Hydrological Characterisation of wetlands: Understanding wetlands-catchment linkages

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INTRODUCTION

A wetland is broadly defined as "a land area that is permanently or seasonally saturated with water, and takes into account aquatic plants and the hydric soils" (Collins, 2005). The amount of water available within a wetland is defined by the hydrology of the catchment in which that wetland is located; yet there is still limited information about the general linkages that exist between wetlands and their catchments. The hydrological process and impact of wetlands on hydrological responses can be investigated using hydrological models. There has been attempts to integrate these processes within a wider catchment scale (e.g. in the ACRU and Pitman models), but approaches to the integration of these processes varies between models. This paper aims to assess the performance of two hydrological models routinely used in South Africa with the wetlands processes included.

MATERIALS AND METHODS

Study area

The GaMampa wetland is used as a case study. The wetland is located within the Mohlapetsi River catchment, which is 263 km2 (Figure 1). This permanently inundated, palustrine, valley bottom wetland lies almost at the outlet of the catchment and covers an area of approximately 1 km2.

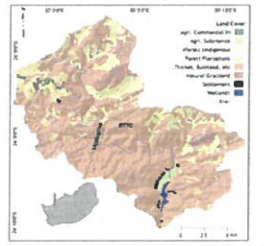

Figure . Land cover of the Mohlapetsi catchment (National Land Cover, 2000) (Inset shows the position of the catchment in South Africa).

Methods

The Pitman (Pitman, 1973; Hughes et al., 2006) and the Agricultural Catchment Research Unit (ACRU, Schulze, 1986; 1995;) models were used to simulate the hydrological impact of wetlands on streamflow. Climate data and parameters to run the Pitman model were obtained from the WR2005 database. The Pitman model was set up twice to simulate streamflow with and without (which has been the most common approach) the wetland module, while the ACRU model only simulated flows with the wetland module. Rainfall and temperature data for the ACRU model were obtained from the Quaternary Catchment Database developed by Schulze et al. (2007). Both models were verified using streamflow data at the outlet of the basin obtained from the Department of Water and Sanitation website (www. dwa.gov.za).

Results

Results were evaluated based on the guidelines for systematic quantification of accuracy in catchment modelling developed by Moriasi et al. (2007, Table 1). The same guidelines were extended to include the coefficient of determination (R2) and for all the statistics based on natural logarithm (ln)-transformed values.

Table 1: Recommended statistics for model performance (Moriasi et al., (2007))

Performance rating	NSE	PBIAS
Very good	0.75 <NSE<1	PBIAS <+/-10
Good	0.65 <NSE<0.75	+/-10 <PBIAS <+/-15
Satisfactory	0.50 <NSE<0.65	+/-15 <PBIAS <+/-25
Unsatisfactory	NSE<0.5	<PBIAS <+/-25

The Pitman Model

Pitman simulation of monthly streamflow without the wetland module was (Table 2) satisfactory in terms of trends (NSE) and very good in terms of average magnitude (PBIAS), with low flow well simulated and majority of high flows were either missed or under simulated (Figure 2)(Table 2) .

Table 2. Model performance statistics for both the ACRU and Pitman Model

Objective Function	Pitman (no wetland)	Pitman (With wetland)	ACRU
R^2	0.569	0.456	0.666
R^2(ln)	0.528	0.390	
NSE	0.566	0.449	0.634
NSE (ln)	0.500	0.356	
PBIAS	-3.004	-7.623	5.406

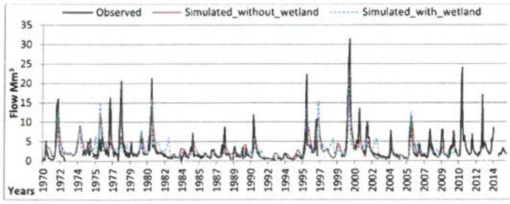

Figure . Observed and simulated results of the Pitman model before and after the inclusion of the wetland module.

Trends are noted within the observed data, with lower flows between 1982 and 1995 (drier period), and higher flows after 1995 (wetter period); which makes it difficult to reproduce the overall pattern of flows with a single non-dynamic set of parameters when the rainfall record of the catchment shows a consistent behaviour which does not help explains the changes in stream flow (Figure 3). The observation might be a result of land use changes.

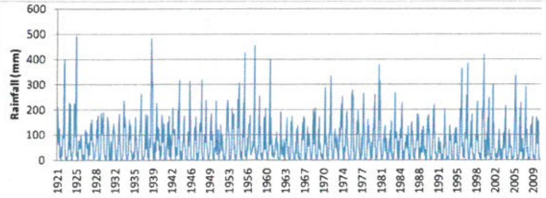

Figure 3 . Rainfall time series of the Mohlapetsi catchment.

Thus, separate flow records (1970-1995 and 1995-2010) yielded better results without additional calibration (Table 3).

Model statistics	1970 - 1995	1995 - 2010
R^2	0.461	0.670
R^2 (ln)	0.481	0.671
NSE	0.452	0.631
NSE (ln)	0.380	0.639
PBIAS	9.608	-18.277
PBIAS (ln)	60.679	-13.199

Simulation with the wetland was (Figure 2,) unsatisfactory in terms of trends (NSE) and very good in terms of average magnitude (PBIAS). The Pitman model operates at a monthly scale; hence it is very difficult to see the impact of the wetland on streamflow. Incorporating the wetland module resulted in an increase in the maximum interflow (ST), groundwater recharge (GW), size of the riparian area (RSF) and time delay function parameters (TL) and a decrease in the value of the evaporation efficiency (R) parameter (Table 4). These changes are expected – the presence of a wetland would lead to an increase in the time taken to move water to the catchment outlet (the delay function performed by a wetland).

Table 4. Parameters used to simulate stream flows with the Pitman model before and after inclusion of the wetland.

Pitman Parameter	No wetland	With wetland
ZMIN	998.000	998
ZAVE	999.000	999
ZMAX	1000.000	1000
ST	705.588	388.908
POW	2.662	2.615
FT	40.793	43.980
GW	2.483	7.483
R	0.340	0.122
TL	0.250	0.641
GPOW	3.909	3.909
RSF	0.200	0.554

The ACRU model

The daily time step ACRU model simulation was satisfactory in terms of in terms of trends (NSE) and Very good in terms of average magnitude (PBIAS) (Table 2). The model was able to reproduce both the overall water balance of the catchment and the timing of the flows. Simulated mean daily flow was comparable to that of the Pitman model. Most low flows were under-simulated by the ACRU model though. The model failed to simulate well all the late wet season or early dry season flows (Figure 4). At this time the wetland releases water rather slowly indicating its attenuation effect (gentler recession curve) and slightly elevated baseflow levels, whereas the model simulates a steeper recession curve that indicated in the observations.The GaMampa wetland and the Mohlapetsi River are sustained by base flow from groundwater from the surrounding catchment especially during the dry season. Thus, since the ACRU model does not have a well-defined ground water component; this may explain the poor simulation of the low flows in this catchment.

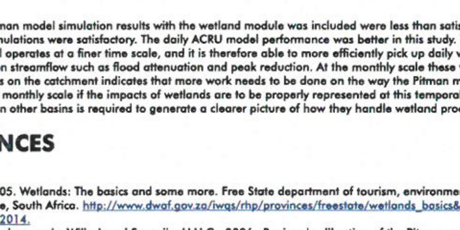

Figure 4. ACRU model simulation in the Mohlapetsi catchment with the wetland

KEY FINDINGS AND RECOMMENDATIONS

The monthly Pitman model simulation results with the wetland module was included were less than satisfactory, while the daily ACRU model simulations were satisfactory. The daily ACRU model performance was better in this study. This is possibly because the ACRU model operates at a finer time scale, and it is therefore able to more efficiently pick up daily variations and impacts of the wetland on streamflow such as flood attenuation and peak reduction. At the monthly scale these variations are masked. Modelling results on the catchment indicates that more work needs to be done on the way the Pitman models handles wetland processes at the monthly scale if the impacts of wetlands are to be properly represented at this temporal scale. Further testing of both models in other basins is required to generate a clearer picture of how they handle wetland processes in their routines.

REFERENCES

Collins, N.B., 2005. Wetlands: The basics and some more. Free State department of tourism, environmental and economic affairs, Free State, South Africa. http://www.dwaf.gov.za/iwqs/rhp/provinces/freestate/wetlands_basics&more accessed on the 14th of January 2014.

Hughes, D.A., Andersson, L., Wilk, J. and Savenije, H.H.G., 2006. Regional calibration of the Pitman model for the Okavango River. Journal of Hydrology 331, 30–42.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., and Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans. Asabe, 50(3), 885-900.

Pitman V., 1973. A mathematical model for generating Monthly River flows from meteorological data in South Africa. Report no 2/73, hydrological research unit, University of Witwatersrand.

Schulze, R.E., 1986. The ACRU model for agro-hydrological decision-making: structure, options and application. Proc. Second South African National Hydrology Symp. University of Natal, Pietermaritzburg, Deptment of Agricultural Engineering, ACRU report 21 345-362.

Schulze, R.E., 1995. Hydrology and Agrohydrology – A text to accompany the ACRU 3.00 Agrohydrological modelling system. Report to the Water Research Commission by the Department of Agricultural Engineering, University of Natal. WRC Report No. TT 69/95. Kwazulu Natal, South Africa.)

Schulze, R.E., Hallowes, L.A., Horan, M.J.C., Lumsden, T.G., Pike, A., Thornton-Dibb, S. and Warburton, M. 2007. South African Quaternary Catchments Database. In: Schulze, R.E. (Editor). 2007. South African Atlas of Climatology and Agrohydrology. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/06, Section 2.3.

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