Jurnal Kejuruteraan 1 (1989) 65-86

Comparison of the HYSIM and the Tank Models in Cho Shui River Basin, Taiwan

A.F.M. Afzal Hossain

ABSTRACT

The Cho Shui river Basin is the second largest basin of Taiwan. To conduct the optimum water resources, utilization study for the basin daily flow data are developed using mainly two models e.g. the HYSIM (Hydrologic Simulation Model), and Tank Model. Both models applied are of rainfall runoff type. The HYSIM model has been applied to ten gauged sites, which is calibrated for short period of record and then daily flow data for 28-years are developed. During calibration more weightage is given on low flows. Tank model latest version is applied to four basins out of the ten. It is observed from the statistical comparison and matching of hydrographs that the results from the HYSIM model are better than that of Tank Model in those four stations.

ABSTRAK

Lembangan Sungai Cho Shui adalah yang kedua terbesar di Taiwan. Kajian ke atas penggunaan sumber-sumber air secara optimum bagi aliran harian lembangan dijalankan terutamanya dengan menggunakan dua model iaitu 'HYSIM' (Hydrologic Simulation Model) dan 'Tank Model'. Kedua-dua model adalah daripada jenis air harian lebat hujan. Model 'HYSIM' digunakan untuk sepuluh tapak yang telah ditolokkan dan dikalibrasikan bagi kala rakaman yang pendek dan kemudian data aliran bagi 28 tahun. Semasa kalibrasi, pemberatan yang lebih diberikan kepada aliran-aliran yang rendah. Versi terbaru bagi "Tank Model" digunakan kepada empat daripada sepuluh lembangan tersebut. Adalah diperhatikan melalui perbandingan statistik dan padanan dengan hidrograf bahawa keputusan daripada model 'HYSIM' lebih baik daripada "Tank Model" bagi keempat-empat tapak tersebut.

INTRODUCTION

Manley (1977) developed the HYSIM model which has the same principle with the model developed by Porter and McMahon (1971). The parameters of the model are to be derived from the measured basin characteristics without reference to gauged flows. This model has seventeen parameters to describe the nature of the basin. Basin area and correction factors are used to compensate for systematic errors in precipitation, potential evapotranspiration, and snowfall measurements.

Variation of time and space is considered in the model. The variation in time is taken into consideration by integrating the run-off over each time increment. The variation in space is considered in two ways. Firstly, the potential infiltration rate is assumed to have a rectangular probability distribution function. Secondly, the basin can be divided as many sub-basins as necessary to represent the hydrological and meteorological heterogeneity of the area. Kinematic methods are used for river routing.

The early application of the model was made for the Dove basin in United Kingdom having a basin area of 883 km^2. This had produced a 45-years of simulated flows which provided high correlation with the recorded flows. The correlation coefficients range from 0.82 to 0.87 for the daily data, and from 0.91 to 0.98 for the monthly data.

Afzal (1981) used this model for the Nam Mae Chan Basin in Thailand having a recorded flow data of only eight years. Considering the basin as ungauged and using the concept of measured basin characteristics, flows were simulated for comparison to the recorded data. This provided correlation coefficients from 0.77 to 0.87 for the daily flows, and 0.88 to 0.99 for the monthly flows. Finally, the model was calibrated through the Rosenbrock Method (Beveridge et al. 1970) for further flow synthesis, but there was insignificant variation of the results obtained.

The wide scope of use of the model covers streamflow generation, extension of data records, real-time flow forecasting, checking of data validation, modelling of groundwater, modelling of soil moisture, and flood studies, especially for ungauged catchments.

TANK MODEL

This model was developed by Sugawara (1961), but the earliest version was introduced by Sugawara and Maruyama (1951). This model is a series of storage-type model to account for the non-linear relationship between rainfall and runoff. The principle is based on the hypothesis that run-off and infiltration are the function of the amount of water stored in the ground. The structure of the model is composed of storage-type models of tanks which are set vertically in series. The structure can represent the existence of several components of discharge such as surface, sub-surface, and base flows.

Subsequent versions of the model were reported by Sugawara et al. (1974 & 1976), but the latest development was made regarding the incorporation of the automatic calibration for the outlet coefficients (Sugawara 1979).

Regarding the application of the model, it was used in various basins like the Bird in the USA, Kitsu in Japan, Bikin in USSR, and the Chao Phraya, Ping, and Nam Mun rivers in Thailand. In some of the above basins, the automatic calibration procedure has been applied giving satisfactory results.

DESCRIPTION OF THE MODELS

A brief summary of the theories of hydrologic models which include the HYSIM model, and the tank model are described here.

HYSIM MODEL

This stimulates the hydrological data of a given site, ungauged or gauged using the observed characteristics of the basin considered. These characteristics are defined in terms of values that corresponds to seventeen parameters that are needed by the model.

The model needs hydrologic and hydraulic characteristics to be evaluated that describes the basin. These informations are used in the synthesis of flow data.

Hydrologic Part The structure of the model represents seven natural storages viz: snow, interception, upper soil horizon, lower soil horizon, transitional groundwater, groundwater, and minor channels. This is shown in Fig. 1. The catchment under con-

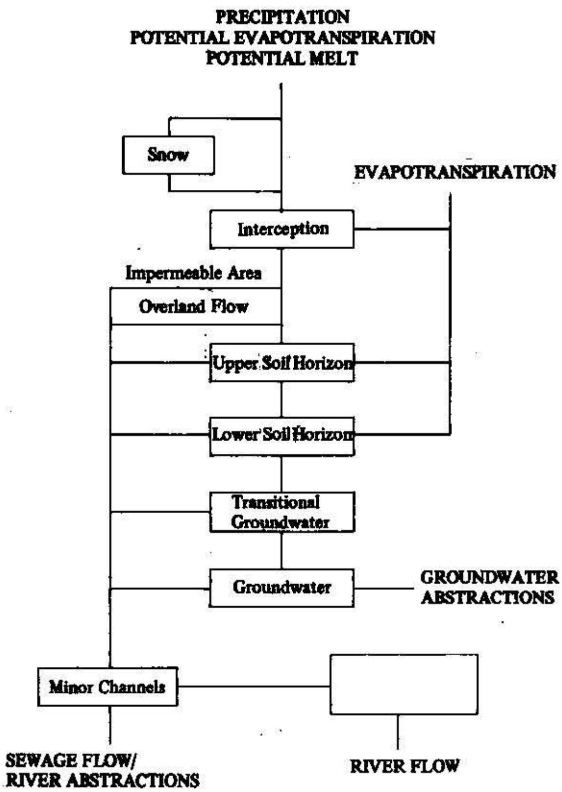


FIGURE 1. HYSIM model structure.

sideration can be divided into a number of subcatchments, each of which should be reasonably homogeneous with respect to soil type and meteorology.

Hydraulic Part The runoff from the minor channels is routed through the major river channels. The river channels are divided into sections, each of which has little variation in hydraulic characteristics along its depth.

Flow in open channels can be described most accurately by Saint Venant (Boley 1958) equations but these equations are not explicitly solvable. The methods of solution that are available are not suitable for a hydrologic model as they require an iterative solution for small time increments. Most of the terms in Saint Venant equations have only minor effects, and flow can be described adequately by the simplified form known as the kinematic method (Lighthill and Witham 1955).

The input data for the model are as follows:

1. Precipitation – This is based from the real precipitation of the basin.
2. Potential evapotranspiration rate – The estimates are based from pan data or empirical relations.
3. Potential melt rate – This can be based from the degree-day method (Chow, 1964) or from a more complex one.
4. Sewage flow/direct abstractions – The net figures are used.
5. Groundwater abstractions.

From these data, none of the items is compulsory. The data can be given in a monthly, daily, or any shorter time scale provided there are integral number of data per day.

TANK MODEL

The tank model is a nonlinear hydrological model designed to derive or generate discharges. This rainfall-runoff model provides a basic hypothesis which states that the run-off and infiltration are functions of the moisture index of the soil.

In the use of the model, there are specific set-ups or arrangements provided for humid and non-humid regions. There are also guides provided in the calibration of its parameters. Here the model used for Humid region is described.

For humid areas, the set-up composes of several tanks arranged vertically in series as shown in Fig. 2. Each of the tanks are provided with outlets representing various movements of water both at the surface and sub-surface. The descriptions of the tank in series are as follows:

The discharge at the bottom outlet of the first tank represents the infiltration. Some parts of the infiltration caught by the second tank are discharged to the side outlet as immediate or sub-surface flows. Those that pass the bottom outlet are the

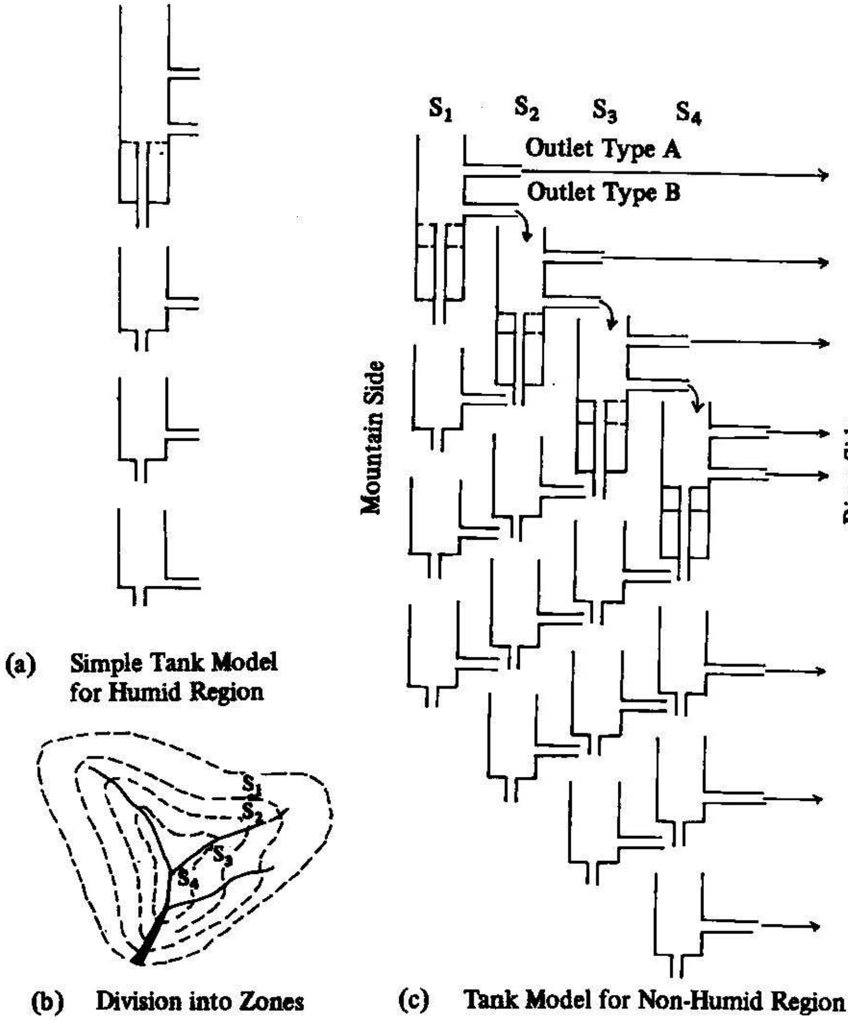


FIGURE 2. Tank model for Humid and Non-Humid regions.

amount being percolated to the third and fourth tanks. From these two last tanks base flows are discharged provided by their side outlets while the bottom outlets allow for the deep percolation process.

The topmost tank is provided with two or three outlets, composing of one or two side outlets for surface discharges, and bottom outlet for the sub-surface movements of flows. The remaining three tanks are likewise provided with outlets, each one with side and bottom outlets.

The computation of discharge flows based from the model requires some initiating numerical values for the unknown parameters. The observed and the derived hydrographs from the computations shall be compared. This leads to adjusting the parameters used until a better fit is demonstrated by the computed hydrograph to the observed hydrograph.

APPLICATION

HYSIM and Tank models have been applied to develop the discharge data of the Cho Shui river basin, central Taiwan, Fig. 3. It is the second largest basin in the Republic of China whose catchment area is 3,155 km^2 and annual precipitation is about 2500 mm. The aim of this study is to compare the flow data developed from HYSIM and Tank models. Finally the better set of developed flow data will be used for the optimum water resources utilization study for hydroelectricity and irrigation of the Cho Shui Project.

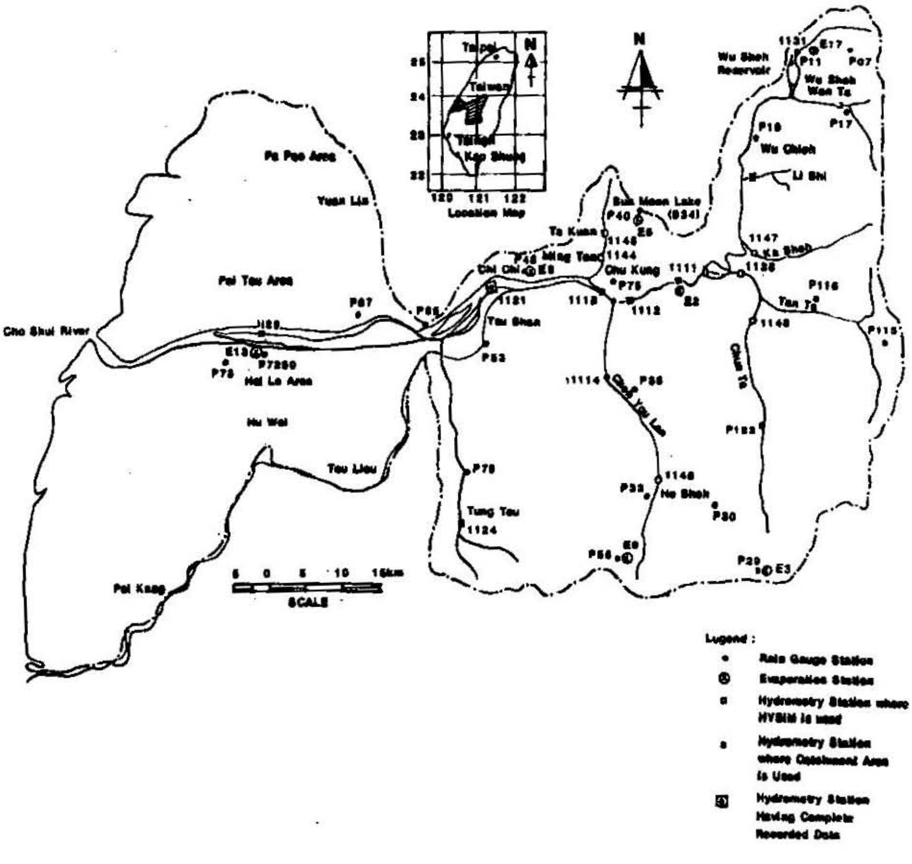


FIGURE 3. Location of Hydro-meteorological Stations Selected for Analysis.

HYSIM MODEL

From the daily flow data provided, seven stations have only few years of flow records while three stations provided longer duration of recorded data. Considering the above stations, the HYSIM model was run and calibrated for daily flows. For comparsison purposes only four stations are cited here. The precipitation and evaporation stations used with their weightages are summarized in Table 1.

TABLE 1. Rainfall and evaporation stations used for simulation and their weights for HYSIM Model

Serial No.	Gauge station	Code of precipitation stations (weightage)	Code of evaporation stations (weightage)
1.	Chun Ta (H48)	P122 (0.44), P29 (0.13) P30 (0.13), P115 (0.15) P116 (0.15)	E2 (0.5), E3 (0.5)
2.	Tan Chun Junction	Inflow from Chunta, P115 (0.5), P116 (0.50)	E2 (05), E3 (0.5)
3.	Ho Sheh (H46)	P33 (0.21), P30 (0.24) P29 (0.23), P55 (0.32)	E3 (0.5), E (0.5)
4.	Wu Chieh	Inflows from Ying Sheh, Ao Wanta, P11 (0.5), P19 (0.5)	E17 (1.10)

Note: (a) The Weights of stations are calculated by using the Thiessen Polygon Method when stations involved are at least three. If the stations involved are less, the simple arithmatic average is taken.
(b) P122 (0.44) indicates the station code at Chun Ta of P122 and weightage of 0.44.

Matching between simulated and recorded hydrographs was good for most stations except for a few cases. Hydrographs of the simulated and recorded flows for three stations are provided in Figs. 4 to 6. The flow means of the daily and monthly data of the recorded and simulated flows were kept as close as possible. Above all, the volume checking was also considered which indicated that the HYSIM model, as used herein, is reliable.

The HYSIM model was calibrated first considering the above criteria. Once the model was calibrated, a set of optimized values for the parameters could be obtained. Using these parameters and the rainfall and evaporation data, the daily flows were generated for the missing periods.

The HYSIM model can deal up to three sub-catchments at a time. The uppermost sub-catchment was simulated first and its outflow becomes the inflow of the successive downstream catchment. Thus, in using inflows from two sub-catchments and the basin data, one can simulate the streamflow at the junction of the three sub-catchments. The case of single catchment is the simplest one. In the case of two sub-catchments, the outflow from the upper one is the inflow to the lower one. Therefore, the upper Chun Ta (H48) can be simulated first and its outflows could be used as inflows to generate the flows at the Tan Chun Junction (H38).

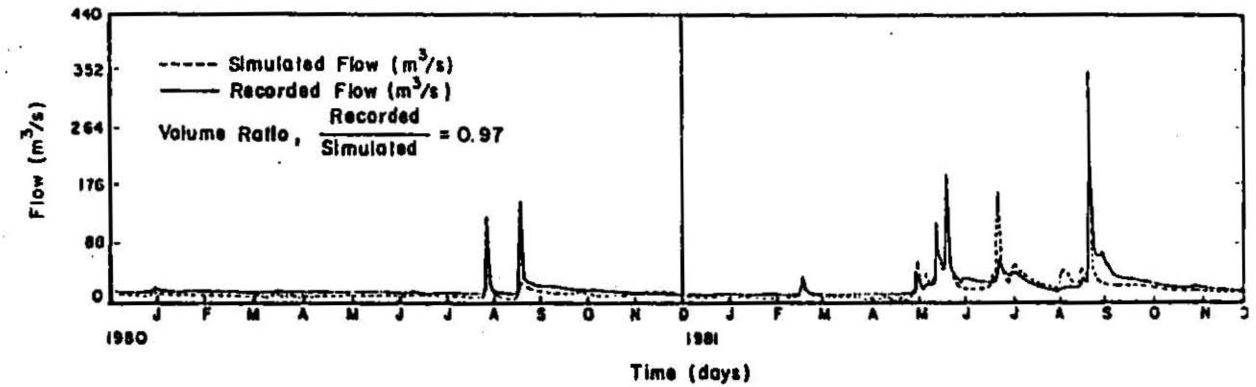


FIGURE 4. Hydrographs of daily flows at Chun Ta for simulated and recorded data.

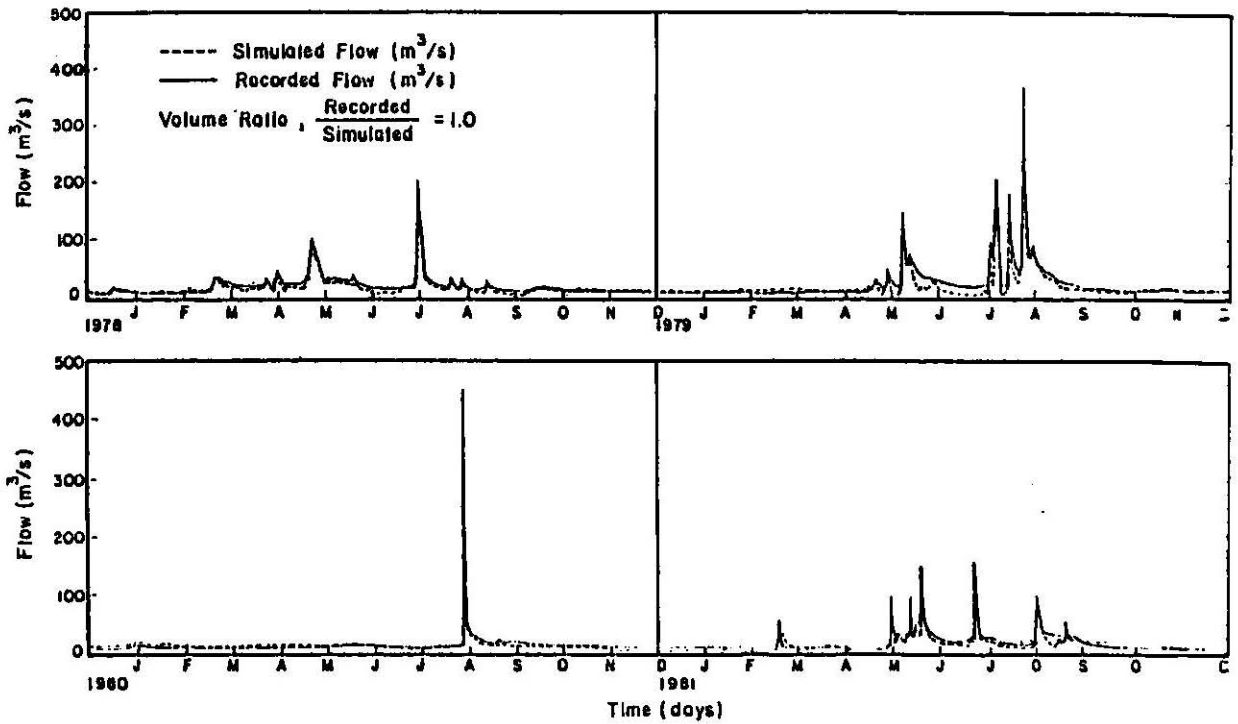


FIGURE 5. Hydrographs of daily flows at Ho Sheh for simulated and recorded data.

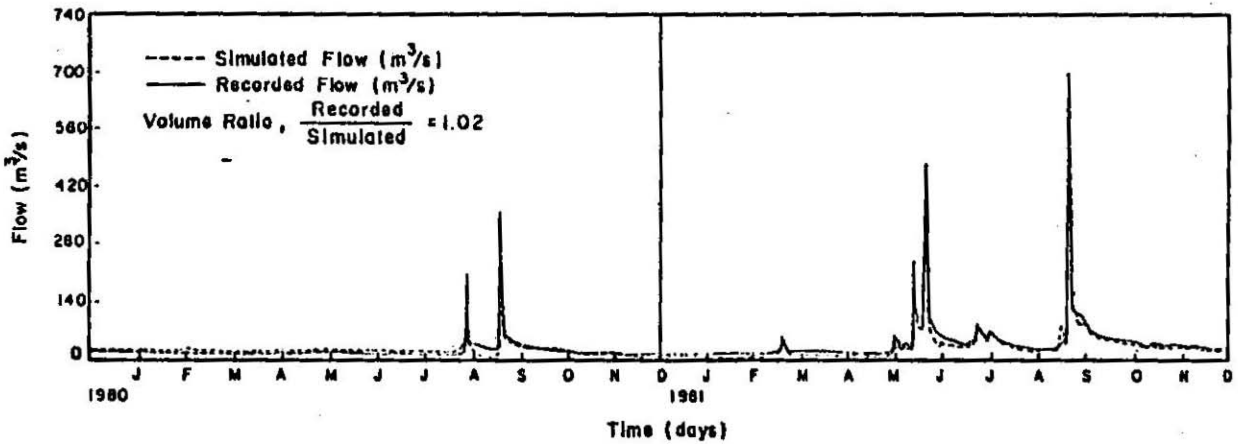


FIGURE 6. Hydrographs of daily flows at Tan Chun Junction for simulated and recorded data.

The data were developed considering two objective functions i.e. giving equal weightage between low and high flows and more weightage to low flows during calibration. Although the statistical results between the two approaches vary very little, the low flows have been increased in the second approach. The statistical results of the two sets (i.e. using objective function with equal weights on the low and high flows, and objective function with more weights given on the low flows) are shown in Tables 2 and 3. Brief descriptions of the sub-catchments which utilized the HYSIM model are given below.

TABLE 2. Summary of results using HYSIM for criterion III including the precipitation and evaporation corrections

Basin (Code)	Area in Sq. km.	Correlation coefficient		Mean daily flows (CMS)		Mean monthly flows (CMS)	
		Daily	Monthly	Sim.	Rec.	Sim.	Rec.
Chun Ta (H48)	411.40	0.72	0.97	15.39	15.62	15.40	15.63
Tan Chun Junction (H38)	700.36	0.83	0.97	24.41	24.95	24.47	25.00
Ho Sheh (H46)	204.72	0.82	0.94	11.59	11.60	11.56	11.57

TABLE 3. Summary of results using HYSIM for criterion I including the precipitation and evaporation corrections.

Basin (Code)	Area in Sq. km.	Correlation coefficient		Mean daily flows (CMS)		Mean monthly flows (CMS)	
		Daily	Montly	Sim.	Rec.	Sim.	Rec.
Chun Ta (H48)	411.40	0.89	0.97	15.62	15.62	15.63	15.63
Tan Chun Junction (H38)	700.36	0.88	0.98	24.83	24.95	24.88	25.00
Ho Sheh (H46)	204.72	0.83	0.94	11.60	11.60	11.57	11.57
Wu Chieh	501.26	0.95	0.98	24.17	24.25	24.15	24.26

Chun Ta (H48) The station has a flow record from 1978 to 1981 but not continuous. This was treated as a single sub-catchment as no other catchment is contributing to it. The missing informations cover the period from January, 1954 to December, 1977 and from July, 1979 to August, 1979.

The model was calibrated on the records of 1980 and 1981. After the calibration, the calculated correlation coefficient for the daily flows was 0.76. However, after applying further refinements by neglecting some days with unnatural high peaks, the coefficient has increased to 0.89.

Ho Sheh (H46) The station has flow records from 1964 to 1967 and from 1978 to 1981. This was treated as a single sub-catchment as no other catchment is contributing to it. For this station, the missing informations cover the period from January, 1954 to December, 1963 and from January, 1968 to December, 1977. Here, the model was calibrated from the records of 1978 to 1981.

Tan Chun Junction (H38) The station has flow records from 1966 to 1969 and 1978 to 1981 but not continuous. This was treated as a combination of two sub-catchments of Tan Ta and Chun Ta which are contributing to it. The missing informations cover the periods from January, 1954 to December, 1965; January, 1970 to December, 1977; and from January to July, 1979. Here, the model was calibrated using the data covering the period of 1980 and 1981.

Wu Chieh (H07) This station has about 28 years recorded flow data. The data at the reservoir at Wu Sheh before April, 1957 was considered as natural flows because before that date the reservoir was yet inoperational. With this, the HYSIM model was calibrated at Wu Chieh using the flow record from 1954 to 1956. This considers the flows at the three sub-catchments comprising those of Ying Sheh, Ao Wan Ta and the uncontrolled flows from the rest of the catchments. This, also, has considered that the flows at Ying Sheh and Ao Wan Ta were classified as natural providing good statistical results. The recorded data covering the year 1954 to March, 1957 were kept unchanged.

TANK MODEL

The latest version of the Tank Model had been applied in four gauging stations of Cho Shui river basin e.g. Tan Chun Junction(H38), Ho Sheh(H46), Chun Ta(H48) and Wu Chieh(H07). The data were developed with proper guidance of Professor Sugawara. The comments of Professor Sugawara regarding the results obtained were considerably good for Wu Chieh (H07), fairly good for Ho Sheh(46), and the other two stations not so good. A good result of calibration is detected from the following points:

1. The minimum value of Criteria of Evaluation (CR) should be around 0.4.
2. Matching of hydrograph of simulated and recorded flow.

In this analysis, the minimum value obtained is 0.69 for station Wu Chieh. A brief description has given below:

Chun Ta (H48) To calibrate this station precipitation data of stations P29, P30, P115, P116 and P122 and that of evaporation data of E2 and E3 were used. Data of 1980 and 1981 were used for calibration.

Another set of trials were made using the precipitation data of stations P122 and P29 and that of Evaporation E2 only. The former set of results are better than the recent set. An example hydrograph is shown in Fig. 7.

Ho Sheh (H46) To calibrate this station precipitation data of stations P29, P30, P33, P55 and that of evaporation data of E9 and E3 were used. Four year's data have been used in calibration i.e. 1978 to 1981. Another set of trials were made using the precipitation data of stations P30, P33, P55 and for that of Evaporation only E9. The former set of results are better than the recent set. The recent set of result is fairly good with CR value 1.06. For an example hydrograph is attached Fig. 8.

Tan Chun Junction (H38) To calibrate this station as well, precipitation data of stations P29, P30, P115, P116 and P122 and that of evaporation data of E2 and E3 were used. Data of 1980 and 1981 were used for calibration. Second set of trials were made using the precipitation data of stations P122, P29 and for evaporation data of station E2 only. The former set of results are better than the recent set. Another set of trials were made using the data of the same stations of second trial but period of calibration for 1981 only. The result obtained is not so good (as the CR value is 2.20). An example hydrograph is shown in Fig. 9.

Wu Chieh (H07) To calibrate this station precipitation data of stations P07, P11, P17, P19 and that of evaporation data of E17 were used. Three year's of data starting from 1954 to 1956 were used for calibration. Results are considerably good with CR value 0.69. The calculated peaks are larger compared with the observed one in January and February of 1954. To adjust such peaks, some modifications in the initial values of soil moisture were made and the result was much improved (Fig. 10).

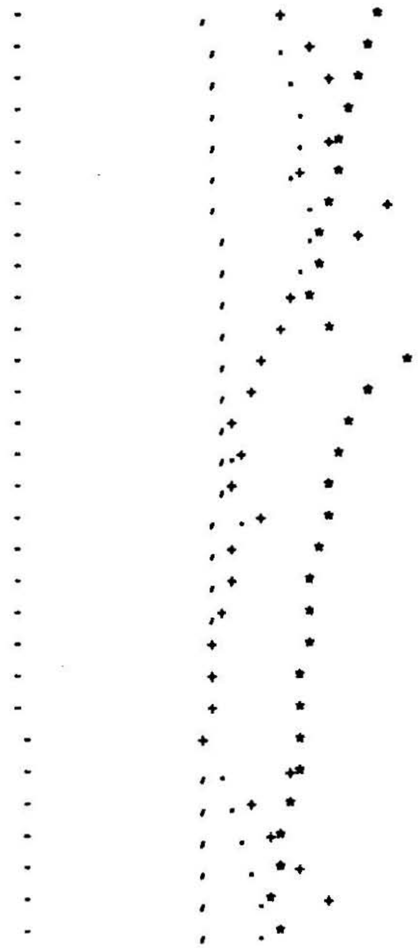
COMPARISON OF FLOW FROM TANK AND HYSIM MODELS

Two criteria have been utilized for comparing the result of Tank Model and HYSIM model e.g. Root Mean Square Error and matching of hydrograph for the daily recorded and simulated flows.

Comparison of Flow from Tank and HYSIM Models Two criteria have been utilized for comparing the result of Tank Model and HYSIM model e.g. Root Mean Square Error and matching of hydrograph for the daily recorded and simulated flows.

Root Mean Square Error may be defined as equal to the square root of the sum of the squares of the differences between simulated and recorded flow divided by the number of events, i.e.

,S	0	3	5.4	6.0	3.7***
,E	13	13	5.4	5.7	4.2***
,P	14	13	5.4	5.4	4.8***
,	16	8	5.4	5.1	5.1***
,	5	9	5.4	5.0	4.7***
,	3	3	5.4	4.9	4.0***
,	31	19	5.4	4.8	6.5***
,	5	8	5.4	4.5	5.4***
,	2	1	5.4	4.4	4.4***
,	0	0	5.4	4.3	3.8***
,	0	0	5.4	4.6	3.5***
,	0	0	5.4	7.2	3.3***
,	0	0	5.4	5.7	3.1***
,	0	0	5.4	5.1	2.9***
,	15	8	5.4	4.9	3.0***
,	5	1	5.4	4.6	2.8***
,	16	4	5.4	4.6	3.4***
,	0	0	5.4	4.5	2.9***
,	0	0	5.4	4.3	2.8***
,	0	0	5.4	4.3	2.7***
,	0	0	5.4	4.2	2.6***
,	0	0	5.4	4.1	2.5***
,	0	0	5.4	4.1	2.5***
,	11	13	5.4	4.1	2.5***
,	24	15	5.4	3.9	3.8***
,	4	4	5.4	3.8	3.2***
,	11	9	5.4	3.7	3.5***
,	19	5	5.4	3.6	4.1***
,	14	12	5.4	3.4	4.6***
,	2	0	5.4	3.6	3.6***

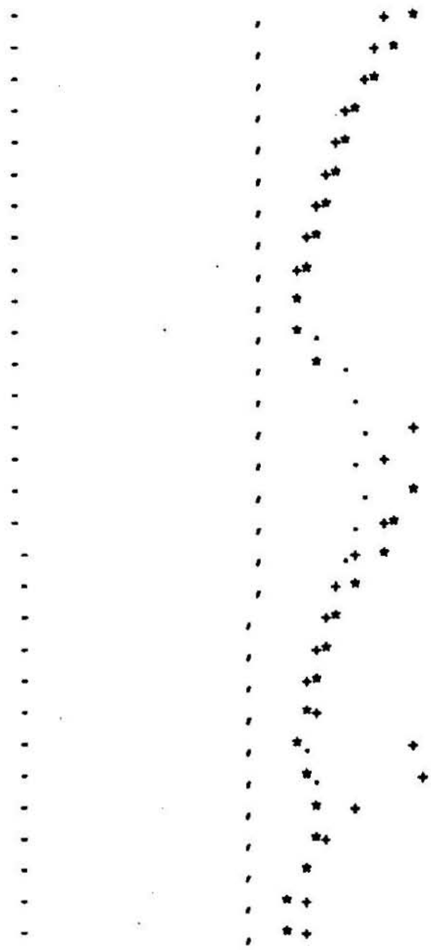


Note: + Simulated Flow
* Recorded Flow

Column 1 = Month
Column 2 = Precipitation of P29
Column 3 = Precipitation of P122
Column 4 = Evaporation of E2
Column 5 = Recorded flow
Column 6 = Simulated flow

FIGURE 7. Hydrographs of simulated and recorded flows at Chun Ta using tank model (latest version).

,S	0	0	0	3.9	6.5	5.5****
,E	0	0	0	3.9	5.7	5.1****
,P	0	0	1	3.9	5.1	4.8****
,	0	0	2	3.9	4.7	4.5****
,	0	0	1	3.9	4.4	4.3****
,	0	2	3	3.9	4.1	4.0****
,	0	0	1	3.9	3.9	3.8****
,	0	0	8	3.9	3.8	3.7****
,	2	3	4	3.9	3.6	3.5****
,	2	3	3	3.9	3.5	3.4****
,	61	3	26	3.9	3.4	8.7****
,	13	2	67	3.9	3.9	14.6****
,	0	0	1	3.9	21.9	9.0****
,	2	0	2	3.9	13.6	6.4****
,	0	0	4	3.9	8.2	5.5****
,	2	0	22	3.9	6.3	6.5****
,	0	0	1	3.9	5.7	5.4****
,	0	0	1	3.9	5.4	4.7****
,	0	0	0	3.9	4.8	4.3****
,	0	0	0	3.9	4.3	4.1****
,	0	0	0	3.9	4.0	3.9****
,	0	0	0	3.9	3.8	3.7****
,	0	4	21	3.9	3.6	3.9****
,	0	2	34	3.9	3.5	6.3****
,	3	3	19	3.9	3.6	6.6****
,	5	0	0	3.9	3.8	4.8****
,	0	0	0	3.9	3.8	4.1****
,	0	0	1	3.9	3.5	3.7****
,	4	2	2	3.9	3.3	3.6****
,	0	4	9	3.9	3.2	3.5****

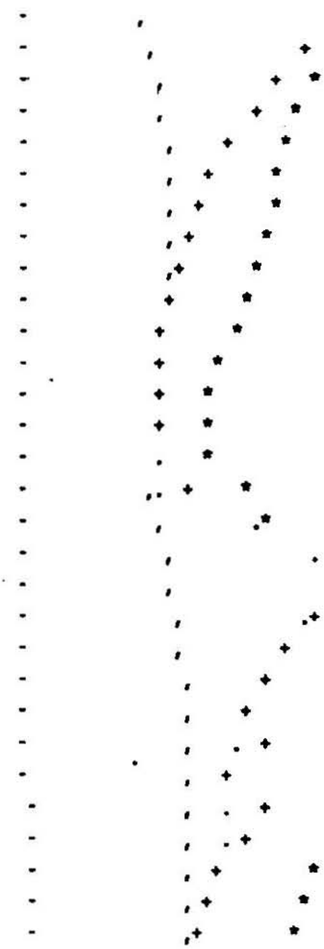


Note: + Simulated Flow
* Recorded Flow

Column 1 = Months
Column 2 = Precipitation of P30
Column 3 = Precipitation of P33
Column 4 = Precipitation of P55
Column 5 = Evaporation of E9
Column 6 = Recorded flow
Column 7 = Simulated flow

FIGURE 8. Hydrographs of simulated and recorded flows at Ho Sheh using tank model (latest version).

,S	0	0	0	0	0	4.0	4.3	4.1***
,E	0	0	0	0	0	4.0	3.9	3.4***
,P	0	0	0	0	0	4.0	3.6	2.9***
,	0	0	0	0	0	4.0	3.3	2.5***
,	0	0	0	0	0	4.0	3.0	2.1***
,	0	0	0	0	0	4.0	2.9	1.9***
,	0	0	0	0	0	4.0	2.8	1.7***
,	7	18	0	1	9	4.0	2.6	1.6***
,	0	0	0	0	0	4.0	2.5	1.5***
,	0	0	0	0	0	4.0	2.3	1.4***
,	0	0	0	0	0	4.0	2.2	1.4***
,	0	0	0	0	0	4.0	2.0	1.4***
,	0	0	0	0	0	4.0	1.8	1.3***
,	0	0	0	0	0	4.0	1.8	1.3***
,	9	3	49	17	7	4.0	1.9	1.8***
,	5	0	15	0	1	4.0	2.4	1.6***
,	15	322	24	65	27	4.0	2.8	11.7***
,	89	21	86	25	26	4.0	43.1	13.6***
,	20	0	0	0	0	4.0	18.3	6.7***
,	0	3	0	0	0	4.0	8.7	3.7***
,	0	0	0	0	0	4.0	6.9	3.0***
,	0	0	0	0	2	4.0	6.0	2.7***
,	2	1	0	0	0	4.0	4.8	2.4***
,	29	25	4	11	3	4.0	4.5	2.7***
,	1	[illegible]	0	0	0	4.0	4.4	2.2***
,	32	2	0	0	1	4.0	4.1	2.7***
,	14	0	0	0	1	4.0	3.8	2.4***
,	0	0	0	0	0	4.0	3.7	2.0***
,	0	0	0	0	0	4.0	3.5	1.9***
,	0	0	0	0	0	4.0	3.3	1.7***

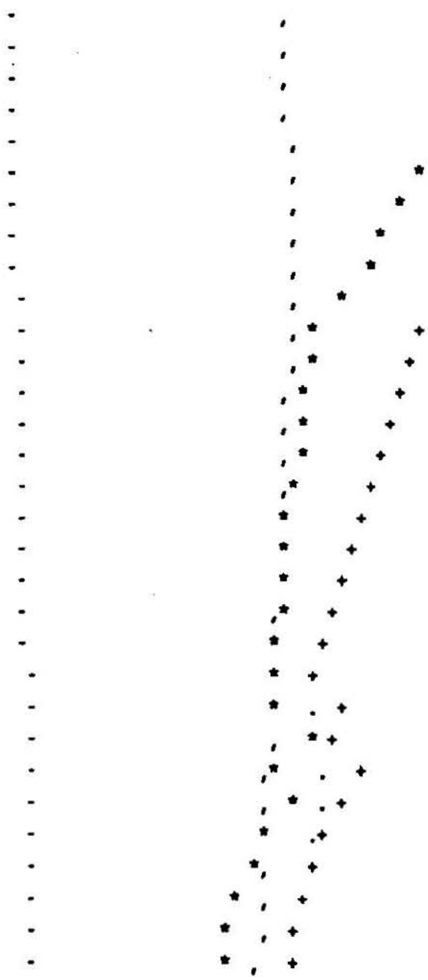


Note: + Simulated Flow
* Recorded Flow

Column 1 = Months
Column 2 = Precipitation of P24
Column 3 = Precipitation of P31
Column 4 = Precipitation of P115
Column 5 = Precipitation of P116
Column 6 = Precipitation of P112
Column 7 = Evaporation of E2
Column 8 = Recorded flow
Column 9 = Simulated flow

FIGURE 9. Hydrographs of simulated and recorded flows at Tan Chun junction using tank model (latest version).

,O	0	0	0	0	3.8	9.2	11.9***
,C	0	38	21	9	3.8	8.8	12.3***
,T	2	8	18	8	3.8	8.4	11.9***
,	3	0	0	0	3.8	8.0	10.6***
,	1	0	0	0	3.8	7.4	9.8***
,	0	0	0	0	3.8	6.4	9.0***
,	0	0	0	4	3.8	5.8	8.4***
,	0	0	0	0	3.8	5.3	7.9***
,	2	0	3	0	3.8	4.9	7.4***
,	0	0	0	0	3.8	4.3	6.9***
,	0	0	6	1	3.8	3.7	6.5***
,	4	0	3	0	3.8	3.6	6.1***
,	0	0	0	0	3.8	3.5	5.8***
,	0	0	0	11	3.8	3.5	5.5***
,	0	0	2	0	3.8	3.5	5.2***
,	0	0	0	0	3.8	3.3	5.0***
,	0	0	0	0	3.8	3.2	4.7***
,	0	0	0	0	3.8	3.1	4.5***
,	0	0	0	0	3.8	3.1	4.3***
,	0	0	0	0	3.8	3.0	4.0***
,	0	0	0	0	3.8	2.9	3.9***
,	0	0	0	0	3.8	2.9	3.7***
,	0	12	8	36	3.8	3.0	4.2***
,	0	0	12	0	3.8	3.7	3.9***
,	0	21	25	9	3.8	3.0	4.7***
,	0	0	0	0	3.8	3.3	4.2***
,	0	0	1	0	3.8	2.8	3.8***
,	0	0	1	0	3.8	2.6	3.6***
,	0	0	2	1	3.8	2.4	3.5***
,	0	0	0	0	3.8	2.3	3.4***
,	0	0	0	0	3.8	2.3	3.2***



Note: + **Simulated Flow**
* **Recorded Flow**

Column 1 = Months
Column 2 = Precipitation of P07
Column 3 = Precipitation of P11
Column 4 = Precipitation of P17
Column 5 = Precipitation of P19
Column 6 = Evaporationl of E17
Column 7 = Recorded flow
Column 8 = Simulated flow

FIGURE 10. Hydrographs of simulated and recorded flows at Wu Chieh using tank model (latest version).

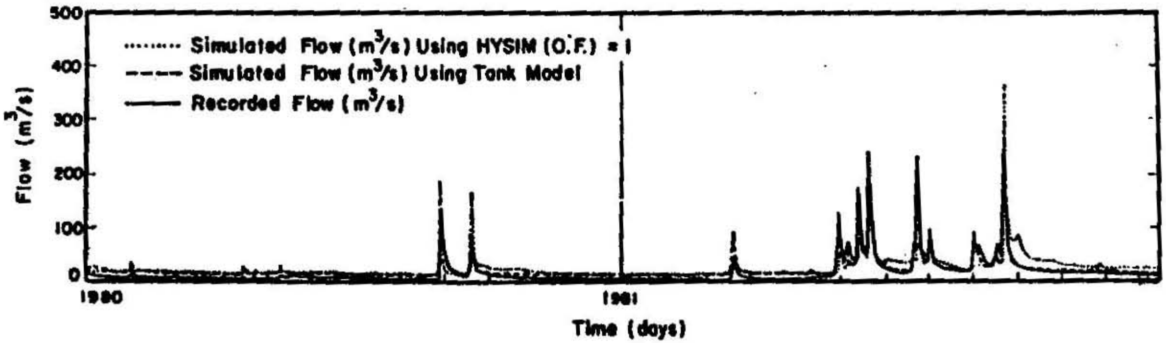


FIGURE 11. Hydrographs showing the comparison of daily glows between recorded and simulated flows from HYSIM and tank model for Chun Ta.

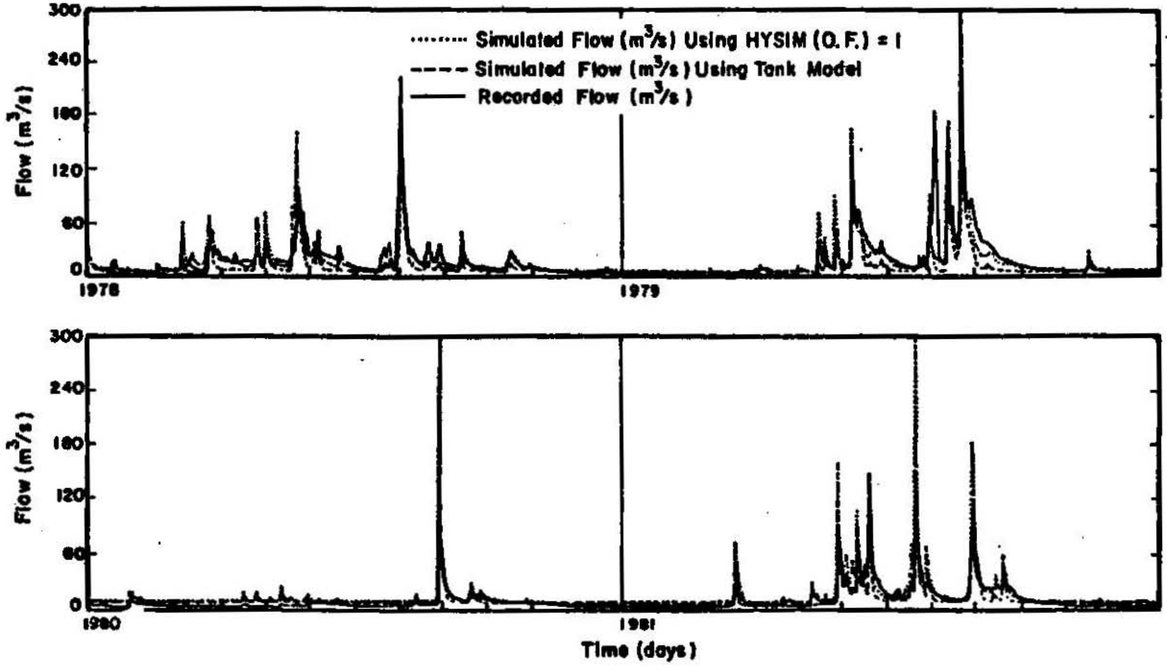


FIGURE 12. Hydroghraphs showing the comparison of daily flows between recorded and simulated flows from HYSIM and tank models for Ho Sheh.

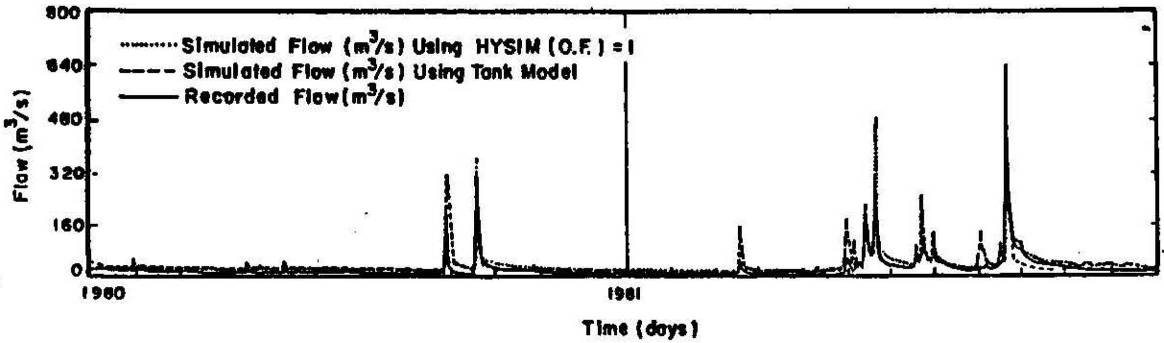


FIGURE 13. Hydrographs showing the comparison of daily flows between recorded and simulated flows from HYSIM and tank models for Tan Chun junction.

$$\text{RMSE} = \sqrt{\left[\frac{\Sigma\,(\text{Sim} - \text{Rec})^2}{\text{N}}\right]}$$

where Sim is the daily Simulated Flow
Rec is the daily Recorded Flow
N is the total number of days

The result of comparison of the Root Mean Square Error of four stations are shown in Table 4. During the calculation of Root Mean Square Error flow data were transformed into same unit.

As an example, the hydrographs showing the comparison of recorded and simulated flows from HYSIM and Tank Models for three catchments e.g. Chun Ta(H48), Ho Sheh (H46) and Tan Chun Junction(H38) are plotted (Fig. 11, Fig. 12 and Fig. 13). The daily flow from HYSIM is considered with criterion one(I) i.e. giving more weightage on the low flows. From the hydrographs it appears that the flows from HYSIM are better matched in those stations. The result from Tank Model is good in matching at Ho Sheh(H46) but the other two stations are not well matched.

TABLE 4. Comparison of Root Mean Square Errors between the recorded simulated daily flows from HYSIM and Tank Models

Basin	Root Mean Square Error (RMSE)			Number of Recorded Years
	HYSIM		Tank	
	Criterion I	Criterion III		
Tank Chun Junction (H38)	20.6	25.4	34.5	2
Ho Sheh (H46)	13.5	14.2	16.8	4
Chun Ta (H48)	14.9	18.1	18.3	2

CONCLUSIONS

HYSIM Model has been used for stream flow data generation, mainly for those stations having short period of recorded data and the result obtained are checked by the Tank Model. From the matching of hydrographs and statistical criterion it was found that the simulated flow from the HYSIM model was better and reliable which was again confirmed by checking of the root mean square error (RMSE) of daily simulated and recorded flow. It was observed that the RMSE value is lower in the case of HYSIM showing better result. The stimulated and recorded flows are very close to each other which shows that the HYSIM model produces better stimulated flow. So the flow developed from HYSIM was finally selected for the optimum analysis of the project.

REFERENCES

Afzal, H. 1981. Use of HYSIM Model for an ungauged basin. M. Thesis, No. WA-80-1. AIT, Bangkok, Thailand.

Beveridge, G.S.G. and Schechter, R.S., 1970 Optimization Theory and Practice, Chemical Engineering Series, Mc Graw Hill, Inc., USA, PP 396–406.

Boley, B.A., 1958, On a Dynamic Model Saint-venant Principle, Technical Report no. 12, Institute of Flight Structure, Department of Civil Engineering and Engineering Mechanics, Columbia University, New York.

Dawday, D. R. and O'Donnel, T, 1965. Mathematical models for catchment behavior. *Jour. of Hydraulics Division, ASCE,* Vol. 91, HY 4: 123-137.

Donald, J. R., L. C., Clyde, C. G., and Smith, R. E. 1979. An application of run-off model strategy for ungauged watersheds. *Water Resources Bulletin,* American Water Resources Association, Vol. 15 (4).

James, L. D. 1973. Hydrology modelling, parameter estimation and watershed characteristics. *Journal of Hydrology,* Vol. 17: 283-302.

Lighthill, M. J. and Whitham, G. B. 1955. On kinematic waves I. — flood movement in long rivers. *Proceedings Royal Society London,* Vol. 229 (1178): 281-316.

Linsley, R. K., Kohler, M. A., and Paulhus, S. L. H. 1975. *Hydrology for Engineers.*

Manley, R. E. 1977a. The soil moisture component of mathematical catchment simulation model. *Journal of Hydrology,* Vol. 35: 341-356.

Manley, R. E. 1978c. Simulation of flows in ungaged basin. *Hydrological Science Bulletin.*

Porter, J. W. and McMahon, T. A. 1971. A model for simulation of streamflow data from climatic records. *Journal of Hydrology,* Vol. 13: 297-324.

Sugawara, M. and Maruyama, H. 1951, On a method of deriving the monthly discharge of the river Naka from monthly precipitation (in Japan). Research memoir of the Ins. of Statistical math. vol. 7, No. 4.

Sugawara, M. 1961. On the analysis of runoff structure about several Japanese rivers. Japanese Journal of Geophysics Vol. 2, No. 4.

Sugawara, M. et al. 1974. Tank model and its application to Bird Creek, Wollombi Brook; Bikin River, Kitsu River, Sanaga River and Nam Mun. Research Note No. 11, National Research Center for Disaster Prevention, Japan.

Sugawara, M. 1976. On a method of forecasting the daily discharge of the Mae Nam, Chao Phraya and its tributaries at several points by means of tank model. Research Notes No. 24, National Research Center for Disaster Prevention, Japan.

Sugawara, M. 1979. Automatic calibration of the tank model. *Hydrological Science Bulletin,* Vol. 24 (3).

Fakulti Kejuruteraan
Universiti Kebangsaan Malaysia
43600 UKM Bangi,
Selangor D.E., Malaysia.