Impact of Alternative Land Use Patterns on Plant Water Use, Surface Water Flow and Drainage on a Topographic Sequence

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Abstract

A 1-D farming systems simulator (APSIM) was coupled with a catchment hydrological framework (FLUSH) to simulate water balance on a topographic sequence in two sub-catchments in Simmons Creek, NSW. The impact of alternative land use options including continuous cropping, rotations, perennial lucerne and forestry were simulated using historical weather data. With annual crops, the valley floor land units were predicted to receive 187 mm/year of extra water in addition to annual rainfall in one year out of 10, and in excess of 94 mm/year in one year in four. In this valley floor position predicted drainage averages around 110 mm/year under annual crops and pastures whereas permanent tree cover or perennial lucerne reduces drainage by up to 99%. Introducing lucerne into a crop rotation reduces drainage by 11%, 67% and 35% on the uphill, slope and valley units respectively. Planting trees on a specific land unit has little impact on the quantities of water predicted to run on to lower units as surface or shallow sub-surface flow. The more significant hydrological impact is on reduction in deep drainage on the units where trees are planted. The work indicates opportunities for the use of lucerne or trees in specific locations where positive hydrological benefits are disproportionately large given the areas taken out of crop production.

Media summary

Simulation study shows opportunities for planting lucerne or trees in specific landscape positions to achieve reductions in deep drainage and to help prevent waterlogging and salinity.

Key Words

Land use change, deep drainage, catchment water balance, agricultural systems modelling, climate variability.

Introduction

A key element in the control of groundwater recharge and salt mobilization in agricultural areas will be the on-farm adoption of high water-use plant species that are carefully positioned in the landscape to meet specific environmental and production objectives. Appropriate targeting of land use change requires knowledge of drainage, recharge, discharge, and salt transport mechanisms at a catchment level as well as a property level for implementation guidelines. Farming systems and catchment hydrological modelling can be used to support such decision making. Paydar and Gallant (2003) developed a modelling Framework for Land Use and Spatial Hydrology (FLUSH) capable of incorporating farming system models applied to hydrologically interlinked land units. Coupled with a simple groundwater model and the farming systems model APSIM, they were able to simulate surface and ground water flow behaviour. In this paper we report a simulation analysis using FLUSH and the APSIM (Keating et al., 2003) on the impact of different cropping systems and perennial vegetations on surface water flow and drainage in two sub-catchments. The aim was to find the most appropriate locations in a catchment for land use change to prevent or mitigate waterlogging and salinity.

Material and Methods

Site specification and climate data

Simmons Creek catchment is located immediately east of the Walbundrie Township in New South Wales, Australia. Two sub-catchments (No 1 and 6 as defined by Paydar and Gallant 2003) in the catchment were chosen and three land units were delineated within each sub-catchment based on the multi-resolution valley bottom flatness topographic index (Gallant and Dowling, 2003). Each of the chosen sub-catchments has an uphill, a middle slope and a valley floor land unit. Water flows from the uphill unit to the slope and then to the valley floor unit. Excess water can be seen in the valley floor units in winter and early spring.

Historical climate records were obtained from the SILO patched data (Jeffery et al., 2001) at the Walbundrie weather station (No. 074115, 35.69^{o}S, 146.72^{o}E). Simulations are shown for 1957-2002 although model initialisation was earlier. Annual rainfall ranges from 200 mm to 1030 mm with a mean of 558 mm. Rainfall distribution within a year and from year to year has been highly variable. On average, spring, summer, autumn and winter rainfall accounts for 26%, 20%, 24% and 30% of the annual rainfall respectively.

The Framework for Land Use and Spatial Hydrology (FLUSH) and the farming systems model APSIM

FLUSH was designed to integrate farming systems models to simulate both vertical and lateral water fluxes in a catchment (Paydar and Gallant, 2003). Water running from an upslope unit supplements precipitation as the supply of water to the surface. Under saturated conditions, sub-surface water outflow from layers upslope is generated by the water balance model and added into appropriate layers down-slope. Only lateral flow under saturated conditions is considered due to the rapid reduction in flow rate below saturation.

APSIM (Keating et al., 2003) was used as the farming systems model to simulate the growth of crops, grasses and trees, plant water uptake, soil water and nutrient balance and lateral water flow. The model has been verified at locations near the study site of this paper (Verburg and Bond, 2003). APSIM version 3.2 was used in the current study, but new Wheat and Forest modules were used prior to their release in APSIM3.3. Other modules used are APSIM-Canola, Lucerne, Slurp, SoilWat2, SoilN2, and Residue2.

Model parameterisation

The area and slope of each unit, the length of the interface with its neighbour, the proportion of the unit's area drained by channels, soil and part of the management parameters were obtained from Paydar and Gallant (2003). Soil hydraulic properties were mostly determined from field survey, measurements on selected soil samples in different land units and subsequent extrapolation (McKenzie et al., 2003). For land units with more than one soil type simulation results were spatially averaged using the areal extent of each soil type within the unit. Soil profile depth is 1.5-2.0 m for uphill units, and 6 m for the slope and valley units. The maximum rooting depth was set to 1.2 m for annual crops, 0.6 m for annual grass and 6 m for perennial lucerne and trees.

The typical current land use consists of 6 years of crop rotation followed by three years of pasture (i.e., two cycles of canola/ wheat/triticale then 3-year pasture). In addition, 11 alternative land use scenarios (Table 1) involving crops in continuous cropping or rotations, annual winter active grasses, perennial lucerne, and farm forestry were also included in the simulation.

Table 1 Scenarios of land use on the currently cropped and uncropped areas of each land unit

Land Use Scenario	Land Use Symbol	Uphill		Slope		Valley	
		Cropped	Uncropped	Cropped	Uncropped	Cropped	Uncropped

1. Continuous canola	CAN_PAS	*canola*	*grass*	*canola*	*grass*	*canola*	*grass*
2. Continuous wheat	WHT_PAS	*wheat*	*grass*	*wheat*	*grass*	*wheat*	*grass*
3. Rotation with pasture	ROT_PAS	*rot_grs*	*grass*	*rot_grs*	*grass*	*rot_grs*	*grass*
4. Continuous pasture	PASTURE	*grass*	*grass*	*grass*	*grass*	*grass*	*grass*
5. Rotation with lucerne *P*	ROT_LUC_PAS	*rot_luc*	*grass*	*rot_luc*	*grass*	*rot_luc*	*grass*
6. Rotation with lucerne *T*	ROT_LUC_TG	*rot_luc*	*tree_grs*	*rot_luc*	*tree_grs*	*rot_luc*	*tree_grs*
7. Forest without undercover	TREE	*tree*	*tree*	*tree*	*tree*	*tree*	*tree*
8. Forest with grass under cover	TREE_GRS	*tree_grs*	*tree_grs*	*tree_grs*	*tree_grs*	*tree_grs*	*tree_grs*
9. Uphill forest cover	UTG_RL	*tree_grs*	*tree_grs*	*rot_luc*	*tree_grs*	*rot_luc*	*tree_grs*
10. Middle slope forest cover	MTG_RL	*rot_luc*	*tree_grs*	*tree_grs*	*tree_grs*	*rot_luc*	*tree_grs*
11.Valley floor forest cover	VTG_RL	*rot_luc*	*tree_grs*	*rot_luc*	*tree_grs*	*tree_grs*	*tree_grs*
12.Continuous lucerne	LUCERNE	*lucerne*	*lucerne*	*lucerne*	*lucerne*	*lucerne*	*lucerne*

canola - continuous canola; *grass* - winter active grass; *lucerne* – perennial lucerne; *rot_grs* - twice 3 year rotation (canola/wheat/triticale) followed by 3 year winter active grass; *rot_luc* - twice 3 year rotation (canola/wheat/triticale) followed by 3 year deep rooted lucerne; *tree* – forest without grass undercover; *tree_grs* – forest with grass undercover; *wheat*- continuous wheat

For annual crops (canola, wheat, triticale), the sowing window was April 30 to June 30. A crop was sown when the accumulated rainfall in 10 consecutive days within the sowing window reached 20 mm for canola or 25 mm for wheat and triticale or at the end of the sowing window if rainfall condition could not be met. A nitrogen rate of 100kgN/ha was used at sowing. After harvest, crop residue was burnt at the end of March. Perennial lucerne was sown in the first year (for continuous lucerne) or in the first year of each rotation cycle (in rotation with lucerne) with the same sowing window and rainfall condition as for wheat. Lucerne had the potential to grow continuously. Once the flowering stage was reached, the plant was cut to 5 cm height and 65% of the biomass was removed. An annual winter active grass was simulated using APSIM-Slurp by specifying the changes in leaf area over time – increasing curvilinearly from zero on day 120 to a maximum of 3.0 on day 215 and decreasing back to zero on day 315. *E. Grandis* was assumed to be fully grown throughout the simulation period. Grass cover under forestry was simulated with APSIM-Slurp by specifying the LAI similar to pasture, but with a maximum of 1.0.

Results

Figure 1 shows the predicted average annual water use of different vegetation types and the deep drainage on the valley floor land unit of sub-catchment 6 without considering upslope inflow. Although continuous wheat leads to slightly greater mean annual water uptake and deep drainage (69 mm/yr), wheat, canola and rotation perform similarly in terms of water use, and the results are sensitive to management. Deep rooted perennial lucerne and trees use more water than crops and pasture and are able to eliminate drainage passing 6 m depth.

The greater drainage with continuous cropping and rotation is a result of the inability of annual crops and pastures to dry the soil profile to sufficient depth. The maximum soil water deficit created by annual crops and pastures is <200 mm, while perennial lucerne and trees could create a deficit up to 592 mm. The larger water deficit provides a bigger buffer against excess rainfall in wet years/seasons, reducing deep drainage beyond the root zone.

Within the topographic sequence, the simulation results in the two sub-catchments are similar, so the following results are for sub-catchment 6. In both sub-catchments the middle slope unit has the largest area. Lateral flow from the top unit is dispersed over the larger area of the middle unit, and is concentrated as it flows from the middle unit to the smaller valley unit. Deep drainage from all units eventually becomes groundwater recharge, some of which will end up in the Billabong Creek.

The simulated lateral outflow (surface plus shallow sub-surface lateral flow leaving each unit) for crop/pasture rotations ranges from 0 to 153 mm/yr from the uphill unit (Fig 2a, b). From the middle slope unit, lateral outflow ranges from 0 to 197 mm/yr, and the probability of exceeding 50 mm/yr and 100 mm/yr are 25% and 10% respectively. That translates to the bottom unit receiving 94 mm/yr of water in one year in four, and 187 mm/yr one year in ten, in addition to annual rainfall. The maximum outflow from the valley bottom to stream channels reaches 260 mm/yr. Continuous lucerne reduces the outflow from each unit (Fig 2c). Forestry results in increased lateral outflow in wet years (Fig 2d). Due to the lateral water contribution from upslope units, the annual evapotranspiration of all vegetation types increases from the uphill, to the slope and to the valley floor unit in wet years (data not shown).

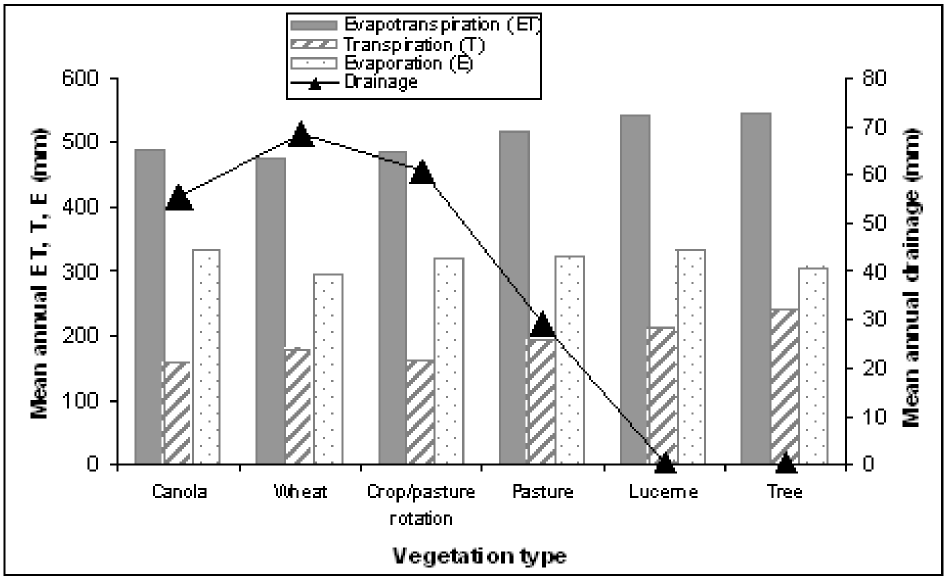

Figure 1 Comparison of average water use and deep drainage of different vegetation types at valley unit of sub-catchment 6 without considering the upslope inflow

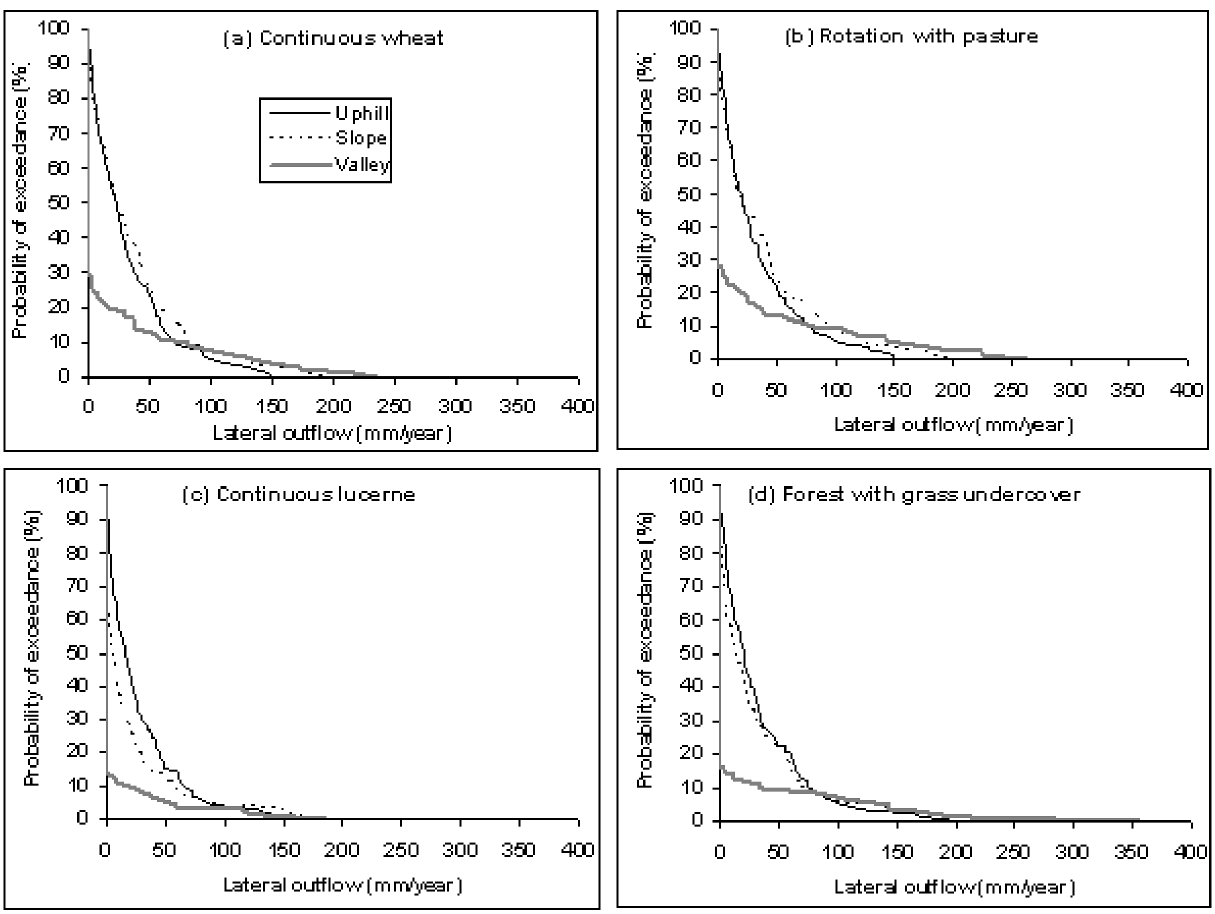

Figure 2 Probability of simulated annual lateral outflow from each land unit of sub-catchment 6 with 4 different land use scenarios.

For continuous cropping and rotations (CAN_PAS, WHT_PAS, ROT_PAS), the greatest predicted drainage occurs from the valley floor unit with an average around 107-116 mm/yr (Fig 3a). Greater drainage was simulated from the uphill unit (39-53 mm/yr) than from the middle slope (29-45 mm/yr) due to the shallow soil depth uphill. Compared with the current rotation option (ROT_PAS), permanent tree cover (TREE, TREE_GRS) eliminated the drainage from the slope unit, and reduced the drainage from the uphill and valley floor units by 93-94% and 96-98% respectively. Perennial lucerne (LUCERNE) eliminated the drainage from the slope and valley units, and reduced the drainage from the uphill unit by 99% (Fig 3a). Using perennial lucerne, instead of winter active pasture, in the fixed rotation (ROT_LUC_PAS) reduced the deep drainage by 11%, 67%, and 35% from the uphill, slope and valley land units respectively (Fig3a). Phase farming by introducing lucerne when the soil profile becomes full may further decrease the deep drainage.

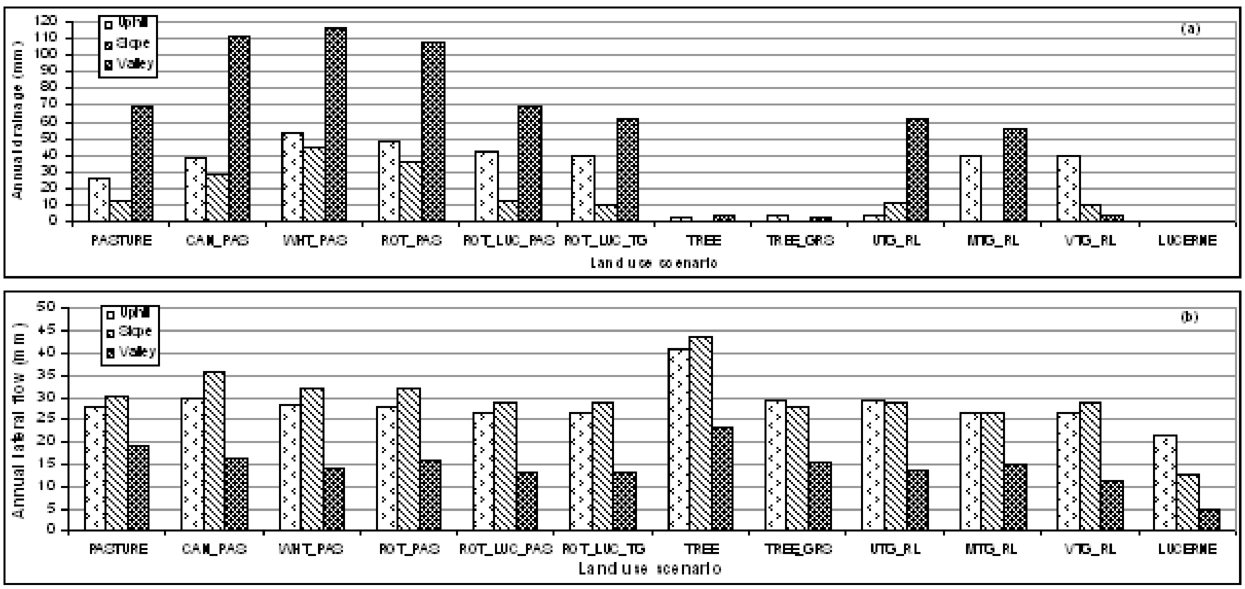

Figure 3 Mean annual deep drainage (a) and lateral water flow leaving each land unit (b) of sub-catchment 6 with different land use patterns (Land use scenarios see Table 1).

Compared with ROT_LUC_TG, planting trees to cover the uphill unit (UTG_RL) reduces deep drainage from the unit by 91% (Fig 3a), but has only a small impact on lateral flow being received by the slope and valley units (Fig 3b). Planting trees to cover the middle slope unit (MTG_RL) completely eliminates deep drainage from this unit, but only reduces the drainage from the valley unit by 10%. Planting trees to cover the whole valley floor unit (VTG_RL) reduced deep drainage from the unit by 94%. This modelling implies that the impact of tree cover for reducing surface flows of water is small, thus planting trees on the top fraction of the sub-catchment would have little impact on the water reaching the valley floor unit through surface or shallow sub-surface flow. Forest without grass undercover significantly increases outflow (Fig 3, TREE) due to increased runoff. This assumes that there is little groundwater contribution sourced from the uphill unit (through deep drainage) that reaches the lower units. It seems likely that the most significant hydrological impact from perennials is through deep drainage from those units where the trees or lucerne are established.

Conclusion

The coupling of the farming systems model APSIM with the catchment hydrological modelling framework FLUSH made it possible to capture management details at farm level and hydrological responses at catchment level. The modelling indicates opportunities for planting lucerne or trees in lower parts of the landscape to harvest water running from upslope. In wet years such a strategy is likely to confer benefits through reduced waterlogging and deep drainage and increased pasture or forest biomass production.

Gains through increased water use are likely to be disproportionately large for the area of land taken out of cropping. In dry years there is little lateral transfer of water to lower landscape units and so the opportunity cost of not cropping in these locations is unlikely to be greater than in any other parts of the landscape.

Acknowledgement

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