DEVELOPMENT AND APPLICATION OF 2-PARAMETERS MONTHLY WATER BALANCE MODEL IN LIMITED DATA SITUATION, THE CASE OF ABAYA-CHAMO BASIN, ETHIOPIA

Seleshi Bekele Awulachew and Prof. Dr.-Ing. Habil H. B. Horlacher
Department of Hydraulic Engineering and Hydro-Mechanics
Dresden University of Technology, Germany

ABSTRACT

A monthly water balance model which can be used to generate runoff with few parameters is developed. The model is particularly useful for simulating runoff in cases of limited hydrometeorological and physical data, and where climatic conditions lead to low or large rainfall variations, like in temperate or semi-arid regions respectively. The model is used to simulate the runoff of 8 sub-catchments of the Abaya and Chamo Lakes drainage in the Rift Valley Lakes Basin of Ethiopia. The results of both calibration and validation show the model performs acceptably well and can be used to generate runoff for similar catchments like the study area considered.

Key Words: *Runoff Simulation, Water Balance, Limited Data Situation, GIS.*

INTRODUCTION

Runoff data that can be utilised for designing water projects with necessary data requirements such as sufficient spatial and temporal resolution is found scarcely in most parts of a developing country like Ethiopia. One way to curb such problems is the use of hydrological models and there by generate runoff, based on causative factors such as meteorological data, provided that such data are available in the study region considered.

Today a number of models and modelling system are available and used in various parts of the world. Categorisation of such models have been provided and discussed by various authors [see such as [1] and 10]. The accuracy of model results is a function of the accuracy of the input data and the degree to which the model structure correctly represents the hydrological process appropriate to the problem. Complex models require complex data, and if the required data can be roughly estimated, it may be better to use a model whose input data are in tune with available data resources, [5].

In places like the study area considered in this paper, not only the runoff data are scarce but also most physical data needed for hydrological models are difficult to obtain in the required coverage or resolutions. Thus, the successful application of sophisticated models with large data requirement is very difficult.

The model in this study uses variables of rainfall and evaporation as an input and runoff as an output on a monthly basis. In the model, 2 optimizable calibration parameters and 6 conceptual functional parameters are employed.

The monthly rainfall-evaporation-runoff models are useful in many ways. Generally the monthly water balance model is mainly applied in three fields, i.e. reconstruction of hydrology of the catchments, assessment of climatic change impacts, and evaluation of the seasonal and geographical patterns of water supply and irrigation demand, [13], (see also [2,12,13]). Particularly for the study area and for other similar areas the developed model can be used to generate runoff data as:

- to fill missing runoff data;
- to extend short record of runoff;
- to generate data for ungauged rivers.

In the past, as reviewed and discussed by [14[, water balance models have been developed at various time scales (e.g. hourly, daily, monthly and yearly) and to a varying degree of complexity. As another example, Vandeweile & et al. [12] developed methodology of monthly water balance models and performed comparative studies. Ye, W. and et al. [15] investigated conceptual rainfall runoff models in low yielding ephemeral catchments.

Short period (such as daily) types of runoff models are quite demanding in terms of data and are difficult to obtain such data in the study region. According to the argument given in [13], the monthly water balance models have been much more complicated for unitizing more information for achieving more physical soundness compared to the start of the beginning of the development of such models in 1950s. The simple monthly water balance model can still be sufficient and useful in terms of runoff simulation, just like the conceptual hydrological model is still of great value in the flood frequency despite the emergence of physical based models. In this study also a two-parameter runoff model has been developed and applied to simulate, extrapolate and predict runoff for the study area, where there is scarcity of data and use of distributed models is difficult.

MODEL EQUATIONS AND INPUT PARAMETERS

The model governing equations and the adopted numerical procedures are described stepwise in the following sections through discussing the input components. Three basic data are needed for calibration. These are precipitation, evapotranspiration and discharge. Additional data such as initial soil moisture as well as parameters range and values are also needed.

Precipitation

In general precipitation, *P*, is an observed parameter and is a major input in to the model. Obviously the accuracy of the observation and computation of aerial values from the network of stations is one of the most important limiting and decisive factor on the reliability of the water balance computations. As discussed in [12], there are both random and systematic errors in rainfall and such errors can affect and have serious impact on performance of water balance models.

In the study area where the model is used, although not adequate network exists, rainfall data as compared to runoff is having better spatial and temporal coverage. To use in the model the point rainfall data should be first processed so that the missing data through regional study should be filled, and record length themselves should be adjusted to equal lengths. Furthermore the point rainfall data should be converted to areal values through modified Thiessen polygon method. While the Thiessen polygon provides the areal value the associated modification enables to adjust the rainfall in to mean watershed elevation. These tasks were performed as pre-processing of data, results are made available and are not discussed in this paper.

Evapotranspiration

Evapotranspiration is the second important parameter in the model under discussion. In this and similar models, it is important to estimate the evapotranspiration as accurately as possible both in terms of space and time. Various methodologies are available to estimate potential evaporation/evapotranspiration, and such methodologies can be referred in standard hydrology texts, such as [5, 9] and etc.

In most studies in the application of water balance models actual evapotranspiration were defined as a function of potential evapotranspiration with inclusion of soil moisture or precipitation see for example the discussion given *by* [14] and [13]. The formula before considering a C parameter, given in the latter reference takes the form:

$$\frac{EA}{PET} = \tanh\left(\frac{P}{PET}\right) \qquad (1)$$

or this can be defined as:

$$EA = f(m) \times PET \qquad (2)$$

where

EA, PET: actual and potential evapotranspiration respectively

$f(m)=f(P,S_{t-1},SMC,PET)$: function of total moisture

The above basic equation takes in this study of the form:

$$f(m) = f_1 = \tanh\left(\frac{P + \frac{S_{t-1}}{SMC}S_{t-1}}{PET}\right) \qquad (3)$$

Where

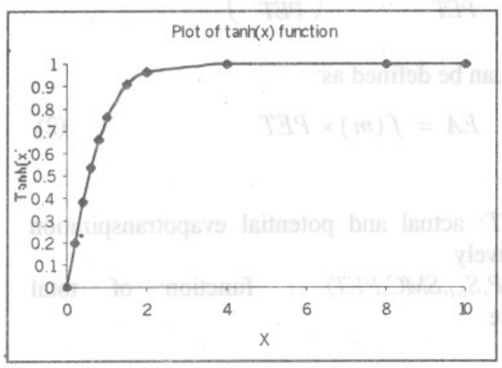
P : precipitation

SMC : field capacity of the catchment and is the second model parameter.

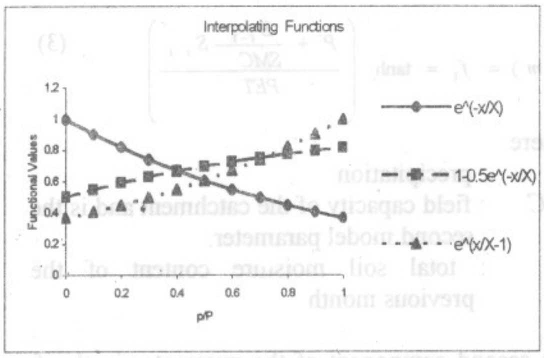
S_{t-1} : total soil moisture content of the previous month

The second component of the numerator in the f_1 function, i.e. $\frac{S_{t-1}}{SMC}S_{t-1}$, which is a linear interpolator function. It takes a value range of 0 for dry and 1 for full wet soil reaching soil moisture capacity, in the tan-hyperbolic function, Fig. 1(a) shows this contraction function. It was added to account the importance of the soil moisture in estimating actual evaporation from potential evaporation.

In effect, the modification can be described as, that in any given month evapotranspiration would take place even without precipitation provided there is sufficient soil moisture. The modification was done after experimenting the model without this second component for the study basin. Similar ideas and very extensive interpolation functions for evapotranspiration, slow and fast runoff computation are provided in [12]. Furthermore, in the writer's opinion the accuracy of f_1 function without this term and with inclusion of only the P-term in areas like the study basin, where the rainfalls are not well distributed throughout the year, is doubtful. In areas where there are good distributions of rainfall throughout the year the inclusion or neglect of the second term may not bring significant difference.



(a)



(b)

Figure 1 Interpolating Functions: (a) Characteristics of tanh(x) function (b) Characteristics of interpolating f_4 and f_5 functions

As the modification factor f_1 doesn't accurately define the variability of the relationship between the actual and potential evapotranspiration, a first model parameter and an evaporation factor, C, is introduced as a multiplying factor. Thus, the equation adopted in the water balance model takes the form:

$$EA = C \times f1 \times PET \quad (4)$$

The potential evapotranspiration, PET, in the above equation and through out the calibration, validation and prediction phases should be obtained as accurate as possible through available computation methodologies. The PET values used were computed using Thornthwaite's method and adjusted with evaporation factor, EF. The method was chosen after evaluating the available data and associated possible method of computation that can be used in the study area. The EF is needed because of the fact that the Thornthwaite's method underestimates evapotranspiration in arid and semi arid areas, see [4, 11] on the subject of under-estimation of Thornthwaite's method.

In the presence of pan data for the evaporation database, or if there is any other better accurate evapotranspiration estimator that can be used in the study region the EF factor is redundant and the discrepancies could be adjusted by the C parameter in the model. After evaluating with few stations pan evaporation data and through comparing the Thornthwaite's method with a more accurate method i.e. Penman-Montheith's method, see [11,5] for the latter method, a factor of about 1.65 is found appropriate to be used. This factor was, however, found for low land gauged areas of the study area where the data were available. Thus, an EF factor of 1.4 was adopted as an average for the entire study region. Similar to the results considered for precipitation, these computations procedures are not provided in this paper.

Monthly Runoff

The monthly runoff is a function of total moisture resulting from current month's P and EA and a component of the moisture in the soil stored from the previous month. The soil moisture stored from the previous month is a balance function of previous month's P, EA and discharge Q. The discharge is estimated by:

$$Q = M \times \tanh\left(\frac{S_{t-1}}{SMC}\right) \quad (5)$$

or can be written as:

$$Q = M \times f2 \quad (6)$$

where

Q : monthly Runoff

M : water content in the soil or can also be redefined as " available total moisture" component

f_2 : Runoff generating factor, from the soil moisture and is a reduction factor

The form of Equation 5 was used in other models such as in that of [13]. In the current study, the function f_2 is still assumed to take a hyperbolic function, for use in the study region and after performing a number of tests, is modified as follows:

$$f_2 = \tanh\left(\frac{S_{t-1} + P - EA}{SMC}\right) \quad (7)$$

The M component in Equation 6 can be treated in two ways, depending on the magnitude of rainfall.

i) For small rainfall, when $P<PET$

$$M = S_{t-1} \times f3 + P - EA \quad (8)$$

ii) For large rainfall magnitude, when P>PET

$$M = S_{t-1} \times f_3 + P_2 - EA + P_1 \times f_4 \quad (9)$$

Where f3, depending on the watershed soil respond condition, and set to be described by:

$$f_3 = 1 - 0.5 \times e^{-\frac{S_{t-1}}{SMC}} \quad (10)$$

The P_1 and P_2 variables are described by:

$$P_1 = P - PET \quad (11)$$

$$P_2 = P - P_1 = PET \quad (12)$$

The f_4 function describes the excess rainfall magnitude and associated direct runoff response in to streams and can made to vary between:

$$f_4 = e^{-\frac{P1}{P}} \quad \text{to} \quad f_4 = e^{-\left(1-\frac{P1}{P}\right)} \quad (13)$$

The functional parameters described above has been conceptualized as follows. The f_2 component reduces the "amount of available total moisture", M, to be removed as runoff. This component is dependent on the available water relative to the field capacity of soil of the catchment. Its value is limited to with the boundary conditions that, the upper bound of $f_2 \leq 1$ and $f_2 \geq 0$ as lower bound.

The component of M function from the soil moisture of the previous month is represented in a reduced form by a factor f_3, as it is not equally available for removal as that of the other components. Thus the factor f_3 modifies the removable soil moisture and assumes the form given by Eq. (1), see also Fig. 1-b above. Which means the removable soil moisture is a function of available total soil moisture relative to the field capacity of the soil, and takes the value between 0.5 to 0.816, and can't provide as equal contribution as that of direct precipitation excess in to runoff.

The conceptualization of Eq. (8) follows that, until the added rainfall is in excess of PET, it is removed by evapotranspiration and runoff. Thus rainfall is considered to be not increasing the soil moisture, as evaporation is removing the moisture of the top soil layer and hence Eq. (8) applies. When the precipitation exceeds the PET part of the rainfall goes to runoff as a function f_4 and the soil moisture also increases with the remaining excess precipitation component. Eqs. (11) to (13) together with Eq. (9) and Fig. 1-b above describe this condition. In particular function f_4 is made a variable, and to take a range which may have values between (1,0.368) to (0.368,1). The alternative functions are reflection of each other and which form to take must be checked and evaluated in calibration and validation phases. The f_4 functional parameter is dependent on particular watershed and its associated response characteristics and also reflects how the areal rainfall is represented from the point rainfall information.

Thus, given the input parameters, P and PET, the unknown parameters are C and SMC as well as initial soil moisture as initial boundary condition. The remaining functions and variables are implicitly defined with respect to the input parameters and the unknown parameters. The C and SMC parameters need to be selected through optimization of the model criteria, and the initial soil moisture can be computed in the model for gauged rivers. For ungauged rivers it can be initially assumed and latter modified using average of the months in the year.

NUMERICAL PROCEDURE

For the available P and PET, the following describe the numerical procedure:

1. *EA* is estimated from Eq. (4)
2. The following balance component, available total moisture, for discharge, *M*, provides *Q* according to Eq. (8) or (9)
3. The remaining soil moisture component at the end of current month is given by :

$$S = S_{t-1} + P - EA - Q \quad (14)$$

4. The component S_{t-1}, which is needed at the beginning, can be defined accurately in the calibration and verification stage by trial and error putting *Qg* in Eq. (6) utilizing Eq. (8) or (9) for M. In case of ungauged watershed data value of S_{t-1} at initial stage is assumed and then can be adjusted from average of the same months in different years. The same principle can also be applied in the calibration and validation stage, but as far as the procedures of numerical solutions are based on optimization by functional evaluation as discussed latter, there is no need to use averaging and the initial soil moisture can be accurately computed.
5 Steps 1 to 4 repeated for the entire intended period of computation.

MODEL PARAMETER ESTIMATION

Model Criteria

Criteria, based on relative error (RE) of volumetric fit between simulated and observed; efficiency criteria, R^2 according to Nasch and Sutcliffe, see [14] and Bias (*B*) are used. The RE criteria is given by:

$$RE = \frac{\sum (Q_g - Q_p)}{\sum Q_g} x100\ \% \quad (15)$$

where
Q_g gauged (observed) data
Q_p simulated runoff

The value of RE is close to zero for good simulation.

The Bias (B) shows the sum of differences between gauged and simulated data divided by data size.

The Nasch and Sutcliffe efficiency criteria is given by R^2 as:

$$R^2 = \frac{F_0 - F}{F_0} \times 100\,\% \quad (16)$$

$$F_0 = \sum (Q_g - Q_{av})^2 \quad (17)$$

$$F = \sum (Q_g - Q_p)^2 \quad (18)$$

$$Q_{av} = \frac{\sum_{i=1}^{N} Q_g}{N} \quad (19)$$

where
Q_{av} average of the observed runoff
N : record length
F_0 : is the sum of square of deviation of observed runoff from the mean
F : is the sum of squared deviation between observed and predicted runoff

Minimization of *F*, in another words a value of *F* close to 0 and R^2 near 100% is a criterion that can describe the performance of a good model, and at the corresponding point good model parameters can be obtained. This can be described in another form as:

$$F = \min \sum \left[Q_g - Q_p(X_t;\beta)\right]^2 \quad (20)$$

Solving the minimization problem furnishes estimates of model parameters, β for the input variables X_t, in this case values of *C*, *SMC* with *P*, *PET* respectively

Parameter Analysis and Optimization

The optimum values are found by automatic optimization based on a search algorithm developed in this study, which searches the minimum of the difference between simulated and gauged stream flows based on Nasch-Sutcliffe efficiency criteria. The search algorithm involves systematic trial alterations (*known as "literation")* of the value of the model parameters, evaluating the functions and eventually computing the model criteria.

Minimization of *F* as in Eq. (20) or in other words, optimization using R^2 as in Eq. (16) was used in this study, and that asserted the globally optimum parameter combinations. After obtaining the globally optimum parameters the remaining criterion are evaluated using the optimum parameters.

The functional parameter f_1 to f_3 are internally computable depending on the input variables. The two options of f_4 can be evaluated by alternatively choosing the functions for a particular watershed under investigation.

Specifically the search algorithm in the calibration period involves:

1. A range of *C* and *SMC* values are assumed
2. For every *SMC* optimum *C* values, which are considered as local optimum parameter combinations are searched through evaluating the numerical equations & the model criterion
3. Among the *C* and *SMC* values, the most optimum values, which satisfy efficient conditions for R^2 or minimum condition for *F*, is searched to obtain global minimum combinations.
4. After obtaining optimal *C* and *SMC* values, the functions are re-evaluated to obtain optimum results.
5. Furthermore, *RE* and *B* values are computed in the model.
6. Finally, the computed parameters together with statistical and graphical analysis helps to observe the model performance.

COMPUTER PROGRAM, MODEL EVALUATION, DISCUSSION AND APPLICATION

Short Description of Computer Program

A Fortran computer program has been developed to aid solving the previously discussed governing equations of the monthly water balance in calibration, evaluation and application stages. The model constitutes three major sub-programs having their own subroutines. The models are executed independently from one another as MOWBAL, EVA and PREDICT sub-models. The structure of the subroutines presented in Fig. 2 below.

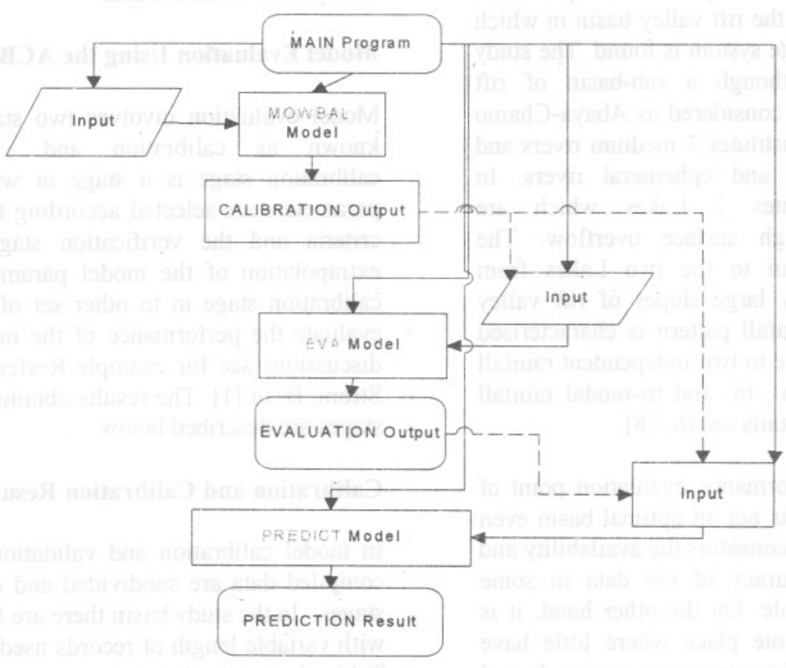


Figure 2 General layout of the structure of water balance model of runoff simulation (Note that the broken line direction of flow lines are optional)

The main program reads the control file & other data input, assigns the output file names, and reads data depending on the decision in the control file which task to perform, i.e. (Calibration, Evaluation or Prediction).

The sub-program MOWBAL, which can be executed independently has been developed to undertake the calibration and write the calibration result in a user defined file. Similarly, the EVA and PREDICT sub-models perform evaluation and runoff generation respectively and could be executed independently. EVA evaluates the optimised parameters from calibration stage. Hence, in addition to the input data through main program needs result of calibration parameters. The PREDICT sub-program using the selected parameters, rainfall and evapotranspiration data simulates runoff.

Description of the Study Basin & River System for Model Evaluation

The study basin for which the above mentioned model was developed and tested is found in southern part of Ethiopia. Figure 3 shows the location on Ethiopian Map and the particular major basin which is the rift valley basin in which the study area drainage system is found. The study drainage system, although a sub-basin of rift valley lakes basin, is considered as Abaya-Chamo Basin (ACB) and constitutes 3 medium rivers and a number of small and ephemeral rivers. In addition it constitutes 2 Lakes which are interconnected through surface overflow. The rivers are draining in to the two Lakes from surrounding relatively large slopes of rift valley escarpments. The rainfall pattern is characterised as complex system due to two independent rainfall origins leading to uni-, bi- and tri-modal rainfall characteristics. For details see [6,7,8].

From the model performance evaluation point of view the study basin is not an optimal basin even in Ethiopia when one considers the availability and quality of data. Accuracy of the data in some gauges are questionable. On the other hand, it is one of the most remote place where little have been done regarding the water resources study and the area is inhabited by large population and due to deforestation and similar human impacts the water resource system and the lakes are heavily affected. As a result the aim in here is to device a mechanism by which the water resources can be assessed for this area based on the available limited data.

As this study is associated with another comprehensive study of water resource investigation and water use planning, a Geographic Information System (GIS) has been developed for the drainage system and given in [7]. As a result of the development of GIS of the drainage basin, river and hydrmeteorlogical gauging systems were correctly represented and useful physical hydrological parameters that can be used in the hydrological model were derived. These parameters include such as area, basin and stream slope, mean basin elevation and etc. The development of GIS, in addition to providing extensive drainage basin data, has provided more accurate results than existing and documented drainage data by Ministry of Water Resources. While the map in Fig. 3 provided a general watershed, subdivided based on major recognisable permanent and ephemeral rivers, the study basin was remodelled using gauge outlet points and the ACB is then subdivided in to 52 watersheds, of which 2 are lake water body of Abaya and Chamo Lakes.

Model Evaluation Using the ACB Data

Model evaluation involves two stages, which are known as calibration and validation. The calibration stage is a stage in which the model parameters are selected according to the set model criteria and the verification stage involves the extrapolation of the model parameters set in the calibration stage in to other set of input data and evaluate the performance of the model. For detail discussions see for example Resfegaard, J. C. and Strom, B. in [1]. The results obtained for these two stages are described below.

Calibration and Calibration Result

In model calibration and validation, the available compiled data are subdivided and used in the two stages. In the study basin there are 8 gauge stations with variable length of records used for calibration. Table 1 shows the rivers, corresponding gauge location, data year and size, model criterion and obtained parameters.

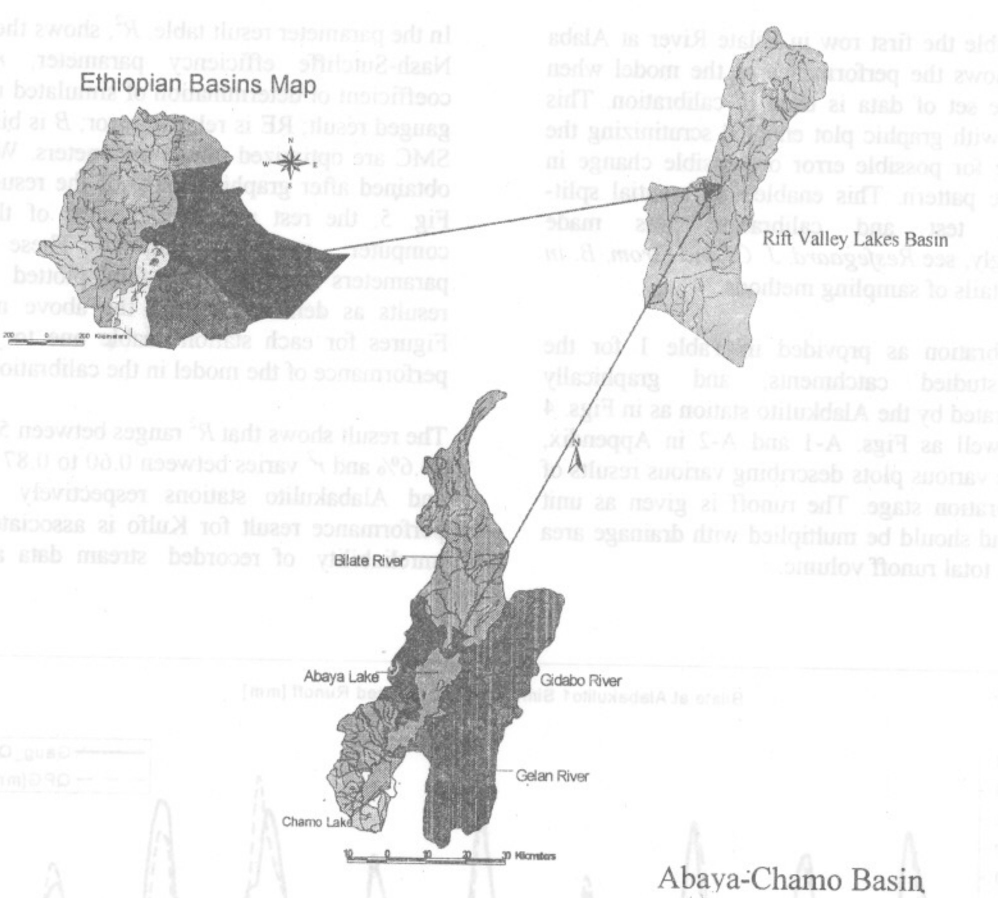


Figure 3 Abaya-Chamo Basin Location on Ethiopian & Rift Valley Drainage Map with Major Rivers

Table 1: Summary of Calibration Parameters Result of MOWBAL Model

River	Watershed Gauge Reference	Range (Yr.)	Data Size	N-S R^2 (%)	Co. det. (r^2)	RE (%)	B (mm)	C	SMC	Remark
Bilate	Bialate at Alabakulito[1]	1971-1993	276	57.42	0.59	-4.03	-0.543	1.433	1500	For the complete data series
	Bilate at Alabakulito	1971-1979	108	86.60	0.87	-2.92	-0.416	1.394	950	
	Bilate at Tenabilate	1971-1979	108	79.87	0.81	-0.01	-0.002	1.385	1000	
	Weiru Tributary[2]	1983-1988	72	75.71	0.76	-0.98	-0.338	1.314	500	
Gidabo	Gidabo at Apposto	1976-1986	132	75.05	0.75	1.37	0.425	1.087	1250	
	Kolla Tributary	1976-1990	180	62.87	0.65	2.03	0.706	1.405	1500	
Gelana	Gelana nr. Yirgacheffe	1980-1989	120	81.34	0.82	0.9	0.409	1.225	700	
Hare	Hare nr. Arbaminch	1980-1988	108	71.61	0.72	0.67	0.193	0.916	850	
Kulfo	Kulfo nr. Arbaminch	1981-1985	60	59.17	0.60	0.37	0.115	0.783	1500	
	Kulfo nr. Arbaminch	1979-1980	24	64.48	0.65	-0.17	-0.082	0.583	1500	For comparing with Evaluation

Note: superscript 1 shows typical example in calibration performance before differential split sampling, superscript 2 shows data used also in evaluation tests in calibration for checking.

In the Table the first row in Bilate River at Alaba Kulito shows the performance of the model when the whole set of data is used in calibration. This together with graphic plot enabled scrutinizing the data base for possible error or possible change in water use pattern. This enabled differential split-sampling test and calibration was made accordingly, see *Resfegaard, J. C. and Strom, B. in (1)* on details of sampling methods.

The calibration as provided in Table 1 for the whole studied catchments, and graphically demonstrated by the Alabkulito station as in Figs. 4 & 5 as well as Figs. A-1 and A-2 in Appendix, show the various plots describing various results of the calibration stage. The runoff is given as unit runoff and should be multiplied with drainage area to obtain total runoff volume.

In the parameter result table, R^2, shows the value of Nash-Sutcliffe efficiency parameter; r^2 shows coefficient of determination of simulated result and gauged result; RE is relative error; B is bias; C and SMC are optimized model parameters. While r^2 is obtained after graphical plots of the result, like in Fig. 5, the rest are direct results of the model computer program output. These tabular parameters together with four plotted graphical results as demonstrated in the above mentioned Figures for each station enable one to judge the performance of the model in the calibration phase.

The result shows that R^2 ranges between 59.17 % to 86.6% and r^2 varies between 0.60 to 0.87 for Kulfo and Alabakulito stations respectively. The low performance result for Kulfo is associated due to unreliability of recorded stream data and poor

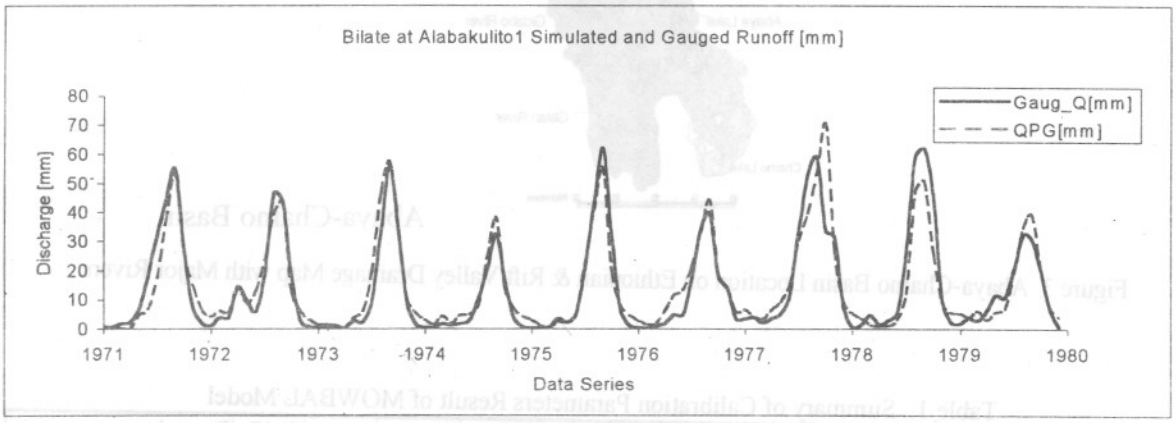


Figure 4 Alabkulito Gauged and simulated runoff plot in the calibration period

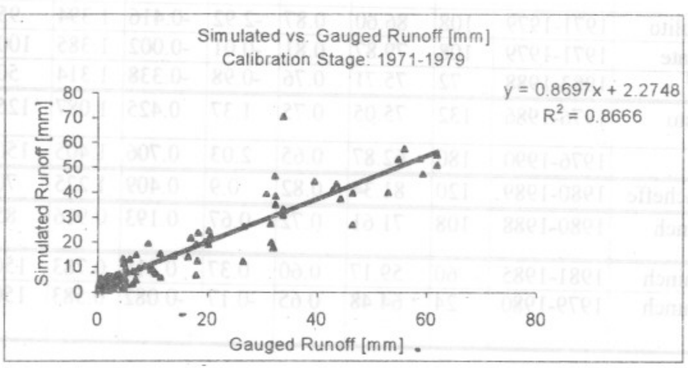


Figure 5 Correlation of gauged and simulated runoff

network of meteorological data coverage. This unreliability later confirmed by the provider of the data source, and also in the model by using the 1981-1985 parameters in 1979-1980 evaluation and obtaining the model parameters again in the calibration and comparing with evaluation result. The other model criterion, i.e. *B*, *RE* as well as the model parameters *C* and *SMC* are also provided

Validation and Results

Validation tests were performed for 9 catchments in the study basin, and their parameters summary results are provided in Table 2 and Figs. 6 and 7 as well as Figs. A3 and A4 in Appendix as a demonstration. In the plots broken lines of gauged data are showing missing values of the recorded data, and it is interesting also to note how the hydrograph of the simulated result at the missing values look like.

The validation result table contains similar parameters with that of calibration. The difference is that parameters *C* and *SMC* are taken from calibration result and used to evaluate the validation data sets. In the remark column, it is shown that, which data element's parameter of the calibration is used in the validation.

The figures are also similar set of data with that of calibration. While Fig. 6 is showing a sample for gauged and simulated runoff plot in the validation phase, Fig. 7 is showing a correlation plot. Furthermore, Figs. A-3 and A-4 in Appendix show additional plots of result of validation stage. Such plots for other stations are not provided in this paper, due to limitation of space.

Table 2: Summary of Evaluation Parameters Result of MOWBAL Model Evaluated by EVA

River	Watershed Gauge Reference	Range (Yr.)	Data Size	C	SMC	N-S R^2(%)	r^2	RE (%)	B (mm)	Remark: Parmeters Used from period
Bilate	Bialate at Alabakulito	1989-1996	93	1.394	950	81.62	0.82	-4.94	-0.76	1971-1979
	Bilate at Tenabilate	1989-1996	93	1.370	1050	68.90	0.70	6.49	0.917	1971-1981
	Batena tr. of Bilate[1]	1988-1990	29	1.394	950	85.53	0.86	-12.64	-1.738	Alabakulito 1971-1979
	Weiru tr. of Bilate	1989-1992	39	1.314	500	71.22	0.72	-1.69	-0.371	1983-1988
Gidabo	Gidabo at Apposto	1987-1996	101	1.087	1250	65.33	0.70	-10.77	-2.918	1976-1986
	Kolla tr. of Gidabo	1991-1996	66	1.405	1500	63.64	0.64	1.97	0.667	1976-1990
Gelana	Gelana nr. Yirgacheffe	1991-1996	60	1.250	650	77.50	0.79	8.95	3.89	1980-1989
Hare	Hare nr. Arbaminch	1991-1993	32	0.916	850	60.83	0.64	-13.47	-3.46	1980-1988
Kulfo	Kulfo nr. Arbaminch[2]	1979-1980	39	0.783	1500	50.50	0.65	20.33	9.67	1981-1985

Note: subscripts 1 shows station used in evaluation only as proxy-basin test

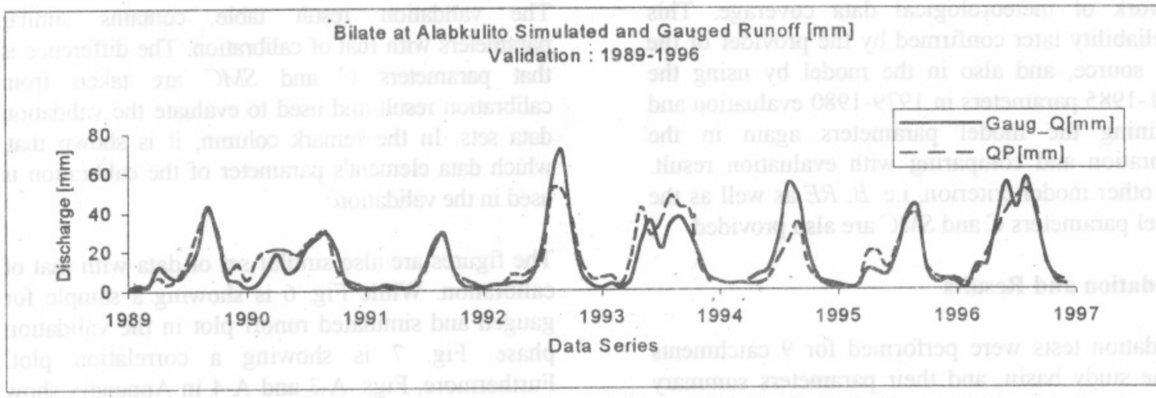


Figure 6 Alabkulito Gauged and simulated runoff plot in the validation period

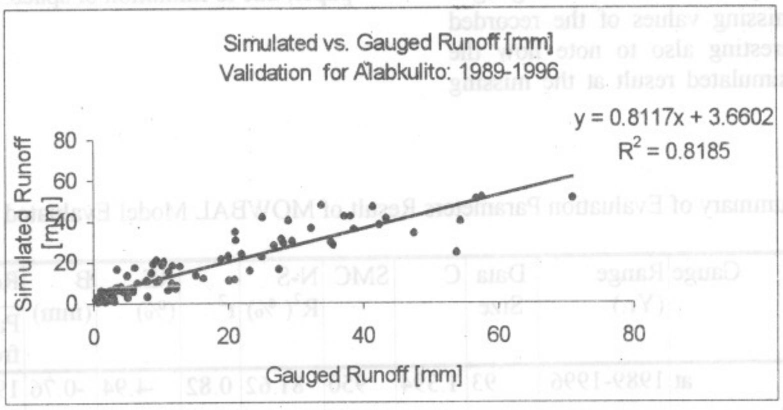


Figure7 Correlation of gauged & simulated runoff

As can be seen from the Table values of R^2 range from 50.5 for Kulfo to 85.53 for Batena. The latter uses the Bilate at Alabkulito parameters, i.e Batena river is evaluated adopting proxy-basin test. In the absence of Kulfo the value ranges between 60.83 to 85.53. The other model criterion bias & relative error are also showing the proposed model evaluation parameter in the validation phase.

APPLICATION OF THE MODEL FOR DATA EXTENSION AND FOR UNGAUGED BASINS IN THE STUDY AREA

The proposed model in the sub-program known as PREDICT is capable of providing both unit and total runoff for ungauged areas if the necessary parameters and input variables can be provided. In filling missing values or extension of runoff data PREDICT can be employed, using the parameters obtained in the calibration stage.

In order to be able to estimate the *C* and *SMC* parameters, such as for ungauged areas, one can perhaps assign regional values from the result of the parameters of neighboring rivers. Investigation was made to find a relationship between *C* and drainage parameters derived in GIS for this particular study area. A useful result, described by Eq. 21, was obtained by relating *C* with basin/watershed slope (BS). Figure 8 shows the relationship of *BS* against *C*.

$$C = 1.5496 - 3.0617\ (BS) \tag{21}$$

and $R^2 = 0.90$

The obtained relationship provided logical result in that the *C* values are dependent on slope because, areas with larger slopes tend to generate higher runoff compared to lower slopes. In the latter, the rain falling on the ground finds sufficient time for evaporation to take place and thus lower the yield of runoff. It should, however be obvious that t he *C*

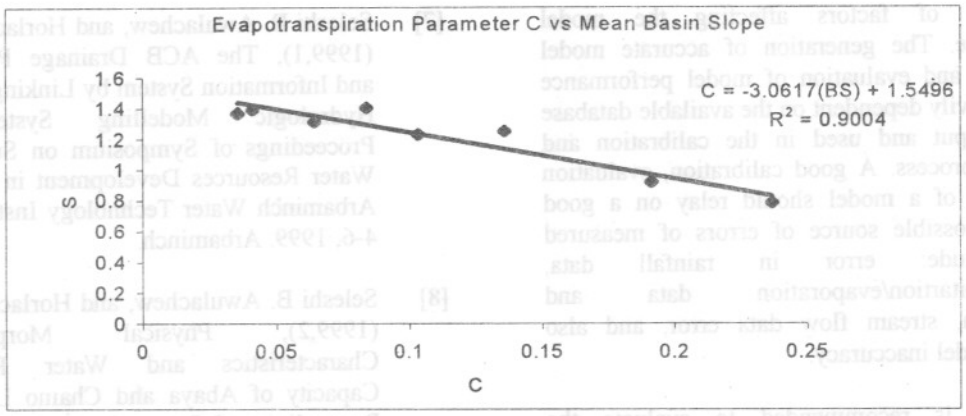


Figure 8 Correlation of Parameter C and Basin Slope

parameter is not only dependent on BS but also on many other and perhaps more important factors influencing evapotranspiration, and one has to use the above equations cautiously. In order to develop a sound parameter estimation method for ungauged areas, one has to test *C* against *BS* itself and other variables with extensive data.

The *SMC* parameter should be dependent on and reflection soil depth and characteristics, aquifer and ground water characteristics and other drainage parameters affecting total soil moisture capacity, which are not subject to direct determination in a lumped conceptual model. If one wants to employ the model for ungauged rivers regional values such as from adjoining rivers or hydrologically similar areas should be adopted. Exact distribution law should be defined based on extensive analysis.

DISCUSSION AND CONCLUSION

Before starting to develop the above discussed model, attempt was made to relate runoff with rainfall as well as rainfall and evaporation on monthly or using previous months (backward sweep) and current month and etc., using regression. These have provided very poor results for predicting runoff[1].
The proposed model which includes "total soil moisture", on the other hand, is capable of simulating the monthly runoff series. The model performance as indicated in both calibration and validation, for an area where little information regarding runoff is available, has provided good results. The adoption of the model can heavily facilitates computation of expected runoff and enhance understanding of the water resource system which can help water use planning and similar purposes.

If influence of outliers, both in calibration and validation, are removed, which was not done in the modeling process and reported result, one can obtain highly significant improvement. If for example just two data elements which are appearing as an outliers in the error graphical plots of calibration result, given in Fig. A-1 in the appendix for Bilate at Alabkulito, which are the data pairs of October 1977 and October 1978, are removed, one obtains a substantial improvement of coefficient of determination of simulated and gauged runoff from a value of 0.87 to a value of 0.92.

The available data in the study region is fully utilized in calibration and validation phase. The model is further utilized to estimated runoff for ungauged rivers of the study basin and the result is utilized in the water balance study of the two Lakes in the basin. The preliminary results of the lakes water balance which are not discussed here indicated the result obtained from the model in this study provided a quite good result of runoff component which can be confirmed by lake water level simulation.
Combining the model with GIS based drainage information also enhanced accurate estimation of drainage and river data and characteristics. This in turn enabled correlation of model parameter with physical characteristics.

The developed model has certain limitations mainly associated to the study region and there are

[1] The regression results are not provided in this study.

a number of factors affecting the model performance. The generation of accurate model parameters and evaluation of model performance itself is heavily dependent on the available database used as input and used in the calibration and validation process. A good calibration, evaluation and testing of a model should relay on a good database. Possible source of errors of measured data include: error in rainfall data, evapotranspitartion/evaporation data and computation, stream flow data error, and also possible model inaccuracy.

Finally, it is recommended to evaluate the performance of model in other rivers of Ethiopia and other similar parts of the world. It is also very useful to undertake a comparative studies with other similar models.

ACKNOWLEDGEMENT

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APPENDIX

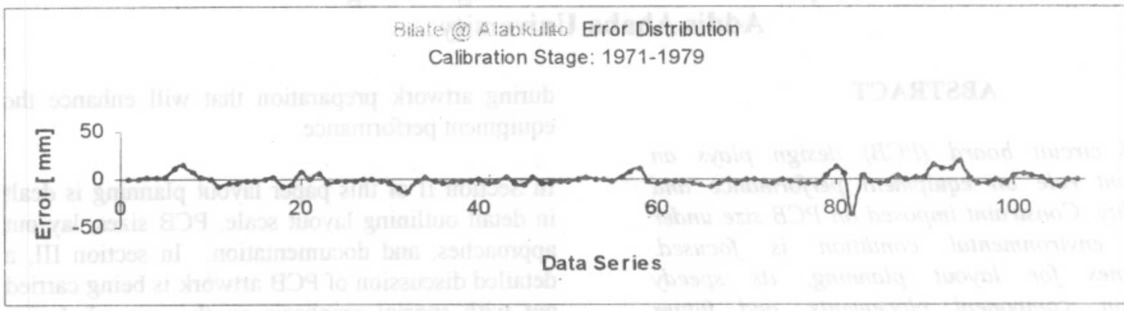

Figure A-1 Gauged and simulated data error distribution

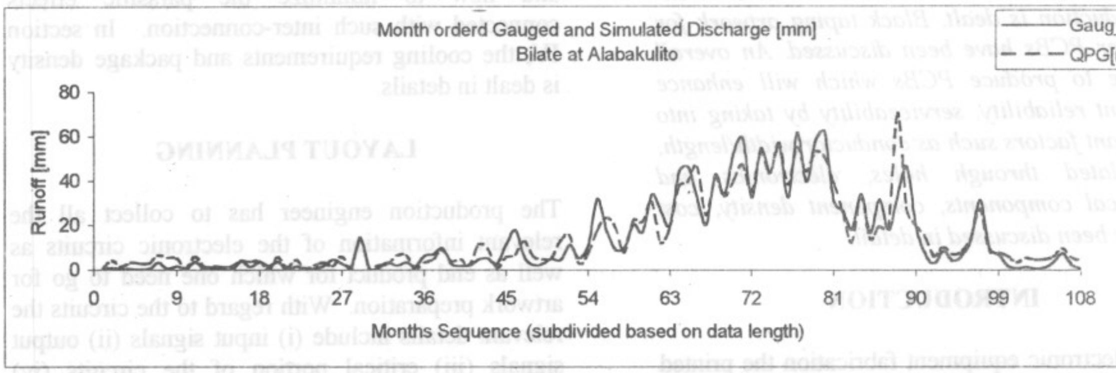

Figure A-2 All years month sequence ordered plots of simulated and gauged data in calibration

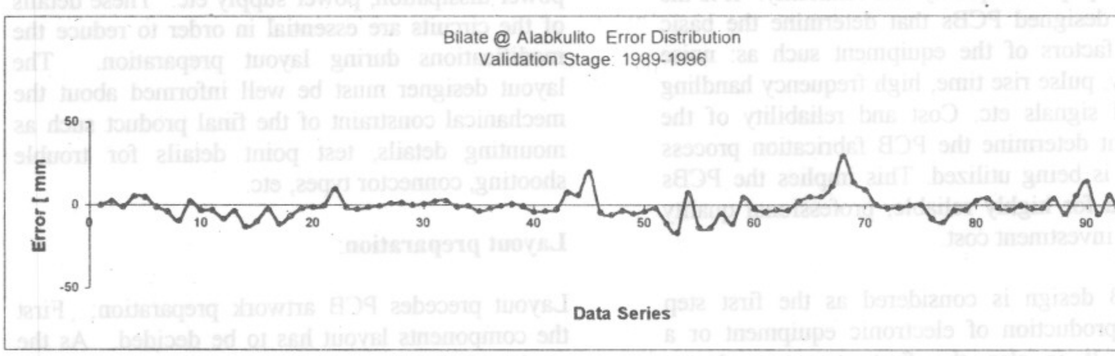

Figure A-3 Gauged and simulated data error distribution in validation period

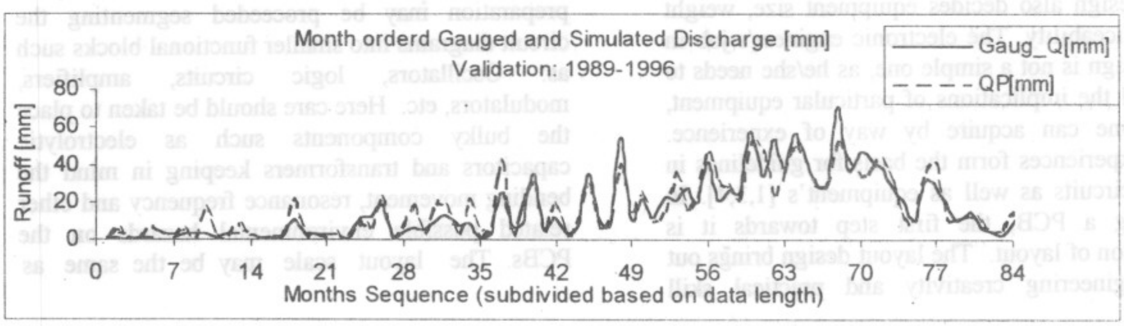

Figure A-4 All years month sequence ordered plot of simulated and gauged validation data