20th International Congress on Modelling and Simulation, Adelaide, Australia, 1–6 December 2013
www.mssanz.org.au/modsim2013

Impact of time resolution on modeling performance in runoff volume and peak discharge estimation

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Abstract: Conceptual rainfall-runoff models have been experiencing many advancements in recent decades. These include improvements in model structure and wider calibration options. More complex model structure allows not only long-term modeling but also those at sub-hourly. Daily runoff volume, for instance, can be calculated at disaggregated timescales. Besides, the incorporation of sub-hourly timescales into continuous simulation models means that these models can now be used to estimate instantaneous flows. Nevertheless, the impact of time resolutions on modeling performance is not clear. Some past studies showed that the impact of timescales on model performance varied from almost no different to significant. While some studies showed higher time resolutions produced better results, the opposite has also been observed in few other studies. In relation to the calibration options, non-statistical measures have also been introduced in addition to the statistical ones.

Parafield Drain (PD) is a water harvesting and reuse scheme involved in the Waterproofing Northern Adelaide (WNA) Project. In order to develop a decision support system (DSS) for PD which includes real-time rainfall-runoff modeling, it is necessary to select the best modeling timescale in terms of model performance. The present study investigates how model performance at PD modeled by WaterCress was affected by modeling time resolutions. In particular, two modeling outputs, i.e. runoff volume and peak discharge, were subjected to the assessment. Daily runoff volume assessment was based on rainfall data at two timescales, 30-min and daily, while flood peaks were estimated at 30-min and 1-h. Parameters of the former were calibrated and validated against 20 months of historic streamflow data, while the latter compared against two historical flood peaks. In relation to the model performance assessment, WaterCress provides 4 performance measures of which three of them are statistical: coefficient of determination (R^2), Nash-Sutcliffe Efficiency (NSE) and Standard Error of Estimate (SEE); and another non-statistical measure: Percentage Volumetric Difference (VD).

In runoff modeling calibration stage, it was found that not every selected performance measures were improved. For example, VD was getting worse whenever the other measures were getting better and so forth. Assessing the model performance was therefore considered to be sufficient by considering multi-objective calibration, one from each statistical and non-statistical measures. Furthermore, a minimum of 9-month streamflow data was required to obtain calibration which was insensitive to the data length. Results also showed that higher time resolution produced slightly better prediction in runoff volume calculation and remarkably improved peak flow estimation.

Keywords: *WaterCress model, stormwater harvesting, rainfall-runoff, modeling time resolution, modeling performance.*

1. INTRODUCTION

Timescale is one factor which affect rainfall-runoff modeling performance. Their impact on modeling performance, however, is not clear (Finnerty et al., 1997). In runoff volume calculation, past studies showed that model predictions were improved by timescales to a varying degrees from insignificant (Moreda et al., 2006) to moderate (Wang et al., 2009) to considerable (Azinoor Azida Abu and Minjiao, 2011) to even significant (Finnerty et al., 1997). Inverse impact has also been noticed in some studies (Diskin and Simon, 1979; Hughes, 1993) in which finer temporal resolutions produced even worse results than that of the coarser ones. Predicting flood peak at different timescales were found to be almost no different (Booij, 2002; Nnadi et al., 1999; Pessoa et al., 1993), whereas Wang et al. (2009) revealed that finer temporal resolution produced better results. In addition, some smaller timescales did not necessarily give closer flood peaks as was found by Atencia et al. (2011). The advantages of modeling the components of hydrologic cycle at appropriate timescales will ease model development as well as help clarifying data requirement (Singh and Woolhiser, 2002).

Rainfall-runoff modeling at sub-daily timescales are usually conducted with hourly (or higher timescales) rainfall as the main input data. In case of such input unavailability, scaling/averaging techniques could be employed. The scaling/averaging techniques, however, should be selected carefully as different scaling techniques could lead to different results as was shown by Kandel et al. (2004). Hourly rainfall data in Azinoor Azida Abu and Minjiao (2011) was averaged in order to obtain the rainfall depth at other resolutions. Kandel et al. (2004) employed two rainfall scaling approach to disaggregate daily rainfall depths into sub-hourly ones. In regard to calculation, runoff volume and flood peak are generally predicted at various fixed timescales provided by the models. One exception is a study by Hughes (1993) in which the modeling timescales depend on the daily rainfall amount in the study catchments. If, for example, the rainfall amount exceeded 10 mm then the temporal resolution would be finer than 1-h. Hughes (1993) states that selecting the appropriate modeling timescales this way needed a more complex iteration. Researchers may also focus on a particular set of observed data such as climate change-induced extreme river discharges only (Booij, 2002). The study objective could also be different such as Hearman and Hinz (2007) in which they focused on point surface runoff whereas others aimed at catchment-scale output.

South Australia is well known as the driest State in the driest inhabited Continent. Waterproofing Northern Adelaide is an initiative to integrate stormwater, waste water, ground water and drinking water systems (Water Smart Australia, 2012) within three suburbs in Northern Adelaide regions: Salisbury, Tea Tree Gully and Playford (Richard Clark and Associates and University of South Australia, 2009). The project's benefits include reducing the pollutants inflowing the ocean as well as the suburbs' reliance on current overexploited water sources (Water Smart Australia, 2012).

The aim of the present study was to investigate the impact of temporal resolution on rainfall-runoff modeling at Parafield Water Harvesting and Reuse (WHR) Scheme. The modeling is focused on predicting daily runoff volume and comparing them at 30-min (30-m) and daily (1-d) resolution. In addition, flood peaks would be estimated and compared at 30-min and hourly (1-h) resolutions. The hydrological modeling of the study area was originally conducted by WaterCress (Water Community Resource Evaluation and Simulation) modeling tool by Richard Clark and Associates and University of South Australia (2009).

The next sections of this paper are organized as follows. The study catchment, WaterCress simulation model are described prior to the methodology section where rainfall-runoff models employed and the hydrology and climatology data are next described. The impact of time resolution on this study is presented in the Results section followed by concluding remarks in the last section.

2. STUDY AREA, DATA AND WATERCRESS MODEL

Parafield Drain Water Harvesting and Reuse (WHR) Scheme is located in the Local Government Area (LGA) of City of Salisbury (see Fig. 1). Total area of the catchment is approximately 1,602 ha; with land use dominated by residential area with some other rural, industrial, commercial zones and municipal open space systems (Myers and Pezzaniti, 2012).

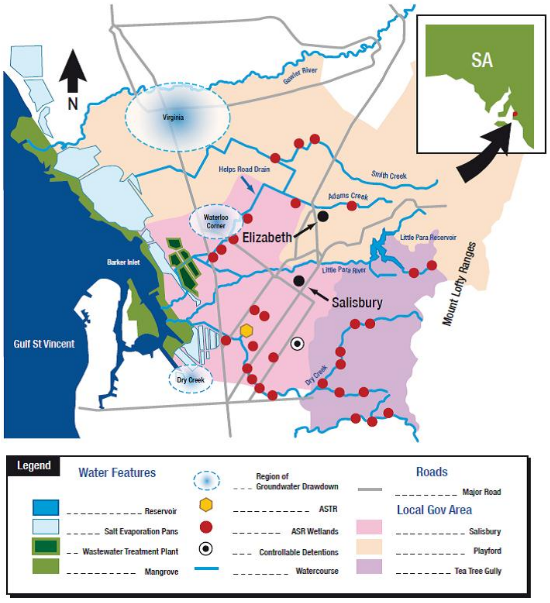

Figure 1. The study area (Water Smart Australia, 2012).

Thirty-minute rainfall data from two pluviometers located at Ridgehaven, Parafield Airport and Salisbury, daily flow data measured at Parafield Drain and evaporation data at Adelaide station were used for this study. Daily data from October 2003 to July 2004 and Aug 2004 to May 2005 were fed into WaterCress model for calibration and validation respectively. Sub-catchments rainfall reads its rainfall from the nearest rainfall gauge. The rainfall data measured at these gauges were multiplied by a factor (between 0 and 1) to represent the likely rainfall over the modelled sub-catchments. The higher the elevation of a sub-catchment, the greater the fraction will be. The annual isohyetal map produced by Australian Bureau of Meteorology showing the long term average rainfall at different sub-catchment locations and at the gauge locations was used to derive the rainfall fraction factors (Clark, 2012).

WaterCress is a model capable of routing water flows through natural and built water systems using continuous simulation approach (Clark and Cresswell, 2011). Sub-hourly to daily timescales are provided so that the model can be used for both runoff volume modelling and flood peak estimation. There are 18 icons to represent various features of the drainage systems including; (Sub)-catchments, dams, weirs, bores, treatment plants, aquifer, in-house demands, irrigation/industrial area and pumps etc. These icons can be linked using flow paths representing natural or man-made drainage channels. A set of icons (nodes) linked with flow path presented in a spatial layout is defined as a project. WaterCress model consists of 3 basic screens i.e. Opening Screen, Project Layout Screen and Output Results Screen. Nine (9) rainfall-runoff models, which were developed in Australia except the Sacramento model, are available in WaterCress Program. The primary data needed is hydrologic data time series while the secondary data include the size and rates of components of the assembled water systems. In order to evaluate the performance of individual nodes, about 90 outputs across 18 nodes are provided. Four measures are available namely Coefficient of Determination (R^2), Nash-Sutcliffe Efficiency (NSE), Standard Error of Estimate (SEE) and Volumetric Difference (VD) to assess the model performance.

3. METHODOLOGY

The modelling timescales can be chosen in the opening screen of WaterCress model. Timescales provided by WaterCress model include 6-min, 10-min, 30-min, hourly (1-h), 2-h and daily. In present work, runoff volumes were modelled in 30-min and daily time scales whereas flood peaks were modelled using 30-min and 1-h time scales. The layout of the Parafield Drain WHR Scheme which was developed by Richard Clark and Associates and University of South Australia (2009) was used in this study. Rainfall-runoff models, WC-1 was chosen to model runoff volume and the sub-daily version of WC-1 which is known as WC-sd model was used to estimate flood peaks. The details of these models can be found in the model's manual which can be downloaded from http://waterselect.com.au/. In order to achieve good model calibrations, a maximum of 4 parameters namely Median Soil Moisture (MSM), Catchment Distribution (CD), Interception Store (IS) and

Pan Soil Factor (PF) need to be adjusted. The WC-sd model has an extra parameter; ALI (Antecedent Loss Index) which is a function of a sub-daily time step.

Daily runoff volumes were modelled using both 30-min and daily rainfall resolution using daily WC-sd and sub-daily WC-1 model, respectively. The modelling performances were assessed using Nash-Sutcliffe Efficiency (NSE) and Volumetric Difference (VD, %). In peak discharge estimation, two flood events occurred on 9/12/2004 and 15/12/2005 were compared against the model predicted flood peaks by WC-sd at 30-m and 1-h time scales. Modelling performance was assessed using the percentage difference between the observed and the modelled peak flows.

4. RESULTS AND DISCUSSIONS

During the calibration, it was found that the three statistical performance measures behave inversely with the non-statistical one. Whenever the R^2, SEE and NSE were getting better, the VD was going worse and vice versa. It was decided then to assess the performance only on NSE and VD, with the minimum and maximum value of 0.70 and 10%, respectively. It was also found that 9 months is the minimum streamflow record required for a calibration which was not affected by the data length.

Figure 2a compares model performance measured in terms of Nash-Sutcliffe Efficiency (NSE) in predicting runoff volume at 30-min and daily time scales. The NSE during both calibration and validation at selected timescales were about 0.90. The modelling efficiency during validation is slightly better than that at the calibration stage.

Figure 2b indicates the effects on daily runoff volume using different time resolutions. Finer temporal resolution does not appear to improve the modelling performance in terms of VD because the difference was about 2%. The percentage Volumetric Difference (VD) in calibration and validation varied from 10% to 4%, respectively. It is also noteworthy that runoff volumes were consistently overestimated at two timescales used. The percentage difference of VD produced at the selected temporal resolutions during calibration stage was found to be 1.8%. Figure 2a and 2b conform with Diskin and Simon (1979) and Sudheer et al. (2007) that calibrating models at disaggregated time resolution (i.e. 30-m) guarantees good modelling performance. It should be noted, however, that the difference in runoff volume modelling performance at selected timescales in the present study was negligible.

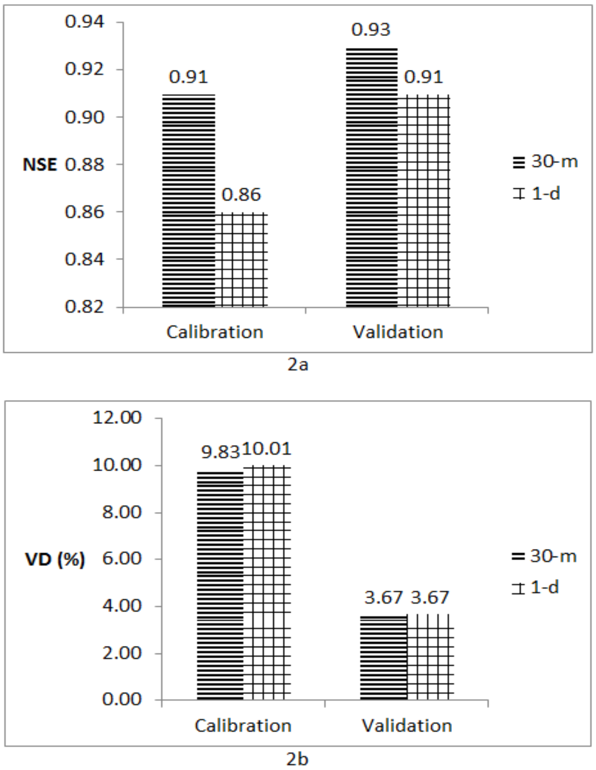

Figure 2. Model performance: (2a) NSE, (2b) VD.

Figure 3 demonstrates that flood peaks were consistently underestimated at the selected temporal resolution. The observed peaks were 6.42 m^3/s and 8.07 m^3/s occurred on 9/12/2004 (Event 1) and 15/12/2005 (Event 2), respectively. In contrast flood peaks were found to be more affected by timescales. Modelled flood peaks were underestimated by 26.58% and 8.57% at 1 hour and 30 minute time scales, respectively.

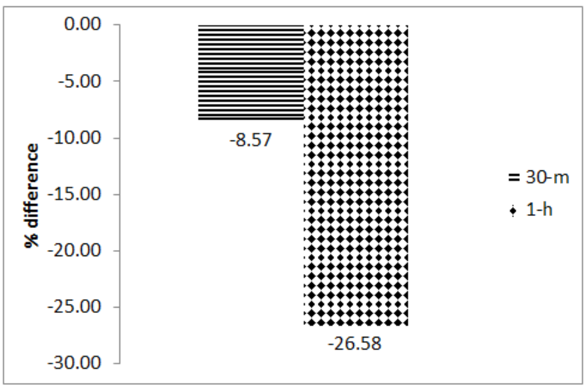

Figure 3. Average differences between observed and estimated peaks

The results presented in Figures 2 and 3 showed that daily runoff volume modelling and peak flow estimation at Parafield Drain WHR Scheme was affected by time resolutions to different degrees. Higher time resolution produced slightly better results in runoff volume and considerable improved flood peak estimations.

5. CONCLUSIONS AND RECOMMENDATION

The impact of modelling resolution on runoff volume modelling and flood peak estimation at Parafield Drain WHR Scheme was explored. Thirty-minute and daily rainfall data were used to predict runoff volume using WC-sd (sub-daily model) and WC-1 (daily model) rainfall-runoff models. In order to produce considerably good results, calibration were based on the minimum of 9-month streamflow data as well as multi-objective performance, one from each statistical and non-statistical measures. Runoff volumes were not significantly affected by temporal resolution in terms of NSE and VD when moving to coarser temporal resolution. Daily runoff volume could well be calculated using daily rainfall data and daily rainfall-runoff model. In contrast, timescales have a major impact on flood peak estimation as compared with runoff volume modelling. Hourly time resolution produced considerably worse results than that of 30-min resolution.

It should be mentioned that the conclusions and findings of this study were conditioned on the data and the watershed selected as well as the models employed. Further investigation is recommended to verify whether or not these conclusions hold for rainfall-runoff models capable of predicting outputs at the same timescales with that of inputs (e.g. SWMM). In order to obtain some more generalized trends between timescales and modelling performance for the study area, these results need to be compared with the timescales recommended in previous studies relating the required timescales with, for example, the catchment's area.

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