Performance evaluation of Tanh and AWBM rainfall-runoff models

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Abstract. The present study compares the performance of two rainfall-runoff models including Tanh model and AWBM model for streamflow simulation. The Tanh model is a 2-parameter empirical model, and the AWBM is a 9-parameter conceptual model. The Tullaroop Creek sub-catchment at central Victoria is selected as the study area. Rainfall and streamflow data measured from the catchment are the major inputs to these models. The Tanh function is used as a simple rainfall-runoff relationship for the Tullaroop Creek catchment and it estimates annual runoff by using curve fitting of the rainfall runoff plot. The AWBM model is calibrated and validated for two periods: 1974-1987 and 1987-2000, respectively. The Nash–Sutcliffe Efficiency is computed to evaluate the efficacy of model predictions. From the results obtained, it is found that the AWBM model can provide adequate estimates of annual runoff at the study catchments than Tanh model.

1. Introduction
The rainfall-runoff modelling is a crucial part for water resource management to control and monitor the water resource [1]. There are many hydrological models to predict the relationship between rainfall and runoff. The hydrological models can be classified into three broad groups, namely empirical, conceptual and physical models [2]. Empirical models are non-linear relationship for rainfall and runoff and they are observation-based models without emphasizing on hydrological process [3]. Conceptual models use the simplified mathematics equations to interrupt hydrological process by consisting water storages with physical elements in the catchment [4]. Physical models apply physical laws and equations in representing hydrological process [2], which can incorporate the variability of spatial and temporal.

Among these rainfall–runoff models, Tanh and AWBM models are chosen for this study. The tanh model is one empirical model and it is widely applied since its simplicity and flexibility. The tanh equation has been used to estimate annual runoff [5], infill missing annual streamflow records [6], the impact of land-use change [7] and assess the effect of the climate change [8]. The AWBM model is one conceptual model and it is commonly used in Australia for water resource management [9]. In the past 30 years, it was widely applied to estimate ungauged catchment runoff [10-12].

This paper describes the comparison of two rainfall-runoff modelling approaches. The models are applied to the Tullaroop Creek in Victoria, Australia. The annual streamflow volumes estimated by the two models are compared with the observed streamflow data to evaluate the accuracy of the two modelling approaches.
2. Materials and methods

2.1. Study area and data
Tullaroop Creek at central Victoria (Figure 1) is the major sub-catchment of the Loddon River Basin with a total catchment area of 743 km². The Tullaroop Creek has a length of 61.8 km, which provides the water for irrigation as well as the city use. The Tullaroop Creek flows through Tullaroop Reservoir and Laanecoorie Reservoir on its way to joining the Loddon River. There is a fairly even distribution of rainfall throughout the year, with almost a third falling in the winter months. Approximately fifty percent of the catchment receives annual average rainfall less than 680 mm.

![Location map for Tullaroop Creek.](image)

Table 1. Rainfall and streamflow datasets.

| Data types               | Periods          |
|-------------------------|------------------|
| Monthly Rainfall (mm)   | 1970-2016        |
| Monthly Streamflow (ML) | 1974-2016        |
| Daily Rainfall (mm)     | 1970-2016        |
| Daily ET (mm)           | 1970-2016        |
| Daily Streamflow (ML/day)| 1974-2000       |

For the Tanh model, the annual rainfall and streamflow values for the selected catchment are needed for scatter plot to determine the fitted equation. For the AWBM model, the daily rainfall, evaporation and streamflow data are input to set up and calibrate.
2.2. Model Description

2.2.1 Tanh model

The Tanh model provides an effective site-based relationship that is primarily used for infilling monthly or annual runoff values based on measured rainfall. The Tanh equation introduced by Boughton (1968) as a simple rainfall-runoff relationship has the form [5].

\[
\text{Runoff} = \text{Rain} - \alpha - \beta \tanh\left(\frac{(\text{Rain} - \alpha)}{\beta}\right)
\]

\[
\alpha = 300 - 60 \times \text{RC}; \quad \beta = 1950 - 200 \times \text{RC} - \alpha
\]

in which Runoff and Rain are predicted runoff and observed rainfall, respectively; \(\alpha\) and \(\beta\) are the estimated parameters. The parameter \(\alpha\) represents the minimum rainfall value below which runoff would not occur, and \(\beta\) is a rate factor controlling additional rainfall losses through the hyperbolic tanh function (\(\beta=0\), no additional losses and \(\beta=\infty\), total loss). Different rainfall-runoff relationships are obtained by varying a runoff characteristic [6], which may range from about 1 to 8, but is typically between 3 and 6.

To achieve the optimal RC value, the objective function Nash Sutcliffe Coefficient of Efficiency (NSE, \(E\)) is used as the criterion.

\[
E = 1 - \frac{\sum (\text{Obs} - \text{Est})^2}{\sum (\text{Obs} - \text{Obs})^2}
\]

in which \(\text{Obs}\) is observed data, \(\text{Est}\) is estimated data, and \(\text{Obs}\) is the mean observed data. \(E\) is 1 for “perfect model”, but it can be negative for a very poor model.

2.2.2 AWBM model

The Australia Water Balance Model (AWBM) is a lumped model based on water balance [5]. It is available from the eWater CRC Toolkit website and is one basic rainfall-runoff model in Rainfall-Runoff Library (RRL). To determine the relationship between rainfall and runoff, AWBM considers the catchment water balance and the foundation is the ‘bucket’ concept [5]. There are nine parameters in the model structure (Figure 2) [13].

![Figure 2. AWBM model structure [12].](image)

The AWBM model divides the whole catchment into three water stores with the different partial areas A1, A2 and A3 and respectively store depths C1, C2 and C3 [14]. The partial areas A1, A2 and
A3 are represented the proportions of the total catchment area and the sum is one [15]. The runoff is composed by baseflow and surface runoff. The baseflow index (BFI) is the ratio of baseflow to the runoff. The discharge of baseflow and surface runoff are determined by the Base flow recession coefficient ($K_b$) and Surface flow recession coefficient ($K_s$) separately [16].

In this model, there are six parameters ($A_1$, $A_2$, $A_3$, $C_1$, $C_2$ and $C_3$) to determine the moisture capacity, two parameters (BFI and $K_b$) are related to the generation of baseflow and only one parameter $K_s$ to estimate the routed surface runoff [17].

3. Results & Discussion

3.1 Rainfall-runoff modelling results

3.1.1 Tanh model

Plot a scatter plot of annual rainfall versus runoff for the Tullaroop Creek catchment between 1974 and 2000 (Figure 3). The runoff is calculated by dividing the streamflow by the catchment area. Through the Nash-Sutcliffe criterion, the optimal RC values can be obtained. The maximum E value is occurred when RC is equal to 4.08. Once the RC value has been determined, the equation of a line-of-best-fit for the rainfall-runoff relationship can be calculated

$$\text{Runoff} = \text{Rain} - 54.93 - 1078.17 \times \tanh \left( \frac{(\text{Rain} - 54.93)}{1078.17} \right)$$

Figure 3. the fitted line for annual rainfall-runoff relationship.

The Tanh relationship for Tullaroop Creek catchment is shown in Figure 3, and shows both simulated and observed data. The annual streamflow between 2001 and 2016 are estimated by substituting the data into the Eq.3 and the mean annual streamflow for the period is 36521.23 ML.

3.1.2 AWBM model

The AWBM has been set up in RRL toolkit. The rainfall, streamflow and evaporation ET data are used for AWBM. The model calibration and validation of the model have been carried out for the periods of 1974 to 1987 and 1987 to 2000, respectively. The optimal parameters of the AWBM were obtained by auto-calibration with genetic algorithm. The calibrated values of different parameters of AWBM in RRL are presented in Table 2. The Nash-Sutcliffe efficiency values for calibration and validation are 0.918 and 0.802, respectively.

| Parameter                     | Optimized value | Range     |
|-------------------------------|-----------------|-----------|
| Partial area of first storage ($A_1$) | 0.144           | 0.000-1.000 |
| Partial area of second storage ($A_2$) | 0.513           | 0.000-1.000 |
| Partial area of third storage ($A_3$) | 0.343           | 0.000-1.000 |
Base flow index (BFI) 0.550 0.000-1.000
Storage capacity of first store ($C_1$) 30 0-50
Storage capacity of second store ($C_2$) 164.6 0-200
Storage capacity of third store ($C_3$) 356.7 0-500
Base flow recession coefficient ($K_b$) 0.959 0.000-1.000
Surface flow recession coefficient ($K_s$) 0.380 0.000-1.000

The comparison of observed and simulated runoff (2001-2016) has been presented in Figure 4. The model outputs can match observed data quite well.

3.2 Comparison of modelling results
Graphical plots and the goodness-of-fits for two models were re-presented after simulations. Figure 4 shows the plots of the observed and modelled runoff. They indicate good matches between the simulations and observations.

To determine the accuracy of two different models, summary statistics can be applied for further analysis [18]. The model error can be defined as the difference between the observed data and predicted data, which to measure the model performance and compare the model simulation.

The mean error is most common statistics since it is easy to calculate and can describe the central tendency. The maximum and minimum error are used to check the accuracy of the extreme event. Standard deviation and skewness can explain the probability distribution of runoff.

|                             | Tanh model error (%) | AWBM model error (%) |
|-----------------------------|----------------------|----------------------|
| Mean                        | 34.29                | -3.69                |
| Maximum                     | 10.11                | 7.58                 |
| Minimum                     | 318.54               | 59.24                |
| Standard deviation          | -0.202               | -0.144               |
| Skewness                    | 0.195                | 0.421                |

Compared with the Tanh model, the fluctuation of the AWBM graph is more consistent with the measured flow. The percent errors of the AWBM model are all less than the Tanh model especially for average value and minimum value.
4. Conclusions
Two rainfall runoff modelling approaches, the Tanh model and the AWBM model are compared in this study, with the models for estimating annual streamflow in Tullaroop Creek catchment. The Tanh Model and the AWBM model can provide adequate estimates of annual streamflow. The Tanh model is easy to use and requires little expertise in hydrology. However, with data comparison they are all not perfect but the AWBM is a better model compared with Tanh model. It is noticed that AWBM captures observed high and low flows better than Tanh model.

Acknowledgements
The author is thankful to civil department of Monash, Dr. Anna Lintern for guiding and providing necessary data for this study.

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