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Improving our capacity to manage hypoxic blackwater events in lowland rivers: The Blackwater Risk Assessment Tool

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ABSTRACT

Blackwater events occur when returning floodwater contains elevated levels of dissolved organic carbon. Normally the export of carbon from floodplains to a river channel is a beneficial process, providing sustenance to lowland river ecosystems. However if the rate of oxygen consumption during decomposition of the organic carbon is faster than it can be replenished from the atmosphere, this can cause hypoxia, with catastrophic short-term consequences for aquatic fauna. Because river regulation has disconnected many floodplains from their source rivers, floodplain inundation is increasingly being actively managed specifically for the benefit of the environment. However, the risk of hypoxic blackwater generation must be considered during such managed floods. This paper describes a new tool for predicting dissolved oxygen and dissolved organic carbon in flood return water, using minimal data inputs. The Blackwater Risk Assessment Tool (BRAT) is based on the same conceptual framework underpinning an earlier, geographically specific, blackwater model. However BRAT differs in a number of significant ways from the earlier model. The BRAT is based on a generic, rather than site-specific, inundation model; and users have the option to use actual hydrographs if these are available. Furthermore, most of the algorithms used to model blackwater generation processes have been refined, reflecting new knowledge generated since the original model was constructed. This includes changes to floodplain litter load estimation methods, algorithms for the temperature dependence of dissolved organic carbon leaching and biotic uptake, and re-aeration rate calculation. Finally, unlike the earlier model, all the algorithms and constants in BRAT are readily accessible so that the model can be customized to suit floodplain ecosystems other than the ones for which it was developed. The model was validated using flood events in Koondrook–Perricoota and Gunbower forests, Australia. Model outputs were in good agreement with observed dissolved oxygen during these flood events with root mean square variation as low as 1.2 mg O_2 L^{-1}.

1. Introduction

Riverine blackwater events occur when water returning from floodplains to river channels contains elevated levels of dissolved organic carbon (DOC). Export of carbon (and other nutrients) from floodplains to river channels provides vital support to riverine food webs (Junk et al., 1989). However, in some instances the flood return water can have adverse effects on the ecological condition of the receiving water. This is the case when the microbial activity fueled by the DOC consumes oxygen in the water column faster than it can be replenished from the atmosphere, leading to hypoxia (low levels of dissolved oxygen (DO) in the water column). Hypoxic blackwater events can have catastrophic effects on the aquatic environment (Whitworth et al., 2012; King et al., 2012). Dissolved oxygen concentrations below 4 mg L^{-1} are generally considered to impose stress on fish and DO below 2 mg L^{-1} is lethal to many aquatic organisms, although these thresholds vary considerably with species and size class (Gehrke, 1988; McNeil and Closs, 2007; Small et al., 2014). For the most part hypoxic blackwater events tend to be relatively localized (*e.g.* Howitt et al., 2007; Hladyz et al., 2011). However, after a decade of drought, extensive flooding in the southern Murray–Darling Basin (south-eastern Australia) during 2010–2011 mobilized several hundred thousand tonnes of DOC into the Murray River and its tributaries (Whitworth et al., 2012). This resulted in a plume of hypoxic water that affected about 2000 km of river channel for up to 6 months (Whitworth et al., 2012) and resulted in the mortality of a substantial number of fish and other aquatic organisms (King et al., 2012).

Because of river regulation, flooding of floodplains is increasingly being actively managed through the provision of water

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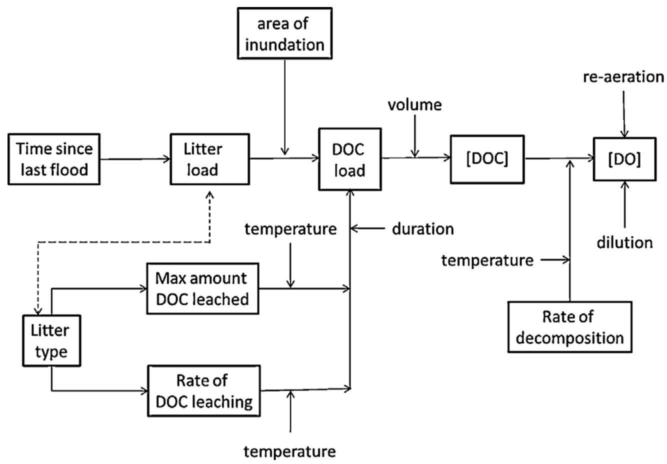

Fig. 1. Underpinning framework on which the Blackwater Risk Assessment Tool is based.

specifically for the benefit of the environment (environmental flows). Carbon export from floodplains during these managed floods can be beneficial to the riverine environment. For example it has been shown that addition of natural DOC can result in a fivefold increase in riverine zooplankton density compared to non-augmented controls (Mitrovic et al., 2014); zooplankton are an important food source for higher organisms. However, the occurrence of hypoxic blackwater as a consequence of floodplain inundation represents a significant environmental risk. This risk needs to be managed within an adaptive management framework. Effective management will be greatly informed by an improvement of our capacity to predict the likelihood of hypoxia during a flood event.

A model for the prediction of blackwater from floodplain inundation already exists (Howitt et al., 2007). While that model created a robust conceptual framework on which to develop predictive capacity for DO and DOC following inundation of a forested floodplain, it did have a number of limitations. First, it had only limited geographical applicability—the original model specifically predicted DO in the Murray and Edward Rivers immediately downstream of Barmah Forest floodplain, south-eastern Australia; and was based on a fairly simple hydrological description of flooding of the forest. Adapting that model to other floodplain ecosystems has subsequently proved difficult (Baldwin et al., 2011). Furthermore, subsequent research (Whitworth et al., 2014) has indicated that a number of algorithms in the original model needed to be revisited. In this paper we introduce an improved tool for predicting hypoxic blackwater following the inundation of floodplains. The Blackwater Risk Assessment Tool (BRAT) is a generic, desktop predictive tool that can be used to forecast DO and DOC concentrations in return water during inundation of an idealized river red gum (*Eucalyptus camaldulensis*) forested floodplain; but can be easily customized to incorporate known hydrology or different vegetation type.

The underlying conceptual framework developed for the original blackwater model (Howitt et al., 2007) essentially has been retained for the new tool (Fig. 1). The concentration of DO downstream is dependent on the rate that DOC is decomposed, which in turn is dependent on both the temperature of the water and the concentration of DOC. The concentration of DOC is related to both the load of DOC generated from plant litter on the floodplain and the volume of flood water. The load of DOC generated on the floodplain is related to the amount and type of litter and the area of inundation. However, the BRAT is now based on a generic, rather than site-specific, inundation model. Users also have the option to input their own hydrological data based on local digital elevation models with either historical (for hindcasting) or proposed (for forecasting) flooding regimes. In addition, most of the algorithms used to model these processes have been refined, reflecting new knowledge generated since the original model was constructed. This includes changes to the way litter loads are assessed, with an option to include actual rather than modelled litter loads as well as the option to define the dominant carbon source (litter or grasses). There have also been changes to the parameters defining the rate of leaching and consumption of DOC from litter, notably including the addition of functions to account for temperature dependence of both leaching and consumption. While the original seasonal temperature modelling algorithm has been retained from Howitt et al. (2007) it can now be modified up or down by a set value, for example, to explore the effects of climate change. The BRAT also treats re-aeration of flood waters in a substantially different manner to the original model. Finally, unlike the Howitt et al. (2007) model, all the algorithms and constants in BRAT are readily accessible in the 'worksheet' tab of the model file (see Supplementary material) so that the model can be customized to suit floodplain ecosystems other than the ones for which it was developed.

Table 1
Parameters requiring user input for prediction of hypoxic blackwater risk.

Parameter	Symbol	Unit
Date of inflow commencement	date	dd/mm/yyyy
Total volume delivered to floodplain	V_{in}	GL
Total duration of floodplain inflows	Y_{in}	days
Maximum floodplain outflow rate	$F_{out,\,max}$	ML day^{-1}
Temperature mode		(Seasonal or fixed)
Water temperature (if fixed)	T_w	°C
Inflow DO mode		(Saturated or custom)
Inflow DO (if custom)	DO_{in}	mg L^{-1}
Inflow DOC (if known)	DOC_{in}	mg L^{-1}
Maximum inundation area	A	ha
Floodplain water transit time	X	days
Litter load	L	g m^{-2}
Dominant litter type		(Litter, grassy or modelled)
River/dilution water discharge/flow rate	F_{dil}	ML day^{-1}
DO in river/dilution water mode		(Saturated or custom)
DO in river/dilution water (if custom)	DO_{dil}	mg L^{-1}
DOC in river/dilution water	DOC_{dil}	mg L^{-1}

2. The Blackwater Risk Assessment Tool

The BRAT operates on a Microsoft Office Excel 2010 platform. A copy of the tool is included in the supplementary material (Appendix A) or available from the authors on request. The tool predicts DO and DOC in flood return water based on flooding of an idealized floodplain and is designed to be used to assess the potential for hypoxic blackwater to occur given a specified set of flood conditions. The model is based on flooding of a river red gum forested floodplain but can be re-parameterized for any type of floodplain.

In this model, water is routed onto a floodplain with a defined maximum input volume, inflow duration and inundation area. Carbon leached from inundated litter on the floodplain and carbon and oxygen consumption from the water column are calculated on daily time steps. Water exits the floodplain after a defined transit time, with a defined maximum outflow rate. Dissolved oxygen and carbon in the outflow water, and in receiving waters immediately after dilution, are calculated on a daily time step. Required user inputs are summarized in Table 1. Recommended values for all other parameters are pre-filled, but may be user-customized if desired using the 'worksheet' tab.