Estimating water quality from Australian grain production systems

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Abstract

A methodology is developed around a pragmatic application of water balance simulation and compilation of experimental datasets to assess changes in hydrology, soil erosion, suspended sediment, nutrient and pesticide losses from grain farm paddocks. After model calibration, the HowLeaky? model was applied to a range of agronomic management practices across the three grain regions of Australia. Sensitivity to management was assessed and absolute values of water quality variables were compared to available water quality objectives. With minimal tuning, HowLeaky? was able to reliably predict hydrology and water quality at the paddock scale across all grain growing regions in Australia. The grain industry can demonstrate with confidence, that it has significantly improved its environmental performance with the adoption of improved management practices.

Introduction

The Grain Research and Development Corporation theme *Improving your farm resource base* focuses on protecting and enhancing grain farms' soil, water, habitat and atmospheric resources to maintain production performance under a variable climate and to demonstrate to consumers and the wider community the sustainable nature of Australian grains production (www.grdc.com.au). Demonstrating the value of agronomic management investment more broadly in Australia through measureable impacts such as improved soil and water quality has been lacking. An opportunity exists for improving the quantification of impacts of management on movement of water, soil and agri-chemicals leaving Australian farms.

Direct measurement of the impact of agronomic practices on natural resource outcomes is expensive and time consuming. One challenge is to develop an efficient process for quantifying water quality signatures (hydrology, sediment, nutrient and pesticide loads and concentrations) for a range of locations, crop rotations and agronomic management options available to grain farmers.

As with any assessment using simulation models, the credibility of estimates is dependent on the database used to develop and test model algorithms.

Methods

Water balance as a basis for describing water quality leaving grain paddocks

This analysis uses water balance as a central methodology. The rationale for a water balance approach is that water balance is by definition conservative, and sediment, nutrients and pesticides are moved by water, either as runoff or deep drainage. Water balance deals with water flows explicitly and when combined with descriptions of soil type, crops, agronomic management and landscape features, provides a physical basis for estimating water quality. HowLeaky? (McClymont et al. 2011) accounts for water flows from rainfall, irrigation, soil water, evapotranspiration, runoff and deep drainage using a daily time step. This study's focus is on surface water quality.

Bringing multiple lines of evidence together

We have found some hydrology - water quality studies which describe interactions between climate, crop and soil conditions and resulting hydrology, sediment, nutrient and pesticide movements, but in all cases, these studies represent a very small sample of the real world. In order to deal with this incomplete and unbalanced data base, we have to build confidence in models, piece by piece, testing and modifying each process as we access more data.

A database was built that summarises ~140 water quality related studies across Australia (http://www.howleaky.net/index.php/library). This data collection uses a hierarchy of detail from simple site descriptions through to complete datasets (so called "Super Sites") that include model parameters and documentation. The number of datasets suited to testing models varies greatly among grain growing regions (Table 1), reflecting the relative importance of runoff, erosion and water quality in respective environments. In some cases, a dataset may only have average or annual values recorded while others will have a time series of daily values for several years duration.

Table 1: "Super Sites" across each grain growing region with measured water quality parameters

Grain Growing Region	Location	Measured	Publication
Northern	Kairi	H,S,N	Cogle et al. 2011
	Gatton	H,S	Tullberg et al. 2001
	Capella	H,S	Carroll et al. 1997
	Greenmount	H,S	Freebairn and Wockner 1986
	Greenwood	H,S	
	Wallumbilla	H,S	Freebairn et al. 2009
	Brigalow Research Station	H,S,N,P	Thornton and Elledge 2014
Southern	Mt Pollock	H,N,P	Holland et al. 2008
Western	Esperance	H	Bakker et al. 2005
	Moora	D,N^*	Anderson et al. 1998

H – Hydrology; S – Sediment; D – Drainage below root zone; N – N: Nutrient (phosphorous and nitrogen); N^* - Nitrate in drainage; P - Pesticides

A pragmatic process for system description

Given the diversity of experimental conditions surveyed and the range of detail in system description, a process was required to describe experiments pragmatically in terms suited to simulation models. The aim was to get sufficient information to parameterise the model to estimate hydrology, erosion, sediment, nutrient and pesticide loads leaving paddocks, without being too burdensome. This was achieved by describing:

- Soil water holding capacity and hydrology characteristics based on local observation, databases such as ApSoil, soil surveys and qualitative assessments of surface structure, profile drainage and water holding capacity. We previously found that approximate soil descriptions were sufficient for reasonable estimates of hydrology (Freebairn et al. 2012);
- A time series of green vegetation and residue cover, typically an average monthly value of green and residue cover (%);
- A phosphorous description using standard soil test data (Robinson et al. 2007) and soil nitrate-nitrogen content as a monthly time series of values in the surface and bottom soil layers for surface and deep drainage losses respectively; and
- Dates and rates of pesticide application with pesticide properties derived from Shaw et al. (2011), Kookana et al. (2010), Rattray et al. (2007) and the Ecotox database (http://cfpub.epa.gov/ecotox/). No tuning to measured herbicide data was undertaken.

The HowLeaky? model was tested against observed data using published values of parameters and tuned to key hydrologic parameters to estimate event and total runoff in a "reasonable" manner without undue attention to detailed agreement. This process allowed for a rapid, yet robust description of each management system when used in conjunction with published descriptions and local knowledge. More detail on the process of system description and the rationale for estimating water quality signatures can be found at www.howleaky.net.

Assessing role of management on hydrology and water quality

Management practices with sufficient data to parameterise the HowLeaky? model included: tillage (stubble burnt, aggressive tillage through to zero tillage); crop types (wheat, sorghum, maize, wheat-canola, with pasture and horticulture studies also used to increase confidence in model estimates); compaction related to normal and controlled traffic; use of raised beds; and herbicide applications for a range of soil types and climates. Observations to test the model included; soil water, runoff, deep drainage, soil erosion, suspended sediment, phosphorous, NO_3-Nitrogen and pesticide (2,4D, atrazine) concentrations and loads.

An ABCD framework (Drewry et al. 2008) was used to test the range of management practice where “A” practice represents futuristic or aspirational best practice, “B” is best practice, “C” is current practice and “D” is poor or out-dated practice. While descriptions of A, B, C and D appear arbitrary, this schema provides a means of exploring responses of hydrology and water quality to a wide range of management practices.

Results

Ability to estimate hydrology and water quality across regions

Figure 1 summarises the models ability to estimate runoff or deep drainage, soil loss (soil movement or suspended sediment) and nutrient or pesticide losses. While Figure 1 somewhat exaggerates model reliability by plotting observations from a wide range of environments, predicted differences due to management (same symbols) are also in good agreement. In all cases, errors in estimated runoff lead to larger errors in water quality variables.

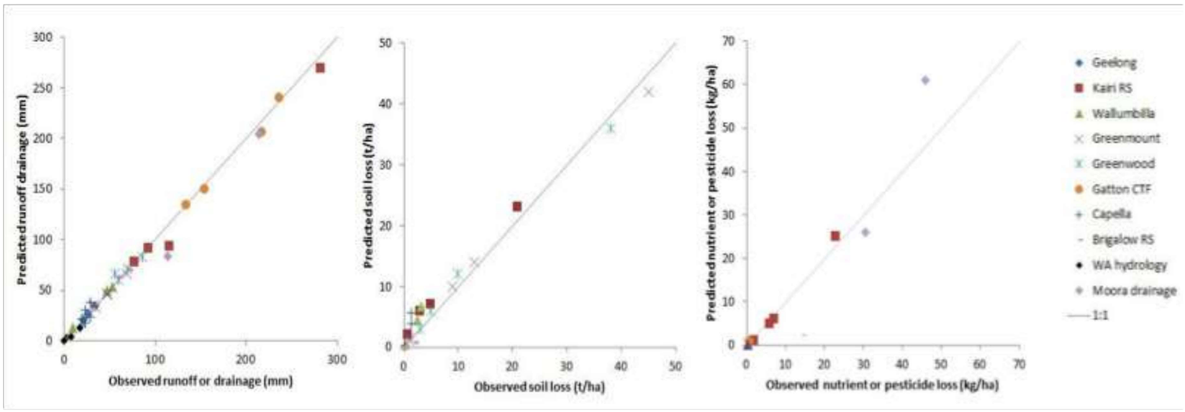

Figure 1. Observed and predicted average annual runoff or deep drainage (N=46), soil loss (N=37) and nutrient or pesticide loss (N=12) for 10 locations across Australia. N refers to the number of average annual observations.

Impact of management practices on water quality attributes

A case study using five management classes in Central Queensland is presented as an example of analyses across Australia’s grain regions. In order to compare management impacts across sites, hydrology and water quality attributes are referenced against the “C” management practice (Figure 2). Responses shown in Figure 2 have been averaged for summer and winter cropping while an A+ treatment was added representing an improved soil condition associated with controlled traffic (Li et al. 2008). While runoff is slightly reduced when C practice is adopted over D practice, sediment and phosphorous losses are reduced more than threefold. Adoption of B and A practice improve most water quality indicators, with A+ management having soil and chemical losses <15% of those under C practice. It should be kept in mind that these ‘model’ estimates assume all the attributes of each agronomic practice are effective. Nevertheless, these analyses are well supported by experimental data, even though brought together in a modelling environment, piece by piece.

We applied the same process to all three grain growing regions. Relative responses to management were similar in the southern region although the magnitude of soil and chemical losses are much smaller. The western region was less responsive to management and the overall risk of off-farm movement is also much lower as runoff is a small part of the water balance. D’Emden et al. (2008) identified that the adoption of no-till (B) cropping practices was approximately 80% in 2000. With this in mind the adoption of B management and associated improvement in water quality leaving the paddock allows the grain industry to promote their environmental credentials.

Conclusions

A pragmatic methodology for applying a water balance model across a wide range of environments has been developed and tested. The HowLeaky? model estimates of runoff, sediment, nutrients and pesticide loads were similar to measurements from catchment studies both in magnitude and responses to management. A database of hydrology and water quality related studies has been populated and is available for general use. The grain industry can apply a range of management practices to improve water quality leaving grain farms, and have made large improvements in management over the last three decades.

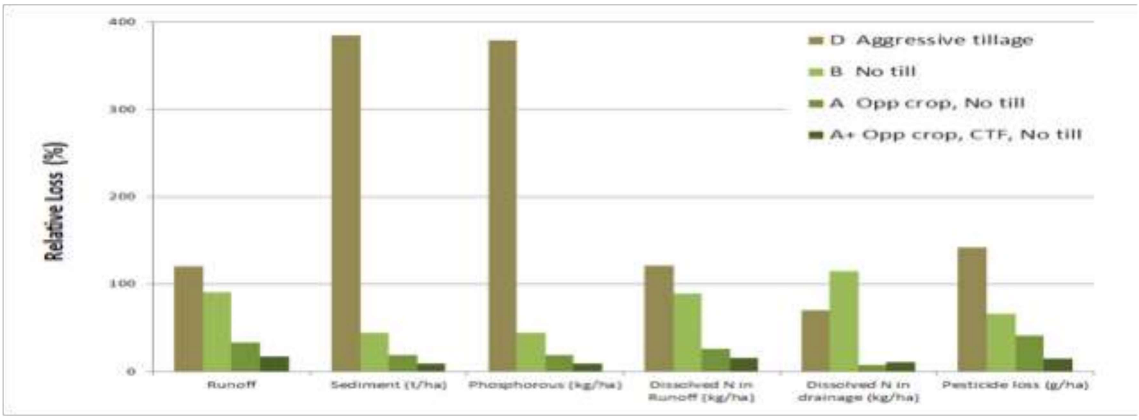

Figure 2. Relative runoff, sediment, phosphorous, nitrate in runoff and deep drainage and pesticide losses for four levels of management relative to "current "C" practice in Central Queensland.

References

Anderson GC, Fillery IRP, Dunin FX, Dolling PJC, Asseng S. 1998. Nitrogen and water flows under pasture -wheat and lupin-wheat rotations in deep sands in Western Australia, 2. Drainage and nitrate leaching. *Australian Journal Agricultural Research* **49**, 345-61.

Bakker DM, Hamilton GJ, Houlbrooke DJ, Spann C. 2005. The effect of raised beds on soil structure, waterlogging, and productivity on duplex soils in Western Australia. *Australian Journal Soil Research* **43**, 575-585.

Carroll C, Halpin M, Burger P, Bell K, Sallaway MM, Yule DF. 1997. The effect of crop type, crop rotation, and tillage practice on runoff and soil loss on a Vertisol in central Queensland. *Australian Journal Soil Research* **35**, 925-39.

Cogle AL, Keating MA, Langford PA, Gunton J, Webb IS. 2011. Runoff, soil loss, and nutrient transport from cropping systems on Red Ferrosols in tropical northern *Australian Journal Soil Research* **49**, 87-97.

D'Emden F, Llewellyn RS, Burton M. 2008. Factors influencing adoption of conservation tillage in Australian cropping regions. *Australian Journal of Agricultural and Resource Economics*, **52**, 169-182.

Freebairn DM, Cutajar JL, Silburn DM. 2012. Assessing water quality from farms – how much detail is required for a model to be useful? Soil Science National Conference, 2-7 Dec. 2012 Hobart.

Freebairn DM, Wockner GH, Hamilton NA, Rowland P. 2009. Impacts of soil conditions on hydrology and water quality from a brown clay in the north-eastern cereal zone of Australia. *Australian Journal Soil Research* **47**, 389-402.

Freebairn DM, Wockner GH. 1986. A study of soil erosion on Vertisols of the Eastern Darling Downs, Queensland. I Effects of surface conditions on soil movement within contour bay catchments. *Australian Journal Soil Research* **24**, 135-58.

Holland JE, White RE, Edis R. 2008. Improved drainage and greater air-filled porosity of raised beds in south-western Victoria. *Australian Journal Soil Research* **46**, 397-402.

Kookana RS, Baskaran S, Naidu R. 1998. Pesticide fate and behaviour in Australian soils in relation to contamination and management of soil and water: a review. *Australian Journal Soil Research* **36**, 715-764.

Li XY, Tullberg JN, Freebairn DM, McLaughlin NB, Li HW. 2008. Effects of tillage and traffic on crop production in dryland farming systems: I. Evaluation of PERFECT soil-crop simulation model. *Soil and Tillage Research* **100**,15-24.

McClymont D, Freebairn DM, Rattray DJ, Robinson JB and White S. 2011. HowLeaky? V 5.40.10: Exploring water balance and water quality implication of different land uses. http://www.howleaky.net/

Robinson JB, Rattray DJ, Freebairn DM, Silburn DM McClymont D. 2007. Using a Simple Hydrologic Model to Link Management to Nutrient Concentrations and Loads in Runoff. MODSIM 2007 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2007, pp. 74-80.

Shaw M, Silburn DM, Thornton C, Robinson B, McClymont D. 2011. Modelling pesticide runoff from paddocks in the Great Barrier Reef using HowLeaky. 19th International Congress on Modelling and Simulation Perth, Australia.

Thornton CM, Elledge AE. 2013. Runoff of Nitrogen, Phosphorus and Sediment from Pasture Legumes: An Enhancement to Reef Catchment Modelling (Project RRRD009). Report to the Reef Rescue Research and Development Program. ISBN: 978-1-925088-11-3.

Tullberg JN, Ziebarth PJ, and Li Y. 2001. Tillage and traffic effects on runoff. *Australian Journal Soil Research* 39: 249-257.Anderson GC, Fillery IRP, Dunin FX, Dolling PJC, Asseng S. 1998. Nitrogen and water flows under pasture -wheat and lupin-wheat rotations in deep sands in Western Australia, 2. Drainage and nitrate leaching. *Australian Journal Soil Research* **49**, 345-61.