Linking farm management with catchment response in a modelling framework

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Abstract

One-dimensional simulation models of farming systems have been used to evaluate production and environmental aspects of farming systems, including the amount of deep drainage lost under crops and pastures. Most of this deep drainage is assumed to contribute recharge to groundwater. In addition, previous studies, most notably in the Liverpool Plains, have identified large anomalies between estimates derived using one-dimensional models of deep drainage lost below the plant root zone and recharge estimates based on hydrograph responses. In this paper we report the integration and application of a one-dimensional farming systems model (GrassGro™) into a catchment framework based on the USDA soil and water assessment tool (SWAT model) with enhanced allowance for lateral flows. The catchment framework was applied to the Hughes Creek sub-catchment of the Goulburn-Broken catchment, which has been identified by the National Action Plan for Salinity as a Victorian priority catchment. Simulation results were validated against three independent approaches: 1) predicted transpiration compared with estimates derived using the broad scale Zhang approach; 2) catchment averaged recharge estimates compared with recharge data embedded in the ABARE model based on the Catchment Characterisation groundwater conceptualisation project; and 3) observed stream flow data. Derived simulation results show good agreement between deep drainage estimates, observed stream flow and available experimental data. Reported results suggest that this framework can be used to assess the off-site impacts of land management decisions in a catchment context and can therefore extend the application of one-dimensional farming systems simulation models for assessing the potential impacts of salinity from agricultural land management.

Key Words

model, catchment, salinity

Introduction

The problem of allocating resources to control salinity, water quality and conserve biodiversity is complex. A great deal of information is needed before sensible decisions can be made. Information will be needed on the external costs and benefits of landscape interventions, including the impact on groundwater recharge, surface water flows, river (in-stream) salinity, nutrient loads in waterways, the hydrological costs of further loss of biodiversity and the on-site costs of implementing landscape change. This information can not be observed directly because the cause (landscape intervention) and effect (external cost or benefit) are separated by space (sometimes hundreds of kilometres) and time (sometimes many decades). This suggests that any assessment of the potential impact of landscape intervention, will need to be estimated (that is derived from models) rather than directly observed.

Currently there are no farming systems models that both operate at catchment scale and are explicitly linked to groundwater. As such, land managers have limited means of assessing whether decisions made at the paddock scale, have off-site catchment impacts (temporal or spatial). This creates a major problem for farmers, funding bodies, catchment managers and policy makers in assessing the public and private benefit (or negative consequences) of land management or where to invest limited resources.

This paper describes the application of a catchment framework based on the USDA soil and water assessment tool (SWAT model) comprising a one-dimensional farming system model with enhanced allowance for lateral flows.

Methods

The farming system model

Estimates of the likely impact of alternative grazing enterprises on deep drainage and the resultant potential of salinity impacts were derived using GrassGro^{TM} (1). GrassGro^{TM} is a one-dimensional model capable of simulating grazing systems and estimating soil moisture budgets and pasture growth. The pasture growth module distinguishes between annual species, perennial species, legumes, grasses and forbs. In order to simulate livestock dynamics and feed intake, shoot tissue is classified into live, senescing, standing dead and litter pools. Each tissue pool is further stratified into dry matter digestibility classes, which are necessary when considering differing grazing enterprises, stocking rates, diet selection and supplementary feed regimes. The water balance module is based on the SWRRB bucket model of Williams *et al*. (2) with modification to the transpiration and soil evaporation algorithms. The revised soil evaporation sub-model is based on Ritchie (3) with modification for the effects of transpiration as proposed by Stapper (4).

Accounting for lateral flows

The redistribution of lateral flows, both sub-surface and overland, was accounted for using the methodology developed by NSW Department of Land and Water Conservation (Rassam *et al*., personal communication). The following relationship was derived based on hillslope modelling results using HYDRUS2D (5) and represents a surface that defines the variation of the horizontal flux ratio with the hill slope angle θ and conductivity ratio K_r,

$$R_h = \frac{a + c\mathrm{Ln}(K_r) + e\mathrm{Ln}(\theta) + g(\mathrm{Ln}(K_r))^2 + i(\mathrm{Ln}(\theta))^2 + k\mathrm{Ln}(K_r)\mathrm{Ln}(\theta)}{1 + b\mathrm{Ln}(K_r) + d\mathrm{Ln}(\theta) + f(\mathrm{Ln}(K_r))^2 + h(\mathrm{Ln}(\theta))^2 + j\mathrm{Ln}(K_r)\mathrm{Ln}(\theta)} \quad (1)$$

where a, b, c, d, e, f, g, h, i, j, and k are fitting parameters, and K_r is the conductivity ratio of the soil layers ($K_{upper\ layer}/K_{lower\ layer}$). The fitting parameters that produced the best fit are listed in Table 1. Equation 1 was found to provide a good fit when compared with the numerical predictions obtained from HYDRUS2D with a maximum error of approximately 10% and average error of less than or equal to 3%. This relationship has subsequently proved to be transferable.

Table 1. Fitting parameters for Equation 1.

a	0.04487067	g	0.01010285
b	-0.11431376	h	0.040556192
c	0.019797884	i	0.01415831
d	-0.35073561	j	0.015858813
e	-0.020606403	k	-0.011046881
f	0.013044911		

The catchment framework

The catchment framework was based on the catchment scale Soil Water Assessment Tool (SWAT) developed by the United States Department of Agriculture. Regional catchments are disaggregated into sub-catchments based on topographic divides and/or user-defined boundaries. Each sub-catchment is connected to adjacent and downstream sub-catchments via stream routing. Within each sub-catchment, a number of hydrologic response units (HRU's) are developed based on soil, slope, climate and land-use overlays. Simulations are then derived for each HRU using a one-dimensional process-based farming system model. In this instance, the generic SWAT one-dimensional hydrologic model was replaced with GrassGro^{TM}, which accounts for pasture phenology and animal biology; these latter elements are essential to simulate grazing enterprises.

Results

The robustness and validity of the modelling approach was evaluated by application of the catchment framework to the upper Goulburn Broken Catchment in Victoria. Within this catchment the average annual rainfall ranges between 575-1700 mm and grazing is the dominant land use. Figure 1 shows the comparison between the mean annual evapotranspiration estimates for pasture derived using the broad scale Zhang approach (6) and those derived using the catchment framework. The catchment framework disaggregated the study area into approximately 1200 polygons. Solutions were then derived using the one-dimensional farming system model for each polygon using interpolated 30-year historical climate data. The lower evapotranspiration results derived using the catchment framework relative to the broad scale Zhang approach are due to the lower fertility assigned to granitic areas within the study area. Unlike the Zhang approach, the catchment framework produces time-series responses at the land management scale rather than the broad scale and also discriminates between individual pasture species.

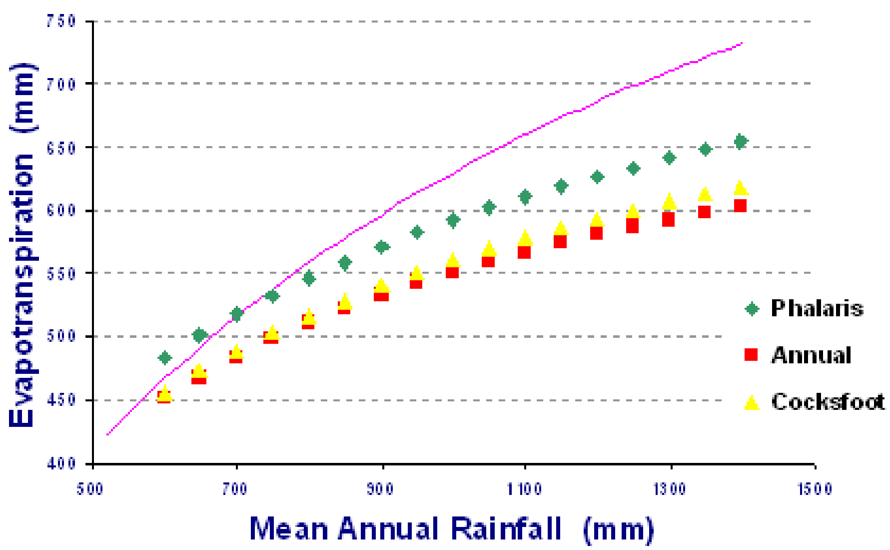

Figure 1. Comparison of evapotranspiration estimates for pasture derived using the Zhang Curve (solid line) and GrassGro^{TM} (symbols).

The lateral redistribution approach was assessed by comparing simulated stream flow against measured data within an unregulated sub-catchment of the study area. Based on these criteria, the Hughes Creek sub-catchment within the upper Goulburn Broken catchment was selected; average annual rainfall in this sub-catchment ranges between 575-975 mm. Additionally, an extensive field study was located within this sub-catchment as part of the Sustainable Grazing System national program (7) and provided validation data. Validation of the model at the paddock scale was based on matching simulated evapotranspiration, runoff and deep drainage to measured data sets.

Figure 2 summarises the simulated Hughes Creek stream flow under perennial and annual grazing pasture systems compared with observed data.

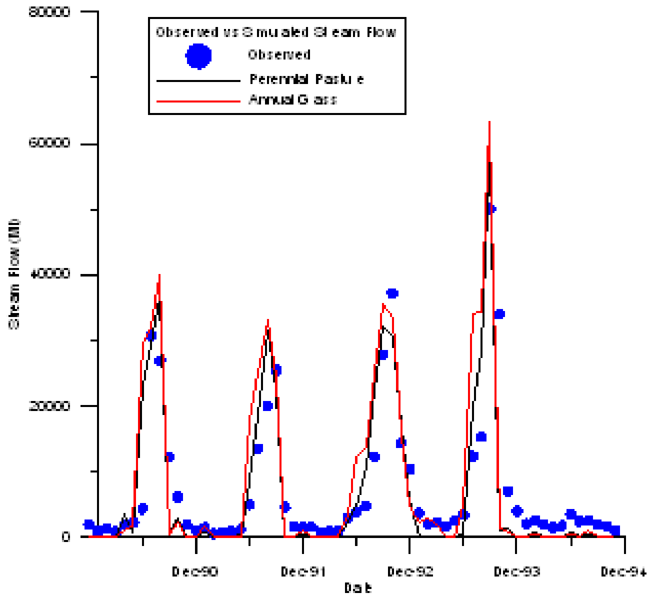

Figure 2. Observed versus simulated stream flow for the Hughes Creek sub-catchment. Current land use is predominantly perennial pasture.

Given that the current land use comprises a mix of perennial and annual species, the simulation results compare favourably with measured stream flow. However, the baseflow contribution is not well represented, as this component was not considered in the simulations. The difference in stream flow response and peak magnitude under perennial and annual pasture systems assuming similar climatic conditions and land management is clearly demonstrated and consistent with results reported by White *et al.* (7). Increased stream flow occurs under annual pasture systems relative to perennial pasture systems. Similarly annual average recharge increases under annual pasture systems as reported in Table 2. Also shown in Table 2 is the catchment averaged annual recharge estimate embedded in the ABARE model (8) for the same catchment. It is shown that the catchment average recharge estimates derived using the catchment framework is in agreement with estimates based on groundwater hydrograph responses.

Table 2. Estimated annual recharge under varying land uses within the Hughes Creek sub catchment, Victoria.

Model	Estimated Annual Recharge
Perennial pasture system	42 mm/year
Annual pasture system	49 mm/year
ABARE (CSIRO/BRS) estimate	46 mm/year

Conclusion

The derived simulation results show good agreement between recharge estimates, observed stream flow and available experimental data. Reported results suggest that this framework coupling one-dimensional farming system models can be used to assess the off-site impacts of land management decisions on surface hydrology in a catchment context. Further enhancements to account for catchment connectivity and salt mobilisation processes will enable the assessment of salinity impacts arising from agricultural land management.

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