toward model development were targeted and effective in delivering the right type of information.

From the outcomes and insights gained through the research utilization and engagement process, detailed plans for integration with the Bushfire RRATs were developed for each of the hazard types. The toolbox consists of three modules which represent the likelihood of post-fire debris flows, flash floods, and water quality impacts. Technical documentation and a user manual were produced to accompany the tool.

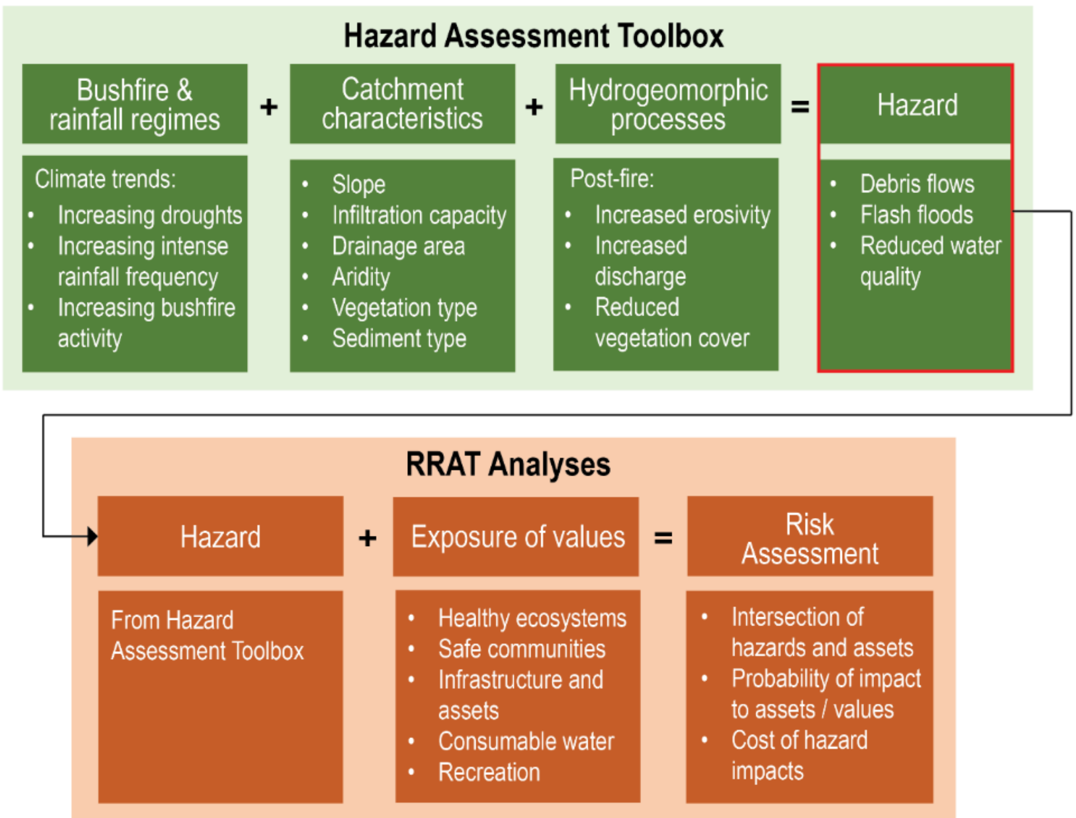

Figure 3. Scope of catchment risk assessment toolbox and its contribution to RRAT risk assessments.

RESULTS AND DISCUSSION

Insights from the collaborative model

There were several factors that contributed to the success of the collaborative model used to develop the Post-Fire Catchment Hazards Toolbox. These factors include:

- Having technical expertise across all three collaborators, which eased communication and limited the amount of cross-disciplinary translation required.
- Flexibility amongst collaborators in terms of the timing of project milestones and delivery.
- Meaningful, two-way engagement between tool developers and end-users.
- Resource availability within DEECA to ensure the tools were able to be embedded into existing emergency response systems.
- Having a champion within the government agency involved, who understands the science and advocated for its integration into mitigation strategies.
- Genuine interest amongst researchers in making an impact with applied research.
- Accepting that models don't need to be perfect and not letting a perfect ideal inhibit the development of a good model.

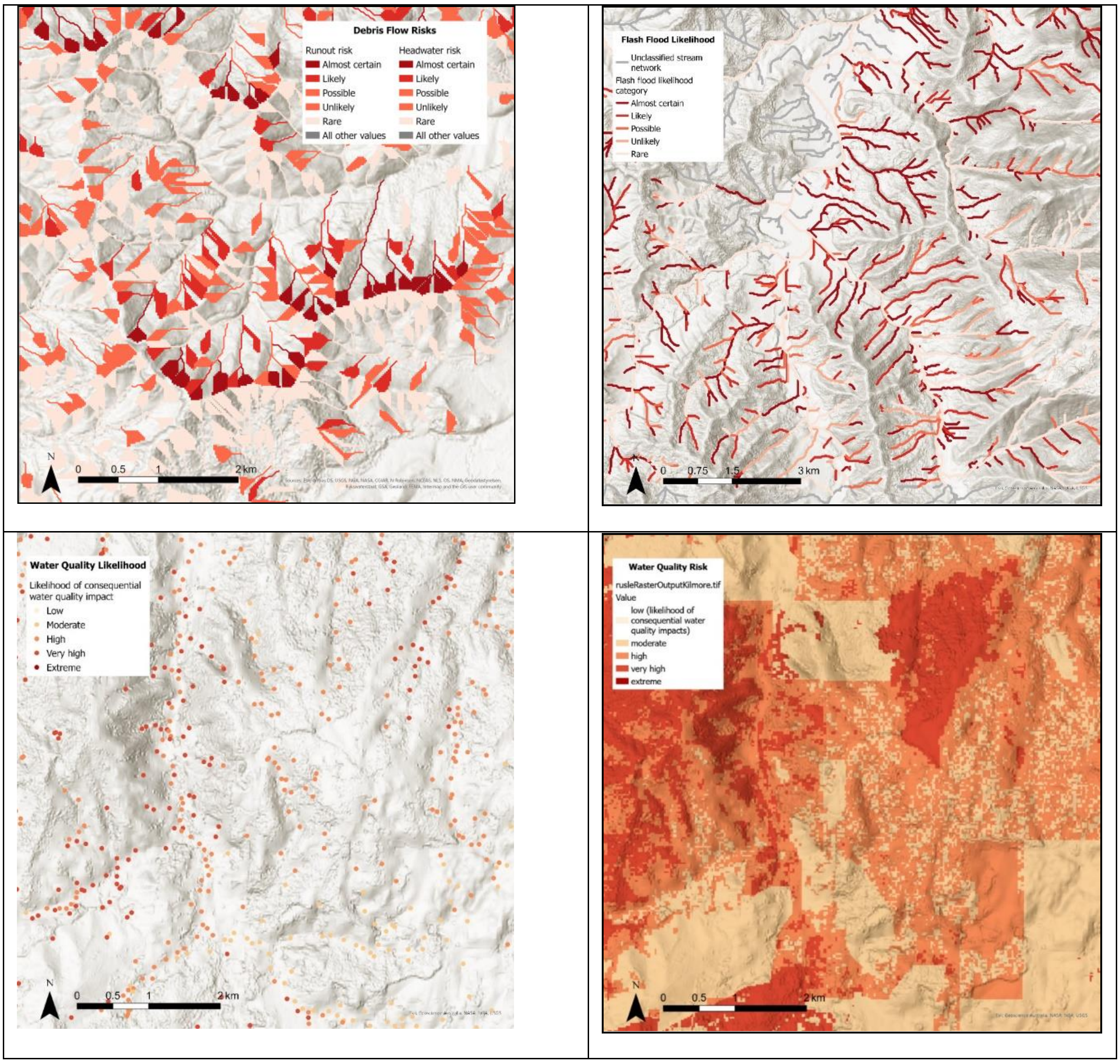

Figure 4 a) Example output from the Debris Flow Module with polygons of debris flow headwaters and paths of debris flow runout. b) Example output from the Flash Flood Module with polylines showing flash flood risk

within the stream network. c) Example of the erosion calculated by the Water Quality module at nodes, which show the likelihood of consequential water quality impact along the stream network from hillslope erosion and debris flows. d) Example raster output from the Water Quality Module with cells showing the likelihood of consequential water quality impact from post-fire RUSLE hillslope erosion.

The outputs – Post-Fire Catchment Hazards toolbox

The three modules making up the tool are summarized here.

The Debris Flow Module integrates multiple models, including a source area determination model, an initiation likelihood model, and a debris flow runout model to quantify debris flow hazards at a landscape-scale. The module contains pre-processed data, such as elevation, aridity index, and rainfall intensity across the state of Victoria, such that the only user-input is the normalized burn ration (dNBR) for the fire of interest. The module outputs layers with the likelihood of debris flow impact assigned to each headwater and runout polygon within the catchment (Figure 4).

The Flash Flood Module considers a flash flood has occurred when the flow rate within a channel exceeds the bankfull discharge or the maximum discharge the channel can accommodate without overflowing its banks. The module defines a flash flood likelihood according to the probability of a rainfall event that generates peak discharge that exceeds the bankfull discharge. With many of the data pre-processed within the tool, the only user-input required is the dNBR of the fire of interest. The module outputs a layer with the likelihood of a flash flood along each segment of the stream network (Figure 4).

The Water Quality Module integrates calculations from the Revised Universal Soil Loss Equation (RUSLE) and output from the Debris Flow Module to estimate the total mean annual erosion rate within the burn area. This integration allows the module to capture sediment erosion from the area upslope of the stream reach of interest and sediment erosion pulses from post-fire debris flows. A burn severity layer of dNBR is the only user input required by the module, and the module outputs the mean annual erosion calculated for nodes and raster cells across the catchment (Figure 4).

Outcomes and notes on model applications

The Post-Fire Catchment Hazards toolbox is the first of its kind in Australia. Catchment managers can now use information on fire severity to rapidly determine likely changes in catchment hazard after a bushfire. Furthermore, the tool can be used as a planning tool to assess the potential impacts from hypothetical fire scenarios, including planned burns. While the tool has been developed based on research from Victorian landscapes, we envisage the modelling frameworks and methods of translating science into practise has application to other Australian jurisdictions.

The lack of operational systems in Australia for assessing post-fire hydrogeomorphic risks is not a reflection of lack of knowledge or data. Instead, we argue that the major constraint is in the lack of incentives within the research sector to translate research outputs into practical outcomes for industry. While there is an increase focus on demonstrating impact through industry uptake, the emphasis within the academic sector remains largely focused on impact through peer-reviewed publications. In this project, DEECA recognised the importance of allocating resources towards not just model development but also model implementation. Elements related to implementation were assigned to professional data scientists working at a consultancy. This meant that researchers at UoM could remain focused on the science, model development, and writing peer-reviewed publications (Keeble et al, 2024).

The collaborative effort needed to integrate science into operational tools for government agencies in this project relied on strong relationships built on trust and mutual understanding. A structured approach outlined project roles and responsibilities, developed pathways for communication, defined the project’s scope and deliverables, and provided clarity around Intellectual Property. Two-way engagement ensured the toolbox is accessible to end-users and produces meaningful outcomes for land managers. Building these cross-industry relationships and developing structured collaborations is key for integrating academic-based knowledge into usable hazard mitigation tools.

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