Runoff Prediction Based on Storage Loss in A Catchment

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RUNOFF PREDICTION BASED ON STORAGE LOSS IN A CATCHMENT

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Runoff prediction using storage loss is based on water balance concept which is simplified as a relation between input (rainfall) and output (runoff). Neglecting other paramethers, storage loss is the difference between rainfall as input and runoff as output, where storage loss can be said as a representative of evaporation, evapotranspiration and infiltration. If the differences are plotted as a curve, they do not perform a linear curve or spread regularly. They distribute randomly. To find out the form and function of the specific curve, the concept of Mathematics is occupied. Fourier Series is applied to figure out the function of that curve. Furthermore that function is used to predict the marginal loss. And runoff is then predicted based on the storage loss.

I. Introduction

Infiltration losses are considered to be the most important source of hydrologic. losses for extreme flood events. This is based on the assumption that the minimum infiltration rate prevails for the duration of the probable maximum storm. This assumption is consistent with the conditions that have been shown to exist during extreme flood events. Historical records have shown that extreme floods are typically preceded by one or more antecedent storms. These antecedent storms have the effect of saturating the soil and producing minimum infiltration rates (Ponce, 1989).

The description above introduces the notion of a storage loss model. The idea of this form of yemodelling is based on the interpretation of the hydrologic cycle within a catchment, which leads to the concept of hydrologic storage (Kusumastuti and Price, 2000). The hydrologic storage refers to an accounting of the various phases of the hydrologic cycle within a catchment, with the aim of ascertaining their relative magnitudes.

Within an appropriate time span, the change in water volume remaining in storage in a catchment is the difference between precipitation and the sum of evaporation, evapotranspiration, infiltration, and surface runoff (Linsley and Franzini, 1979). This can be described with the equation: AS = P - (E+T+I+Q) in which AS = change in storage, P = rainfall, E = evaporation, T evapotranspiration, I = infiltration, and Q = surface runoff.

Assuming AS = 0 (no change in storage within a given time span), the equation above can be reduced to L=P-Q in which L = losses, equal to the sum of evaporation, evapotranspiration, and infiltration. This equation states that losses is equal to rainfall minus runoff.

In determination model that simplification is just not enough for describing a catchment. A detail information about all of catchment parameters are needed if we want to model the a catchment. However, data that we can collect from the field is so limited that merely rainfall and runoff data available. And that is sufficient for this storage loss model which relies on rainfall and runoff data.

Fourier approximation is able to demonstrate that any periodic function can be stated in infinite sinusoid series in which their frequency is related each other as a harmony. In this research Fourier Series is adopted to model the marginal loss storage. Some coefficients such

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as sine and cosine coefficients, frequency, and period are calculated and furthermore used for: building storage loss model.

II. Study Area

This research located in two catchments in Lampung province, Way PengubuanTerbanggi Besar and Way Besai Sumber Jaya. Upstream of Way Pengubuan is located in Northern 2 Lampung and the downstream part is in Center Lampung. This river has a meandering shape with slightly slope. The land use is dominated with garden, forest and agriculture field. The second catchment, Way Besai, is located in Sumber Jaya, Western Lampung, with area of 389 km'. This catchment is a hilly catchment which is dominated by garden and forest. Since April 1994, a big dam was build in this catchment by PLTA for Electrical Resources purpose.

The type of data used in this research are rainfall and runoff data as main data and topography, land use, climate, radiation and evaporation as supporting data. The rainfall data will be used as input in modeling storage loss and the discharge as output. From collecting data activity, there are ten years rainfall data available from four rain gauges that available in Way Pengubuan Catchment Area. Besides, the discharge data of this catchment also available which is noted in discharge station 1-78-00-10 located in Terbanggi Besar. The rainfall data of Way Besai catchment area available for 15 years since 1986 to 2000 collected from 5 rain gauges and one runoff station located in Sukapura.

III. Research Procedure

a. Loss in a catchment

In a catchment, rainfall is considered as an input and runoff is considered as an output. To find out the loss in a catchment,

- Multiply monthly rainfall by the appropriate area
- Multiply the average monthly by the number of days in a month. Do not forget to convert the units to the model units, that is m^3/s.
- Sum up all the inputs, For the upstream catchment : $\Sigma\ (P * A)$
- Reduce the input by the output : $\Sigma\ (P * A) - Q$
- Calculate the cumulative of $\Sigma\ (P * A) - Q$. After this step, the curve for the cumulative loss with respect to time can be drawn and the equation of the trend line can be found.
- The marginal loss is the difference between the curve and the line ordinate.

b. Modelling Marginal Loss

Based on the information about losses in a particular catchment, we want to predict the runoff in that catchment. This is done by extracting the Fourier series component from the marginal loss curve. In some engineering cases, it is found that some functions are periodic, so that trigonometry function is needed to model. Most curve fitting merely see monomial combination $1, x, x^2, x^3, ..., x^m$ which only match with linier or curve function.

The procedure for predicting the runoff in the marginal loss storage model is described as follows :

- Extract the component of Fourier series from the marginal loss curve so that some A components like sine and cosine coefficients, frequency, and period are found (Chapra and Canale, 1994). This component is then used to predict the loss by the equation :

  $$y = \alpha_{0} + \alpha_{1} \cos(\omega_0 t) + b_1 \sin(\omega_0 t) + \alpha_2 \cos(2\omega_0 t) + b_2 \sin(2\omega_0 t) n + \ldots + \alpha j \cos(j\omega_0 t) + bj \sin(j\omega_0 t)$$

  where : $\omega_0 = 2\pi f$, and $f = \frac{1}{T}$

  f = frequency

  T = period

- The runoff Q is calculated as follows :

  $\Sigma P - \Sigma Q$ = cumulative loss

  = a + bt + y

where the cumulative loss is composed by the trend line (a + bf) obtained from the cumulative loss graph and the predicted marginal loss (y). Cumulative runoff can be calculated from :

$\Sigma Q = -a - bt - y + \Sigma P$.

The runoff Q is the difference between Q for the next and the current time.

$$Q^n = \sum^{n+1} Q - \sum^{n} Q$$

IV. Results and Discussion l

IV.1. Test of Consistency Data

In long term measurements inconsistency data is often caused by the change of gauge position or lack in installing the gauge. To check consistency data Double Mass Curve **Method** is used in this research. Method to check data by connecting the cumulative depth of rainfall in the tested station and average of cumulative depth of rainfall in surrounding station. In this test, it is obtained that rainfall data for both Way Besai and Way Pengubuan are consistent enough. This condition is shown by the deviation of double mass curve which is quite small as demonstrated by the graph below, an example of consistency test Station Sumber Jaya Way Besai.

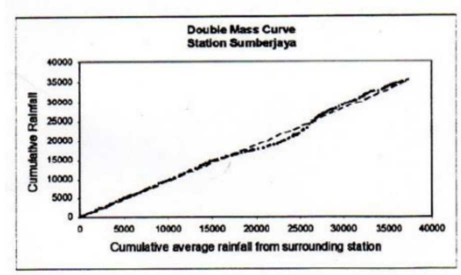

Figure 1. Consistency test result of rainfall data of Way Besai

IV.2. Calculation of Storage Loss

a. Calculation of Storage Loss of Way Pengubuan Catchment Area .

“ In this model, rainfall data is used as input and discharge data as output. Storage loss are the result of total rainfall volume minus discharge as given in the equation before. From this modeling it is obtained the monthly storage loss and the cumulative storage loss of Way Pengubuan with the equation of the trend line is y = 211.13 x — 3819.1.

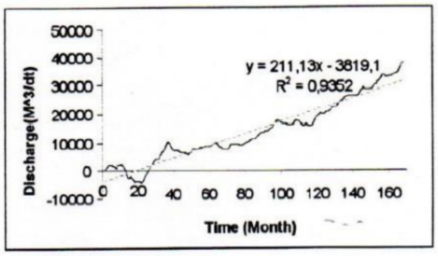

Figure 2. Cumultive storage loss of Way Pengubuan

An irregular curve called Marginal Loss Curve is obtained from cumulative storage loss 4. minus the ordinate of the line of equation. This Marginal Loss curve is shown bellow :

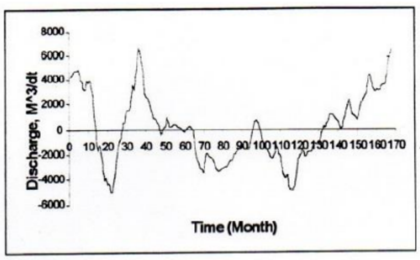

Figure 3. Marginal Loss Curve of Way Pengubuan

Based on the information about the storage loss, we can define runoff of Way Pengubuan by extracting the Fourier component of the marginal loss curve.

b. Calculation of Storage Loss of Way Besai Catchment Area

Using the equation given before, cumulative storage loss and marginal moss of Way Besai can be drawn and presented below respectively. The equation of the trend line using linear "e regression is y = 236.51x + 1283.5.

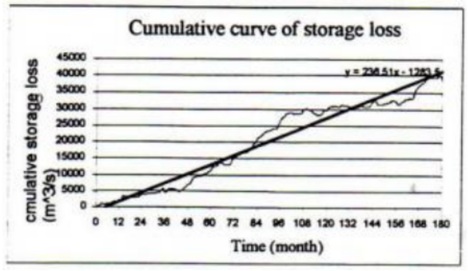

Figure 4. Cumulativestrorage Loss Curve of Way Besai

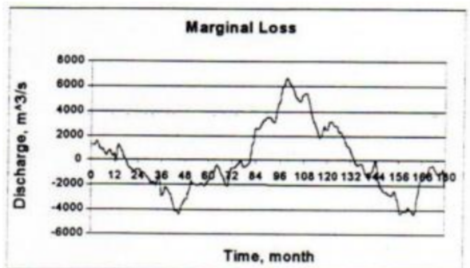

Figure 5. Marginal Loss of Way Besai

From figure 5, it is shown that the dominant period of the curve is start from 18 month and end at 134" month. By assuming that this period will be repeated, it has happened before and will continue for the next, the data in 18 to 134" data will be used to train the model and the rest data will be used to test the model.

The next stage is to extract the Fourier Series, in which in this research is done manually. The general form of Fourier Series are :

$$y(t)= a_0 + a_1 \cos(\omega_0 t) + b_1 \sin(\omega_0 t) + a_2 \cos(2\omega_0 t) + b_2 \sin(2\omega_0 t) + \cdots \dots \dots + a_m \cos(m\omega_0 t) + b_m \sin(m\omega_0 t)$$

With : $\omega_0 = 2\pi f$

$$f = \frac{1}{T}$$

Substituting into the equation above, we obtain an equation :

$$y(t) = a_0 + a_1 \cos\left(\frac{2\pi}{T} t\right) + b_1 \sin\left(\frac{2\pi}{T} t\right) + a_2 \cos\left(2\frac{2\pi}{T} t\right) + b_2 \sin\left(2\frac{2\pi}{T}\right) + \cdots \dots \dots . + a_m \cos\left(m\frac{2\pi}{T_0} t\right) + b_m \sin\left(m\frac{2\pi}{T} t\right)$$

where : $a_0 = \frac{\sum y}{n}$

$$a_1 = \frac{2}{n} \sum y \cos(j w_0 t)$$

$$b_1 = \frac{2}{n} \sum y \sin(j\omega_0 t)$$

$$j = 1, 2, 3 \dots \dots . , m$$

Using those equations above, the Fourier series coefficients for Way Besai are obtained and presented in the table below :

Table 1. Fourier Series Coefficient for Way Besai

Order *(J)*	Coefficient Cosinus (a)	Coefficient Sinus (b)	Period Of Data
1	335.125	-3689.049	72
2	-757.67	1089.584	48
3	153.283	724.999	36
4	-257.686	-274.799	28.8
5	-88.444	316.183	24
6	-230.775	420.81	20.5714
7	153.055	151.101	18
8	167.943	-38.323	16
9	53.567	163.198	14.4
10	6.658	-8.748	13.0909

After the coefficient obtained then they may be arranged in a form below :

$$y(t) = 514.917 - 335.125\cos\left(\frac{2\pi}{144}t\right) - 3168.049\sin\left(\frac{2\pi}{144}t\right) - 757.670\cos\left(2\frac{2\pi}{144}t\right) + 1089.584\sin\left(2\frac{2\pi}{144}\right) + \cdots \ldots\ldots + 6.658\cos\left(10\frac{2\pi}{144}t\right) - 8.748\sin\left(10\frac{2\pi}{144}t\right)$$

IV.3. Runoff Modeling

After proceeding several steps in this modelling including defining some important coefficients of Fourier Series, modelling runoff can be done. Those coefficients are arrange in the form of Fourier series function $y = y = a^o \cos 2\pi\omega^o t + b^o \sin 2\pi\omega^o t + \ldots\ldots$ to calculate the value of the function. Runoff is then calculated by $\sum P - \sum Q = a + bt + y$., so that $\sum Q = \sum P - (a + bt + y)$ a and b in last equation is the linear trend as calculated before. Finally the runoff modeling can be done and training of the model is shown in the following graph. The computed result fits to the observed data quite well with coefficient of efficiency 0.7275.

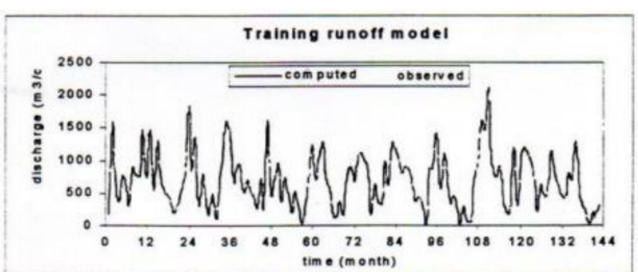

Figure 6. Training model of Way Besai

IV.4. Test of Model

The objective of testing a model is to check the feasibility of the model especially in prediction. The method used for testing is the same method in training, while the data used is from January 1997 to December 2000. Result of testing the model on Way Besai catchment area is presented in the graph below, and the goodness of fit for testing model is 0.7962.

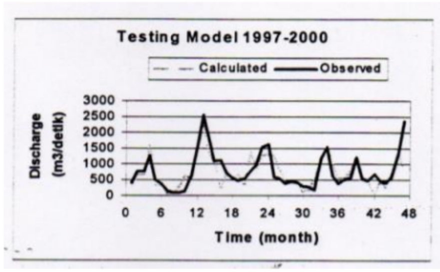

Figure 7. Test of model on Way Besai

V. Conclusion

The idea of marginal loss storage model based on the interpretation of the hydrologic cycle within a catchment, leads to the concept of hydrologic storage. The hydrologic storage refers to an accounting of the various phases of the hydrologic cycle within a catchment, with the aim of ascertaining their relative magnitudes. The equation of this model states that the losses are equal to the rainfall minus the runoff. The performance of the marginal loss storage model shows good results both in training and testing. ~

VI. Acknowledgements

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