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Assessing the spatial variation of dairy farm total phosphorous losses in the Duck river, NW Tasmania

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Abstract: The Duck is a highly developed 540 km^2 catchment in the northwest corner of Tasmania, with nutrient exports dominated by dairy production (Pinto et al. 2003) undertaken on approximately 19% of the total area. To calculate total phosphorus loads delivered to the Duck estuary, a model was developed using the WaterCAST framework. The daily time step model was created using a ground truthed version of the Australian Bureau of Regional Sciences (2003) land use map, a 5km climate grid (Jeffery et al 2001) and the AWBM rainfall runoff model (Nash Sutcliffe Criterion (NS)=0.88 and R^2= 0.91). The nutrient generation component used the event mean concentration, dry weather concentration method (Chiew et al. 2002) and was parameterised using end of catchment and within catchment nutrient samples taken by the Tasmanian Department of Primary Industries and Water from 1999 to 2001 (Pinto et al. 2003). The resulting modelled outputs were verified using DPIW monthly grab samples collected from 2003 onwards (www.water.dpiw.tas.gov.au) resulting in a NS=0.64 and R^2=0.66. The process of model parameterisation uncovered large differences in total phosphorous generation rates from dairy pastures throughout the catchment, and to a lesser extent grazing modified pastures (Table 1). These results were backed up with significant differences in the soil test Olsen phosphorus levels.

Table 1: Regionally specific event mean concentration (EMC) and dry weather concentrations (DWC) for the land uses Grazing modified pastures and Dairy pastures (mg/L)

	Upper and East		Mid		Lower	
	DWC	EMC	DWC	EMC	DWC	EMC
Grazing modified pastures	0.012	0.12	0.05	0.9	0.06	0.09
Dairy pastures	0.02	0.18	0.08	1.5	0.08	5.00

The lumped conceptual nature of the WaterCAST model means that conclusions about processes driving the regional differences detected cannot be drawn. However, this model can be used to prioritise further, more detailed investigations, designed to begin elucidating underlying mechanisms and potentially effective interventions. This is the focus of ongoing work.

Keywords: *Dairy production, total phosphorus, water quality, Tasmania, WaterCAST, catchment modelling.*

1. INTRODUCTION

The Duck River catchment is a highly developed 540 km^2 drainage basin in the northwest corner of Tasmania, dominated by dairy production (19% of the total area). The Duck has a gentle gradient with an elevation of approximately 200m above sea level in the far south and east, then trending from low hills to undulating plains and river terraces. Extensive low lying areas comprised of drained swamps are prone to water logging in winter, resulting in the extensive use of "hump and hollow" drainage (Pinto et al. 2003).

Land management practices in the catchment appear to have significantly impacted water quality, particularly total phosphorus (TP), resulting in much higher nutrient loads than other Tasmanian catchments (Pinto et al. 2003). As there is growing awareness of water quality issues by catchment stakeholders in Australia (Letcher et al. 2002), this is potentially a divisive issue because, as well as the dairy industry, the Duck also supports recreational activities and a significant shellfish industry (Pinto et al. 2003). This catchment also forms part of the Robbins Passage wetlands, the largest and most diverse community of migratory and resident shorebirds in Tasmania (Spruzen et al. 2008). Therefore it is important to understand the sources of nutrients in the catchment to facilitate changes in management or undertake interventions to improve water quality. This is of particular interest to the dairy industry as previous work in the neighbouring Montagu catchment identified dairy as the major source of nutrient pollution (Holz 2007).

Due to low phosphorus parent materials and *in situ* weathering, Australian soils are typically low in TP (Handreck 1997), meaning high rates of TP in water quality samples indicate anthropogenic influences and to some extent intensity of management. Therefore, to understand differences in dairy farm management throughout the Duck catchment TP was chosen for this investigation. As there is currently a lack of high frequency (daily to sub daily) data to accurately predict end-of-catchment nutrient fluxes for the Duck catchment (although equipment has been installed and is currently being tested), catchment and sub-catchment scale modeling was required.

2. MODEL STRUCTURE

WaterCAST, an evolution of E2 (Argent et al. 2004), was chosen to model the spatial variation in TP concentrations in the Duck. WaterCAST is a lumped, semi-distributed, conceptual catchment modelling framework that allows modellers to construct models by selecting and linking component models from a range of options (Argent et al. 2008). Multiple component models are available for rainfall/runoff, nutrient generation, attenuation, catchment structures (links and nodes) and routing. Numerous plugin applications have also been created and are continuing to be developed. Important stages in the development of a WaterCAST model include land use assessment, subcatchment delineation, rainfall runoff model calibration and nutrient generation model calibration.

2.1. Land use assessment

Land use in Tasmania was assessed by the Bureau of Rural Sciences (Drenen 2003) and a geographic information systems (GIS) layer created (http://adl.brs.gov.au/mapserv/landuse/). However, land use areas in Duck catchment were not verified. As a result any reference to dairy production (irrigated modified pastures) in the Duck catchment was completely absent. To correct this deficiency an A0 map of the catchments' land uses was produced and discussed with David Krushka, the DPIW Regional Water Management Officer in charge of monitoring irrigation licences in the area. Areas of irrigated pastures were drawn on this map, which were then validated by driving around the catchment and making some slight boundary adjustments. Some areas of plantation forestry were also identified. The land use GIS layer was then updated and the new land use areas were imported into WaterCAST (Figure 1) as "functional units" (Argent et al. 2008).

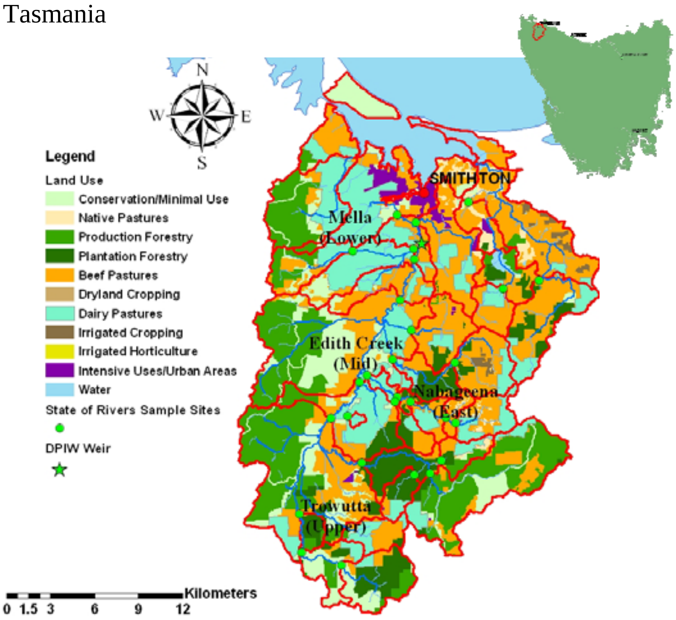

Figure 1: The Duck catchment location (top left), Land use information, catchment regions and sampling locations.

2.2. Catchment delineation

Catchment boundaries in Tasmanian catchments have been created as part of the Tasmanian Conservation of Freshwater Ecosystem Values project (CFEV) (DPIW 2008). However, as the catchment boundaries from CFEV could not be readily adjusted to calculate areas upstream of specific points of interest (data points), a hydrological model was constructed using CatchmentSIM (Ryan and Boyd 2003), a digital elevation model (DEM) and stream lines (CFEV database v1.0 2005). The state government DEM for Tasmania (TasDEM) had significant areas of flat terrain in the Duck catchment that had been 'pit filled' to the nearest 10m elevation, meaning that the standard breaching and pit filling algorithms in CatchmentSIM could not resolve the hydrology. Therefore a DEM was created using ANUDEM version 4.6.3 in ArcGIS. Inputs were the Tasmanian 10m contours, CFEV stream lines, spot heights from the 1:25000 Tas Maps Series and a 2km buffered catchment boundary. The resulting increase in resolution from the DEM created allowed the catchment to be hydrologically processed. Once the catchment boundary was created, areas upstream of DPIW monitoring stations were delineated forming the sub-catchments for subsequent modelling. These boundaries were then imported into WaterCAST and the appropriate river flow connections (links and nodes) were created (Figure 2).

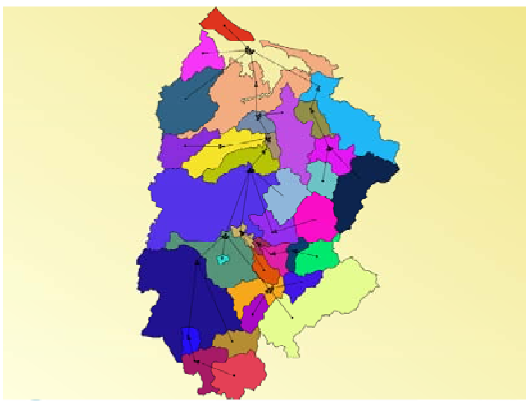

Figure 2: Link and node arrangements of the Duck WaterCAST model.

2.3. Rainfall runoff model calibration

The most important part of a WaterCAST model is the rainfall/runoff component. This requires catchment area, data river flows, rainfall and evaporation. The SILO data base allows access to grids of climate data interpolated using splining and krigging techniques from point observations (Jeffrey et al. 2001). These data grids were used for rainfall, evaporation or potential evapotranspiration (PET) components of WaterCAST.

The initial phase of rainfall runoff modelling is competed for the whole catchment using climate information from the centre of the catchment using the Rainfall Runoff Library (RRL) (Podger 2004). RRL contains five lumped conceptual rainfall runoff models and eight calibration optimisers. For the Duck catchment AWBM was the best fitting model with a Nash Sutcliffe Criterion (NS) of 0.90 and an R^2 of 0.90. The parameters from RRL were then used in WaterCAST. SILO data drills on an approximately 5km grid (Jeffrey et al. 2001) were then imported to take into account spatial variation in rainfall and evaporation. The rainfall runoff model was calibrated at the DPIW Scotchtown Road weir with a NS=0.88 and R^2=0.91 (Figure 3).

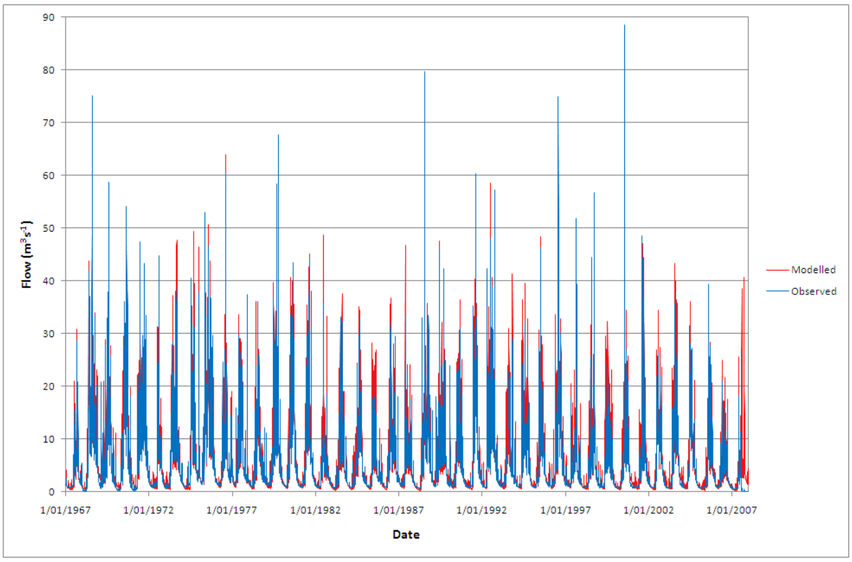

Figure 3: Modelled and observed flows for the AWBM rainfall/runoff model.

2.4. Nutrient model calibration

Nutrient generation rates for each land use was determined using the event mean concentration (EMC), dry weather concentration (DWC) approach (Chiew et al. 2002). Initial values for EMC and DWC for the Duck catchment were obtained from a previous E2 model developed in the neighbouring Montagu catchment (Holz and Weber 2007). These values were then adjusted to fit observed concentrations from samples taken throughout the catchment between 1999 and 2001 (Pinto et al. 2003). The adjustment process started in furthest upstream catchments with the fewest land uses. These EMC and DWC parameters were then checked the next sampling site, with the process ending at the subcatchment of the DPIW monitoring station at Scotchtown Road. The fit of the model was then tested using data collected from 2003 the Scotchtown Road station as part of the Baseline Water Quality Monitoring Program (BWQMP), obtained from the Water Information Systems database (WIST, www.water.dpiw.tas.gov.au). No attenuation was used as previous work indicated that using the attenuation capabilities of WaterCAST would result in excessively reduced phosphorus concentrations in this catchment (Holz and Weber 2007).

2.5. Soil testing

Extensive soil nutrient testing is been undertaken in the Duck catchment as part of the an NHT funded project by the Tasmanian Institute of Agricultural Research (TIAR), in conjunction with DairyTas, called ‘Adoption of nutrient budgeting for sustainable dairy farms and healthy rivers’. All suitable paddocks on each participating property were sampled. Suitable paddocks were generally larger than 1ha and did not have fertiliser applied within the 5-6 weeks prior sampling. Paddocks were sampled with a 7.5 cm corer. 30 cores were collected from each paddock, making up one composite sample, collected in a plastic sample bag and labelled accordingly. Cores were not collected from urine or dung patches, in gateways, on fence lines, areas of high traffic or in the bottom quarter of the hollows of ‘hump and hollow’ drains. Cores were taken in a representative fashion (transect) across each paddock, a straight line to diagonally opposite corners in rectangular paddocks for example. Samples were stored in eskies out of direct sunlight while out in the field. Samples were transferred to aluminium trays for drying in ovens at 40˚C for at least 48 hours before grinding and sieving to 2mm.

Preliminary paddock results were divided in regions (Figure 1) and analysed using a Kruskal-Wallis test (Proc NPAR1WAY) in SAS version 9.2 (SAS Institute, Cary, NC).

3. RESULTS

3.1. Land use percentages.

The land use assessment indicated that dairy pastures constitute approximately 19% of the total catchment area and 18% of the area upstream of the Scotchtown Road weir (Table 2). This land use assessment did not discriminate between beef production and runoff pastures for dairy heifers and silage production, which were both deemed to be "Grazing modified pastures". Therefore some extra area could be attributed to dairy production, albeit not as intensively managed as areas containing milking herds.

Table 2: Duck land use percentages

Land use	Whole catchment Area (ha)	Above Scotchtown Road Area (ha)
Grazing modified pastures	18662	10141
Grazing natural vegetation	976	220
Irrigated cropping	349	116
Dairy pastures	10530	6266
Manufacturing and industrial	85	
Marsh/wetland	406	
Mining	138	33
Nature conservation/minimal use	6562	4843
Plantation forestry	5019	4343
Production forestry	10673	8555
Reservoir/dam	175	
Residential	451	4
Services	184	
Transport and communication	75	10
Total	**54210**	**34533**

3.2. Total phosphorus concentrations

The verification of the Duck model using data from the BWQMP resulted in an NS=0.60 and an R^2=0.66 (Figure 4). However, regional parameterisation of EMC and DWC values indicated that the land uses "dairy pastures" and "grazing modified pastures" in the lower areas of the catchment had much greater TP losses than the mid catchment; and the mid catchment had much greater losses than the upper and eastern catchments (Table 3). Altering all other land use EMC and DWC parameters at the subcatchment level was not justified by the subcatchment data fitting process meaning the EMC and DWC values for these land uses were kept consistent throughout the catchment. The biggest change required to the EMC values was for a tributary, Geales Creek at Mella, just upstream of the Scotchtown Road weir. This subcatchment required an EMC of 5 mg/L to fit observed data.

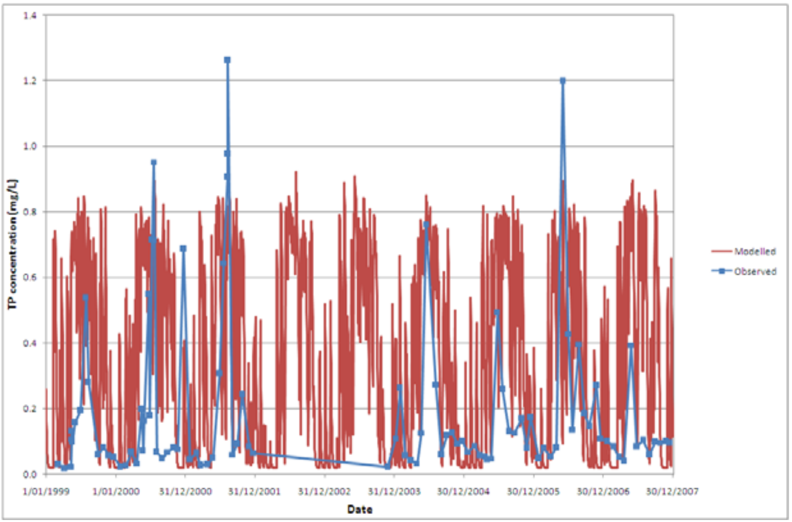

Figure 4: Modelled and observed total phosphorus concentrations.

Table 3: Event mean concentrations (EMC) and dry weather concentrations (DWC) for the Duck Catchment and regionally specific changes for the mid and lower regions (mg/L)

	Upper and East		Mid		Lower	
	DWC	EMC	DWC	EMC	DWC	EMC
Grazing modified pastures	0.012	0.12	0.05	0.9	0.06	0.09
Grazing natural vegetation	0.007	0.015				
Irrigated cropping	0.6	3.00				
Dairy pastures	0.02	0.18	0.08	1.5	0.08	5.00
Mining	0.11	0.28				
Nature conservation	0.005	0.01				
Plantation forestry	0.008	0.06				
Production forestry	0.008	0.05				
Residential	0.07	0.28				
Transport and communication	0.007	0.015				

3.3. Soil test results

Preliminary soil test results indicate the Olsen P levels on soils in the lower catchment were significantly higher than the mid catchment, which was in turn significantly higher than the upper and eastern catchment (Table 4).

Table 4: Soil test Olsen phosphorus results.

				Kruskal-Wallis test probability (*P*)		
Catchment Region	**Modelled Dairy TP EMC (mg/L)**	***n***	**Mean Olsen P ± SE (mg/kg)**	**Trowutta (Upper West)**	**Edith (Mid)**	**Mella (Lower)**
Nabageena (East)	0.2	191	29.48 ± 1.16	0.6016	<0.0001	<0.0001
Trowutta (Upper West)	0.2	174	27.91 ± 0.70		<0.0001	<0.0001
Edith (Mid)	1.5	108	37.75 ± 1.09			<0.0001

Mella (Lower)	5.0	133	53.58 ± 1.65			

4. DISCUSSION AND CONCLUSIONS

Work from Tasmania by Holz (2007) indicated that the contribution of dairy pastures to nutrient losses in northwest Tasmanian was significantly higher than previously published studies. The results from this WaterCAST modelling indicate that dairy pastures within regions of a catchment can have large variations in TP losses. These findings are backed up by the soil test results. These regional differences could be driven by a number of factors including percentage land use, distance to stream, percentage of intact riparian vegetation, the extent of hump and hollow drainage, soil characteristics including acid sulphate soils etc. While the WaterCAST model is a lumped conceptual model and cannot be used to interpret factors driving the differences detected, it can be used to prioritise further, more detailed investigations, designed to begin elucidating underlying mechanisms and potentially effective interventions. This is the focus of further work.

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