PREDICTION OF WATER YIELD OF MOUNT *BANAHAW* WATERSHEDS IN QUEZON PROVINCE, PHILIPPINES USING HYDROLOGIC WATER BALANCE MODEL

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ABSTRACT

The study was conducted to determine the potential water of Mount *Banahaw* watersheds using hydrologic water yield model. The study specifically aimed to predict the monthly streamflow of the watershed after determining the parameters of the model by optimization process using monthly precipitation, monthly potential evapotranspiration and observed streamflow of the watershed as input to the model.

The research site was the *Janagdong* River Watershed and the *Dumacaa* River Watershed in Quezon Province, Philippines. The hydrometeorological data of both watersheds from 1986 to 1989 and 1998 to 1999 were used in the study.

The value of parameters a_1=0.09; a_2=0.44; a_3=0.01; a_4=0.03; a_5=2.00 for *Janagdong* River Watershed and the value of parameters a_1=0.01; a_2=0.37; a_3=0.20; a_4=0.03; a_5=2.10 for Dumacaa River Watershed was obtained. The use of these parameters were able to predict the streamflow of the two watersheds. The use of these parameters produced a significant correlation of the predicted and observed streamflow of both watersheds at 0.01 level. The test of the difference of the means of the predicted and observed streamflow of both watersheds was found not significant at 0.05 level.

Key Words : water yield, streamflow, watershed, water balance model

INTRODUCTION

Background of the Study

Mount *Banahaw* de Lucban is located approximately 130 Km. South of Manila, Philippines. It is bounded by the towns of Lucban, Tayabas and Sariaya in Quezon Province and Majayjay in Laguna Province. The huge mountain serves as the source of water for domestic uses and for agricultural production in the areas aside from the rainfall that occurs regularly. Mount *Banahaw* has an elevation of approximately 1,800 meters above sea level. Due to its high elevation, water flows by gravity to the surrounding communities.

The water demand for domestic use and agricultural purposes of the surrounding communities is increasing. This is due to industrialization and development of the surrounding communities and increasing population. The main activity of the metropolitan waterworks and local governments is to allocate and exploit the water resources to satisfy the demand of the consumers without taking into consideration how much is the potential available water. This can be attributed not for the lack of knowledge but due to wait and see attitude. An action will be done when there is already a problem. In water resources development activities the work can not be done overnight due to its complexity and influence of nature.

Despite of the availability of some climatic data from the surrounding meteorological stations of the watershed, there is no single attempt to develop a model to estimate the potential water. Hence, this is a preliminary attempt.

Objectives of the Study

The objectives of the research are directed to:

1. predict the monthly streamflow of the watershed using monthly precipitation and potential evapotranspiration as input to the model, and
2. determine the model parameters that will determine potential streamflow of the watershed.

Significance of the Study

As the research is the first of its kind in the Mount *Banahaw* watershed, it will be of great help to Southern Luzon Polytechnic College as a government institution responsible for the management of the huge mountain. The output of the research will give information from long record of climatic data for important consideration in project development, planning of water resource utilization and conservation practices in the watershed.

Specifically, the result of this research will be very useful for:

1. Preparation of plan for conservation practices.
2. Designing water impounding structure for water storage and irrigation purposes
3. Allocation of available water for domestic and agricultural use.
4. Evaluation of the available water for future use.
5. Prediction of monthly streamflow.

RESEARCH METHODOLOGY

The Model Used and Its Parameters

There are several models that have been developed to predict water yield from watersheds, such as Alred and Haan (1996), Droogers and Kite (1999), Putu Sudira (1989), Sahid Susanto (1991), and also the model to predict salinity of the watershed by Borg, et. al. (1988).

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The water balance model developed by Van Der Beken and Byloos in 1977 (Singh, 1989) was used in this study. The general equation of the models is expressed as:

$$\Delta S = N_p - V_Q - R \quad [1]$$

The different components and the relationships of factors affecting the model are the following:

1. Evapotranspiration.
   The evapotranspiration is described by equation 2 as:

   $$E_a = E_p\ [1 - \exp(-a_1 S)] \quad [2]$$

2. Effective Precipitation.
   The effective precipitation in relation to actual precipitation and actual evapotranspiration is described by equation no 3.

   $$N_p = V_p - E_a \quad [3]$$

3. Streamflow
   The streamflow in the watershed in relation to the storage at the beginning of the month, effective precipitation and constant parameters is described by equation no. 4.

   $$V_Q = a_2 S + a_3 N_p \quad [4]$$

4. Deep Percolation and Canal Loss
   The deep percolation and canal loss in relation to storage at the beginning of the month and constant parameters is described by equation no. 5.

   $$R = a_4 S - a_5 \quad [5]$$

5. Initial Storage
   The initial storage can be estimated by correlating with the long-term average discharge volumes. As an initial estimate,

   $$S_i = 2\bar{S} \quad [6]$$

Data Gathered

The water balance model used climatic data and streamflow records. These data were obtained from government intitutions such as Philippine Atmospheric Geophysical and Services Administration in Quezon City and local stations in the field; National Irrigation Administration in the Quezon City and Lucena City; Department of Agriculture and Organization for Industrial, Spiritual and Cultural Advancement Center in Lucban, Quezon. The potential evapotranspiration from the watersheds was computed using the Penman-Monteith method (Smith, 1993).

Parameters of the Model and optimization Process

Estimation of values of the five parameters were determined by optimization process. The initial values used were the values used by Van Der Beken and Byloos (Singh, 1986 and Siti, 1990) as presented in Table 1. The first output of the computer program was compared to the monthly observed streamflow of the watershed for the same year. Further, in the optimization process, one step higher and one step lower was made to every value of the parameter as seen in Table 1. The new values were subtituted one-by-one to the value of parameter as input to the computer program. The initial process done is to determine the trend of the predicted streamflow as compared to the observed streamflow.

Table 1. Initial Values of Parameter of Model for Optimization Process.

Parameters	Value of Parameter One Step Lower Than Standard Value	Standard Value	Value of Parameter One Step Higher Than Standard Value
a_1 (Soil Texture)	0.005	0.01	0.02
a_2 (Soil Texture)	0.170	0.27	0.37
a_3 (Degree of Urban.)	0.100	0.20	0.30
a_4 (Percolation)	0.020	0.03	0.04
a_5 (Canal Loss)	1.000	3.00	4.00

The trend gave direction whether to increase or decrease the value of the parameter and to select the parameters that has strong influence of the desired results. In this research the observed and predicted streamflow are governed by the following criteria to finish the iteration:

1. Highest value of coefficient of correlation is obtained from the observed and predicted streamflow.
2. The correlation coefficient is significant at 0.05 level.
3. The difference between the mean of the observed and predicted streamflow is not significant.
4. Smallest value of percent error is obtained, and
5. Sensitivity test is giving almost similar value but opposite in sign.

The final value of the parameter was selected after adding and subtracting smaller amount to the parameter determined earlier. A minimum of 33 iteration is required to finish the determination of parameters.

Analysis of Data

Analysis of data gathered was done by:

1) Computing the mean, standard deviation, determining the maximum and minimum values, chi-square test and drawing the graph of the climatic data and streamflow,
2) Correlating the predicted (independent) and observed streamflow (dependent) for each month of the year,
3) Testing of the difference between predicted and observed streamflow, and
4) Computing the percent error.

Validity of the Model

After the five parameters of the model has been determined using Janagdong River Watershed from 1984-1989 it was validated in the same watershed for the year 1987 - 1989 and in Dumacaa River Watershed for the year 1998 to 1999.

Sensitivity Analysis

Sensitivity analysis was done by observing the output of the model after the changes in model parameters has been made. The changes used were +5% and -5% and +10% and -10% for parameters a_1, a_2, a_3, a_4 and a_5. Percent difference was computed by comparing the standard predicted streamflow and the "changed" predicted value for Janagdong River Watersheds.

RESULTS AND DISCUSSION

Watershed Parameters Used in the Model

The values of these parameters determined by optimization are presented in Table 2. Higher values for parameters a_1 and a_2 were noted as compared to the standard values mentioned in Table 1 due to the presence of sandy soil texture of the Janagdong River Watershed. This is in conformity with the publication of Singh, (1989) that the value or parameter a_2 will increase if the soil texture becomes sandy. The value of parameter a_3 is lower than the values established by Van Der Beken and Byloos (Singh, 1989). This is attributed to the low urbanization of the watershed. The existing vegetation and forest cover of the watershed is maintained as evidenced by continuous tree planting activities in the area, prohibition of cutting of trees in the watershed because it is national park and the voluntary evacuation of the occupied land in the watershed by local farmers.

Table 2. Numerical Values of Five Parameters of the Model Determined in Janagdong River Watershed from 1984-1986.

Parameters	Numerical Values
a_1	0.09
a_2	0.44
a_3	0.01
a_4	0.03
a_5	2.00

Observed and Simulated Streamflow

The monthly predicted streamflow determined in the optimization process and the observed streamflow are presented in Table 3. The unit of the predicted streamflow was changed to become volumetric unit by considering the area of the watersheds.

Statistical analysis revealed that the observed and predicted streamflow are highly associated as revealed by a correlation value of 0.888. Test of the degree of association of the predicted and observed monthly streamflow revealed that the two are highly correlated. The computed r-value 0.88 is higher than the tabulated r-value of .424 at 0.01 level of significance. Test of difference between the two means of monthly observed and predicted streamflow revealed that they are not significant. The computed t-value is lower than the tabulated value of 2.032 at 0.05 level of significance. For the 3-year period the average percentage of error is 26.04 %.

Table 3. Monthly Predicted and Observed Streamflow From 1984-1986 in *Janagdong* River Watershed, million cubic meters.

	1984		1985		1986	
Month	Predicted Streamflow	Observed Streamflow	Predicted Streamflow	Observed Streamflow	Predicted Streamflow	Observed Streamflow
Jan	7.28172782	6.82992	4.4249177	8.115552	7.37405818	6.508512
Feb	3.9062383	4.620672	2.44253046	4.088448	2.98293465	2.999808
Mar	1.90484188	4.15152	7.66191169	7.660224	1.5816856	2.81232
Apr	3.58851324	4.536	5.08460827	4.30272	2.32304412	2.69568
May	3.80847676	3.348	7.71350808	11.24928	2.16282379	3.160512
Jun	5.61706567	4.7952	12.3626135	13.37472	8.32723344	6.71328
Jul	2.50227366	5.22288	4.91100994	10.31184	12.5852926	9.1065
Aug	7.1215075	4.312224	0.2781981	2.598048	7.33060862	8.222688
Sep	9.28583987	8.39808	13.4950183	10.60128	5.67409325	6.03936
Oct	17.9648942	21.721824	13.2370364	12.267072	30.0710344	20.48976
Nov	7.77053564	13.27104	14.1929272	13.97088	18.0137749	17.98848
Dec	4.77522997	6.56208	9.41347301	10.901088	7.13236987	10.499328
Total	75.52714451	87.76944	95.2177527	109.441152	105.5589534	97.236228
Mean	6.293928709	7.31412	7.93481272	9.120096	8.796579452	8.103019

df = 34

$r_{tab(0.05)} = 0.329$

$r_{tab(0.01)} = 0.424$

The relationship of the observed and predicted monthly streamflow, generally follows the same trend for the 3-year period. This is illustrated in Figure 1.

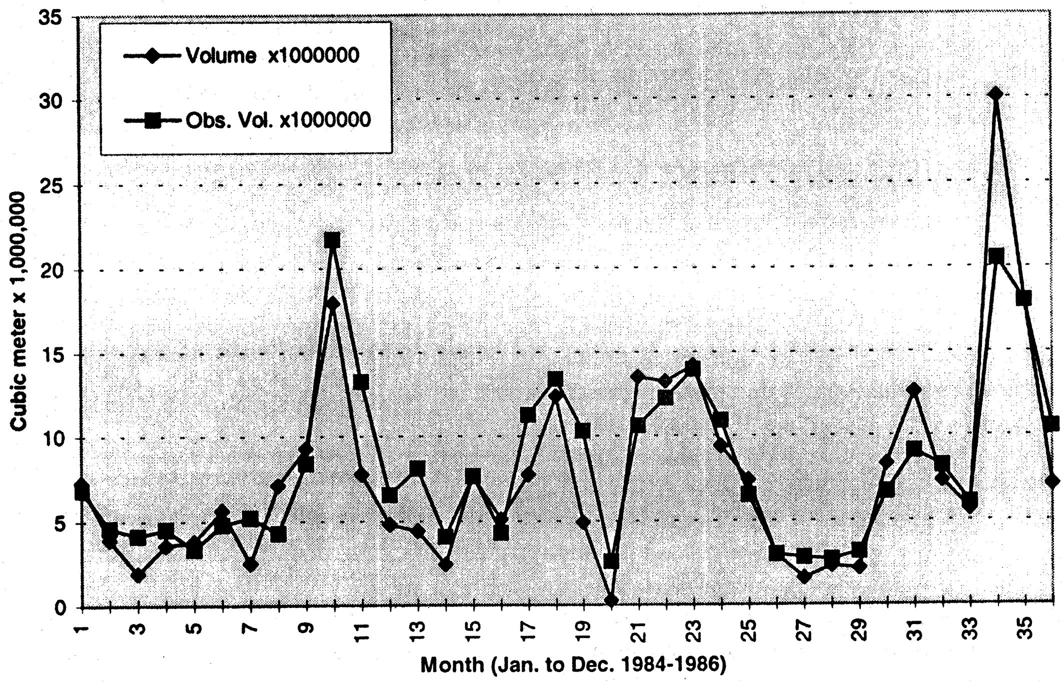

Figure 1. Graph of predicted and observed streamflow of *Janagdong* River Watershed using a1, a2, a3, a4 and a5 parameters form 1984-1986.

Validation of the Model

Validation of the model was done in the same watershed but on different period, i.e. from 1987 to 1989. The same model parameters were used with the assumptions that there is no changes in the condition of the watershed as to vegetation and surface cover. Likewise, the moisture storage in the soil is assumed the same as that of the previous years. Although these are assumptions but it is supported by the fact that the watershed is planted with permanent crop such as coconut and fruit trees on the lower portion and permanent forest on the upper portion of the watershed.

1. Janagdong River Watershed

The use of 5 parameters of the water balance model revealed that it could be used in the same watershed for the succeeding years of 1987–1989. The summary of the findings for *Janagdong* watershed is presented in Table 4 for the year 1987 to 1989. The mean monthly predicted and observed streamflow is 8, 017, 957 and 8, 009, 837 cubic meters, respectively, for the 3 years period. The computed correlation coefficient of 0.952, 0.868, and 0.752 for the year 1987, 1988, 1989 respectively are significant at 0.01 level of significance. The average percent error for the 3-year period are 17.80, 34.80 and 33.02 for 1987, 1988, 1989 respectively. The differences between the means of the observed and predicted values are not significant at 0.05 level.

Table 4. Test of the Validity of the Model on Janagdong River Watershed using the Parameters obtained in Janagdong River Watershed,1984-1986.

Year	Mean Predicted Streamflow x 10^3 m³	Mean Observed Streamflow x 10^6 m³	Correlation Coefficient r	Percent Error	t-ratio
1987	7.265434	7.439411	0.952	17.80	0.3358
1988	9.510103	9.487705	0.868	34.80	0.0195
1989	7.278333	7.102387	0.752	33.02	0.2644

df=10
$r_{tab(0.05)}=0.576$
$r_{tab(0.05)}=0.708$

df=11
$t_{tab(0.05)}=2.201$
$t_{tab(0.01)}=3.106$

2. Dumacaa River Watershed

The model and its parameters determined in *Janagdong* River Watershed is tried in *Dumacaa* River Watershed with the assumptions that:

1. The two watersheds are almost the same. This is based on fact that the two are part of huge mountain Mount *Banahao*.
2. Both watersheds has coconut, forest and grasslands as its main crop for more than 50 years.
3. Both watersheds have the same hydrometeorological conditions.

The same value of model parameters derived from *Janagdong* River Watershed were used to simulate the water yield of *Dumacaa* River Watershed from 1998 to 1999. Table 5 presents the summary of computation. Like in Janagdong River Watershed the model was able to simulate the streamflow of Dumacaa River but with different results.

Validation of results revealed that the predicted and observed streamflows are significantly correlated with correlation coefficient of 0.918. This association is further supported by the graph on Figure 6. The graph shows that the monthly predicted and observed streamflow generally follows the same trend.

However, the difference between the mean of the predicted and observed streamflow was found significant. The computed t-value of 2.274 was found higher than the t-tab of 2.101 at 0.05 level of significance. Therefore, it can be concluded that the parameters of the model can not be used to estimate the streamflow of *Dumacaa* River.

Table 5. Test of the Validity of the Model on *Dumacaa* River Watershed Parameters obtained in Janagdong River Watershed.

Year	Mean Predicted Streamflow	Mean Observed Streamflow	Correlation Coefficient r	Percent Error	t-ratio
1998-1999	9.446250272	11.650695	0.918	39.4	2.2784

df=17
$r_{tab(0.05)} = .456$
$r_{tab(0.01)} = .575$

df=18
$t_{tab(0.05)} = 2.101$
$t_{tab(0.02)} = 2.552$
$t_{tab(0.01)} = 2.878$

For *Dumacaa* River Watershed new optimization process was done to determine the value of parameters of the model. The determined values after the optimization process are presented in Table 6. A value of a_1=0.01 and a_2=0.37 shows that the soils texture of the watershed is not sandy as compared to the soil texture of *Janagdong* River Watershed. This is supported by the report the Municipal Planning and Development Coordinator of Lucban, Quezon (1998) that the soil classification of the watershed is Antipolo Sandy Clay. The value of a_3=0.20 shows that the watershed is more urbanized than that of *Janagdong* River Watershed. This is due to the fact that the greater portion of *Dumacaa* River Watershed is privately owned land.

Table 6. Values of the Parameters of the Model for *Dumacaa* River Watershed.

Parameters	Numeric Value
a1	0.01
a2	0.37
a3	0.2
a4	0.03
a5	2.1

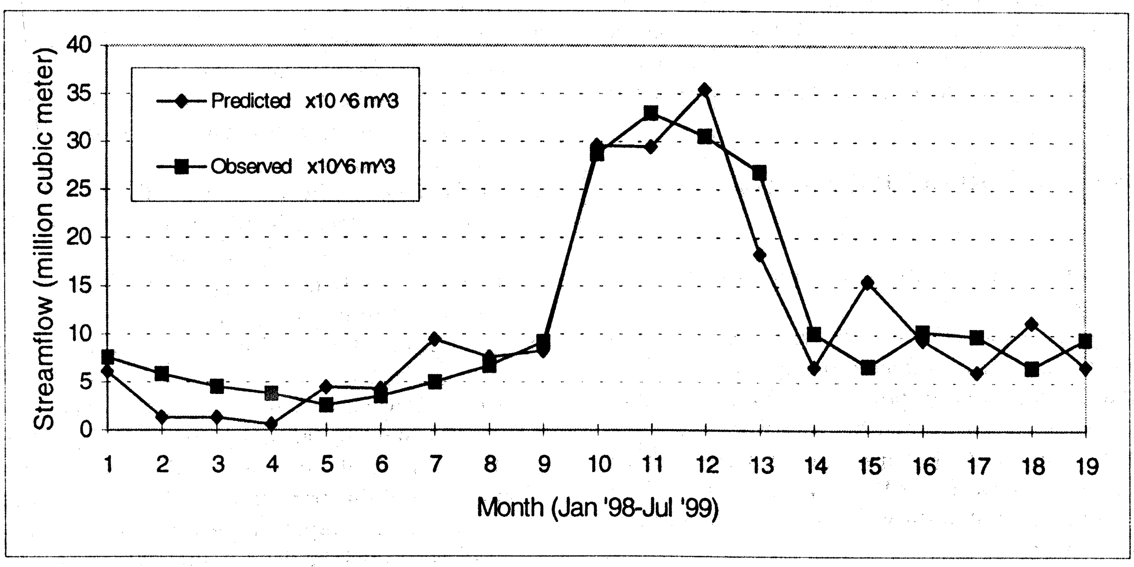

Figure 2. Relationship of monthly predicted and observed streamflow of *Dumacaa* River in 1998 and 1999

4.7. Sensitivity Analysis

To identify the parameter of the model that is very influential to the determination of simulated runoff, sensitivity analysis was done. This was obtained by adding and subtracting 5% and 10% of the standard value to the standard value. Analysis revealed that a_2, i.e. the parameter related to soil texture is the most sensitive as compared to all other parameters for *Janagdong* River Watershed watersheds. An increase of 5% of this parameter resulted to 3.41% increase on the streamflow. On the contrary a decrease of 5% to the parameter resulted to a decrease on the streamflow of 3.52%. The parameter a_1, i.e. that is related to soil texture is the least sensitive as compared to all other parameters.

The parameter a_4, i.e. related to deep percolation is the second more sensitive for watershed. However, the trend is in the opposite direction. An increase in the value of a_4 predicted a decrease of the predicted streamflow and vice versa.

The parameters a_3 and a_5 is also sensitive but to a lesser degree for both watersheds. The trend is in the opposite direction. An increase of the value of parameter produced a decrease in the predicted streamflow and a decrease in the value of parameters resulted to an increase in the predicted streamflow.

For *Dumacaa* River Watershed the a_2 (parameter related to soil texture) parameter is the most sensitive to changes made like in Janadong River Watershed. An increase of 5% of this parameter resulted to 3.754% increase on the streamflow. On the contrary a decrease of 5% to the parameter resulted to a decrease on the streamflow of 3.856%. The a_5 parameter is the least sensitive to changes made.

The parameter a_1 is the second most sensitive. A change of +5% resulted toa decrease of 1.73% on the volume of streamflow and a decrease of 5% produced an increase of 1.91% on the streamflow. The parameter a_4 and a_5 produced minimal change. The percent changes is present in Table 7.

CONCLUSION AND RECOMMENDATION

Conclusion

The result of the study leads to formulate the following conclusions:

1 The monthly streamflow of *Janagdong* River Watershed can be estimated using the monthly precipitation and monthly potential evapotranspiration recorded from the nearest hydrometeorological stations using the Van Der Beeken and Byloos water balance model. For *Dumacaa* River Watershed, the streamflow can be predicted but further research is necessary to validate the result.

2 The parameters of the model to determine the monthly streamflow of *Janagdong* River Watershed are a_1=0.09; a_2=0.44; a_3=0.01; a_4=0.03; a_5=2.00 and the value of a_1=0.01; a_2=0.37; a_3=0.20; a_4=0.03; a_5=2.10 are the value of parameters for *Dumacaa* River Watershed.

Table 7. Effect of Changing the Parameters a_1 to a_5 with Respect to Standard Predicted Streamflow for Janagdong and Dumacaa River Watersheds.

Parameter	% Change to Parameters	Percent Difference			
		JRW 1987	JRW 1988	JRW 1989	DRW 1998-1999
a1	+ 5	0	0	0	-1.73
	- 5	0	0	0	1.92
	+ 10	0	0	0	-3.3
	- 10	0	0	0	4.04
a2	+ 5	3.45	3.41	3.41	3.75
	- 5	-3.56	-3.52	-3.51	-3.86
	+ 10	6.8	6.73	6.71	7.41
	- 10	-7.23	-7.15	-7.13	-7.82
a3	+ 5	-0.03	0.01	0.01	-0.12
	- 5	0.03	-0.01	-0.01	0.15
	+ 10	-0.07	0.01	0.03	-0.31
	- 10	0.07	-0.01	-0.03	0.31
a4	+ 5	-0.2	-0.15	-0.13	-0.17
	- 5	0.2	0.15	0.13	0.17
	+ 10	-0.4	-0.29	-0.027	-0.33
	- 10	0.4	0.29	0.26	0.33
a5	+ 5	0.07	0.05	0.04	0.06
	- 5	-0.07	-0.05	0.04	-0.06
	+ 10	0.13	0.1	0.09	0.12
	- 10	-0.13	-0.1	-0.09	-0.12

Recommendations

Based on the study, the following recommendations are suggested:

1. The model is applicable for small watershed because it does not consider other hydrologic characteristics such as interception, surface storage and the time lag from rainfall occurrence to measured runoff at the gauging station.
2. The model can be used to predict the streamflow of other sub-watersheds of Mount Banahaw. This is necessary to have early precaution of the occurrence of flood on low-lying areas during the rainy season and typhoon season of the year.
3. Establishment of hydrometeorological station within the watershed is necessary so that the measured streamflow and measured climatic data represent the real situation of the study area, thereby more accurate result of simulation can be obtained. Submission of proposal of this project to local government units, non-government organizations and other funding institutions will be done to finance this project.
4. For the improvement of the study following are further recommended:
   a. Proper survey of the land use pattern of the watershed should be done. Land use pattern is changing regularly due to farming activities in

addition to the natural changes. Hence, an update is necessary to re-calibrate the model parameters.

b. The use of other parameters or model should also be done. The availability of more advance computer facilities can improve the research.
c. A research on geomorphological characteristics of the watershed and the runoff should be done for ungauged watershed like Mount Banahaw.

BIBLIOGRAPHY

Allred, B. and C.T. Haan, 1996. SWMHMS - Small Watershed Monthly Hydrologic Modeling System. Water Res. Bull. 32 (3) : 541 – 552

Anonymous. 1995. Region 4 Janagdong River Irrigation System Improvement Component II OSP National Irrigation Administration, Quezon City, Philippines.

Borg, H., R.W. Bell, and L.C. Loh, 1988. Streamflow and Stream Salinity in a Small Water Supply Catchment in Southwest Western Australia After Reforestation. J. Hydrology, 103 (1988) : 323 – 333.

Droogers, P. and G. Kite, 1999. Water Productivity from Integrated Basin Modeling. Irrigation and Drainage Systems, 1013 : 275 - 290

Putu Sudira. 1989. "Runoff Prediction Model Based on Soil Moisture Analysis." Unpublished Dissertation, University of the Philippines, Los Banos, Laguna, Philippines.

Sahid Susanto and Yoshiro Kaida. 1991. "Tropical Hydrology Simulation Model 1 for Watershed Management." J. Japan Soc. Hydrology and Water Resources. Vol.4 No. 2 43-53.

Singh,Vijay P. 1989. Hydrologic Systems Volume I Rainfall-Runoff Modeling. Prentice Hall, Englewood Cliffs, New Jersey.

Singh,Vijay P. 1989. Hydrologic Systems Volume II Watershed Modeling. Prentice Hall, Englewood Cliffs, New Jersey.

Siti Khoiriyah. 1995. Model Hidrologi Air (Water Yield) Untuk Daerah Aliran Sungai Kecil. (Unpublished Thesis). Jurusan Mekanisasi Pertanian, Fakultas Teknologi Pertainian, Universitas Gadjah Mada, Yogyakarta, Indonesia.

Smith, Martin. 1993. Climwat for Cropwat A Climatic Database for Irrigation Planning and Management, FAO. Rome, Italy.

List of Symbols

ΔS = change in storage
N_p = is effective precipitation
V_p = actual precipitation
V_Q = is the stream flow
R = is the net loss resulting from deep percolation
E_a = is the actual evapotranspiration
E_p = is the potential evapotranspiration
a_1 = is a parameter related to soil texture
a_2 = is a parameter related to soil texture
a_3 = is a parameter related to degree of urbanization
a_4 = is a parameter related to deep percolation
a_5 = is a parameter related to canal loss
$\bar{S}$ = average water storage
S_i = is the storage at the beginning of the month i