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Integrating farming systems and landscape processes to assess management impacts on suspended sediment loads

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ABSTRACT

A catchment-scale framework was developed to assess the contribution of sediment sources from farm management actions, gully and streambank erosion on the suspended sediment loads delivered to rivers and associated wetlands and floodplains for two catchments (Avon Richardson, 2885 km^2 and Avoca, 4550 km^2) in Victoria, south-eastern Australia. After considering commonly available data sets, outputs from the point-scale model (HowLeaky2008) were coupled to a catchment scale framework (CatchMODS). Spatially constant, linear scaling factors were used to link point-scale water surplus to streamflow and gross soil loss to hillslope erosion. The model was calibrated against discharge and suspended sediment loads estimated at water quality monitoring gauging stations. Following calibration, estimates of annual and monthly streamflow and 10-year average annual sediment loads were in good agreement with observations. Catchment-scale outputs, particularly sediment loads, were sensitive to scaling factors. The high sensitivity coupled with limited data hindered tight identification of sediment scaling parameters, therefore sediment outputs were uncertain, particularly in the Avoca catchment. Propagation of uncertainty in parameter estimation to model estimates was assessed qualitatively. The boundaries of model estimations were assessed by retaining predictions of behavioural parameter sets, defined as parameter sets that resulted in efficiencies of sediment load and specific sediment yield estimations not more than 5% lower than the efficiency of the optimal parameter set. Under current management conditions, mean annual suspended sediment load at the Avon-Richardson catchment outlet was estimated to be 3350 (3300–3700) t y^{-1}, of which hillslope erosion contributed 65% (60–80%) and gully erosion 35% (20–40%). In the Avoca catchment, annual suspended sediment load was estimated to be 4000 (3500–5100) t y^{-1}, of which hillslope erosion contributed 17% (5–24%), gully erosion 72% (55–93%), and streambank erosion 11% (1–21%). In the Avon-Richardson catchment management scenarios showed that alternative farming systems focussed on retaining vegetation cover throughout the year would yield a 50 per cent reduction of suspended sediment load, estimated at 1700 t y^{-1}. In contrast, fencing and revegetation of connected gullies was estimated to yield the largest reduction in suspended sediment load (1770 t y^{-1}, 44% of current load) in the Avoca catchment. The framework provides an improved tool to make more informed decisions about how much suspended sediment loads can be reduced in response to farm management actions, gully and streambank protection. Its primary strength lies in the ability to propagate farm management impacts to the catchment scale. Other valuable features for use by natural resource management agencies include a high level of transparency, availability of user-friendly interfaces, and a modular structure that provides flexibility and adaptability to new systems.

1. Introduction

As in North America and Europe (National Research Council, 2008; Stoate et al., 2009), water quality problems caused by soil erosion from agricultural systems are becoming increasingly common in Australia (Department of Natural Resources and Environment, 2002a; Summers et al., 1999; Waterhouse et al., 2010). In Victoria for example, in 2002 only 22% of river reaches

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were classified as being in good or excellent condition (Department of Natural Resources and Environment, 2002b). Knowing the contributions from various sources, and costs associated with management strategies for sediment reduction is important for decision-makers such as catchment management agencies and governments to spend available public funding cost-effectively (e.g. Lynam et al., 2010).

Catchment-scale models can be used to assess the contributions of major sources of sediments to a stream network (Drewry et al., 2006). Application of semi-distributed models (i.e. lumped at the subcatchment-scale), such as SedNet (Prosser et al., 2001; Hancock et al., 2007; Wilkinson et al., 2009) have resulted in improved assessment of contributions of hillslope, gully and streambank erosion in medium and large basins (i.e. >3000 km^2; Wilkinson et al., 2009) in Australia, commensurate with the level of limited available water quality data. Although SedNet is one of the most commonly used models in Australia, assessment of the impact of farm management actions (for example changing pasture species or tillage practices) on sediment load reduction is hampered because agricultural land is typically defined into broad land-use categories, and impact of current and alternative land management in specific environmental conditions cannot be quantified.

Point-scale models, which simulates vertical fluxes of water and associated contaminants in a soil column, can be used to quantify the impact of farm management on water quality (sediment, nutrients, and pesticides) of a field or paddock under different soil and climatic conditions (e.g. Rattray et al., 2004; Freebairn et al., 2010; White et al., 2010), and can also be used to assess where farm management is likely to be most efficient in reducing agricultural impacts on water quality (Connolly et al., 1999, 2001; Robinson et al., 2010). The impact of farm management changes on sediment load reduction at the catchment scale, however depends on the environmental context, i.e. catchment hydrology and landscape erosion processes.

Given the importance of gully and streambank erosion processes in many Australian catchments (Australian Government, 2008), coupling point and semi-distributed catchment models has greater potential to improve assessment of farm management impacts at the catchment scale, than the use of uncoupled point-scale models or semi-distributed catchment models alone. Coupling of models at different scales simplifies simulation of complex systems and maintains the process understanding embedded in the single models, but it comes at the cost of higher data requirements, which may not always be available (Hansen and Jones, 2000; Freni et al., 2009; Cerco et al., 2010).

The aim of the research was to develop a catchment scale framework suitable for management decision makers to assess the contributions of farm management actions, gully stabilisation and streambank protection on suspended sediment loads to rivers and associated wetlands and floodplains.

2. Study areas

The framework was developed and tested in two locations, the Avon–Richardson and the Avoca catchments in north-central Victoria, southeast Australia (Fig. 1).

2.1. Avon-Richardson catchment

The Avon-Richardson catchment (36.5°S 143°E) was initially selected for model development and testing. It is an endorheic basin that extends over 2885 km^2 (Fig. 2). Topography is predominantly flat, with over 70% of the catchment having slopes <5%. Rainfall is winter dominant and highly variable; both the Avon and Richardson rivers are ephemeral and can have no streamflow particularly during the summer months (Vigiak et al., 2009).

Agriculture is the dominant land use, with open forest comprising <5% of the catchment area. There are three main farming system zones: grazed pastures in the southern hills (average rainfall approximately 550 mm y^{-1}), mixed farming systems (comprising both grazing and cropping) in the mid-catchment (average rainfall approximately 450 mm y^{-1}), and crop dominant systems in the flat northern part of the catchment (average rainfall approximately 400 mm y^{-1}). Cropping and grazing

Fig. 1. Location of the Avon-Richardson and Avoca catchments in Victoria (highlighted in the grey box), southeast Australia.