Using E2 To Model The Impacts Of Bushfires On Water Quality In South-Eastern Australia

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EXTENDED ABSTRACT

Approximately 1.3 million ha of forested and agricultural land in eastern Victoria, Australia, was burnt by bushfires in early 2003. The impact of these fires on the water quality in rivers and storages has the potential to be significant.

This paper describes a modelling process to assess the impacts of the fires on water quality of receiving waters and river systems in the fire-affected catchments. More specifically, this study set out to;

1. Construct and parameterise models using the E2 catchment modelling framework to represent the flow, and sediment and nutrient loads for the water storages and river systems in fire-affected catchments in eastern Victoria.
2. Assess the likely impacts of the fires on loads of total suspended sediments (TSS), total nitrogen (TN) and total phosphorus (TP) in the water storages and rivers of the fire-affected catchments.

E2 is a modelling framework that provides a flexible approach to whole-of-catchment modelling. It allows the creation of integrated models through the process of selection and linkage of component models. E2 may be configured to predict flow and constituent sediments and nutrient loads at any point in a river network over time.

Digital elevation models (DEM) of the four catchments were imported into E2, and sub-catchment boundaries were delineated. Rainfall surfaces derived from spatial interpolation of ground-based observation data onto a 5 km x 5 km grid was pre-processed to provide a weighted average daily rainfall for each sub-catchment. Data of long term mean monthly potential evapotranspiration (PET) was also used as inputs to the rainfall-runoff models. Model parameters were determined by calibration against observed flows at stream gauging stations.

Digitised landuse layers were reclassified in E2 to form three functional units (FU's); *Forest, Agriculture* and *Other*. A second digitised landuse layer incorporating the burnt areas was imported into the model to create a 'burnt' scenario.

Values of constituent concentration (for dry weather concentration, DWC, and event mean concentration, EMC) were applied to each FU so that predicted loads equalled the loads calculated from pre- and post-fire water quality data at monitoring stations within each catchment.

Pre- and post-fire loads of TSS, TN and TP predicted by the model at points of interest (catchment outlets and water storages) were then compared in terms of the relative long term changes (rather than absolute changes) in loads.

These predictions of load increases carry important assumptions and limitations including; outputs are long term averages, no allowance has been made for changes in streamflow, for recovery of vegetation, or for the storage, deposition or remobilisation of sediments and nutrients. Furthermore, there are uncertainties with the constituent data used to calibrate the model, assumptions were made when assigning values of DWC and EMC to FU's, and assumptions were made on behaviour of constituents in water storages.

Proportional increases in loads at the catchment outlets were generally smaller than increases observed at the water quality monitoring sites. These differences reflect the proximity of the monitoring stations to the burnt areas, the total percentage of catchment burnt, and the amount of rainfall.

The model predicted that, compared to pre-fire conditions, the Ovens, Kiewa, Hume and Snowy catchments would deliver, on average, approximately 27 times greater TSS, 4.9 times greater TN, and 7.9 times the amount of TP.

1. INTRODUCTION

During January and February 2003, approximately 1.3 million ha of forested and agricultural land in eastern Victoria, Australia, was burnt by bushfires. The burnt region incorporates several catchments, which drain into a number of key water storages including Hume and Dartmouth Dams and also the Gippsland Lakes. The impact of these fires on the water quality of water courses and receiving bodies has the potential to be significant. Water storages and rivers in the fire affected catchments, the Ovens, Kiewa, Hume and Snowy, are among those resources potentially affected by the fires.

A program was initiated to facilitate measurement and prediction of the magnitude and duration of the effects of the fires on water quality changes, and to provide an assessment of the implications for water resource management.

One of the tasks within this program focuses on modelling the impacts of the fires on water quality within the fire-affected catchments. This paper describes the modelling process to assess the impacts of the fires on water quality of receiving waters and river systems in the Ovens, Kiewa, Hume and Snowy catchments.

Modelling was undertaken using the E2 modelling framework developed by the Cooperative Research Centre (CRCCH) and available online at http://www.toolkit.net.au/.

More specifically, the two objectives of this study were:

1. Using the E2 catchment modelling framework, to construct and parameterise models to represent the flow and nutrient loads for the water storages and river systems for fire-affected catchments in south-eastern Australia.

2. To assess the likely impacts of the fires on sediment and nutrient loads in the water storages and rivers of the fire-affected catchments.

2. OVERVIEW OF E2 MODELLING FRAMEWORK

E2 is a modelling framework that provides a flexible approach to whole-of-catchment modelling (Argent *et al*., 2005 and Murray *et al*., 2005). It allows the creation of integrated models through the process of selection and linkage of component models. Models within E2 are grouped according to function (network geometry, rainfall runoff, constituent generation, filters, routing). E2 provides a flexible structure, allowing the user to select a level of model complexity appropriate to the problem being investigated and available data and knowledge.

Models created using E2 can simulate the hydrologic behaviour of any sized catchment with tens to hundreds of sub-catchments. E2 may be configured to predict flow and constituent sediments and nutrient loads at any point in a river network over time.

The main model structure is "node-link" where sub-catchments feed water and material fluxes into nodes, from where they are routed down through links. Sub-catchment processes are represented by up to three types of processes; runoff generation, constituent generation, and filtering. Processes occurring along the flow links are represented by processes of routing, water storages, sources and sinks, and decay and enrichment.

Spatial information including elevation, landuse, management, climate and soil may be used in modelling with this sub-catchment node-link structure.

E2 can operate at sub-daily, daily or monthly time steps, and can report at monthly to decadal scales.

3. MODEL CONSTRUCTION, DEVELOPMENT AND CALIBRATION

3.1. Spatial

A 20m digital elevation model (DEM) of Victoria (DPI & DSE, 2004) was used to delineate upstream sub-catchments associated with water quality monitoring stations (for water quality calibration), gauging stations (for flow calibration) and other points of interest. Gauging stations were selected so that their upstream catchment areas, covered as much of the area burnt by the 2003 bushfires as possible. Figure 1 shows eastern Victoria, with the fire affected areas, and the catchment areas (Ovens, Kiewa, Hume and Snowy) modelled in this study. It also includes the Gippsland Lakes catchment to the south for completeness.

The DEM was resampled at a resolution of 250 m, converted to an ASCII grid file, and imported into E2, where sinks within the DEM were filled, and the stream network and sub-catchment boundaries were delineated. The stream threshold was set so that sub-catchment size was no greater than 20-50 km.

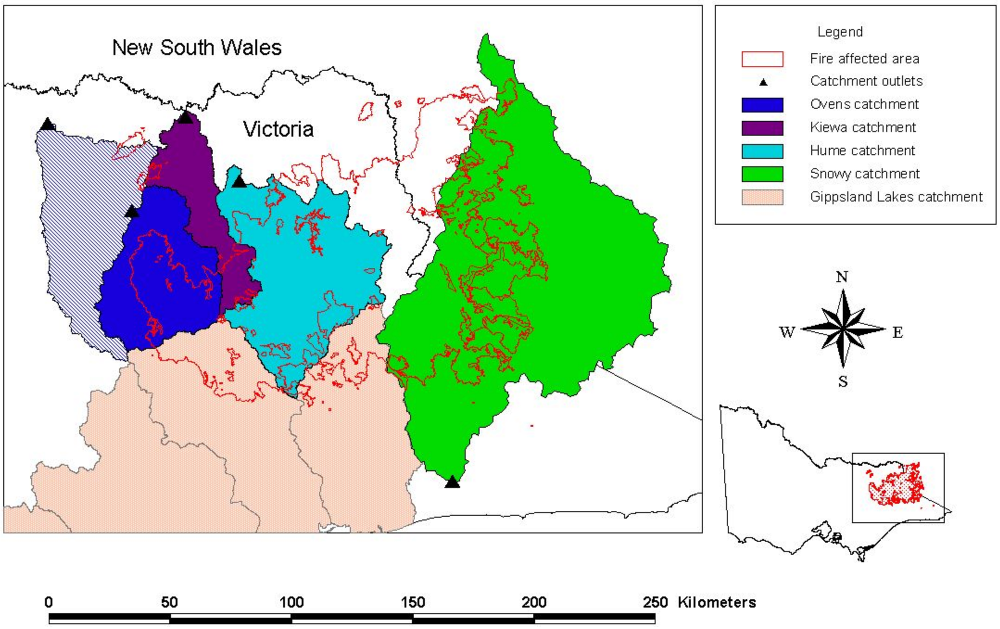

Figure 1. A map of eastern Victoria showing the fire affected areas, and the catchment areas modelled within this study.

3.2. Climate

Rainfall data was obtained from the SILO Data Drill. The SILO climate surfaces have been derived from spatial interpolation of ground-based observation data onto a 0.05. latitude/longitude (5km x 5km) grid on a daily time basis (Jeffrey *et al.*, 2001). The rainfall data was pre-processed to provide a weighted average daily rainfall for each sub-catchment before being imported into E2. This process resulted in each sub-catchment being assigned its own unique rainfall sequence over the simulation period of 1980 to 1999 inclusive.

Data for areal potential evapotranspiration (PET) was obtained from the Bureau of Meteorology. This data represents the long term mean monthly PET (mm/month) on a 10 x 10 km grid resolution. Values of areal PET were converted to average total daily PET for model simulations.

Rainfall was represented spatially across the catchments, because the response of sediment and nutrient loads to forest fires is highly dependent on subsequent rainfall amount and distribution. Average sub-catchment size was kept relatively small (less than 20-50 km^2) to allow a reasonable representation of the rainfall and PET distribution across each catchment.

3.3. Hydrology

A 'bucket-style' rainfall-runoff model based on Denmead and Shaw (1962) was used in the E2 models (Figure 2). This model has two main parameters; the size of the store (S_{max}), and the leakage rate (B). Cell runoff is the sum of 'leakage' and any excess runoff if the store is full. This then becomes an input to the downstream cell. Water enters the store via rainfall and is removed from the store via evapotranspiration, runoff and leakage.

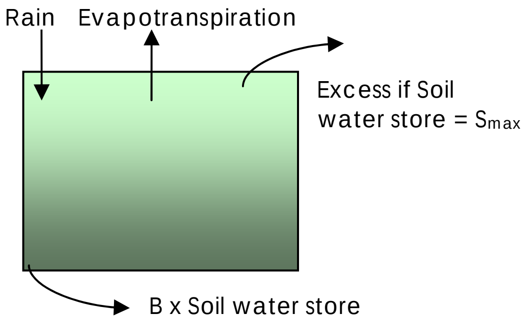

Figure 2. Conceptual basis of the bucket model.

Evapotranspiration (ET) is estimated from the monthly areal potential (based on an interpolated surface from the Bureau of Meteorology) to allow for some control on actual evapotranspiration (ET_a) due to soil water (S), with the maximum ET (ET_{max}) defined as a function of vegetation (Figure 3). The model uses the value of ET_a if cell water is at S_a, or ET_{max}, if soil water is at 0.7 x S_{max} (S_b in Figure 3) or above. In winter, the actual rate tends to be controlled by the potential value whereas in summer, soil water or vegetation controls can limit the rate.

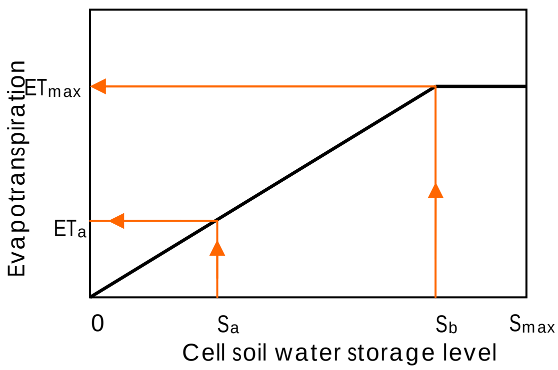

Figure 3. Conceptual approach to representing evapotranspiration.

Parameters for the rainfall-runoff model were determined by calibration against observed flows at stream gauging stations. Parameters for catchment areas above water storages were obtained by calibrating to gauging stations above the respective water storage. Releases from water storages were calibrated to observed flows at gauges below the dam outlet.

Flow was calibrated over the period of 1980 to 1999 inclusive. This allowed the optimum calibration for the available data. This period was chosen to contain series of relatively dry and wet years, and as such represented the variation in rainfall observed over the region. The model was run for one year prior to the calibration period (1979), so that the soil water store was representative of the water storage at the commencement of the calibration period.

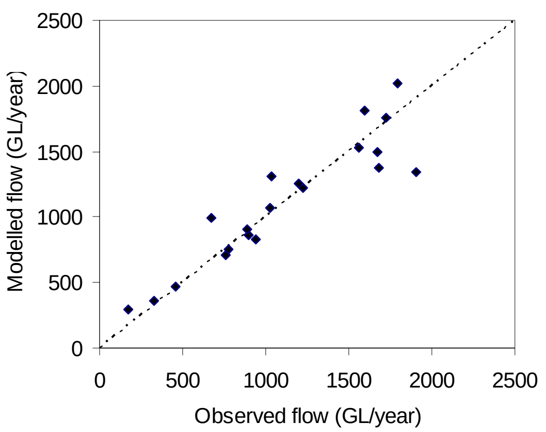

Figure 4. Annual modelled flows against predicted flows for the Ovens catchment.

Calibration of streamflow was first performed on the highest gauging stations within each respective catchment. Sub-catchments progressively closer to the catchment outlet were then calibrated, while leaving the rainfall-runoff parameters unchanged for sub-catchments further up the catchment.

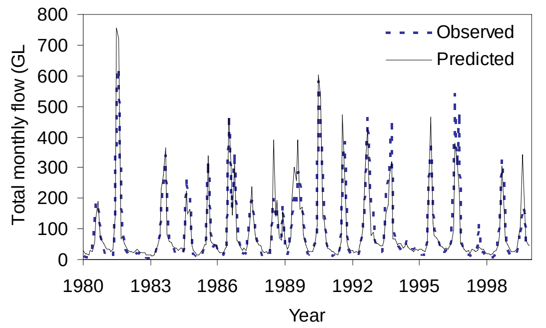

Figure 5. Observed and predicted total monthly flows for the Ovens catchment.

Flow was calibrated on annual, monthly and daily time steps. Greater emphasis was given to calibrating streamflow to observed flow on an annual basis, so that the predicted average long term streamflow was the same as the observed long term average flow. Figures 4 and 5 provide examples of flow calibration results on an annual and monthly basis respectively (for the Ovens catchment in this case).

3.4. Land Use

A digitised land use layer containing polygon features for Victoria was obtained from DSE's Corporate Geospatial Data Library (DPI & DSE, 2004). A digitised land use layer containing polygon features for the NSW portion of the Snowy catchment (Bordas and Lesslie, 2002) was obtained from the Bureau of Rural Sciences Canberra. The files were converted to grid datasets using standard GIS processing (ESRI/ArcInfo). Landuses were reclassified in E2 to form three functional units (FU's); *Forest* (native forest, remnant vegetation, hardwood and softwood plantations), *Agriculture* (pasture, cropping and horticulture) and *Other* (mainly urban).

3.5. Constituent Generation

The event mean concentration (EMC) and dry weather concentration (DWC) model was applied to constituent generation for this modelling exercise. In this case, a fixed constituent concentration is applied to each functional unit (FU). For a given FU, the EMC value is applied to surface (quick) flow, and DWC value applied to slow (base) flow. The EMC/DWC output data are a scaled derivation of the input data, where flow is scaled by concentration to give output load. This dual approach is preferable to the 'effective mean concentration' approach, since the model was run on a daily time step, and flows can easily be identified as baseflow or event flow.

The location in the stream network at which water quality data are available will effect the interpretation significantly. The water quality data represents values for DWC and EMC appropriate for a particular land use at a particular scale. However, if that catchment has many land uses, it is not possible to derive DWC and EMC values for individual landuses from that data, as it represents a net DWC/EMC from the catchment.

Different land uses generally have different generation rates, and so should be represented by different DWC/EMC values. In the absence of any specific data to assign specific values to each land use, we have applied a weighting to each land use to reflect differences in constituent generation from each one. Weighting were derived from values of DWC and EMC in a study by Chiew and Scanlon (2002).

Values for dry weather concentrations (DWC) and event mean concentrations (EMC) were 'tied' together by applying a fixed multiplication factor to the forest concentrations using the differences calculated from data from Chiew and Scanlon (2002). Water quality monitoring stations for which pre- and post-fire sediment and nutrient loads were calculated by Sheridan *et al*., (2004) were used to calibrate the generation of constituents in the models. Sets of concentrations for DWC and EMC for each functional unit were increased and/or decreased iteratively until the observed pre-fire loads for TSS, TN and TP were reached.

Once this had been achieved, a new digitised land use layer incorporating burnt areas of forest, agriculture and other, was imported into the model to create a 'burnt' scenario. Functional units, representing the burnt versions of the original 3, were added. Values of DWC and EMC for each functional unit were adjusted iteratively until the observed post-fire loads for TSS, TN and TP (as calculated by Sheridan *et al*., 2004) were obtained. Pre- and post-fire loads of TSS, TN and TP predicted by the model at points of interest (catchment outlets and water storages) were then compared in terms of the relative long term changes (rather than absolute changes) in loads.

Constituent mean concentrations of water released from water storages were represented by a set of constant values for pre-fire conditions, and a set of values for post-fire conditions. The values were first calculated for the Dartmouth Reservoir (Hume catchment), using changes in pre- and post-fire water quality data from a monitoring station downstream of the reservoir (Mitta Mitta River@)Colemans) together with post-fire water quality data taken by Alexander (2004) from within the reservoir at the dam wall. Pre-fire water quality data for Lake Buffalo (Ovens catchment) was scaled up using the factor changes for the Dartmouth Reservoir after allowance was made for differences in the proportion of the catchment area burnt (86% for the Dartmouth Reservoir and 35% for Lake Buffalo).

3.6. Model assumptions and limitations

The simulations and resulting predictions of load increases carry the assumptions and limitations listed below:

- The model outputs are based on long term flow and rainfall distribution (between 1980-1999)
- No separate allowance is made for recovery or management activities since the fires
- No allowance has been made for changes in runoff generation in response to the fires
- No allowance if made for the storage, deposition or remobilisation of sediments and nutrients. Nutrients entering water storages are 'reset' by calibrating water leaving the storage to observed water quality data
- No runoff routing, constituent routing or constituent filtering models were applied
- There are uncertainties associated with calculations of changes in loads from the water quality data used to calibrate the model
- Water quality data represents a catchment with several land uses. It is not possible, from the data available, to calculate constituent generation parameters for individual functional units. Therefore, a weighting was applied to the functional units, to represent the relative differences in these generation parameters observed in other studies
- The fate of increased sediment and nutrient loads to the water storages in the study area (Lake Buffalo and Lake Dartmouth) is not known. Concentrations of water released from the water storages was set as a constant for pre- and post-fire conditions, representing the average pre and post-fire concentrations observed at water quality monitoring stations below the water storages.

4. POTENTIAL IMPACT OF THE FIRES ON WATER QUALITY

Once the model had been calibrated to represent the observed proportional increases in loads at the

Table 1. Predicted factor changes in loads of TSS, TN and TP resulting from the bushfires.

Catchment	Gauging station	Area (km^2)	Mean flow ('000 ML/yr)	% burnt	TSS	TN	TP
					factor increase in load		
Ovens	Ovens@Bright[a]	493	218	55	24	9.4	8.8
	Lake Buffalo[b]	1,142	443*	35	11	4.5	4.3
	Ovens@Rocky Pt[b]	2,969	1,116	43	17	5.3	5.6
	Ovens@Peechelba[c]	6,360	1,750	21	16	2.1	1.7
Kiewa	Kiewa@Bandiana[a]	1,714	675	23	1.4	1.4	1.0
Hume	Mitta@Hinommunjie[a]	1,525	407	83	167	20	36
	Dartmouth Dam[b]	3,568	749*	86	175	20	38
	Mitta@Tallandoon[b]	4,774	1,160	80	72	5.0	11
Snowy	Snowy@McKillops[a]	10,654	613	27	113	25	100
	Snowy@Jarahmond[b]	13,485	910	29	140	32	142
Average for inland-flowing catchments (Ovens, Kiewa & Hume)					15	2.7	2.8
Average for all four catchments					27	4.9	7.9

[a] water quality monitoring stations; [b] predicted using spatial E2 model
[c] extrapolated from E2 prediction; [*] predicted flow from E2

respective water quality monitoring station, model predictions of loads pre- and post fire at catchment outlets and at the water storages were examined to determine the estimated impacts of the fires relative to pre-fire conditions. The predicted proportional increases in loads at the points of interest resulting from the bushfires are listed in Table 1.

Proportional increases in loads at the catchment outlets were generally smaller than increases observed at the water quality monitoring sites (those calculated by Sheridan *et al*. 2004, and used to calibrate the models). These differences reflect the proximity of the monitoring stations to the burnt areas, the total percentage of catchment burnt, and the amount of rainfall. The simulations indicate that the magnitude of impacts decreases further down the catchment.

Very high increases in loads were predicted at the Dartmouth Dam within the Hume catchment, with loads entering the dam being 175 (TSS), 20 (TN) and 38 (TP) higher after the fires (Table 1). However, no significant impact has been detected of these increased nutrient and sediment loads on water within the dam at one year after the fires (Alexander, 2004). Furthermore, increases in concentrations of these constituents in water released from the dam were much less (x2.1 for TSS, x1.3 for TN and x1.2 for TP) suggesting that mixing and/or deposition of these constituents is occurring and/or the additional sediments and nutrients have not yet made their way to the dam outlet. Consequently, increases in loads predicted at the outlet of the Hume catchment were substantially smaller than those predicted at the entry of the dam.

The Snowy was the only catchment in which the predicted increase in loads was greater at the catchment outlet, than at the water quality monitoring station higher in the catchment. This can be explained by additional burnt areas below the station, resulting in a greater proportion of the catchment burnt (above the catchment outlet) and the proximity of the station to the outlet. Increases in sediment and nutrient loads may have detrimental effects on river health, particularly during low flow periods.

The Ovens, Kiewa and Hume catchments all lead inland towards the Murray River. Here, issues relating to river health and the associated problems of algal blooms are more critical. Model simulations suggest that increases of x15 for TSS, x2.7 for TN, and x2.8 for TP may occur across these three inland flowing catchments.

5. CONCLUSIONS

The E2 modelling framework was effectively applied to assess the likely impacts of bushfires on water quality at several points of interest.

The model predicted that, when compared to pre-fire conditions (and under the same long term average climatic conditions) the fire-affected catchments of the Ovens, Kiewa, Hume and

Snowy would deliver, on average, approximately 27 times greater TSS, 4.9 times greater TN, and 7.9 times the amount of TP.

Processes not represented in the model if included, may reduce the predicted increases in loads, including the process of storage of sediment and adsorbed nutrients within stream channels in the lower reaches of the stream network. Recovery of the fire-affected areas was also not represented in this modelling exercise. Therefore, observed increases in loads are likely to be less than the values reported here for the various scenarios.

The predictions made of the effects of bushfires on water quality will provide valuable information to water resource managers in their post-fire response and recovery programs.

The assumptions made in this modelling study are crucial to the magnitude of the predictions made, and required careful thought and justification during the modelling process. There is considerable scope for improving representations in the model as more data become available, allowing refining of the results.

6. ACKNOWLEDGMENTS

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