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HYDROLOGICAL MODELS FOR CIDANAU WATERSHED

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Abstract

Hydrological models are necessary in assessing water resources and valuable tool for water resources management. This paper describes applications of Tank model, storage function model and artificial neural networks (ANN) for Cidanau watershed in Indonesia. The Tank model consists of a series of 4 tanks and 5 outflows with 12 independent parameters. Storage function model has 3 parameters. Genetic algorithm (GA) was used for finding the optimum parameters of the tank model and the storage function model. Back-propagation was used in the learning rule of ANN. A series of daily rainfall, evapotranspiration and discharge data for 6 years (1996-2001) from Cidanau watershed was used. The accuracy is evaluated by statistical performance index, the shape of hydrographs and the flood peaks. The results show that tank model, storage function model and ANN are successful in predicting watershed discharge in Cidanau watershed. Comparison of the accuracy of ANN, Tank model and storage function model show that ANN is better than the other models. These hydrological models have been developed in form of application program under Windows and applicable to use in other watershed.

Keywords   hydrological models, Cidanau watershed, application program

INTRODUCTION

Hydrological models have become an essential tool for water resources planning, development and management. They are for example use to analyze the quantity and quality of stream flow, reservoir system operations, groundwater development and protection, surface water and groundwater conjunctive use management, water distribution system, water use, and a range of water resources management activities (Wurbs 1998). Hydrological models are employed to understand dynamic interaction between climate and land-surface hydrology. An assessment of the impact of climate change on national water resource and agricultural productivity is made possible by the use of hydrological models.

There are several well known general hydrological models in current use in the world. These models vary significantly in the model construct of each individual component process, partly because these models serve somewhat different purposes. HEC-HMS is considered the standard model in the private sector in the United States for the design of drainage system, quantifying the effect of land-use change on flooding, etc. The WATFLOOD model is popular in Canada for hydrologic simulation. TOPMODEL is standard model for hydrologic analysis in many European countries. The Tank models are well accepted in Japan. The Xinanjiang model is commonly used model in China (Singh and Woolhiser, 2002).

The objective this work is to develop program application of hydrological models for Cidanau watershed in Banten, Indonesia and comparison of hydrological models performance. Three hydrological models is tried to develop. They are tank model, storage function model and artificial neural network. They are known as a lumped

models. One of the advantages of such a lumped model is that unlike distributed models it demands only daily rainfall, evapotranspiration and discharge data.

MATERIAL AND METHOD

Study Area and Data Availability

The models are developed for Cidanau watershed in Banten Indonesia (Figure 1). The Cidanau watershed is located at 5°21'-6o21' South and 105°7'-106°22' East and covering the area of 221.1 km². Serial average daily rainfall, evapotranspiration and discharge was used in model calibration in 1996 until 1998 and in model verification in 1999 until 2001.
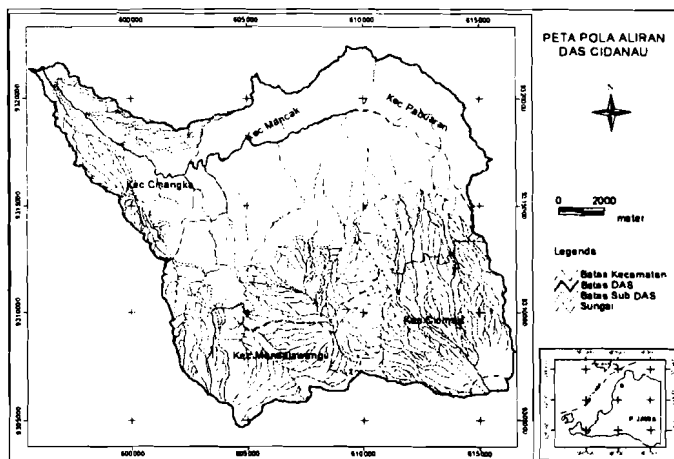

Figure 1. Cidanau watershed

Tank Model Structure

The Tank model comprises of many of simple tanks with outlets arranged vertically one above other. The structure suggested by Sugawara (1974) for the case of humid regions comprises of four tanks in vertical series (Figure 2). This model structure is known as a standard tank model.

Rainfall, the input to hydrologic system, is transformed as output as the stream discharge. The net stream discharge is the sum of the discharge from the outlets of the tank, which are obtained deducting evapotranspiration from rainfall. The intensity rainfall governs the behavior of the model. As such, the water percolating down through the bottom outlets (representing infiltration) and side outlets (runoff in case of first tank, interflow in case of the second tank and base flow in case third and fourth tanks) is derived in a way by parameter of model (Tingsanchali, 2001).

The parameters of tank the Tank model can be classified into three types
1) Runoff coefficient of each tank (A, B, C and D) called as A1, A2, B1, C1 and D1.
2) Infiltration coefficient of each tank called as A0, B0 and C0.
3) Storage parameters – as height of the side outlets of each tank which include HA1, HA2, HB1 and HC1.

Parameters of the tank model are as follows and are shown in figure 2 can also divided according to the tank like
TANK A : A0, A1, A2, HA1 and HA2
TANK B : B0, B1 and HB1
TANK C : C0, C1 and HC1
TANK D : D1
The variables as runoff amount from the side outlets (Ya1, Ya2, Yb1, Yc1 and Yd1, respectively) and infiltration amount from bottom outlets (Ya0, Yb0 and Yc0, respectively) are expressed based on the values of parameters mentioned above. The parameters of storage in each tank govern the process as infiltration or runoff depending on the outlet position and the storage depth.

The overall water balance should conform to the following equation:

$$\frac{dH}{dt} = P(t) - ET(t) - Y(t)$$

(1)

where, H is the total storage (mm), P is rainfall (mm/day), ET is evapo-transpiration (mm/day), Y is total outflow (mm/day) and t is time (day). The total out flow must comprise the outflow from each tank, and it can be expressed follows:

$$Y(t) = Ya(t) + Yb(t) + Yc(t) + Yd(t) \qquad (2)$$

Whilst, the water balance equation in individual tank can be written in the following equations:

TANK A

$$\frac{dHa}{dt} = P(t) - ET(t) - Ya(t) \qquad (3)$$

TANK B

$$\frac{dHb}{dt} = Ya0(t) - Yb(t) \qquad (4)$$

TANK C

$$\frac{dHc}{dt} = Yb0(t) - Yc(t) \qquad (5)$$

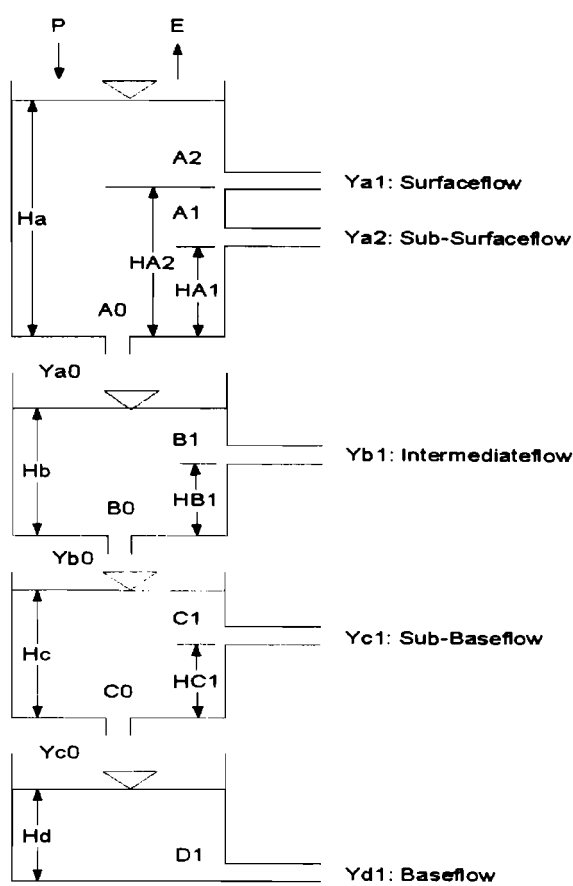TANK D

$$\frac{dHd}{dt} = Yc0(t) - Yd(t) \qquad (6)$$

Figure 2. Schematic Standard Tank model

Storage Function Model
SF model is a simple model for flood runoff. SF model was developed by Kimura (1961) and used successfully since 1961 in all parts of Japan and East Asia. Model input is hydrograph of rainfall and output is hydrograph of discharge.

Runoff is simply expressed by the following storage function:
$$S = KQ^p$$

(7)

$$\frac{dS}{dt} = fP(t) - Q(t)$$

(8)

Where, S is storage of rainfall (mm), q is rate of discharge (mm/day), r is rainfall (mm/day). Parameters K, p and f can be estimated from the observed data.

ANN Model Structure

ANN was used for hydrologic modeling in the 1990s. Because ANN have ability to recursively learn from data and can result in significant savings in time required for model development, they are particularly suited for modeling nonlinear system where traditional parameter estimation techniques are not convenient.
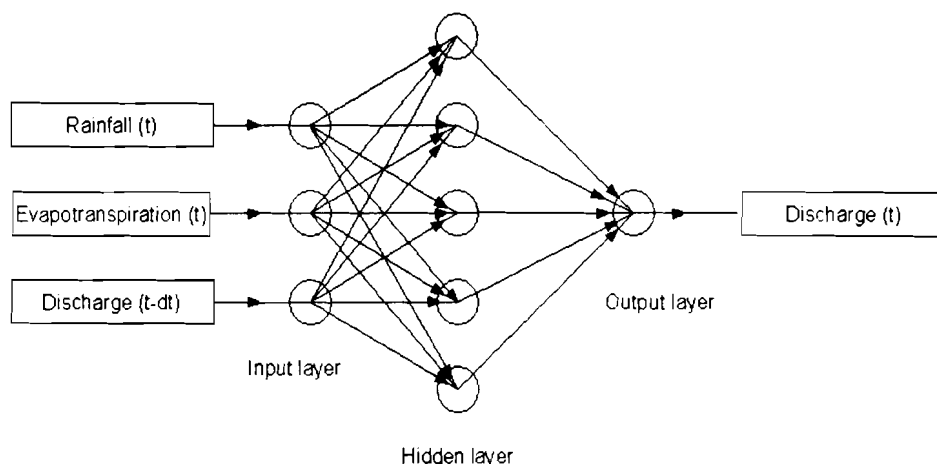

Figure 3. Network ANN model

Time delay ANN is used within 3 node in input layer, 5 node in hidden layer and 1 node in output layer. The ANN inputs are rainfall in t time, evapotranspiration in t time and discharge in t-dt time. The ANN output is discharge in t time (Figure 3).

ANN model can be described as follows:

$$H_j = \sum_i v_{ji} x_i \tag{9}$$

$$y_j = f(H_j) \tag{10}$$

$$I_k = \sum_j w_{kj} y_j \tag{11}$$

$$z_k = f(I_k) \tag{12}$$

where x is input, v is weight from input node to hidden node, w is weight from hidden node to output node, and f is sigmoid function, which is formulated as follows:

$$f(x) = \frac{1}{1 + e^{-\beta x}} \tag{13}$$

where β is gain or sigmoid function slope.

Model Calibration

Optimization methods have been developed for parameters model estimation. Tank model and SF model use genetic algorithm for finding the optimum of their parameter. Least square criterion was become the objective function. ANN model uses back-propagation for finding their weight. This method was known as power full method, but this method is need long time to get best weight. Serial average daily rainfall, evapotranspiration and discharge was used in model calibration in 1996 until 1998.

Model Performance

Sixteen common statistics for evaluation of models performance were used R (Coefficient correlation), R^2 (Nash-Sutcliffe Coefficient), CD (*Coefficient of Determination*), RMSE (*Root Square Mean Error*), MAE (*Mean Absolute Error*), LOG (*Log Root Square Mean Error*), Standard x, Squared Standard x, MRE (*Mean Relative Error*), RR (*Root Square Relative Error*), NRMSE (*Normalized Root Mean Square Error*), NME (*Normalized Mean Error*), EI (*Model Efficiency*), APD (*Average Percentage Deviation*), ARE (*Area Relative Error*) and ARI (*Annual Run of Index*).

1. $$R^2 = \frac{\left(\sum\limits_{i=1}^{N}\left(Qc_i - \frac{1}{N}\sum\limits_{i=1}^{N}Qc_i\right)\left(Qo_i - \frac{1}{N}\sum\limits_{i=1}^{N}Qo_i\right)\right)^2}{\sum\limits_{i=1}^{N}\left(Qc_i - \frac{1}{N}\sum\limits_{i=1}^{N}Qo_i\right)^2 \sum\limits_{i=1}^{N}\left(Qo_i - \frac{1}{N}\sum\limits_{i=1}^{N}Qo_i\right)^2}$$ (14)

2. $$R = \sqrt{R^2}$$ (15)

3. $$RMSE = \sqrt{\frac{1}{N}\sum\limits_{i=1}^{N}\left(Qc_i - Qo_i\right)^2}$$ (16)

4. $$MAE = \frac{1}{N}\sum\limits_{i=1}^{N}\left|Qc_i - Qo_i\right|$$ (17)

5. $$LOG = \sqrt{\frac{1}{N}\sum\limits_{i=1}^{N}\left(\log Qc_i - \log Qo_i\right)^2}$$ (18)

6. $$\chi = \frac{1}{N}\sum\limits_{i=1}^{N}\frac{\left|Qc_i - Qo_i\right|}{\sqrt{Qo_i}}$$ (19)

7. $$\chi^2 = \frac{1}{N}\sum\limits_{i=1}^{N}\frac{\left|Qc_i - Qo_i\right|^2}{Qo_i}$$ (20)

8. $$MRE = \frac{1}{N}\sum\limits_{i=1}^{N}\frac{\left|Qc_i - Qo_i\right|}{Qo_i}$$ (21)

9. $$RR = \sqrt{\frac{1}{N}\sum\limits_{i=1}^{N}\frac{\left(Qc_i - Qo_i\right)^2}{Qo_i^2}}$$ (22)

10. $$NRMSE = \frac{\sqrt{\frac{1}{N}\sum\limits_{i=1}^{N}\left(Qc_i - Qo_i\right)^2}}{\frac{1}{N}\sum\limits_{i=1}^{N}Qo_i}$$ (23)

11. $$NME = \frac{\frac{1}{N}\sum\limits_{i=1}^{N}Qc_i - \frac{1}{N}\sum\limits_{i=1}^{N}Qo_i}{\frac{1}{N}\sum\limits_{i=1}^{N}Qo_i}$$ (24)

12. $$EI = 1 - \frac{\sum\limits_{i=1}^{N}\left(Qo_i - Qc_i\right)^2}{\sum\limits_{i=1}^{N}\left(Qo_i - \frac{1}{N}\sum\limits_{i=1}^{N}Qo_i\right)^2}$$ (25)

13. $APD = \dfrac{100}{N}\sqrt{\displaystyle\sum_{i=1}^{N}\left(\dfrac{Qo_i - Qc_i}{Qo_i}\right)^2}$ (26)

14. $ARE = \dfrac{\displaystyle\sum_{i=1}^{N}\left|Qo_i - Qc_i\right|}{\displaystyle\sum_{i=1}^{N}Qo_i}$ (27)

15. $CD = \dfrac{\displaystyle\sum_{i=1}^{N}\left(Qo_i - \left|Qo_i - Qc_i\right|\right)^2}{\displaystyle\sum_{i=1}^{N}\left(Qo_i\right)^2}$ (28)

16. $ARI = 1 - \dfrac{\displaystyle\sum_{i=1}^{N}Qo_i - \displaystyle\sum_{i=1}^{N}Qc_i}{\displaystyle\sum_{i=1}^{N}Qo_i}$ (29)

17. $EWB = \dfrac{\displaystyle\sum_{i=1}^{N}Qc_i - \displaystyle\sum_{i=1}^{N}Qo_i}{\displaystyle\sum_{i=1}^{N}Qo_i}$ (30)

RESULT AND DISCUSSIONS

Tank model, SF model and ANN model prediction and observed hydrograph were presented in Figure 5, Figure 6 and Figure 7, respectively. The results show that tank model, storage function model and ANN are successful in predicting watershed discharge in Cidanau watershed. Highest peak flow analysis show tank model, SF model and ANN can be best reached in 1996, 1997, 2000 and 2001, respectively. Highest peak flow can't be reached by models in 1998 and 1999, respectively. This is happened because the environment in Cidanau watershed is changed.

Table 1 resumes results calibration and verification for ANN model, Tank model and SF model, with marked values corresponding with the best performance according to the criteria in each row. ANN model become best model for calibration but SF model become best model for verification. Comparison of the accuracy of ANN, Tank model and storage function model show that ANN is better than the other models.

These hydrological models have been developed in form of application program under Windows, using Borland Delphi 5 programming. Basically this program receives inputs of date, rainfall, potential evapotranspiration, and river discharges in mm/day unit. The outputs can be saved in the form of ASCII file for all parameters, error analysis and discharges prediction. The hydrographic and regression curves can be saved in JPG file. Figure 7, 8 and 9 show the main window of the Tank model, the SF model and The ANN model, respectively.
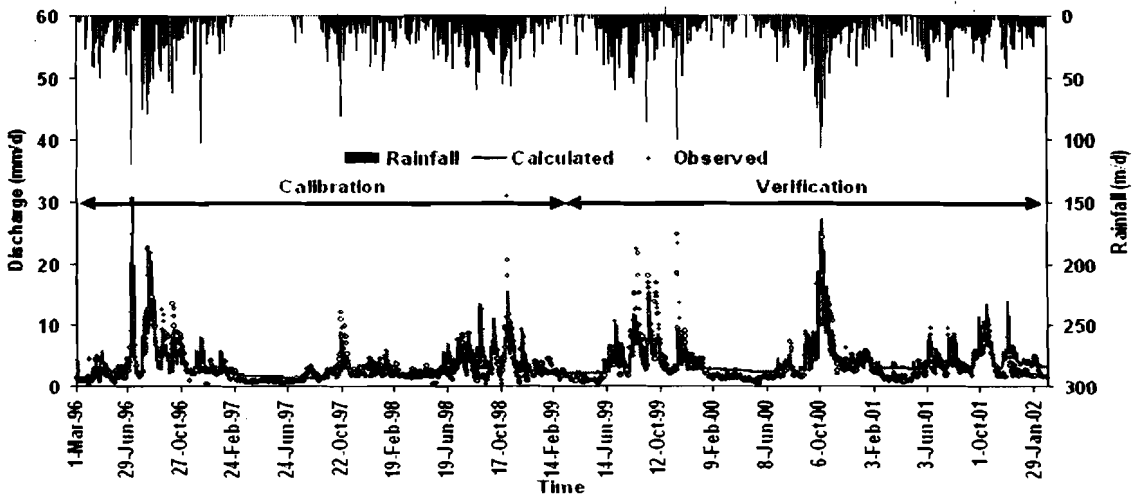
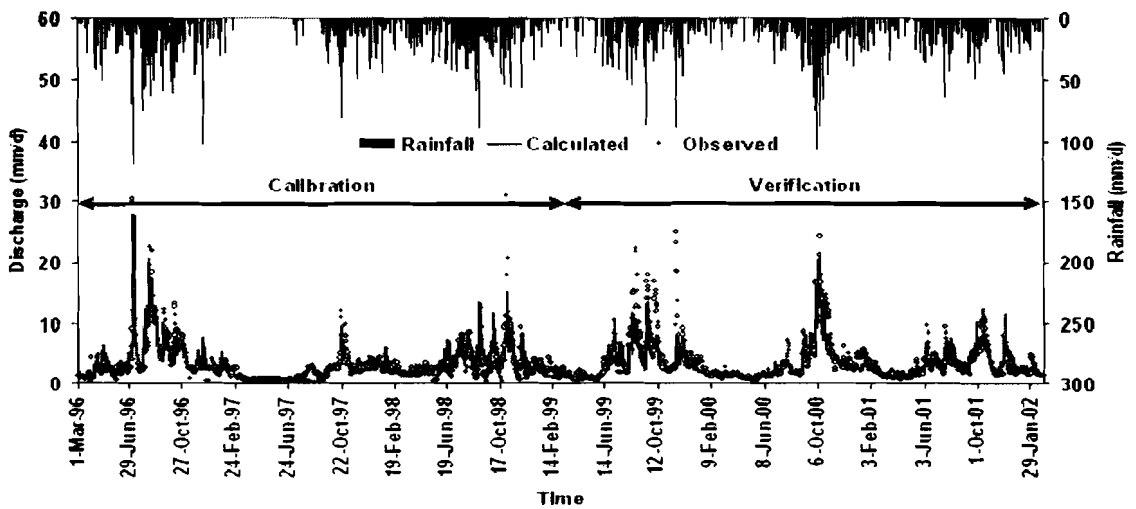Figure 4. Comparison between Tank model prediction and observed hydrograph

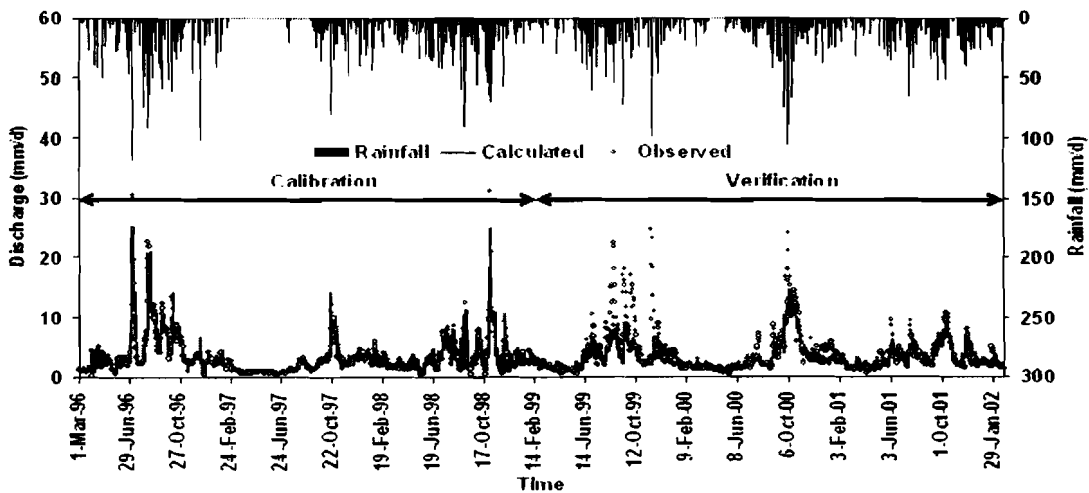Figure 5. Comparison between SF model prediction and observed hydrograph

Figure 6. Comparison between ANN model prediction and observed hydrograph

Table 1. Evaluation of models for hydrograph prediction

| Parameter	Calibration			Verification		
	ANN	Tank model	SF model	ANN	Tank model	SF model
R	**0.90**	0.88	0.86	0.83	0.81	**0.84**
R2	**0.81**	0.77	0.75	0.68	0.65	**0.70**
ARI	**1.00**	0.99	1.00	0.85	1.15	**0.86**
EI	**0.88**	0.77	0.75	0.61	0.65	**0.70**
CD	**0.69**	0.60	0.57	0.46	0.53	**0.51**
RMSE	**1.17**	1.61	1.69	2.21	2.08	**1.94**
APD	**0.02**	0.03	0.04	0.02	0.03	**0.01**
MAE	**0.58**	1.13	1.21	1.19	1.47	**1.12**
LOG	**0.02**	0.25	0.36	0.04	0.25	**0.18**
Xi	**0.32**	0.72	0.77	0.58	0.89	**0.54**
Xi2	**0.26**	0.95	1.09	0.62	1.25	**0.53**
MRE	**0.24**	0.59	0.62	0.36	0.66	**0.31**
RR	**0.60**	1.14	1.21	0.56	0.98	**0.43**
NRMSE	**0.36**	0.50	0.52	0.59	0.56	**0.52**
NME	**0.00**	-0.01	0.00	-0.15	0.15	**-0.14**
ARE	**0.18**	0.35	0.37	0.32	0.39	**0.30**
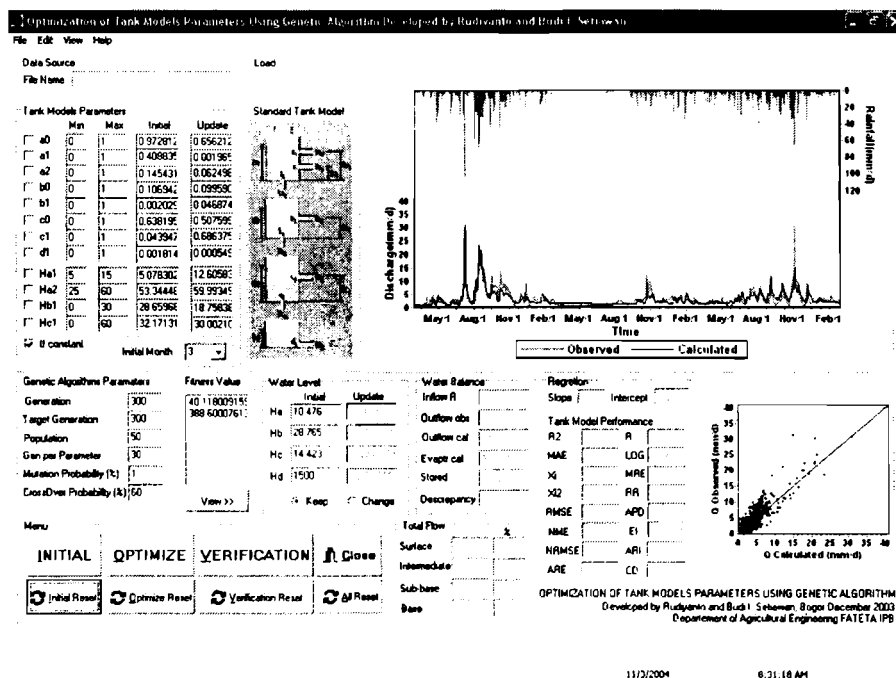
Figure 7. Main window of the Tank model optimizer program
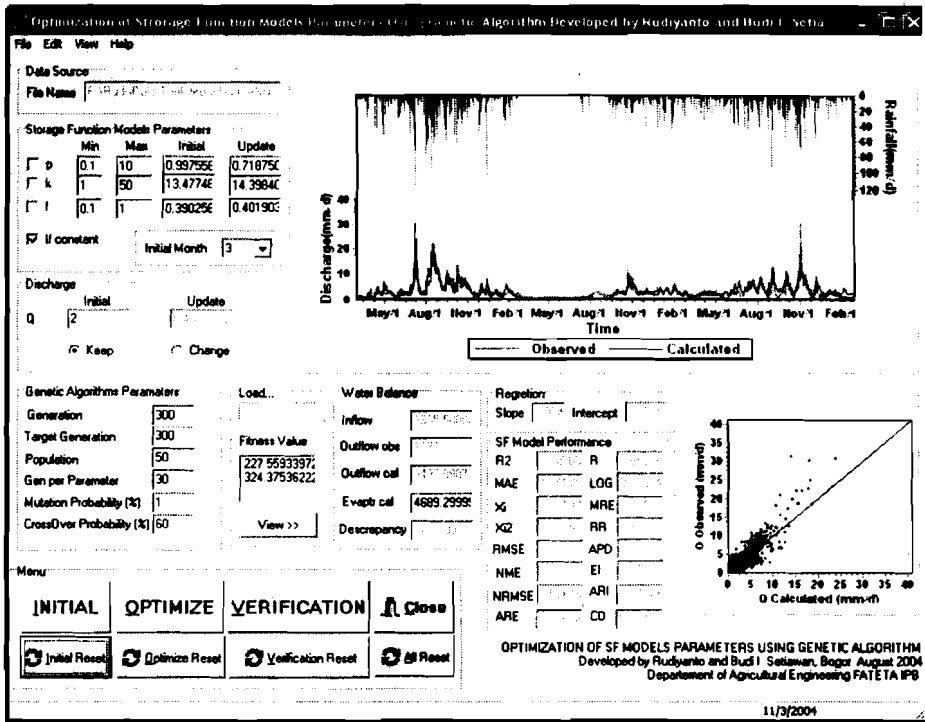
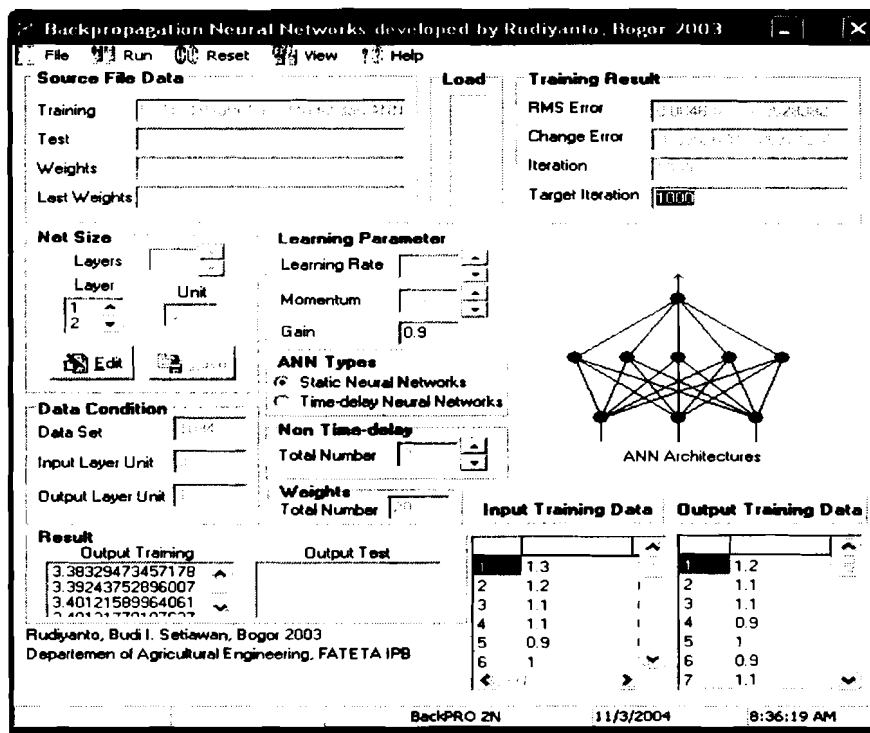Figure 8. Main window of the SF model optimizer program

Figure 9. Main window of the ANN model program

CONCLUSSIONS

Hydrological Models that developed is successful in predicting watershed discharge in Cidanau watershed. Comparison of the accuracy of ANN, Tank model and storage function model show that ANN is better than the other models.

REFRENCES

Fu, L., Neural Networks In Computer Intelligence, McGraw-Hill, Inc, Singapore, 1994.

Heryansyah, A., M. Y. J. Purwanto and A. Goto, Runoff Modelling in Cidanau Watershed, Banten Province, Indonesia, Proceedings of the 2nd Seminar Toward Harmonization Between Development and Environmental Conservation in Biological Production, JSPS-DGHE Core University Program in Applied Biosciences, The University of Tokyo, Japan, pp 13~18, 2003.

Kimura, T. 1961. The flood runoff analysis method by the storage function model (in Japanese). The Public Works research Institute, Ministry of Construction. Japan.

Patterson, D. W., Artificial Neural Networks Theory and Application, Printice Hall, New York, 1996.

Setiawan, B. I., T. Fukuda and Y. Nakano. 2003. Developing procedures for optimization of Tank models parameters. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Manuscript L W 01 006. June 2003.

Sing, V. P., and D. A. Woolhiser, Mathematical and Modeling of Watershed Hydrology. Journal of Hydrologic Engineering. Vol. 7, no. 4. July 21, pp 270~292, 2002.

Sugawara, M., et al. 1974. Tank model and its application to Bird Creek, Wollombi Brook, Bikin River, Kitsu River, Sanga River and Nam Mune. Research Note, *National Research Center for Disaster Prevention, No. 11*, Kyoto, Japan, 1–64.

Suprayogi, S. 2003. Prediksi ketersediaan air mengunakan tank model dan pendekatan artificial neural network (studi kasus sub DAS Ciriung Kabupaten Serang). Disertasi Pascasarjana IPB. Bogor.

Tingsanchali, T. 2001. Aplication combined Tank model and AR model in flood foorecasting. http://www.dhisoftware.com/uc2001/papers01/057/057.htm [21 Agustus 2003]: 13 p.

Wurbs, R. A. 1998. Dissemination of generalized water resources models in the United States. *Water Int.*, 23, 190–198.