

UNIVERSITY OF SOUTHERN QUEENSLAND

**MODELLING HERBICIDE MOVEMENT FROM FARM TO
CATCHMENT USING THE SWAT MODEL**

A Dissertation submitted by

Danny James Rattray, B. Eng

For the award of

Masters of Engineering

2008

ACKNOWLEDGEMENTS

I would firstly like to thank Dr. Mark Porter. His instructive comments and ideas were of a great support to me. He also showed incredible patience waiting for me to deliver the final manuscript. Thanks also to the University of Southern Queensland for the opportunity provided to me to achieve this academic goal.

Thank you to the numerous colleagues who have supported me along the way, in particular Dr. David Freebairn and Dr. Mark Silburn have provided mentoring and been a source of inspiration for many years. Thanks also to the examiners who provided valuable feedback, Dr. Lachlan Newham and Dr. Simon Lott.

And of course thank you to my wife Pru, and my children, who have given me their love and support, and most importantly were often the source of much loved distraction.

ABSTRACT

Water quality in Australia's northern grains farming areas often exceeds water quality trigger values for suspended sediments, nutrients and some herbicides (CBWC, 1999). While there are many land uses in these areas that contribute to the resultant water quality, of particular concern for the grains farming industry is the widespread detection in rivers of chemicals used by their industry, namely atrazine and metolachlor. A comparison of Hodgson Creek catchment (South East Queensland, Australia) herbicide data with national water quality guidelines shows that trigger values are frequently exceeded.

That water quality trigger values are exceeded is expected for a highly modified catchment such as Hodgson Creek, and the Australian New Zealand Environment and Conservation Council (ANZECC) (2000) guidelines make provision that in such catchments, locally derived targets should be set. Natural resource managers therefore require skills in linking planned management with their ability to set or meet targets.

The opportunity suggested itself for using catchment modelling to set realistic targets for water quality based on the adoption of best management farming practices. This study investigated the suitability of the Soil and Water Assessment Tool (SWAT) to fulfil this modelling role in an Australian context of land use management. To test the suitability of SWAT to fulfil this role, the study aimed to determine the feasibility of using the model to explicitly depict farm management practices at a paddock scale to estimate resultant catchment water quality outcomes.

SWAT operates as two distinct sub-models. A hydrologic response unit (HRU) (the paddock scale model) generates runoff and constituents, and the output of many HRU are summed and routed through a stream network. The method for calibration of SWAT proposed in the user manual (Neitsch *et al.*, 2001) is to calibrate against streamflow before calibrating sediment and then herbicides. The logic of testing in a process dependent order is sensible, however the method proposed by Neitsch *et al.* (2001) assumes that the HRU processes are reliable and

calibration only need consider catchment scale processes. A review of the literature suggested that there had been limited testing of HRU process in studies where SWAT had been applied.

Data available for model testing came from both paddock and catchment studies. The effects of cultivation management practices on runoff and erosion have been well characterised for the study area by Freebairn and Wockner (1996). Atrazine dissipation in soil and loss in runoff was available from a study of a commercial farm in the Hodgson Creek catchment (Ratray *et al*, 2007). An ambient and event based water quality monitoring for suspended sediments and herbicides provided data for the Hodgson Creek catchment for the period 1999 to 2004 (Ratray, unpublished data).

The model required minimal calibration to achieve good predictions of crop yields and surface cover for winter crops. However, testing of summer cropping component revealed structural problems in SWAT associated with the end of a calendar year. Testing also revealed that perennial pastures and trees are modelled with unrealistic fluctuations in biomass and leaf area index.

The model was able to represent hydrology well across a range of scales (1-50,000 ha). Catchment scale runoff data was well matched for a range of tillage treatments. The model was found to be able to attain a good prediction of monthly runoff at the catchment scale. This is consistent with the finding of most other SWAT studies.

The model was able to represent average annual erosion reasonably well using the Universal Soil Loss Equation (USLE) when tested at the HRU scale (1 ha) against a range of tillage management data. When tested at the catchment scale the model was found to be able to match average annual sediment loads for the catchment however annual variability in sediment loads was poorly matched.

Testing of the herbicide model for SWAT found that model compared poorly with paddock scale trial data. The reason for poor model performance can be attributed to an inadequate representation of processes and model output was unrealistic

compared to our understanding of herbicide transport processes. When the model was tested at a catchment scale it was found to compare very poorly with catchment scale observations. This can be explained in part by the deficiencies of the HRU herbicide model, but is also due in part to difficulties in parameterisation of spatial and temporal inputs at the catchment scale.

While SWAT provides a model with detailed physical processes, the capacity to apply the model is let down by an inability to practically determine the spatial and temporal extent of the farming practices (i.e. where and when are tillage and herbicides applied in the catchment). The challenge to applying SWAT is that farming practices in Australia vary markedly from year to year. SWAT requires the user to input crop practices in as a fixed rotation while Australia's highly variable climate with unreliable seasonal weather patterns results in opportunistic farming practices. Hence this is a major limitation in the model's ability to predict catchment outcomes, particularly for herbicides where off site losses are highly dependant on application timing. In attempting to validate herbicide losses at the whole of catchment scale it became apparent that uncertainty in the temporal variation of farm operations within the catchment poses a major limitation to accurately reproducing observations at the catchment outlet.

It is concluded that that there is limited usefulness of SWAT for investigating the impacts of land management on catchment scale herbicide transport for Australian conditions.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION	1
1.1. STUDY AIM AND OBJECTIVES	1
1.2. A NEED FOR A PROCESS TO INTEGRATE PADDOCK MANAGEMENT INTO CATCHMENT WATER QUALITY ASSESSMENT	2
CHAPTER 2. LITERATURE REVIEW	7
2.1. SELECTING A MODEL FOR THIS STUDY	7
2.2. OVERVIEW OF THE SOIL AND WATER ASSESSMENT TOOL	11
2.3. APPLICATIONS OF THE SOIL AND WATER ASSESSMENT TOOL	27
2.4. DESCRIPTION OF THE CASE STUDY AREA (HODGSON CREEK CATCHMENT) AND GRAIN FARMING PRODUCTION SYSTEM	31
2.5. PADDOCK MANAGEMENT PRACTICES TO REDUCE HERBICIDE LOSSES OFF FARM	38
CHAPTER 3. DATA SOURCES AND MODEL CALIBRATION	43
3.1. MODEL INPUT DATA	43
3.2. OBSERVED SOIL AND WATER DATA	52
3.3. PARAMETERISATION AND CALIBRATION METHOD	58
CHAPTER 4. RESULTS	66
4.1. MODEL PERFORMANCE AT PADDOCK SCALE	66
4.2. MODEL PERFORMANCE AT THE CATCHMENT SCALE	81

CHAPTER 5. DISCUSSION	86
5.1. SWAT MODEL PERFORMANCE IN THIS STUDY	86
5.2. MODEL STRUCTURE AND COMPLEXITY	93
5.3. APPLYING SWAT IN WATER QUALITY ASSESSMENT	96
5.4. MODEL IMPROVEMENTS AND FUTURE WORK	100
CHAPTER 6. CONCLUSION	103
CHAPTER 7. REFERENCES	106
APPENDIX A : MAPS	113
Map 1 : LOCALITY MAP SHOWING GAUGING STATION, RESEARCH SITES AND CLIMATE STATIONS.	114
Map 2 : DIGITAL ELEVATION MODEL (DEM).	115
Map 3 :DETAILED SOILS MAP.	116
Map 4 :SIMPLIFIED SOILS MAP.	117
Map 5 : LAND USE MAP	118
APPENDIX B : FORTRAN SOURCE CODE CHANGES	119

LIST OF FIGURES

Figure 1 : Sub-catchment delineation of the Hodgson Creek Catchment as used in this study.....	13
Figure 2: Schematic representation of a HRU hydrologic cycle (Source: Neitsch <i>et al.</i> , 2001).....	15
Figure 3: Prism and wedge storages in a reach segment (Source: Neitsch <i>et al.</i> , 2001)...	16
Figure 4: Example of optimal plant leaf area index curve development as a function of plant heat units for a plant to reach maturity (Source: Neitsch <i>et al.</i> , 2001).	17
Figure 5: Herbicide fate and transport in SWAT (Source: Neitsch <i>et al.</i> , 2001).....	23
Figure 6 : Cambooya Shire crop planted areas for winter and summer cereal crops (Source: Gutheridge, 2004).....	34
Figure 7: Cambooya Shire crop yields for winter and summer cereal crops (Source: Gutheridge, 2004).	35
Figure 8 : Sorghum crop stages and herbicide choices. (Source: QDPI, 2000).....	38
Figure 9 : Relationship between bulk density and volumetric moisture.	47
Figure 10 : Volumetric moisture characteristics for soil depth profile as outputted from SWAT for an Irving clay.	48
Figure 11 : Daily Streamflow (Megalitres per day) at Hodgson Creek G.S. for the period May 1987 – June 2004.....	55
Figure 12 : Average Monthly Streamflow (Megalitres) at Hodgson Creek G.S. for the period May 1987 – June 2004.....	56
Figure 13 : Monthly suspended sediment load at Hodgson Creek G.S. for the period 1999-2004.....	57
Figure 14: Monthly herbicide load at Hodgson Creek G.S. for the period 1999-2004.....	57
Figure 15 : Screen shot of Browser (2.15) time series analysis tool.....	60

Figure 16 : Leaf area index patterns modelled by SWAT for a wheat crop when dormancy is active, where the dormant phase runs from late April to early July.....	64
Figure 17 : Observed vs. predicted covers (%) for wheat stubble for a range of tillage treatments.....	68
Figure 18: Time series surface cover (kg/ha) for a range of tillage treatments	69
Figure 19: Modelled sorghum surface and residue cover showing model errors associated with the end of the calendar year.....	70
Figure 20: Leaf area index, biomass for forest land use as modelled by SWAT.....	71
Figure 21: Time series of observed and predicted soil water for Greenmount wheat, bare fallow (1976-1990).....	73
Figure 22: Herbicide loss sensitivity to half life scale	77
Figure 23: Observed and predicted atrazine loads and Observed atrazine concentrations (Cowarrie, atrazine applied at 2.5kg/ha active ingredient applied 1 October 2001).....	79
Figure 24: Atrazine lost (% of total application) with application date varied by month.	80
Figure 25 : Observed and predicted monthly flows at Hodgson Creek G.S.	82
Figure 26 : Scatter plot of observed and predicted monthly flows at Hodgson Creek G.S.	83
Figure 27: Observed and predicted annual sediment loads at Hodgson Creek G.S.....	84
Figure 28: Observed and predicted annual Atrazine loads at Hodgson Creek G.S.	85
Figure 29 : Process representation of edge of paddock filters where the arrows show direction of flow, the dotted area represents herbicide application area and the cross hatched area represents filter area.....	92

LIST OF TABLES

Table 1 : Trigger values for protection of aquatic ecosystems (ANZECC, 2000) ¹ and (CBWC, 2002) ² and observed median values for the Hodgson Creek G.S.	3
Table 2 : Trigger level values for atrazine and metolachlor for human health (NHMRC, 2004) and maximum observed values at Hodgson Creek G.S. (Ratray, unpublished data).	4
Table 3 : Trigger level values for protection of aquatic ecosystems (ANZECC, 2000). The maximum observed values for the Hodgson Creek G.S. (1999-2005) was 8.3 µg/L (n=74) (Ratray, unpublished data).	5
Table 4 : Herbicide application best management practices to reduce environmental risks	41
Table 5: Soil hydrological parameters for Hodgson Creek SWAT model	45
Table 6: Soil physical parameters for Hodgson Creek SWAT model	46
Table 7: Summary of soils and land use area ratio's (%) for Hodgson Creek catchment.	49
Table 8 : Summary of atrazine degradation studies conducted on Australian soils (Source: Kookana <i>et al.</i> , 1998).	51
Table 9 : Summary of atrazine sorption coefficients studies conducted on Australian soils (Source: Kookana <i>et al.</i> , 1998)	52
Table 10 : Greenmount trial treatments by year and bay number each treatment was applied.....	53
Table 11 : Data set details for the Greenmount conservation tillage trials	54
Table 12 : Data set details for the Cowarrie herbicide transport trial	54
Table 13 : Observed and predicted wheat yields (t/ha) for a range of tillage treatments..	67

Table 14 : R ² for observed Greenmount trial data versus predicted soil water for a range of tillage treatments.	72
Table 15 : R ² for observed Greenmount trial data versus predicted daily runoff and curve numbers for a range of tillage treatments.	74
Table 16 : Observed as predicted erosion for a range of tillage treatments (1976-1990).	74
Table 17 : Annual average water balance and erosion for a heavy black clay soil (Irving) with Greenmount climate(1901-2001) for a range of land uses and management scenarios.	76
Table 18: Filtering capacity of a range of edge of paddock filter widths.	81