Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Ecological Modelling 187 (2005) 60–70
ECOLOGICAL MODELLING
www.elsevier.com/locate/ecolmodel

Modelling the effects of land-use modifications to control nutrient loads from an agricultural catchment in Western Australia

C. Zammit[a,b], M. Sivapalan[a,*], P. Kelsey[b], N.R. Viney[c]

[a] Centre for Water Research, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia
[b] Western Australian Department of Environment, Hyatt Building, 3 Plain Street, East Perth, WA 6004, Australia
[c] CSIRO Land and Water, Private Bag No. 5, Wembley, WA 6913, Australia

Available online 19 February 2005

Abstract

The estuary of the Swan and Canning Rivers in Western Australia is becoming increasingly prone to algal blooms, fish deaths and other biochemical problems that are thought to be associated with increasing eutrophication. Phosphorus and nitrogen enrichment are seen as the two most common causes of such eutrophication, with both elements being transported in streamflow and with concentrations strongly dependent upon land-use in the catchment. Many of the efforts to prevent and control eutrophication in the estuary are focused on managing land-use within the catchment. In this paper, the large-scale catchment model (LASCAM) is applied to Ellen Brook, a rural catchment located within the Swan River catchment, to simulate catchment exports of phosphorus and nitrogen, under a range of land cover scenarios that are designed to control the eutrophication. The scenarios, which are related to different management options for the catchment, are: (i) reforestation of agricultural land; (ii) reduction in fertiliser application; and (iii) urbanisation following a highway development. The model results show that: (i) full reforestation of agricultural land is expected to reduce phosphorus and nitrogen export by 50 and 85%, respectively; (ii) a proportionally greater reduction of phosphorus and nitrogen export occurs for smaller areas of reforestation than for larger areas; (iii) reduction in phosphorus fertiliser application produces a linear response with respect to phosphorus export; (iv) urbanisation increases runoff due to the larger impermeable areas causing an increase of overland flow during storms; and (v) phosphorus and nitrogen loads are expected to increase about 4 and 12%, respectively, during the 10 years following urbanisation.

Keywords: Land-use management; Nutrient loads; Agricultural catchments; Water quality modelling; Eutrophication

1. Introduction

Ecological processes and biodiversity of estuarine and coastal waters in many parts of the world are under threat from increasing anthropogenic inputs of nutrients (Cloern, 2001). Many of these increases are attributed to expansion of human populations along the

* Corresponding author. Tel.: +61 8 6488 2320;
fax: +61 8 6488 1015.
E-mail address: sivapala@cwr.uwa.edu.au (M. Sivapalan).

0304-3800/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolmodel.2005.01.024

riparian zone of major rivers and coastal catchments (Ritchie and Weaver, 1993). These threats are particularly significant in Australia where 80% of the population lives within 50 km of the coast and most of the drainage catchments have undergone large-scale land clearing and hydrological modifications since European settlement (Harris, 2001). As a result, algal blooms (such as cyanobacterial blooms) are increasingly frequent because of the general decline of the water quality. These algal blooms have social, economic and environmental consequences for the population living along the shore, such as fish kills or closure of rivers to recreation and fishing (as occurred in the Swan River Estuary, Western Australia, in February 2000).

The enrichment of aquatic systems with nutrients is normally a slow process that occurs naturally as the water bodies age. Human activity in a catchment generally increases the export of nutrients to rivers and streams and accelerates the rate of eutrophication of receiving water bodies (Sharpley et al., 1994). In freshwaters, phosphorus is regarded as the primary-limiting nutrient, while in marine systems nitrogen is considered to be more important. Phosphorus is widely regarded as the limiting nutrient in estuaries of the southwest of Western Australia (McComb and Davis, 1993) and acts as the main regulator of the algal blooms in the Swan-Canning Estuary located near Perth, Western Australia.

The ecology of the Swan-Canning Estuary, especially that of phytoplankton, has been a major focus of research and management effort in the 1990s. The aim of the management has been to reduce the amount of nitrogen and phosphorus applied to the landscape, and to reduce leaching losses to the estuary from agricultural and urban catchments.

Much of the estuary catchment has been cleared for agricultural and urban land-uses, and contributes considerable amounts of nutrient through fertiliser, animal wastes and septic tank effluent (Gerritse et al., 1990), transported to the streams and estuaries in groundwater and overland flow. In order to assess the change in water quality of the tributaries of the estuary due to climate change or land-use modifications, and to determine strategies to improve the health of the estuary, a modelling tool is required.

This paper presents the results of the application of the LASCAM hydrological and water quality model to Ellen Brook, a rural catchment of the Swan-Canning Estuary. The effects of three management scenarios: the reforestation of parts of the catchment, a decrease in fertiliser application and increased urbanisation are simulated for a 10-year period following initiation of each of the management options.

2. Large-scale catchment model (LASCAM)

The large-scale catchment model (LASCAM) has been developed to predict the impacts of land-use and climate changes on the daily trends of streamflow, salinity, sediment and nutrient yields in large catchments, over long time periods (Sivapalan et al., 1996a,b,c, 2002; Viney and Sivapalan, 1999, 2001; Viney et al., 2000).

LASCAM is a complex conceptual model with a daily time step. The basic building blocks are subcatchments organised around the river network. All hydrological and water quality processes are modelled at the subcatchment scale; the resultant flows and loads are aggregated via the stream network to produce the response of the catchment at the main outlet, and also at any number of intermediate points on the stream network.

The general structure of the nutrient models and the way in which they relate to the underlying water and sediment balance models is presented in Viney et al. (2000). Phosphorus and nitrogen are modelled in both dissolved and particulate forms. In the case of nitrogen, the soluble component is further discriminated into nitrate–nitrogen and ammonium–nitrogen. The soluble nutrients are transported in surface and subsurface water fluxes, and once in the stream they are routed conservatively. Particulate nutrients, which are assumed to be either organic or inorganic components attached to eroded sediment material (derived from upslope erosion or from bank and bed erosion in the stream channel), are transported non-conservatively. That is, particulate exchanges occur between the bed and the flow, which means that the mass of particulate nutrients in suspension is not conserved. However, the particulate routing model is conservative in the sense that it assumes that there is no cycling or uptake of nutrients once they are in the stream.