A Comparative Study of Different Hydrological Model and Their Application in Bass River Catchment

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Abstract. In this paper, the rainfall-runoff process was simulated by three hydrological models of SMAR, Sacramento and Tank based on Bass river catchment in the State of Victoria, Australia. The results of the three models are compared by Nash-Sutcliffe coefficient and RE (relative error coefficient of total runoff), which showed that the Nash-Sutcliffe coefficients of the three models are all above 80\%, however, considering the RE, only the Sacramento model is kept within 10\%, which meets the requirements during the both calibration and verification periods. Therefore, it can be found that the Sacramento model is the most ideal hydrological model for the chosen catchment. The results can be used in hydrological forecasting, soil and water management, environmental planning and etc.

1. Introduction

The catchment hydrological model uses the catchment as a simulation object to simulate the hydrological cycle processes such as a series of rainfall and runoffs occurring in the catchment. The catchment is generalized into a system, and the hydrological phenomena (generally rainfall, snowmelt, and sediment transport and evapotranspiration capacity of the catchment) are calculated and the model output results are obtained (such as the section flow of the catchment and the actual runoff of the catchment, actual evapotranspiration, etc.). So as to further analyze and study the catchment water resources and achieve the requirements for rational evaluation, allocation, development and utilization of water resources. In addition, hydrological model support is needed in many aspects such as flood control and disaster mitigation, reservoir scheduling, ecological environment water demand, water resources development and utilization, roads, urban planning, non-point source pollution assessment, and human activities[1].

The catchment hydrological model was born in the rapid development of computer technology and the increasingly perfect development of system theory. After the vigorous development at the end of the 20th century and with the increasingly prominent water resources problems, a large number of catchment hydrological models emerged. At present, the hydrological model of the catchment is mainly divided into the following two categories: the catchment hydrological simulation model and the catchment water resources management model. The catchment hydrological simulation model is divided into a lumped type and a distributed model. With the increase of catchment variables, the prediction reliability of lumped model decreases and some potential but important environmental problems will often be neglected, such as Xin'anjiang(China) model, WARP, SMAR, Tank model, and the US Sacramento model. Etc. The distributed model can not only give the results of the hydrological process, but also reflect its dynamic change process, so as to clearly understand and improve hydrological predictions, such as SWAT, TOPMODEL, STREAM, SWIM, etc. In the discussion of
this paper, the author uses the SMAR, Tank and Sacramento model as an example to analyze the application of the Bass River catchment in Victoria, Australia.

2. Study Area
The Bass River, a perennial river of the Western Port catchment, is located in the West Gippsland region of the Australian state of Victoria. The basin area of Bass River is 52 square kilometres, rises below the locale of Woodleigh, with its headwaters drawn from the Strzelecki Ranges, north of the town of Korumburra. The river flows generally south by west, joined by one minor tributary, before reaching its river mouth and emptying into the Western Port, west of the town of Bass within the Bass Coast Shire.

The river is 59 kilometres long and falls 60 meters on the river. The average annual rainfall is 1108 mm and the average annual evaporation is 889 mm. Figure 1 shows the Bass River catchment and water system.

![Figure 1. Bass River Catchment and Water System](image)

3. Model Introduction

3.1. SMAR Model
As a lumped conceptual hydrological model, infiltration and soil water evaporation are important parts of runoff yield calculation. The original intention of the model is that the confluence process can be simulated by linear structure, while the water balance stage, such as the runoff formation stage, is non-linear. The non-linear problem can be solved by using the runoff generation part of the SAMR model, so as to achieve the purpose of accurately simulating the runoff process. The model has fewer parameters, simple structure and concept, and is easy to be applied. The two water sources are divided into underground runoff and surface runoff[2].

It is possible to obtain good simulation results in watersheds with relatively flat watersheds, not very abundant underground runoff, good vegetation condition and less humid climate. The surface runoff of catchment is Nash unit, and the underground runoff is delayed linear reservoir[3].

3.2. Tank Model
The model was first proposed by Japan and is a rainfall runoff model for calculating the runoff process through rainfall process, which is widely used. The tank model assumes that the outflow and infiltration in the catchment a function of the corresponding reservoir depth in the catchment. From this point of view, a catchment is regarded as a water tank, and various links (flow generation, slope convergence, river convergence, etc.) in the process of rain-flood transformation in the catchment are
simulated by several interconnected water tanks[4]. The tank model considers that the outflow of each tank represents a runoff: surface runoff, soil middle stream, shallow underground runoff and deep underground runoff, and the water storage depth in the water tank are controlled to calculate the runoff and convergence of the catchment and Infiltration process[5].

3.3. Sacramento Model
The model is a deterministic, conceptual lumped parameter model that is improved and developed by the California forecasting center based on the fourth Stanford model[6]. The Sacramento model is mainly composed of six parts: rainfall, snowmelt, evapotranspiration, infiltration, total inflow of river network and its confluence. Based on the characteristics of soil water storage, infiltration, drainage and evapotranspiration, it is a comprehensive model of river runoff catchment to simulate water temperature cycle. The soil water content calculation model is the central component of the system. The model is relatively well-functioning and can be applied to large and medium river catchment, as well as to humid and arid areas[7].

4. Results and Discussion
4.1. Hydrological Model Simulation
In this paper, daily rainfall, evapotranspiration and runoff data of Bass river Catchment in Victoria, Australia from 1974 to 1983, were used in the simulation. This 10 years’ data can basically meet the calibration and verification needs of hydrological model. Data were sourced from the Francis Chiew / Tom McMahon set.

Nash-Sutcliffe efficiency coefficient $R^2$ and relative error coefficient of total runoff $RE$ are often used to evaluate the efficiency and accuracy of catchment hydrological models. In this study, these two indicators are chosen to evaluate the model performance[8].

1974-1980 was chosen as the model calibration period, and the rest of year 1981-1983 as the model verification period, a three months period was regarded as the warm-up period of the models. The results are shown in Figure 2, and Table 1.
Runoff simulation is one of the main functions of hydrological simulation. As it can be seen, the overall simulation of the three models in the catchment is pretty with the Nash-Sutcliffe coefficients are all above 85%.

As far as Nash-Sutcliffe coefficient is concerned, the Nash-Sutcliffe coefficients of SMAR, Sacramento and Tank models, during calibration period, are 92.30%, 92.30% and 94.89% respectively, and during verification period, are 89.84%, 89.79% and 88.83% respectively. It can be seen that the results of Sacramento model are the best, followed by SMAR model, and Tank model is slightly worse. But in general, if Nash-Sutcliffe coefficient is more than 60%, then it can be applied to practical work, which means the three results all meet the accuracy requirements.

Considering RE, the Sacramento model has the best results, with the number for calibration and verification period are 4.76% and 3.65% respectively, followed by SMAR model. However, Tank
model has the worst results, which are all over the 10%, beyond the acceptable range. So it is known that the Tank model is not suitable for Bass River.

In summary, Sacramento model is relatively satisfactory both in terms of its application results in the catchment and its structure itself, so it is selected as the optimal model applied to the Bass River Catchment.

4.2. Conclusion
In general, the catchment hydrological model meets the eligibility criteria: Nash-Sutcliffe efficiency coefficient exceeds 60%, and the relative error is less than 10%. That is, in the data analysis, we think that the closer the efficiency coefficient of Nash-Sutcliffe is to 1, the closer the relative error is to 0, which is the optimal value. Although the Nash-Sutcliffe efficiency coefficient of the Tank model satisfies the requirements, its relative error does not meet the requirements, indicating that the model is not suitable for the catchment; the Nash-Sutcliffe efficiency coefficient of the SMAR model satisfies the requirements, but the relative error of its inspection period does not reach the standard, so it is considered that this model is not very suitable for this catchment; the Sacramento model Nash-Sutcliffe efficiency coefficient and relative error are all qualified, and overall, the Sacramento model is also optimized. From the perspective of model structure, the Sacramento model has relatively complete functions, can be applied to large and medium catchment, as well as to humid and arid areas.

Therefore, from the application analysis of the three models selected in the Bass catchment, the Sacramento model is most suitable for the hydrological simulation of the catchment.

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6. References
[1] Changgao He, Zengchuan Dong and Weibin Chen. Summary of research on watershed hydrological model[J]. Jiangxi Water Resources Science & Technology, 2008, 3(1):20-24.
[2] Lihua Xiong, Xiaojing Wei and Min Wan. The comparison of two uncertainty research methods in hydrological model[J]. Journal of Wuhan University, 2009, 42(2):137-142.
[3] Guangsheng Wang, Shichun Xia. SMAR model and its improvement [J]. Hydrology, 1998, 18 (S1):28-30.
[4] Youlin Li. The basic principle and application of Tank model[J].Gansu Water Resources and Hydropower Technology, 2000, 36(4):229-232.
[5] Zhiyong Luo, Bingliang Yang and Xiaoxiang Guan etc. Simulation and adaptability of different hydrological models in Jinxin watershed[J]. Journal of North China University of Water Resources and Hydropower(Natural science edition), 2018, 39(3):6-12.
[6] Xue Leng, Zhicheng Guan. The improved application of Sacramento model[J]. Jilin Water Conservancy, 2003(5):37-39.
[7] K.Katsanou, N.Lambrakis. Modelling the Hellenic karst catchments with the Sacramento Soil Moisture Accounting model[J]. Hydrogeology Journal, 2017, 25(3):757-769.
[8] Weihua Zhang, Yu Li, Chaofu Wei and Junying Jin. A comparative study of hydrological model and their application in Broken catchment[J]. Journal of Southwest China Normal University, 2011, 32(4):211-216.