A rapid risk assessment procedure for post-fire hydrologic hazards:

2009/10 fire season

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This work, or any part thereof, should be cited as;


Cover photo: (Top) Post fire debris flow near Licola following the 2007 Great Divide fire. (Bottom) The West Kiewa River following the 2007 Great Divide fire.
Overview
The Victorian Department of Sustainability and Environment (DSE) is developing a rapid risk assessment process to enable the relative comparison of post-fire hazards to values and assets resulting from a range of processes. For example, fire may threaten the survival of an isolated threatened species. Identification of this risk enables a management response.

One of the aims of the risk assessment is to rank hazards for the purpose of prioritization of emergency response resource allocation, based on evaluating the consequence and likelihood of risks. Hazards with the highest rank should receive the highest priority for consideration of emergency funding.

Hydrologic processes are one of a range of threatening processes. Hydrologic processes can threaten ecosystems and species, physical infrastructure, economic and social wellbeing, and in the worst case threaten human life.

The aim of this technical report is to:

1. Identify the key post-fire hydrologic risks.
2. Propose methods to rank these risks.

The rapid risk assessment methods proposed in this report are being produced in a short time-frame to enable implementation for the 2009-10 fire season. The methods should therefore be considered a first-cut, and will require further development before being adopted in following fire seasons. Recommendations for areas of further development are included in the report.

The rapid risk assessment methods proposed in this report share many of the objectives of the US-based Burned Area Emergency Response (BAER) assessments which followed the Victorian Black Saturday fires in 2009. However the assessment methods differ in several important ways. Firstly the resources (both financial and technical) to undertake and implement the risk assessment are considerably less in Australia than in the US. The assessment methodology must reflect this constraint. Secondly, the proposed methodology shifts the focus of the risk assessment towards post-fire debris flows, an extreme form of post fire erosion that has been associated with a range of hazards following the 2003 and 2007 fires in Victoria.

Design criteria for hydrologic rapid risk assessment method
Risk assessment methods must be compatible with the technical and financial resources allocated to implementation of the assessment procedure. Briefing meetings with Ben Plowman and Ian Rutherfurd on the 4/11/09 and with Ben Plowman on the 11/11/09 prior to the development of this risk assessment outlined the following design criteria to be considered during the development phase.

- Resources for completion of the hydrologic rapid risk assessment are in the order of 7 full-time equivalent (FTE) person days.
- With this level of resourcing, the risk assessment must be largely a desktop exercise, with the field component limited to a “reality check” of the desk-top assessment.
The risk assessment should be operational within 3 weeks, for implementation on December 1 2009. The first year will therefore be a trial, with further development required prior to subsequent fire years.

Risk assessment should be consistent with the consequence & likelihood matrix (see Appendix) used to compare all post fire risks.

The risk assessment can assume rapid access to a fire severity layer (not soil severity) via the US BAER team.

The risk assessment is to be implemented within DSE. We assume that responsible DSE group has substantial GIS capacity for vector data analysis (eg. Mapping), some capacity for grid-based analysis (eg. Map algebra), and limited capacity for complex algorithm coding and implementation (eg. Visual Basic scripts).

Risks include public land assets and public-on-to-private land.

The risk assessment is designed for, and restricted to, Victorian upland forested areas dominated by clay loam soils; eg. The Great Dividing Range, the Otway’s, the Strzelecki’s, and the Central Highlands. Application to other geologies, soils (eg. sands of the Grampians) or landscapes will require further development of the risk assessment.

Hydrologic risks
The objective of this report is to describe methods for ranking the relative risks associated with post-fire hydrologic processes. Catchment hydrology, soil erosion and water quality are altered in many ways due to fire. In this assessment we focus on three key post-fire hydrologic risks to human life and wellbeing, infrastructure, environment, and economic wellbeing;

1. debris flows risk
2. water quality risk
3. flooding risk

Flooding results from increased peak flows and can result in loss of life and damage to infrastructure. Flooding following the 2007 Great Divide fires resulted in serious damage to regional roading infrastructure, flooding of the town of Licola, and resulted in the Glennmaggie dam experiencing a major flood event. Flooding from burnt areas in South Eastern Australia is typically associated with large east-coast low pressure systems.

Debris flows have been observed following the 2003, 2007, and 2009 wildfires in Victoria. Debris flows are generated in steep upper catchments from intense convective rain cells. While these extreme erosion events are of short duration (<20min) and limited extent (<500ha), they generate tens of thousands of tons of debris (rock, soil, logs, etc). This debris often destroys roading infrastructure, and can threaten buildings and human life. For example, the only loss of life associated with the 2003 Alpine Fire, which burnt over 1.3M ha, resulted from a post fire debris flow in the Buckland valley in NE Victoria. Research to demine the conditions under which post-fire debris flows are generated in Victoria has only recently been initiated (Nyman et al. 2008,2009; Sheridan et al. 2009; Nyman et al. in prep.) In the US, this risk is taken very seriously, following the recent death of a group of campers from a post fire debris flow. Areas at risk of post fire debris flow have been mapped, and debris flow warnings are issued by the
weather service when severe thunderstorms are predicted to intersect with burned areas. Debris flows can also pose risks to isolated populations of threatened aquatic species. After the 2003 fires, some threatened fish populations were relocated out of the fire affected area until after the area had recovered from the fire.

Water quality impacts are the most commonly observed post-fire hydrologic impact, resulting from hillslope and channel erosion. The degree of impact is highly variable, from no impact in some instances, to 100 and 1000 fold increases in constituent concentrations (eg. Sediment). The most common impact is on towns drawing water directly from affected streams, often with limited water treatment capacity. These towns, such as Bright in NE Victoria, have experienced 100’s of “boil water” notices in the last five years as a result of large fires. In the worst case water supply reservoirs can become heavily contaminated resulting in loss of water supply. For example, following the 2003 fires in Canberra, the cities reservoir was taken off-line for more than a year. Fortunately, Canberra was able to switch to a reservoir in an unburned catchment while a new water treatment plant was constructed to treat the contaminated water supply. Water quality can also pose risks to isolated populations of threatened aquatic species.

**Spatial datasets available for assessment**
The following datasets are currently available, or can be sourced or derived, for use in the post-fire hydrologic risk assessment;

- A 20m resolution digital elevation model (DEM)
- Ecological vegetation class (EVC) vector layer
- Burn severity layer
- Rainfall erosivity grid at 0.25 degree spacing
- Stream network vector layer
Risk assessment methods for threatening processes

Identifying locations with high debris flow generation risk
The processes and properties of post-fire debris flow generation are described in the Appendix. Based on this knowledge, a map-algebra based algorithm (Equation 1) is proposed that can be implemented in a GIS to categorize areas based on the risk of debris flow generation at the 20m grid resolution.

\[
Debris\ flow\ index = S \times EVC \times V \times T
\]  

(Eq 1)

Where:

- \(S\) is the slope index value from Table 2
- \(EVC\) is the ecological vegetation class index value from Table 2
- \(V\) is the burn severity index from Table 1
- \(T\) is the stream order index from Table 2

Fire severity is based on the following post-burn descriptions commonly used within the Department of Sustainability and Environment. Classes can be based on a manual field assessment, or can be mapped spatially from remotely sensed Normalized Difference Vegetation Index (NDVI) data. Although it would be desirable, no method is currently proposed to convert the vegetation burn severity into a soil burn severity due to the limited resources available for post-fire soil measurements in the field (see Recommendations).

Table 1. Fire severity classes.

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very severe</td>
<td>Crown burnt</td>
</tr>
<tr>
<td>Severe</td>
<td>Severe crown scorch</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate crown scorch</td>
</tr>
<tr>
<td>Light</td>
<td>Light crown scorch</td>
</tr>
<tr>
<td>Unburnt</td>
<td>Unburnt</td>
</tr>
</tbody>
</table>
The multiplicative algorithm requires some pre-processing of spatial data;

- Polygons for EVC classes must be converted to grid values at the resolution of the DEM. These are then reclassified based on the rule-set given in Table 2.
- The DEM must be used to derive a grid of slope values
- The DEM must be used to derive a pit-filled flow-accumulation grid. The vector based stream network layer can then be used to identify sub-basins that only contain first order streams (or alternatively, the stream order algorithm in ArcGIS can be utilized)

Table 2. Index values for application in the debris flow algorithm given by Equation 1.

<table>
<thead>
<tr>
<th>Slope (degrees)</th>
<th>&lt;25</th>
<th>&gt;=25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index value</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>EVC</td>
<td>Dry forest*</td>
<td>All other forest types</td>
</tr>
<tr>
<td>Index value</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Burn Severity*</td>
<td>≥Severe</td>
<td>Moderate</td>
</tr>
<tr>
<td>Index value</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Stream order*</td>
<td>1</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Index value</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

A: includes sub-categories of dry forest including grassy dry forest, shrubby dry forest etc.
B: pixels in basins that contain first order streams ONLY are given an index value of 1, all other pixels are assigned an index value = 0
C: See table for burn severity classification

Table 3. Debris flow risk categories resulting from the application of Table 1 and Equation 1.

<table>
<thead>
<tr>
<th>Debris flow index</th>
<th>Debris flow likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Highly improbable (1:100,000 chance)</td>
</tr>
<tr>
<td>1</td>
<td>Very unlikely (1:10,000 chance)</td>
</tr>
<tr>
<td>2</td>
<td>Possible (1:100 chance) to Unlikely (1:1000 chance)</td>
</tr>
<tr>
<td>3</td>
<td>Highly probable (1:10 chance) to Possible (1:100 chance)</td>
</tr>
</tbody>
</table>

How to use the output
The output from the debris flow risk assessment is a colored map showing areas with high, moderate, low, and no risk of debris flow generation. Assets a short distance downstream from these generation areas are at risk of physical impacts from large debris, including rocks and logs >30cm diameter. Culvert based road-stream crossings in upper catchments are particularly vulnerable to this process, with the entire road often being washed away at the crossing once the culvert becomes blocked. Consequences for isolated rural communities can be considerable. Buildings and camping areas within close proximity to drainage lines (these do not have to be running streams) are also vulnerable.

The bulk of the large debris is quickly deposited as the stream gradient reduces. However the fine sediment generated from the debris flow can be carried 100’s of kilometers, as was the case with the Buckland Valley post-fire debris flow in 2003. Water supply infrastructure within this range of the areas at risk of debris flow generation should also be considered at risk.
Debris flow runout distances (ie. The distance the “large” material travels before depositing) can be modelled by a range of methods, from complex and detailed numerical simulations of non-Newtonian flows requiring large parameter sets and detailed LIDAR based DEM's, through to simple empirical rules based on topography. If the horizontal distance of the run-out is \( L \), and the elevation drop over this distance is \( H \), then Iverson (1997) report a range of \( L/H \) ratios for different debris flow types, ranging in value from 2 to 25. Analysis of \( L/H \) ratios from 9 Victorian post-fire debris flow sites, from 6 separate storm events result in a mean \( L/H = 3.65 \), (range 2.79 – 4.61) (Nyman pers comm., 2009.). While it should be noted that this analysis is purely empirical, these \( L/H \) values do provide some guide as to the extent of the risk corridor associated with recent post fire debris flows in Victorian uplands. A safety factor should be applied to these ratios. Note that flash floods and/or “hyper concentrated” floods are likely to occur below the main debris flow deposit.

**Other comments**

Rainfall data (eg. Annual totals, erosivity, IFD) are not used in the debris flow risk assessment at this stage for two reasons:

1. A limited set of data exists on the rainfall intensity-duration thresholds required for initiation of runoff-generated post-fire debris flows.
2. Poor spatial accuracy of the interpolated IFD contours in the forested areas at risk of debris flows.

For 2009 the output maps from this risk assessment should be used in a qualitative way to identify assets at risk downstream from the debris flow risk areas. More advanced GIS based algorithms can be developed in the future to spatially link risks to assets with debris flow locations. The literature on debris flows provides good guidance on run-out distances for debris flows. The algorithms would utilize flow accumulation layers derived from the DEM to link debris flows with assets, and debris flow run-out length functions drawn from the geomorphic literature to identify areas at risk of physical impact by large debris. In the interim the empirical \( L/H \) ratios reported above can be used as a guide.

The index values applied to the EVC class, burn severity and slope are based on the limited available data for SE Australia, collected by University of Melbourne researchers since the 2003 Victorian fires. More research is required to refine these index values, and to consider the relative influence of other important factors, for example indices of landscape convergence and divergence.
Water quality risk at a point

Water quality risk is calculated at the point of the asset in the drainage network. This will usually be a high value asset such as a water supply take-off point or at an in-stream location of ecological value. A map-algebra based algorithm (Equation 2) is proposed that can be implemented in a GIS to generate a grid of pollutant generation values. These are then aggregated for the catchment area upstream of the asset.

The pollutant generation potential (with respect to the asset) of each cell $\Psi$ is given by;

$$\Psi = G \times S \times EVC \times V \times R$$  \hspace{1cm} (Eq 2)

where

$G$ is the index with value of 1 if the cell is within the catchment above the asset, and value 0 if the cell is not in the catchment

$EVC$ is the ecological vegetation class index value from Table 4

$V$ is the burn severity index from Table 4

$R$ is the rainfall erosivity index from Table 4

$S$ is the slope adjustment factor for rill and interill hillslope erosion processes, calculated from Sheridan et al. (2003);

$$S = -1.12 + 16.05/[1 + \exp(2.61 - 8.32 \sin \theta)]$$  \hspace{1cm} (Eq 3)

Where $\theta$ is the slope angle in degrees. Equation 3 is a logistic equation normalized to 1 at 9% slope.

The pollutant generation potential $\Psi$ will equal zero for all cells that are not in the catchment upstream of the asset. The $\Psi_{i,j}$ are then summed for the entire $m \times n$ grid, adjusted for the level of connectivity between the hillslope and the stream upstream of the asset, and normalized for the catchment size;

$$Water\ quality\ risk\ index = \frac{C \sum_{i=1}^{m} \sum_{j=1}^{n} \Psi_{i,j}}{\text{count of cells where } G=1}$$  \hspace{1cm} (Eq 4)

$I,j$ are the index values for the cell location within a grid of $m$ by $n$ cells

$C$ is the connectivity index between the hillslope and the stream, and reflects the effects of connectivity on water quality. $C$ is calculated as the ratio of the number of high burn severity cells ($V=5$) intersecting the stream network ($T=1$), to the total number of cells intersecting the stream network ($T=1$), in the catchment upstream of the location of the asset ($G=1$). The function is scaled to vary in value from 0 (buffer unburnt) to 1 (buffer all burnt);

$$C = Connectivity\ index = \left( \frac{\text{count of cells where } V=5 \text{ AND } T=1 \text{ AND } G=1}{\text{count of cells where } T=1 \text{ AND } G=1} \right)$$  \hspace{1cm} (Eq 5)
where $T$ is the stream intersection index with value 0 if the cell does not intersect the stream network, and value 1 if the cell does intersect the stream network. Equation 4 is not defined where there is no defined stream network in the catchment as the denominator will be zero, however it is assumed that catchments not containing streams will also not contain the assets of interest ie. Stream off-takes and aquatic habitats.

The multiplicative algorithm requires some pre-processing of spatial data:

- The DEM must be used to derive a pit-filled flow-accumulation grid and to delineate the catchment above the asset point (the pour point).
- Polygons for EVC classes must be converted to grid values at the resolution of the DEM. These are then reclassified based on the rule-set given in Table 4.
- A grid of slope values is derived from the DEM.
- The 0.025 degree rainfall erosivity grid must be re-sampled at the resolution of the DEM.

Table 4. Index values for application in the water quality algorithm (Equations 2-5).

<table>
<thead>
<tr>
<th>Property</th>
<th>Index Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (G)</td>
<td></td>
</tr>
<tr>
<td>Index value</td>
<td>Upstream of asset</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>EVC</td>
<td></td>
</tr>
<tr>
<td>Index value</td>
<td>Dry</td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Burn Severity$^a$ (V)</td>
<td>≥Severe</td>
</tr>
<tr>
<td>Index value</td>
<td>5</td>
</tr>
<tr>
<td>Erosivity$^b$ (R)</td>
<td>&lt;900</td>
</tr>
<tr>
<td>Index value</td>
<td>1</td>
</tr>
<tr>
<td>Stream intersection (T)</td>
<td>Cell intersects stream</td>
</tr>
<tr>
<td>Index value</td>
<td>1</td>
</tr>
</tbody>
</table>

$^a$: Sheridan and Rosewell (2003). $^b$: See Table 1 for burn severity classification.

Table 5. DRAFT Water quality risk categories resulting from the application of Table 4 and Equations 2-5.

<table>
<thead>
<tr>
<th>Water quality index value$^c$</th>
<th>Risk of substantial water quality impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Zero risk (streamside buffer intact)</td>
</tr>
<tr>
<td>&gt;0-70?</td>
<td>Very unlikely (1:10,000 chance)</td>
</tr>
<tr>
<td>&gt;70-140?</td>
<td>Possible (1:100 chance) to Unlikely (1:1000 chance)</td>
</tr>
<tr>
<td>&gt;140-700?</td>
<td>Highly probable (1:10 chance) to Possible (1:100 chance)</td>
</tr>
<tr>
<td>&gt;700-3000?</td>
<td>Almost certain (more than 1:10 chance)</td>
</tr>
</tbody>
</table>

$^c$: Categories are indicative only and require calibration using data from experimental water catchments affected by fire.
Water quality index categories in Table 5 are indicative only and require calibration against a set of catchments with known post fire water quality responses. Initial catchments that may be used for calibration are:

- Long Corner Creek Research Catchments, near lake Buffalo, NE Victoria, 2006 (prescribed fire)
- Cropper Creek Hydrologic research catchments, near lake Buffalo, NE Victoria, 2007
- East Kiewa Research Catchments, near Myrtleford, NE Victoria, 2003
- Armstrong Catchment (Melbourne Water) near the Upper Yarra, 2009
- West Kiewa catchment, NE Victoria, 2003, 2007

In addition, a group of large burnt catchments in Eastern Victoria were monitored for water quality impacts following the 2003 fire and may be useful for calibration.

**How to use the output**

The water quality risk value calculated at the point of an in-stream asset will vary between zero and ca. 3000 (given the index values provided in Table 4) and can be used in several ways. Firstly, the value can be compared to point values calculated for other water quality related assets. Alternatively, the value can be expressed as a relative proportion of the worst case when all the catchment is burnt at high severity (V=5), and the connectivity index therefore is at a maximum (C=1).

\[
\text{Water quality risk relative to worst case} = \frac{\text{Water quality risk index}}{\text{Water quality risk index (V=5, C=1)}}
\]  

(Eq 6)

**Other Comments**

There are many possible methods for estimating risk to water quality due to fire. Methods differ in the degree of technical knowledge required to parameterize and execute the models. The approach proposed here is at the simple end of the spectrum, and is similar to a spatial implementation of the Universal Soil Loss Equation (USLE), used widely around the world to consider land use impacts on soil erosion and water quality. Chafer (2008) employed a USLE based modeling approach in Sydney water catchments following fire. The Burned Area Emergency Response (BAER) team from the US uses a probabilistic implementation of the Water Erosion Prediction Project (WEPP), a process-based erosion model developed for US agriculture and forested landscapes.

Future development of this algorithm should incorporate flow accumulation or slope length effects. Soil types/geology/regolith can also be incorporated, although mapping information for Victorian forest soils is very limited at present, and it is possible that EVC captures much of the soil effect in the current algorithm.
Change in flood risk
The flooding risk is calculated at the point of the asset in the drainage network. This will usually be a high value asset such as a drainage structure, road, or human settlement. A quantitative assessment of the change in flooding risk is not proposed for implementation in the 2009-10 fire season due to both the limited time for the algorithm development and the limited data for parameterization. It is recommended that a more quantitative method be developed for the 2010-11 fire season.

For the 2009-10 fire season a map-algebra based algorithm (Equation 7) is proposed that can be implemented in a GIS to generate a grid of runoff generation potential values. These are then aggregated for the catchment area upstream of the asset to provide a qualitative measure of change to flooding risk.

The runoff-generation potential of each cell $\beta$ is given by;

$$\beta = G \times EVC \times V$$  \hspace{1cm} (Eq 7)

where

$G$ is the index with value of 1 if the cell is within the catchment above the asset, and value 0 if the cell is not in the catchment

$EVC$ is the ecological vegetation class index value from Table 6

$V$ is the burn severity index from Table 6

These flood generation values $\beta_{i,j}$ are then summed for the entire $m \times n$ grid and normalized for the catchment size;

$$\text{Flood risk index} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \beta_{i,j}}{\text{count of cells where } G=1}$$  \hspace{1cm} (Eq 8)

$i,j$ are the index values for the cell location within a grid of $m$ by $n$ cells

Table 6. Index values for application in the flood risk algorithm.

<table>
<thead>
<tr>
<th>Property</th>
<th>Location (G) Index Value</th>
<th>Upstream of asset</th>
<th>Not upstream of asset</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>EVC</td>
<td>Index value</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Damp</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wet</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Burn Severity (V)</td>
<td>Index value</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\geq$Severe</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Light</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Unburnt</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 7. Flood risk index categories resulting from the application of Table 6 and Equation 8.

<table>
<thead>
<tr>
<th>Flood factor</th>
<th>Flood risk</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>Minimal change</td>
<td>The risk of flooding has not changed substantially from the unburnt state</td>
</tr>
<tr>
<td>&gt;2-3</td>
<td>Moderate increase</td>
<td>There is some increase in flooding risk due to the fire</td>
</tr>
<tr>
<td>&gt;3-4</td>
<td>Maximum increase</td>
<td>There is a substantial increase in flooding risk due to the fire</td>
</tr>
</tbody>
</table>

**How to use the output**

The output provides a simple index of the change in flood risk due to the combination of burn severity and forest type (EVC). Interpretation of this index is given in Table 6. High severity burns in dry forests are considered to create the greatest risk. Low severity burns in wet forest result in no change to the flood risk. The algorithm does not currently capture the effects of catchment size or the arrangement of burnt and unburnt areas relative to the drainage network.

**Other Comments**

Many methods exist for the estimation of the recurrence interval of flood peaks (eg. The rational method, SCS Curve Number, numerical hydrologic routing). However, little high quality data exists on the relationship between fire and peak flows in large catchments, because rainfall stations are poorly represented in remote forested catchments. The development of quantitative algorithms therefore requires considerable care and analysis of a range of published and unpublished data sources if such quantitative methods are to be credible and defendable. This analysis should be undertaken prior to the 2010 fire season.

Equations 6 and 7 do not capture the effect of the spatial arrangement of burned and non-burned areas in relation to the drainage network. In the future a cost-distance algorithm should be included to weight burned cells in relation to proximity to the drainage network. An example of this approach is given by Moody et al. (2008).
Recommendations

1. The methods described in this report have been developed in a short time frame for the 2009 fire season. The proposed methods should be re-evaluated and updated before application in 2010. Higher resolution, more sophisticated modelling may be justified where high value assets are involved.

2. Calibration of the risk index values against post fire catchments with known hydrologic responses (with respect to debris flows, water quality and flooding) is recommended prior to the 2010-11 fire season.

3. The magnitude-frequency of post-fire debris flows are poorly understood at present in Australia. The 2009 draft of the risk assessment assumes a binary state (debris flows on or off). Future development of the risk assessment should aim to quantify the variability in the magnitude of debris flows eg. Volumes generated so as to better quantify downstream risk. Surveys of post 2009 burnt landscapes are recommended to quantify the frequency of debris-flows and relate occurrences to geomorphic and geological parameters.

4. Vegetation burn severity is usually mapped after a fire, however for hydrologic risks it is the soil burn severity that is the relevant post-fire property. Vegetation severity is used as a surrogate because it is easier to map. Methods exist to convert vegetation burn severity to soil burn severity (eg.see US BAER team field methods), however these are not currently proposed for Victoria as the resources are not available to undertake the necessary field measurements. Future development of this risk assessment should aim to incorporate post-fire field soil survey to convert vegetation burn severity to soil burn severity.

5. Risk assessment resource allocation should be scale-dependent of as a function of fire size, which could realistically vary by 3 orders of magnitude in a fire season.
Selected references and reading guide


Lane P.N.J., Feikema P.M., Sherwin C.B., Peel M.C., Freebairn A. Modelling the long term water yield impact of wildfire and other forest disturbance. Submitted to Environmental Modelling and Software.


Lane P.N.J., Sherwin C.B., Peel M.C. and Freebairn A.C. (2008) Impact of the 2003 Alpine Bushfires on Streamflow - Predicting the long-term impacts of bushfire on water yield. MDBC Publication No. 24/08


Smith H.G, Sheridan G.J., Lane P.N.J. and Sherwin C.B. Paired Eucalyptus forest catchment study of prescribed fire effects on suspended sediment and nutrient exports in south-eastern Australia. Submitted to International Journal of Wildland Fire

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Appendix

Post-fire debris flow processes

Prior to the current research program there was no published literature on post-fire debris flows in SE Australia. Knowledge has been gained from study of debris flows that occurred following the 2006-07 fires in Victoria, and from the international literature, particularly from the West Coast of the USA. Victorian post-fire debris flows that have been studied in 2008 (Nyman et al. 2008,2009; Sheridan et al. 2009) include;

- Tawonga Gap, near Bright
- Tamboritha Road, near Licola
- Jameson-Licola Road, near Licola
- Yarrarabulla, near Mt Buffalo
- Rose River, near Lake Buffalo

The international literature is dominated by the findings of Susan Cannon from the United States Geological Survey in the USA. Our current working hypothesis/model of post-fire debris flows is given below. The model is based on literature and field observations, and is yet to be tested and is the basis of current research.

Post-fire debris flows result from infiltration-excess runoff generation following short intense storms. These storms have an average recurrence interval of around 2-5 years, and in the observed cases have been limited in spatial extent to <5km². Hillslope runoff in steep (>25 degrees) convergent upper catchments with shallow clay-loam soils causes bulking of loose hillslope materials such as ash, soil, and rocks. It is likely the runoff rate is enhanced by water repellence. The debris flows are more common on dry north facing slopes with shallow soils and an overstory less than 15m high. The surface of the soil is stripped to a depth of several centimeters, apparently to the depth at which roots have been combusted. Solid materials accumulate downslope at a faster rate than the water, resulting in a highly erosive fluid with low water content. In convergent gully heads these materials concentrate rapidly and initiate a debris flow (at around 100 m from the catchment divide), which usually causes the channel to erode to bedrock.

It is possible that the moving front of the debris flow (known as the snout) is where most of the channel erosion takes place, and passes very quickly, in the order of 20 to 30 seconds. Much of the water lags behind the debris flow, and transports the eroded fine material. The debris flows generate very high channel loads in areas where gullies converge and soil depths in the channel are greatest (many meters deep). As the slope decreases below 15 degrees a debris flow fan is produced as the larger material deposits. The finer material is then washed through into the drainage network by the following runoff flow. The total load from a group of debris flows is commonly in the order of 10,000's of tons.
Victorian Ecological Vegetation Classes (EVC)
A description of EVC classes can be found at;

### Bushfire RRATs - Risk Methodology: Consequence Table

<table>
<thead>
<tr>
<th>Performance level</th>
<th>Minor Harm</th>
<th>Moderate Harm</th>
<th>Major Harm</th>
<th>Extreme Harm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-1</td>
<td>-3</td>
<td>-10</td>
<td>-30</td>
</tr>
<tr>
<td><strong>Public Safety</strong></td>
<td>Loss of well-being</td>
<td>1 fatality or serious injury</td>
<td>Between 1 and 10 fatalities or serious injuries</td>
<td>Greater than 10 fatalities/serious injuries</td>
</tr>
<tr>
<td>eg. A risk that threatens life</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Infrastructure</strong></td>
<td>Minor damage to critical infrastructure causes inconvenience to users</td>
<td>Moderate damage to critical infrastructure requires short-term work to repair</td>
<td>Major damage to critical infrastructure requires long-term work to repair</td>
<td>Critical infrastructure damaged beyond repair</td>
</tr>
<tr>
<td>eg. A risk that threatens critical infrastructure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Environment - Biodiversity</strong></td>
<td>Species threatened</td>
<td>Extinction of a local species</td>
<td>Extinction of a species</td>
<td>Extinction of multiple species</td>
</tr>
<tr>
<td>eg. A risk that threatens the ecosystem</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Environment - Cultural Heritage</strong></td>
<td>Some disturbance to cultural heritage site/value</td>
<td>High degree of disturbance to cultural heritage site/value</td>
<td>Destruction of a cultural heritage site/value</td>
<td>Complete destruction of multiple cultural heritage sites/values</td>
</tr>
<tr>
<td>eg. A risk that disturbs or destructs a cultural heritage site/value</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Commercial</strong></td>
<td>Loss of up to $1 million</td>
<td>Loss of $1 to $10 million</td>
<td>Loss of $10 to $100 million</td>
<td>Loss greater than $100 million</td>
</tr>
<tr>
<td>eg. A risk that jeopardises economic/commercial return for a product</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Access/Amenity/Utility</strong></td>
<td>Minor damage to public facilities and utilities causes inconvenience to users</td>
<td>Moderate delay to access towns and utilities</td>
<td>Extended delays to access towns and utilities</td>
<td>Loss of a township, public facilities and utilities</td>
</tr>
<tr>
<td>eg. A risk that denies access to townships, public facilities and utilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Political/Reputation</strong></td>
<td>Minor negative media attention with no political pressure</td>
<td>Public/media criticism at local level with some political pressure</td>
<td>Major public/media criticism at state level with major political pressure</td>
<td>Public enquiry at international/national level with extreme political pressure</td>
</tr>
<tr>
<td>eg. A risk that threatens the reputation of the Vic Gov or has the potential to spark a political debate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Rapid risk assessment for post-fire hydrologic hazards

Risk Criteria – Score the likelihood of the risk event occurring

### Likelihood Guide

<table>
<thead>
<tr>
<th>Qualitative Description</th>
<th>Order of Magnitude Probability (over a given timeframe, e.g. 1 year, life of project etc)</th>
<th>Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Certain</td>
<td>1 (or 0.999, 99.9%)</td>
<td>Certain, or as near to as makes no difference</td>
</tr>
<tr>
<td>B. Almost certain</td>
<td>0.1 to 1 (Relevant specialist to estimate value to say, nearest 5%)</td>
<td>One or more incidents of a similar nature has occurred here</td>
</tr>
<tr>
<td>C. Highly probable</td>
<td>0.1 (1 in 10 chance)</td>
<td>A previous incident of a similar nature has occurred here</td>
</tr>
<tr>
<td>D. Possible</td>
<td>0.01 (1 in 100 chance)</td>
<td>Could have occurred already without intervention</td>
</tr>
<tr>
<td>E. Unlikely</td>
<td>0.001 (1 in 1,000 chance)</td>
<td>Recorded recently elsewhere</td>
</tr>
<tr>
<td>F. Very unlikely</td>
<td>$1 \times 10^{-4}$ (1 in 10,000 chance)</td>
<td>It has happened elsewhere</td>
</tr>
<tr>
<td>G. Highly improbable</td>
<td>$1 \times 10^{-5}$ (1 in 100,000 chance)</td>
<td>Published information exists, but in a slightly different context</td>
</tr>
<tr>
<td>H. Almost impossible</td>
<td>$1 \times 10^{-6}$ (1 in 1 million chance)</td>
<td>No published information on a similar case</td>
</tr>
</tbody>
</table>