available at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ecolmodel

Modelling blackwater: Predicting water quality during flooding of lowland river forests

Julia A. Howitt, Darren S. Baldwin, Gavin N. Rees, Janice L. Williams*

Murray-Darling Freshwater Research Centre, P.O. Box 991, Wodonga, Vic. 3689, Australia

ARTICLE INFO

Article history:
Received 30 June 2005
Received in revised form
5 November 2006
Accepted 15 November 2006
Published on line 19 December 2006

Keywords:
Water quality
Dissolved oxygen
Eucalyptus camaldulensis
Barmah-Millewa Forest
Dissolved organic carbon
River Murray

ABSTRACT

The blackwater model was developed to predict adverse water quality associated with flooding of the Barmah-Millewa Forests on the River Murray. Specifically, the model examines the likelihood and severity of blackwater events—high dissolved organic carbon associated with low dissolved oxygen. The Barmah-Millewa Forests are dominated by an overstorey of River Red Gum (*Eucalyptus camaldulensis*) and the litter from these trees contributes a substantial proportion of the pulse of dissolved organic matter released from the floodplain during flooding. This model examines rates of litter accumulation and decay on the floodplain (prior to and during flooding), rates of carbon leaching, microbial degradation, oxygen consumption, reaeration processes and the effects of flow on the concentrations of dissolved organic carbon and dissolved oxygen in the water column (both on the floodplain and in the river channel downstream). The model has been calibrated with data from two blackwater events that have taken place in these forests within the last 5 years. Scenario testing with the model highlights the particularly important roles of flow and temperature in the development of anoxia. Pooled floods and those in the warmest months of the year are substantially more likely to result in blackwater events than floods in cooler times of the year and involving more water exchange between the river channel and the floodplain.

1. Introduction

Blackwater events are defined here as flood events with elevated levels of dissolved organic carbon (DOC) sufficient to give the water column a dark ‘tea’ colour associated with reduced levels of dissolved oxygen in the water column, either on the floodplain or in the river channel. These events are a natural part of the ecology of lowland river systems and have been reported since before periods of significant river regulation (Anon., 1866). During a flood, carbon compounds are leached from leaf litter laying on the floodplain. The amount of carbon leached will depend on a number of factors, such as the type and age of leaf litter, the amount of litter that has accumulated on the floodplain and whether or not the litter has been flooded before. If floods occur more frequently, then less carbon is leached from the litter.

The carbon and nutrients leached from litter on the floodplain are believed to play an important role in the functioning of river systems. Studies have shown that, in some instances, much of the production that occurs in the river channel is based on carbon that has come from the river’s floodplain (Junk et al., 1989). Therefore, it is important that there is the opportunity for flooding to occur to allow the movement of carbon from the floodplain to the river channel. However, blackwater events can markedly change water quality. Microorganisms can immediately use about one-third of the

* *Corresponding author*. Present address: School of Life and Environmental Sciences, Deakin University, P.O. Box 423, Warrnambool, Vic. 3280, Australia. Tel.: +61 3 5563 3461; fax: +61 3 55633462.
E-mail address: julia.howitt@deakin.edu.au (J.A. Howitt).
0304-3800/$ – see front matter
doi:10.1016/j.ecolmodel.2006.11.017

carbon leached from the leaf litter (Baldwin, 1999). As the microorganisms consume the dissolved carbon they use up oxygen in the water—often at a rate faster than the oxygen can be replenished. Therefore, blackwater plumes often have very low levels of dissolved oxygen. It is considered that from an ecological point of view, the worst effect of high input of organic matter into a waterway is the reduction in dissolved oxygen concentration (Salles et al., 2006). The lack of dissolved oxygen can cause the death of fish and other aquatic animals in the plume. Australian native fish and other large aquatic organisms require at least 2 mg L^{-1} of oxygen in the water to survive, but may begin to suffer at levels below 4–5 mg O_2 L^{-1} (Gehrke, 1988). For example, artificial flooding of the Barmah-Millewa Forest, a River Red Gum (*Eucalyptus camaldulensis* Dehn) Forest on the Murray River in Australia, in 2000 resulted in 'blackwater' returning to the river, causing a significant degradation of water quality leading to fish and crustacean deaths (Baldwin et al., 2001).

Therefore, in rivers where the flow is regulated by humans, river managers are faced with the quandary of on the one-hand, ensuring that the floodplains are flooded at least occasionally so that carbon and nutrients stored on the floodplain can be returned to the river channel to stimulate riverine productivity, but on the other, making sure that the quality of the returned water is not so poor as to result in death of fish or other aquatic organisms.

The aim of the current project was to develop a simple process-based model that could be used by river managers to predict the likelihood and severity of blackwater events following the flooding of forested floodplains. Other models exist that examine the interaction between natural organic matter and dissolved oxygen in a variety of aquatic systems (e.g. Pereira et al., 1994; Park and Uchrin, 1997), but this model is the first to combine predictions of litter accumulation on the floodplain prior to flooding, inputs during the flood and then the corresponding DOC leaching and oxygen consumption on the floodplain. This model links time since last flood, time of flood and size and duration of flood to the export and breakdown of carbon from the floodplain and subsequent decrease in dissolved oxygen at a given point down stream of a forest and can be used to optimize the timing and duration of environmental water allocations to limit the effects of the flood on the water quality downstream of a forest. In the first instance, the model has been developed for a specific River-Red Gum Forest but the approach can be generalized to other types of forest in other locations.

2. Area description

This model was developed as a process model for lowland river forests, particularly River Red Gum (*E. camaldulensis*) Forests. Design and testing of the initial phase of the model has been specific to the Barmah-Millewa Forest, with the intention of later generalising the model to other lowland rivers.

The Barmah-Millewa Forest is the largest River Red Gum Forest in the world, covering an area of approximately 60,000 ha (Barmah-Millewa Forum, 2000). The forest grows on the floodplain of the Murray River, in the region surrounding the point where the Edward River anabranch separates from the Murray between Echuca, Deniliquin and Tocumwal (see Fig. 1). The Barmah Forest is located in Victoria and the Millewa group of forests is located in New South Wales. In addition to the River Red Gum, the forest contains swamps and marshes, rushlands, grasslands, lakes, billabongs (oxbow lakes), streams and patches of forest dominated by other eucalypt species (Chesterfield et al., 1984; Chesterfield, 1986).

The flooding of the Barmah-Millewa Forest is coming under increasing scrutiny as the effects of the use of Murray River water on the ecology of the river and its floodplain are examined. The Barmah-Millewa Forest is located downstream of the Hume Weir and Yarrawonga Weir and, as a result, the natural pattern of forest flooding has been disrupted. The forest now experiences a decrease in winter and spring flooding, and more late-spring/summer flooding. Several cases of blackwater events have been reported associated with summer flooding in the forest (these vary from major events to localised areas of blackwater in the forest) (McKinnon, 1997; Glazebrook and Robertson, 1999; Barmah-Millewa-Forum, 2001; Robertson et al., 2001).

3. Methods and model development

3.1. Model structure

The model (blackwater) considers a number of aspects of floodplain ecology and chemistry to predict the concentrations of DOC and dissolved oxygen in floodwaters on the floodplain, and then downstream of the forests in the river systems. The basic premise of the model is that water entering the floodplain comes in contact with litter from the overstorey trees and with grasses, leading to the leaching of dissolved organic carbon. The input of this new organic carbon to the water column leads to an increase in microbial activity leading to an increase in the consumption of dissolved oxygen. The model uses seasonal rates of litterfall to predict the amount of litter present on the floodplain at the time of flooding, and then links the leaching of DOC to degradation processes to predict daily concentrations of DOC and dissolved oxygen, as will be outlined in more detail below.

This model is designed to allow managers to examine the effects of a variety of flood management options on the likelihood and impact of blackwater events during the flooding of a River Red Gum Forest. To this end, the model has been designed to allow as many of the variables as possible to be input by the user with each run. This model has been developed using the Visual Basic for Applications programming language and runs as a macro in Microsoft® Excel 2002. Entering flood variables has been simplified for the user through the use of customised input forms (which appear as pop-up boxes as the model executes). The data required for each simulation can vary depending upon the flood conditions chosen, and are summarised in Table 1. In addition to the variables listed in the table, the user is also asked to approximate the shape of the hydrograph by specifying the number of days after flood onset that the flood height reaches key values. For a single-peak flood, these key heights are when the flood rises to 50%, 75% and 100% of the peak, and then falls to 75%, 50% and 40% of the peak height. In the case of a flood with two major peaks