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A Streamflow Simulation Model for A Semi-Arid Region

Adnan A. Saad

L. Douglas James

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ADNAN A. SAAD

Ministry of Planning
Riyadh, Saudi Arabia

L. DOUGLAS JAMES

Utah Water Research Laboratory
Utah State University, Logan, Utah 84322

A streamflow simulation model which would reproduce the essential feature of the hydrologic regime of a semi-arid region, in this case Jordan, was developed and described. The model is intended to fit conditions which exist in such a region. The hydrologic processes components which represent the evaporation and the base flow distinguish the Jordan model from others. Development of each function of the model and its constants was based on all the minimal amount of data available. One year of data was used to calibrate the model for Wadi Zerqa watershed. The model was then applied to simulate four years of streamflow. Simulation of daily flows especially low flows was successful. A close reproduction of monthly flow volumes was achieved. Simulation results suggest that flow diversion occurred during the summer months. Such practice is commonly used in the area for irrigation purposes. Errors in simulation resulted both from the approximate representation of the hydrologic processes and from the errors in rainfall and streamflow data. The streamflow records, which are characterized by low flows, suggest utilizing the average absolute value of prediction error rather than the standard error of simulation as a statistical tool for measuring the accuracy of simulation results.

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INTRODUCTION

Many watershed streamflow models have been developed for application in conditions of climate, runoff regime, and data availability common to the United States. The Stanford Watershed Model [Crawford and Linsley, 1966] and its adaptations cover each element of the hydrologic cycle. Success with such a complex model depends upon the availability and accuracy of data on meteorological and physical characteristics, the skill of the personnel utilizing the model and the objectives for utilizing the model. Accurate streamflow simulation requires a structuring of the model elements that matches field conditions and calibration for a specific watershed [James and Burges, 1979].

In Jordan the climate is semi-arid. The few storms and dry streams greatly reduce useful data. Many recorded measurements are of questionable quality. Finally, the hydrologic information most desired for water resources management in Jordan is on groundwater recharge and watershed yield. These applications require model selection and calibration emphasizing flow volume rather than flood hydrograph simulation. A model derived to fit conditions which prevail in Jordan and its application to one watershed is described below.

MODEL DEVELOPMENT

The Jordan watershed model is designed to simulate streamflow for water supply planning application in this semi-arid region from data available in this country [Saad, 1978]. The model contains infiltration, soil moisture storages, drainage, groundwater recharge and evapotranspiration components and inputs daily rainfall and daily pan evaporation data. The basic elements of the model are shown in Figure 1. The seven rectangular boxes represent moisture storage and the eight circles represent hydrologic process functions. The mathematical relationships of the model components are listed in the Appendix.

One year of data for Wadi Zerqa watershed was used to calibrate the model parameters. The second stage was to accept the parameters to be the true ones and run the model to simulate four years of streamflow.

Daily Rainfall

Daily weighted average rainfall over the basin provides the moisture input. Amounts can be estimated by utilizing rainfall isohyets. Once the isohyetal map is drawn, stations can be selected to represent the average value between each isohyet. The weighted rainfall is computed by multiplying each station rainfall by its weight computed from the isohyetal map.

Depression Storage

Little interception occurs in Jordan because vegetation is of low density. Considerable rainfall, however, is trapped in the many depressions associated with the poorly developed drainage system, characteristic of an arid climate.

The incoming moisture is allocated to depression storage which has a capacity that varies over the land surface to a maximum capacity of WCEPT as shown in Figure 2. The concept of cumulative frequency distribution of infiltration capacities [Crawford and Linsley, 1966] was adapted to represent the variability in depression capacity. Figure 2 illustrates moisture allocation. The incoming moisture supply, EMFR, is allocated to depression storage (shaded area, TCEPT) and potential infiltration, EMFI. Evaporation from moisture in depression storage occurs at a potential rate, PET. Any moisture remaining in storage, after satisfying evaporation demand, may infiltrate.

Runoff From Impervious Areas

Impervious areas normally constitute a small portion of a natural basin. However, in some instances a considerable portion is mountainous with steep rocky hills. Runoff from these areas is modeled as runoff from an impervious area. There are situations where after the runoff flows from the mountain, a portion of this flow seeps into the ground and forms transmission losses. The remaining portion reaches the channel as impervious area runoff.

Infiltration to A Horizon

Excess moisture from depression storage and transmission losses are combined to make up the potential infiltration to the upper soil storage. The infiltration process is modeled by an exponential decay function as shown in Figure 3a. The point infiltration, PINF, is a function of the moisture available in A Horizon storage, AHOR, its capacity, AHORD, decay exponent value, ALFN, and minimum and maximum infiltration rates, FMIN and FMAX, respectively. The areal variations of infiltration capacity concept [Crawford and Linsley, 1966] is used to convert point potential infiltration to average infiltration over a basin (Figure 3b). Modeling of the surface runoff volumes for smaller storms improved when compared with results assuming uniform infiltration rate.

Surface Runoff

Surface runoff volume is the excess moisture that remains after the infiltration process takes place. The surface runoff component of the streamflow is a portion of this volume as determined by the parameter FSRO, the fraction of surface runoff volume [Tennessee Valley Authority, 1972; Betson, 1976]. The other portion remains as surface runoff storage to be depleted at a specific rate governed by SROK, the surface runoff recession factor. The surface runoff process and the surface runoff volume in transit are illustrated in Figure 4.

Soil Moisture Storages

Soil moisture storage is divided into two compartments, A Horizon moisture storage and B Horizon moisture storage. The upper soil is shallow and has a limited moisture capacity. The soil in its total depth is not homogeneous and does not have uniform characteristics. In the long dry period, the upper soil forms a hard layer known as a pan. The lower soil, while sealed by the upper dry soil, continues to be affected by the evaporation process at a very reduced rate. Evaporation proceeds at different rates from the upper soil moisture storage and from the lower soil moisture storage. Infiltration and interflow processes take place in the upper soil. Drainage from the upper soil to the lower soil takes place at a rate determined by the permeability of the lower soil. Finally, groundwater recharge takes place when moisture is transferred from the lower soil to the groundwater reservoir.

Drainage

The process by which moisture moves downward from A Horizon to B Horizon is called drainage. The amount of moisture to be drained is is controlled by the maximum drainage capacity, the amount of moisture in A Horizon and B Horizon. The available moisture in each storage is normalized by dividing each amount by the corresponding storage capacity.

<u>Interflow</u>

Interflow or lateral flow is modeled in a simple manner to avoid excessive complexity of the model. A moisture accounting is performed on the A Horizon storage. The input to the system is the incoming moisture from infiltration. The output is the outgoing moisture via drainage and evaporation. When A Horizon storage exceeds its capacity, the excess moisture moves laterally as interflow volume to the interflow storage. Interflow is routed daily utilizing a prespecified interflow recession factor.

<u>Groundwater Recharge</u>

Recharge occurs from B Horizon moisture storage to feed the groundwater reservoir. The rate of recharge is controlled by the incoming moisture from A Horizon storage and by the amount of moisture already available in B Horizon storage. Some models [Ross, 1970] assume that recharge, or percolation to groundwater, occurs only when the ratio of the moisture available in the upper soil to the upper soil capacity is greater than the ratio of the moisture in lower soil to the lower soil capacity. In other models [Betson, 1976 and Sittner et al, 1969] the inflow to groundwater is represented as a function of the surface runoff. Although simulation results from these models seem satisfactory, recharge functions are developed on an artificial basis to induce groundwater recharges.

In this model, the moisture, DRAIN, which moves from A Horizon storage to B Horizon storage is considered a potential groundwater recharge. The amount of recharged moisture is governed by the ratio of available moisture in B Horizon to the B Horizon storage capacity. Groundwater recharge model is better illustrated as shown in Figure 5.

It was found that the value of REXP is sensitive in determining the recharge and, therefore sensitive, in determining low flows. Therefore, instead of making REXP a fixed value, better low flow simulation results were obtained by considering this exponent as an input parameter subject to changes from basin to basin.

The geological formations in a semi-arid region such as Jordan plays an important role in determining the low flows which appear in the channel. A portion of the recharged water finds its way to deep aquifers. In addition, many springs and seeps are located in the basins. The majority of flows from these sources are fully utilized as a water supply by various communities in the area. It would be difficult to try to model these losses as they are impossible to determine quantitatively. The approach adopted here was to assume that a portion of the recharged moisture is lost through utilization of spring water and by percolation to deep aquifers.

Groundwater Reservoir

If the channel bed of a wadi intersects the water table, the intercepted groundwater causes perennial flow. The rate of flow, however, varies with the level of the water table, and this in turn depends on the amount of recharge from the upper soils. Accordingly, recorded streamflow data indicate variable base flow recession curves. Slopes are nearly flat during dry periods. Steeper recession curves are observed during wetter periods. Between, there is a general transition of recession curves slopes on streamflow curves time semi-log plots.

The effect can be modeled by applying a relationship between the base flow recession rate and groundwater storage. Let PGWK represent the maximum recession constant which corresponds to the minimum groundwater storage, QMIN,.during dry periods. Also let SGWK represent the minimum recession constant which corresponds to the maximum groundwater storage, QMAX, during wet periods. The desired relationship between base flow recession rate, GWRK, and groundwater storage, PGWR is developed as illustrated in Figure 6. The value of ALGW, QMAX, and QMIN were fixed based on the model calibration for Wadi Zerqa watershed. ALGW, with a value of 0.05, QMAX, with a value of 50.00 mm, and QMIN, with a value equal to the initial groundwater storage gave satisfactory results. If the groundwater storage value falls below the preassigned value, the corresponding recession constant approaches a maximum valve at 1.0.

Evapotranspiration

In order to estimate potential evaporation from free surface water, daily pan evaporation measurements were used. It was found that the average monthly temperatures near Fresno, California closely approximated those in Amman [Bureau of Reclamation, 1953]. Pan coefficients which are used in the model were assumed to be the same coefficients used in the Fresno area. The estimated potential evaporation was obtained by multiplying the daily pan evaporation measurements by the monthly pan coefficients.

Under the hot Jordanian sun, the quick drying of the A Horizon seals the moisture within the lower B Horizon and protects it for later use by the desert vegetation. In the early stages of the rainy period each year, when there is no soil moisture available, the amount of evaporation is limited to the amount of rainfall. Evaporation from a drying soil is a characteristic of the Jordan hydrologic cycle from April through November or December each year.

Evaporation was modeled from three moisture storages, namely, depression storage, A Horizon moisture storage, and B Horizon moisture storage. Moisture in depression storage evaporates at a potential rate. Evaporation from the upper soils occurs if there is moisture available there. During the rainy months where precipitation exceeds evaporation, soil will gradually become fully covered by vegetation. Potential evaporation demand during this period is met from the available moisture in A Horizon. Evaporation rates become pregressively more dependent on water stored in the soil. The evaporation rates remain at nearly potential rates until the available water storage of the top soil, within the root zone, is nearly depleted. At this point, as the resistance to water movement through the soil to the root surface increases, the evaporation rate falls rapidly. At this stage the layer of the soil within the root zone will be a layer of essentially dry material. This dry layer serves as a barrier to evaporation of the soil moisture available in the layer of soil below the root zone, i.e., the B Horizon.

Evaporation from A Horizon is modeled as shown in Figure 7a. It is computed by multiplying the unmet potential evaporation, ETD_A by the ratio of the available moisture in A Horizon, AHOR and its storage capacity, AHORD raised to a pwoer, ETAP. A value of the exponent of 0.075 was found satisfactory in order to simulate evaporation from the upper soil at a rapid rate.

Evaporation from the lower soil takes place at a reduced rate for reasons previously mentioned. That is not the case in humid areas where deeply rooted trees penetrate the soil and consume moisture by transpiration. Evaporation from B Horizon, TETB is modeled as illustrated in Figure 7b and a function of the unmet potential evaporation, ETD_B, available moisture, BHOR and storage capacity, BHORD. From many simulation runs, a value of 0.05 was selected for the exponent ALEB. The maximum value of the evaporation parameter, EPAR is 1.00. The purpose of introducing this parameter is to give flexibility in estimating the actual evaporation from the soil. Figure 7b indicates the low rate of evaporation during dry periods when the soil moisture deficiency (BHORD-BHOR) is large.

Water only evaporates from groundwater storage if there is a shallow water table. Measurements of groundwater evaporation from bare soils in the Western United States has shown extremely low rates when the water table is deeper than 120 cm. [Simons, 1967]. No provision was made for evaporation from groundwater storage due to the fact that the depth of the water table is much deeper in the Jordanian watersheds.

Parameters Estimation and Optimization

There are 20 input variables required to run the model listed in Table 1. The constants are those parameters which are not optimized and can be determined from observed runoff data and the physical characteristics of a given basin. Ten parameters were selected to be optimized simultaneously utilizing the direct search technique [Jeeves and Hooke, 1961; Munro, 1971; Lumb et al, 1975]

MODEL APPLICATION

The Jordan Watershed Model was applied to simulate streamflow of

Zerqa River. Five years of data were available (1969-1973) from the Natural Resources Authority in Amman. The 1969 water year was selected for parameters optimization. Streamflow was simulated for the remaining water years.

Description of Wadi Zerqa Watershed

The Zerqa River is the second principal tributary of the Jordan River (Figure 8). The watershed area is 3116 square kilometers at the gage near New Jerash Road. The watershed lies within the North-Eastern Highlands and the Eastern Plateau regions. The average slope of the river bed is about ten meters per kilometer. The headwaters elevation is about 1400 near Salkhad. The altitudes range from 600 to 800 meters in the Eastern Plateau and gradually decend to 100 meters below sea level near the gage site.

Rainfall

Daily precipitation is measured in the Zerqa River basin at the 46 stations shown in Figure 8. The raingage locations represent the higher elevations. Figure 8 also illustrates the average annual rainfall for the 30 years from 1931 to 1960 prepared by the Natural Resources Authority. Five isohyetal maps were prepared for the period of analysis. They reflect the general topography of the basin.

Streamflow

The Zerqa flood flow is characterized by a sharp rise of the flood hydrograph and a quick recession. Low flows are characteristic of the streamflow during the rainless days. The annual peak during the period of study varied from 10.4 to 107.00 cubic meters per second. Low flow varied from 0.160 to 0.670 cubic meters per second. The mean annual discharge of the five year period was 14.57 mm over the basin.

Evaporation

Daily values of pan evaporation were recorded at King Hussein Evaporation station near Amman. The average annual value during the period 1969-1973 was 2587 mm.

Results of Simulation

The 1969 water year was selected for the optimization run. The constant values, the initial and the optimized values of the parameters are listed in Table 2. The value of the maximum infiltration rate, FMAX, for example, is similar to the value used in the Harza-Baker Report, 1955. The soil moisture capacity, the sum of AHORD and BHORD, closely approximate the conclusions of the British consultant Sir MacDonald, 1965.

Streamflow simulation was carried out for the four year period beginning with the 1970 water year. The model was successful in simulating daily flows except where streamflow and precipitation are questionable. The model gave better results in reproducing low flows than flood flows. Simulation was more successful on a monthly basis than a daily basis. The monthly observed and simulated flow volumes are listed in Table 3. Man-made activities such as flow diversion can be detected (Table 3). It is apparant that diversion, probably for irrigation, started on May 1971. The water from return irrigation started to contribute gradually to the streamflow. During this period, the observed flow was rising to catch up with the simulated flow on November, 1972. Similar observation was repeated on May, 1972. Excluding this phenomenon, low flows are well simulated throughout the four years.

Statistical analyses were performed on the predicted daily flows for the five years of record. The sum of the squared errors was 8.5690 square millimeters. The squared error of only one simulated flow was large enough to reduce this value by about 60 percent as illustrated in the following example:

The observed streamflow hydrograph during the period from April 12-17, 1971 was 2.11, 107.00, 54.70, 41.70, 29.80 and 18.60 cubic meters per second. The model prediction was 4.66, 26.79, 61.03, 37.03, 27.25, and 15.92 cubic meters per second. The squared error of the simulated flow on April 13, 1971 was 4.946 square millimeters. The standard error of daily prediction, excluding some of the flood flows in the five year of record, was 48 percent. The sum of the absolute value of the errors was 29.0841 millimeters which corresponds to an average absolute value of the simulation error of 40 percent. The standard error of the predicted monthly flows for the simulation period was 42 percent. This was largely dependent on the simulated peak flow errors. The average absolute value of the prediction error was 31 percent.

The annual simulated flows (Table 3) indicate that the model under-simulated the flows of the 1969, 1970 and 1971 water years. The annual flows of the 1972 and the 1973 water years were overestimated. The apparent data error of the 1970 streamflow, especially in January and March, was partly responsible for the gross undersimulation. The quality of data of the 1973 water year and the possible flow diversion, beginning in May, 1972 and March, 1973 contributed to the overprediction of the annual flow for these two years. The standard error of prediction of the calibrated 1969 water year was 9 percent; that for the period of simulation was 18 percent. The standard error was reduced to 11 percent when the annual flows of the 1970 and the 1973 water years were excluded.

SUMMARY

A streamflow simulation model which would reproduce the essential feature of the hydrologic regime of a semi-arid region, in this case Jordan, was developed and described. The model is intended to fit conditions which exist in such a region. The hydrologic processes components which represent the evaporation and the base flow distinguish the Jordan model from others. Development of each function of the model and its constants was based on all the minimal amount of data available.

One year of data was used to calibrate the model for Wadi Zerqa watershed. The model was then applied to simulate four years of streamflow. Simulation of daily flows especially low flows was successful. A close reproduction of monthly flow volumes was achieved. Simulation results suggest that flow diversion occurred during the summer months. Such practice is commonly used in the area for irrigation purposes. Errors in simulation resulted both from the approximate representation of the hydrologic processes and from the errors in rainfall and streamflow data.

The streamflow records, which are characterized by low flows, suggest utilizing the average absolute value of prediction error rather than the standard error of simulation as a statistical tool for measuring the accuracy of simulation results.

APPENDIX

MATHEMATICAL RELATIONSHIPS OF MODEL COMPONENTS

1. Moisture to depression storage:

$$TCEPT = EMFR - EMFR^2/(2.0 * WCEPT) \quad (A1)$$

when rainfall is less than depression storage capacity

and $TECPT = WCEPT/2.0$ (A2)

when rainfall exceeds depression storage capacity

Excess moisture after (A1) or (A2) above = $EMFI = EMFR - TCEPT$ (A3)

2. Runoff from impervious areas:

$$PSRO = EMFI * PIMP\ (1.0 - TRLOS) \quad (A4)$$

3. Infiltration:

$$PINF = (FMAX - CNIF) + CNIF * EXP(-ALFN * AHOR) \quad (A5)$$

where $CNIF = (FMAX - FMIN)/(1 - EXP(-ALFN * AHORD))$ (A6)

Infiltration to A Horizon:

$$AINF = EMTA - EMTA^2/(2.0 * PINF), \text{ when } EMTA < PINF \quad (A7)$$

and $AINF = PINF/2.0$, when $EMTA > PINF$ (A8)

4. Surface runoff:

$$SURVOL = EMTA - AINF \quad (A9)$$

Routed surface runoff, $SURO_i = FSRO * SURVOL_i + (1.0 - SROK) * SURES_i$ (A10)

Surface runoff storage at the end of the ith day (A11)

$$= SURES_{i+1} = SURES_i + (1.0 - FSRO) * SURVOL_i - (1.0 - SROK)\ SURES_i$$

5. Drainage from A Horizon to B Horizon:

$$DRAIN = BHORP * (AHOR/AHORD)^{2.00} * (1 - (BHOR/BHORD))^{2.00} \quad (A12)$$

APPENDIX (Cont'd.)

6. Interflow:

$$IFRO_i = (1.0 - FROK) * IFRES_i \qquad (A13)$$

Interflow storage at the end of the ith day

$$IFRES_{i+1} = IFRES_i + IFVOL_i - IFRO_i \qquad (A14)$$

7. Groundwater recharge:

$$RECHA = DRAIN * (BHOR/BHORD)^{REXP} \qquad (A15)$$

Groundwater loss to deep aquifers, seeps and springs:

$$GWLOS = DLOSS * RECHA \qquad (A16)$$

8. Relationship between base flow recession constant and groundwater storage:

$$GWRK = (PGWK - EXPON) + EXPON * EXP\ (-ALGW\ (PGWR - QMIN)) \qquad (A17)$$

where $EXPON = (PGWK-SGWK)/1-EXP\ (\ -ALGW\ (QMAX - QMIN)\ ) \qquad (A18)$

9. Evaporation:

Evaporation from A Horizon:

$$TETA = ETD_A * (AHOR/AHORD)^{ETAP} \qquad (A19)$$

Evaporation from B Horizon:

$$TETB = EPAR * ETD_B * EXP\ (-ALEB\ (BHORD - BHOR)) \qquad (A20)$$

NOTATION

AHOR available moisture in A Horizon

AHORD maximum storage capacity of A Horizon

AINF average infiltration rate

ALEB B Horizon evaporation decay exponent

ALFN infiltration function decay exponent

ALGW base flow recession rate function decay exponent

BGWR initial groundwater reservoir storage

BHOR available moisture in B Horizon

NOTATION (Cont'd.)

BHORD maximum storage capacity of B Horizon

BHORP maximum drainage rate

BSMI initial soil moisture in B Horizon

CNIF infiltration function constant

DLOSS fraction of groundwater recharge lost to deep aquifers and springs

DRAIN drainage rate

EMFI excess moisture after moisture is allocated to depression storage

EMFR daily rainfall

EMTA moisture supply to A Horizon

EMTR transmission losses

EPAR B Horizon evaporation reduction parameter

ETAP A Horizon evaporation function exponent

ETD_A potential evaporation minus evaporation from depression storage

ETD_B potential evaporation minus evaporation from depression storage and A Horizon

EXP exponential e

EXPON base flow recession rate function constant

FMAX maximum point infiltration rate

FMIN minimum (steady state) infiltration rate

FROK interflow recession constant

FSRO fraction of surface runoff volume

GWLOS lost moisture to deep aquifers and springs

GWRK base flow recession constant

GWRO simulated daily base flow

IFRES interflow reservoir volume

IFRO simulated daily interflow

IFVOL added interflow volume when A Horizon is exceeded

NOTATION (Cont'd)

PET	potential evaporation
PGWK	maximum base flow recession constant
PGWR	groundwater storage
PIMP	fraction of total drainage area which is impervious
PINF	point infiltration rate
PSRO	simulated runoff from impervious areas
QMAX	maximum groundwater storage which corresponds to SGWK
QMIN	minimum groundwater storage which corresponds to PGWK
RECHA	recharged moisture from B Horizon to groundwater reservoir
REXP	recharge function decay exponent
SGWK	minimum base flow recession constant
SQKM	drainage area
SROK	surface runoff recession constant
SURES	surface runoff volume storage
SURO	simulated surface runoff
SURVOL	surface runoff volume
TCEPT	moisture allocated to depression storage
TETA	evaporation from A Horizon
TETB	evaporation from B Horizon
TRLOS	fraction of impervious area runoff in transition
WCEPT	maximum depression storage capacity

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TABLE 1. List of Constants and Parameters Used in the Jordan Watershed Model.

Constant	Definition
BSMI	Initial soil moisture in B Horizon, mm
BGWR	Initial groundwater reservoir storage, mm
SQKM	Drainage area in square kilometers
WCEPT	Maximum depression storage capacity, mm
FROK	Interflow recession constant
SGWK	Minimum base flow recession constant
PGWK	Maximum base flow recession constant
SROK	Surface runoff recession constant
PIMP	Fraction of drainage area which is impervious
TRLOS	Fraction of impervious area runoff lost in transition

Parameter	Definition
FMAX	Maximum point infiltration rate, mm/day
FMIN	Minimum (steady state) infiltration rate, mm/day
ALFN	Infiltration function decay exponent
AHORD	Maximum storage capacity of A Horizon, mm
BHORP	Maximum drainage rates, mm/day
FSRO	Fraction of surface runoff volume parameter
REXP	Recharge function decay exponent
BHORD	Maximum storage capacity of B Horizon, mm
EPAR	B Horizon evaporation reduction parameter, fraction
DLOSS	Fraction of groundwater recharge lost to deep aquifers and springs

TABLE 2. List of the Fixed Parameter Values and the Initial and Final Values of the Optimized Parameters for the Zerqa River Watershed.

THE FOLLOWING IS THE FIXED AND INITIAL PARAMETER VALUES

PARAMETER	BSMI	BGWR	WCEPT	SOKM	FRCK	SGWK	PGWK	SROK	PIMP	TRLCS
FIXED VALUE	20.000	33.000	4.000	3116.000	.300	.990	.999	.250	0.000	0.000

PARAMETER	FMAX	FMIN	ALFN	AHORD	BHORP	FSRO	RCXP	BHORD	EPAR	DLOSS
INITIAL VALUE	420.000	30.000	.100	50.000	10.000	.100	1.000	90.000	.500	0.000
UPPER LIMIT	600.000	60.000	.400	100.000	50.000	.150	4.000	200.000	1.000	.800
LOWER LIMIT	300.000	10.000	.050	20.000	5.000	.100	1.000	60.000	.500	0.000
INCREMENT	5.000	1.000	.005	1.000	1.000	.005	.050	1.000	.025	.025

THE FOLLOWING IS THE FINAL OPTIMIZATION RESULTS

PARAMETER	FMAX	FMIN	ALFN	AHORD	BHORP	FSRO	REXP	BHORD	EPAR	DLOSS
BEST VALUE	595.000	33.000	.060	68.000	10.000	.145	2.000	105.000	.725	.450

TABLE 3. Monthly Observed and Simulated Flows of the Zerqa River for the 1969-1973 Water Years. (Values are in Millimeters)

	1969 W. Y.		1970 W. Y.		1971 W. Y.		1972 W. Y.		1973 W. Y.	
Month	Obs	Sim	Obs	Sim	Obs	Sim	Obs	Sim	Obs	Sim
Oct	0.79	1.01	1.02	0.88	0.85	0.67	0.56	0.65	0.35	0.71
Nov	0.97	0.97	1.05	0.83	0.90	0.64	0.71	0.69	0.79	1.16
Dec	1.30	1.13	1.09	0.82	1.12	0.79	2.44	2.61	0.51	0.68
Jan	2.11	2.50	1.92	1.38	1.75	0.77	1.29	0.90	1.36	2.02
Feb	2.03	1.04	1.26	0.85	0.89	0.64	1.64	1.35	0.72	0.75
Mar	9.07	7.81	2.51	1.76	1.15	0.89	1.53	1.30	1.06	0.96
Apr	2.07	1.98	1.18	0.78	7.76	5.56	1.41	0.86	0.41	0.65
May	1.52	1.06	1.03	0.78	0.38	0.76	0.35	0.83	0.44	0.65
Jun	1.04	0.95	0.95	0.73	0.25	0.72	0.20	0.77	0.46	0.61
Jul	0.85	0.96	0.84	0.73	0.22	0.72	0.25	0.77	0.42	0.61
Aug	0.67	0.93	1.32	0.71	0.19	0.70	0.36	0.75	0.37	0.59
Sep	0.87	0.87	1.39	0.67	0.27	0.65	0.35	0.70	0.30	0.56
Annual	23.29	21.21	15.56	10.92	15.73	13.51	11.09	12.18	7.10	9.95

refer to page 12!!
for explanation
(diversion during summer
months)

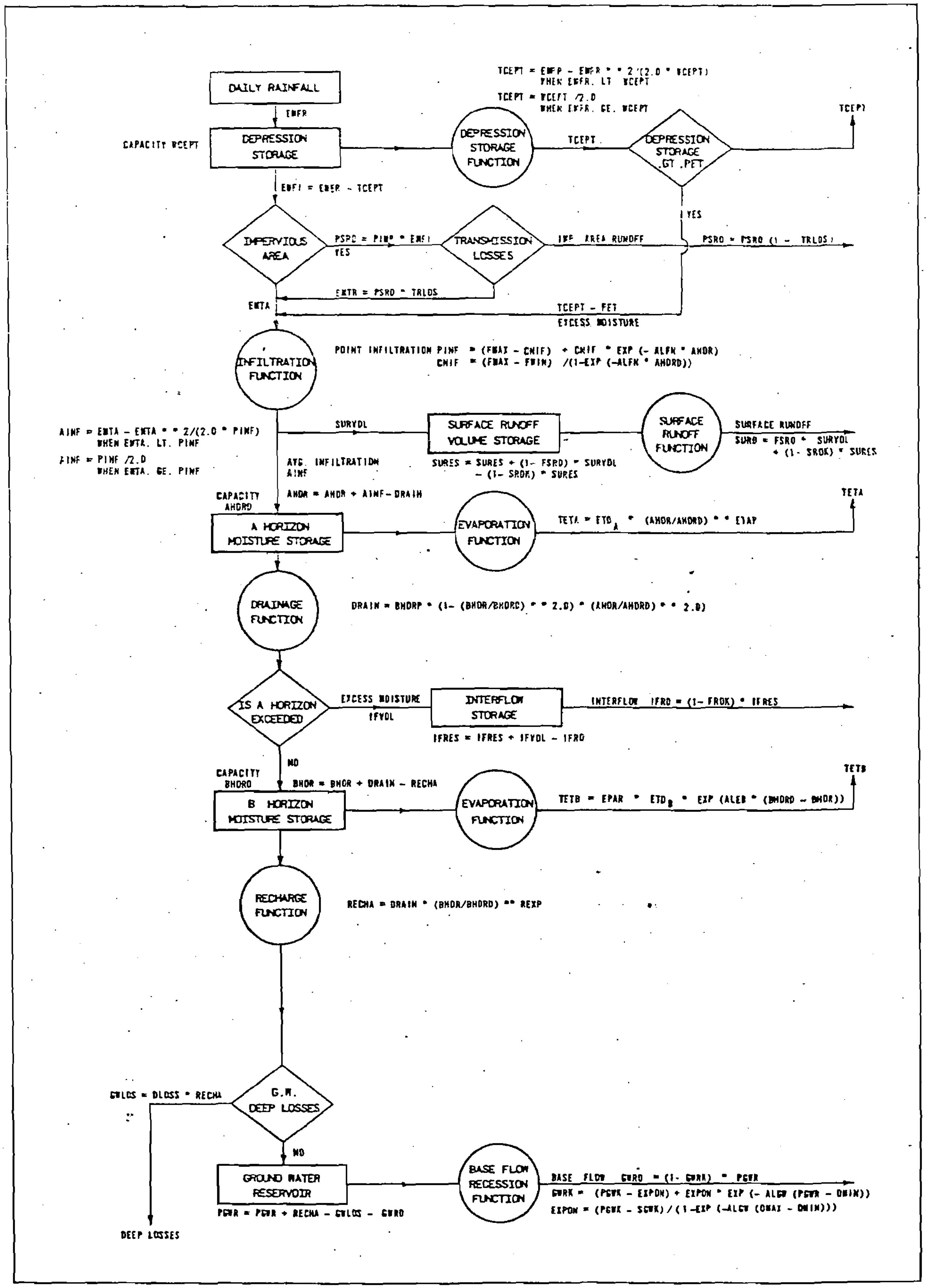

Figure 1. Moisture Accounting Flow Chart of the Jordan Watershed Model

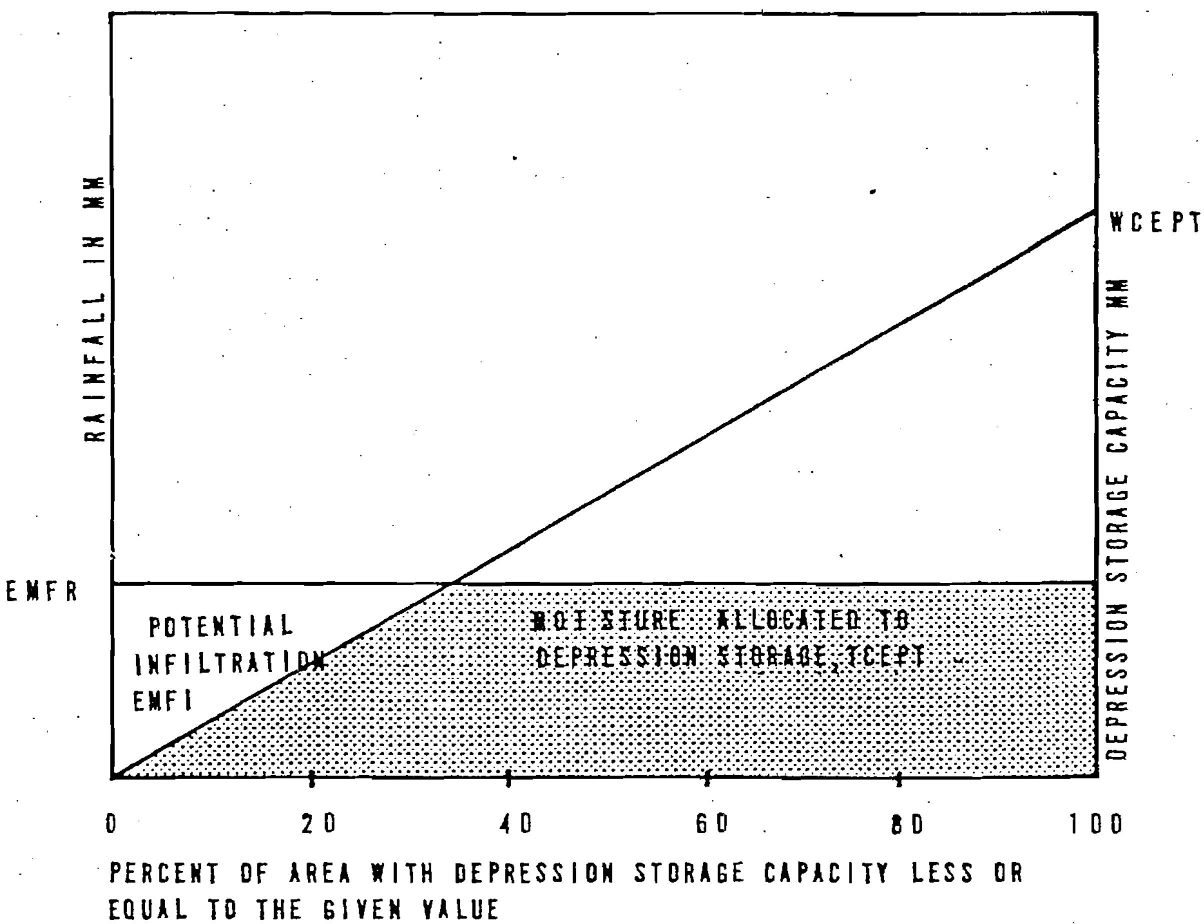

Figure 2. Moisture Allocation to Depression Storage.

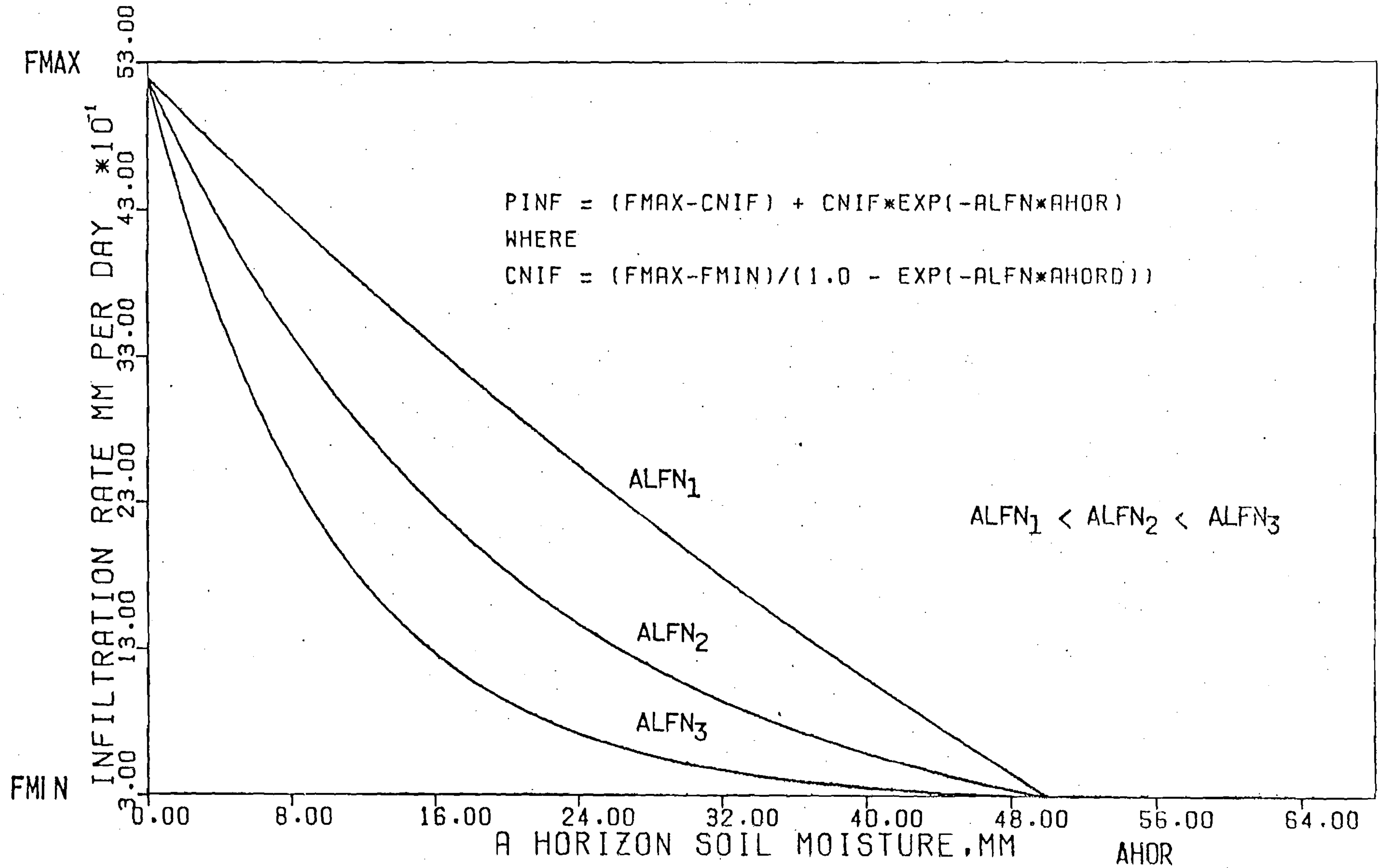

Figure 3a. Point Infiltration Rate Model.

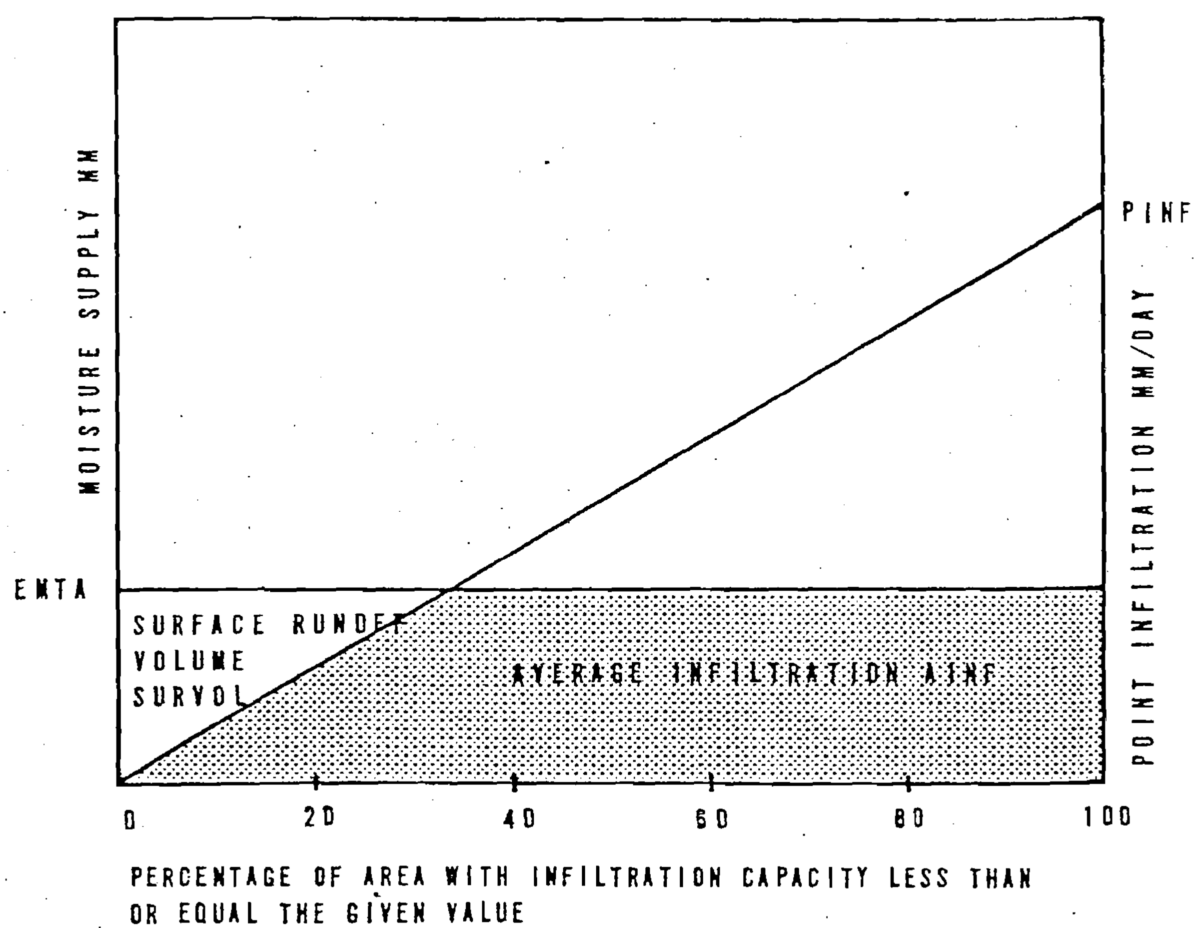

Figure 3b. Average Infiltration Rate Model.

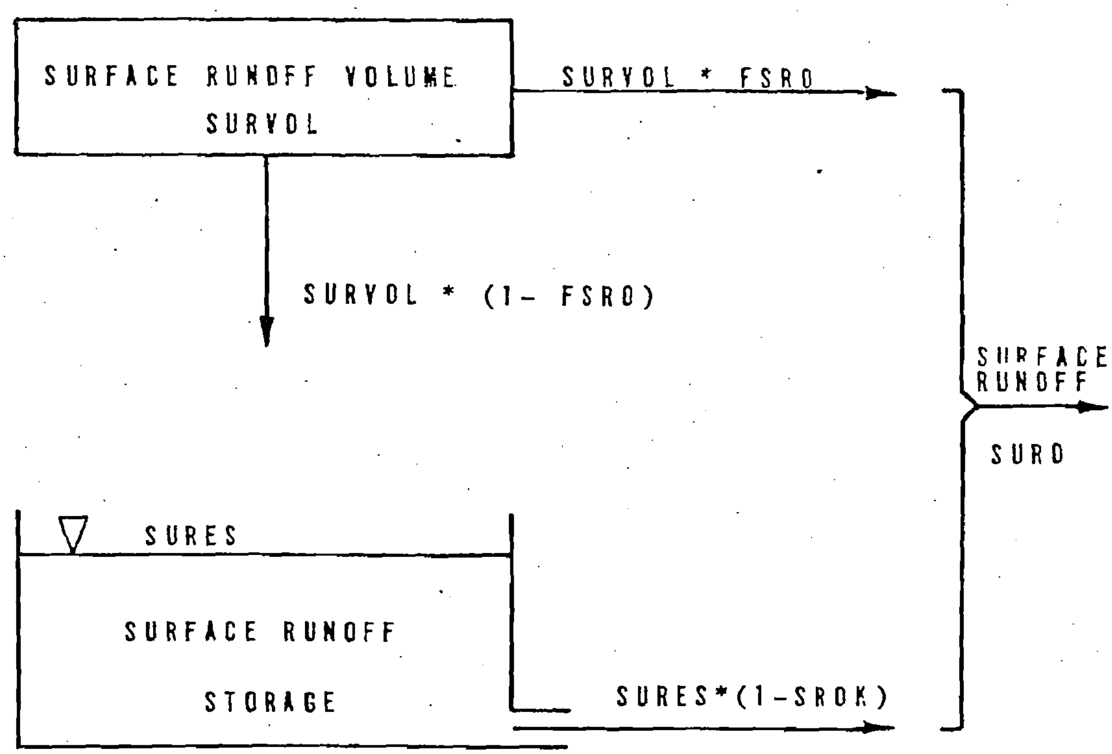

Figure 4. Schematic Diagram of the Surface Runoff Model.

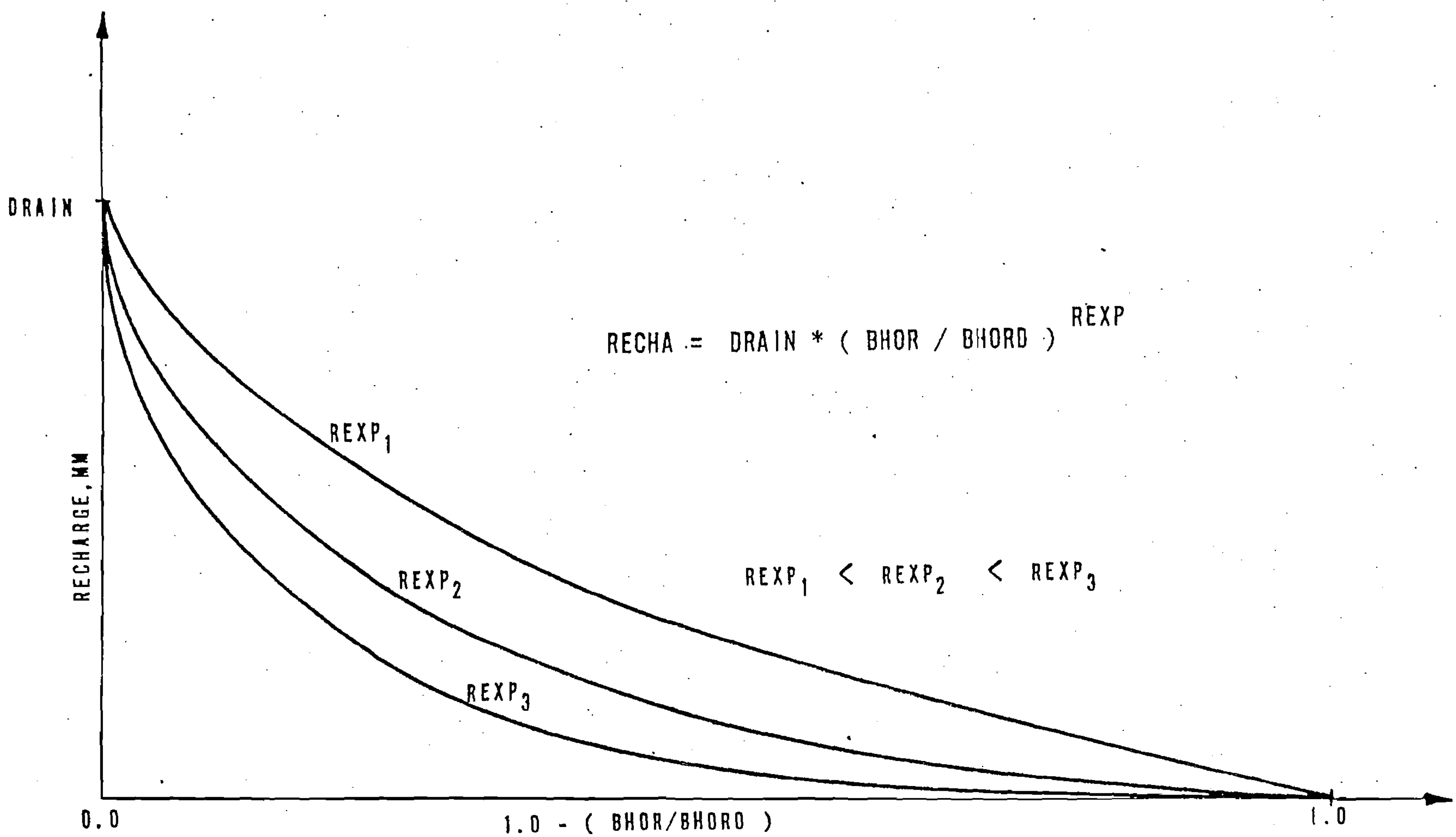

Figure 5. Groundwater Recharge Model.

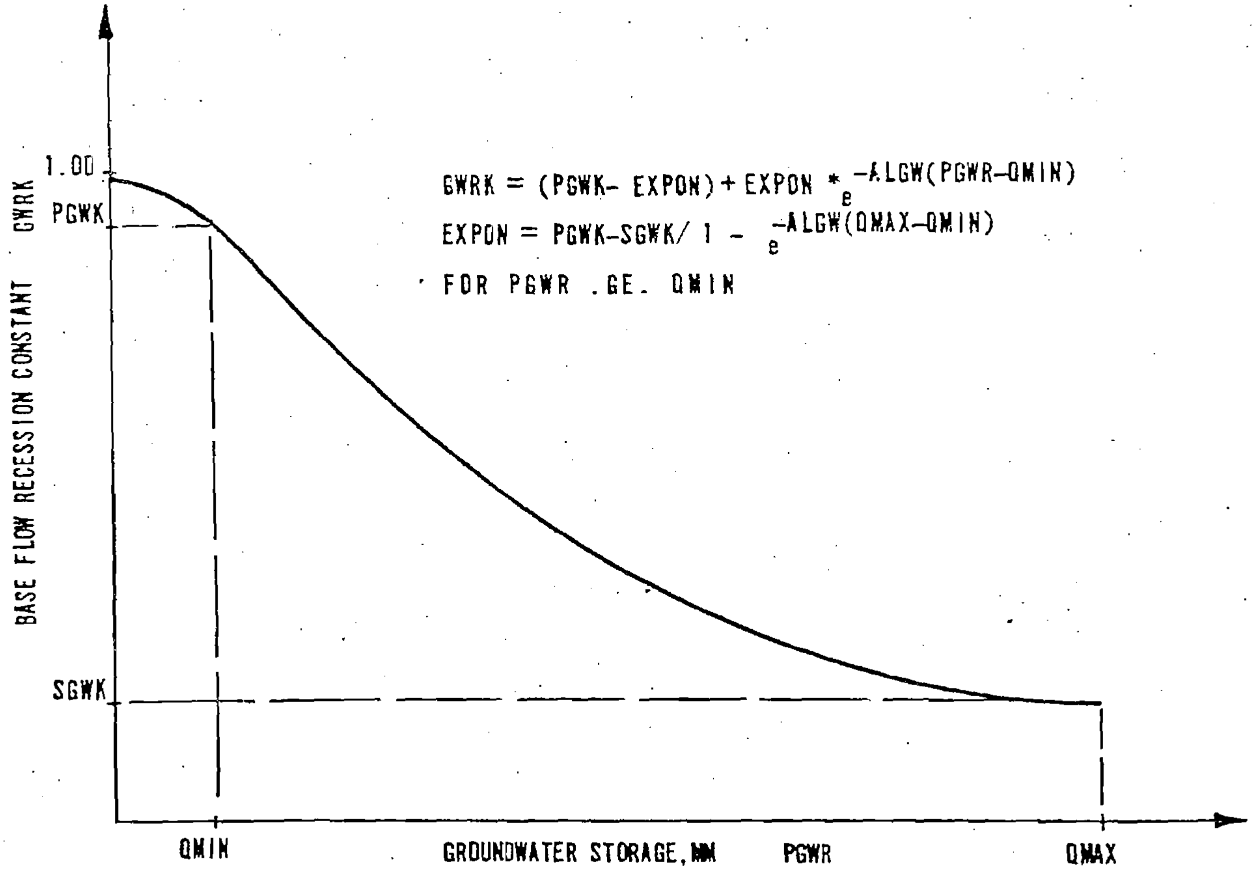

Figure 6. Base Flow Recession Constant Model

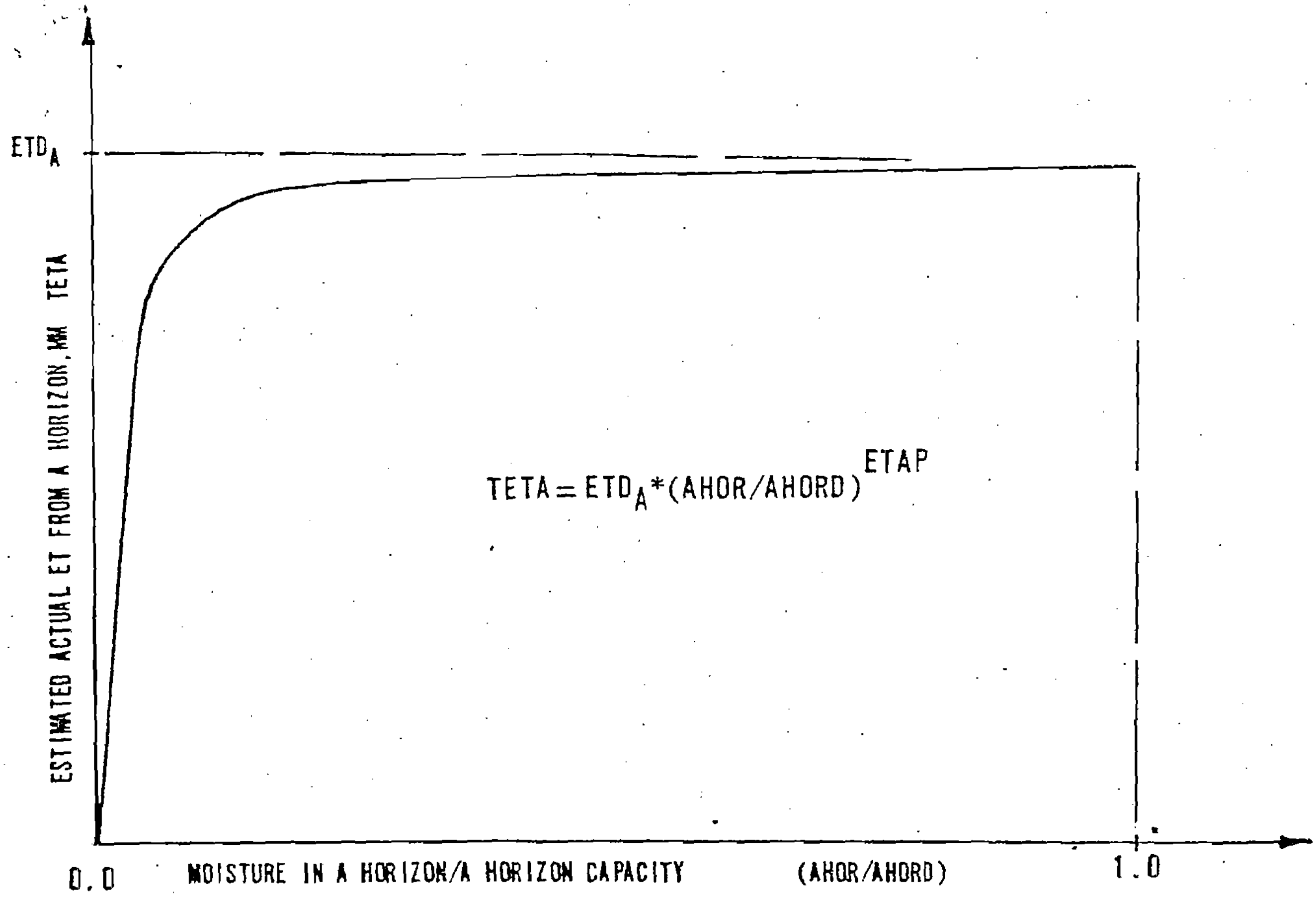

Figure 7a. A Horizon Evaporation Model.

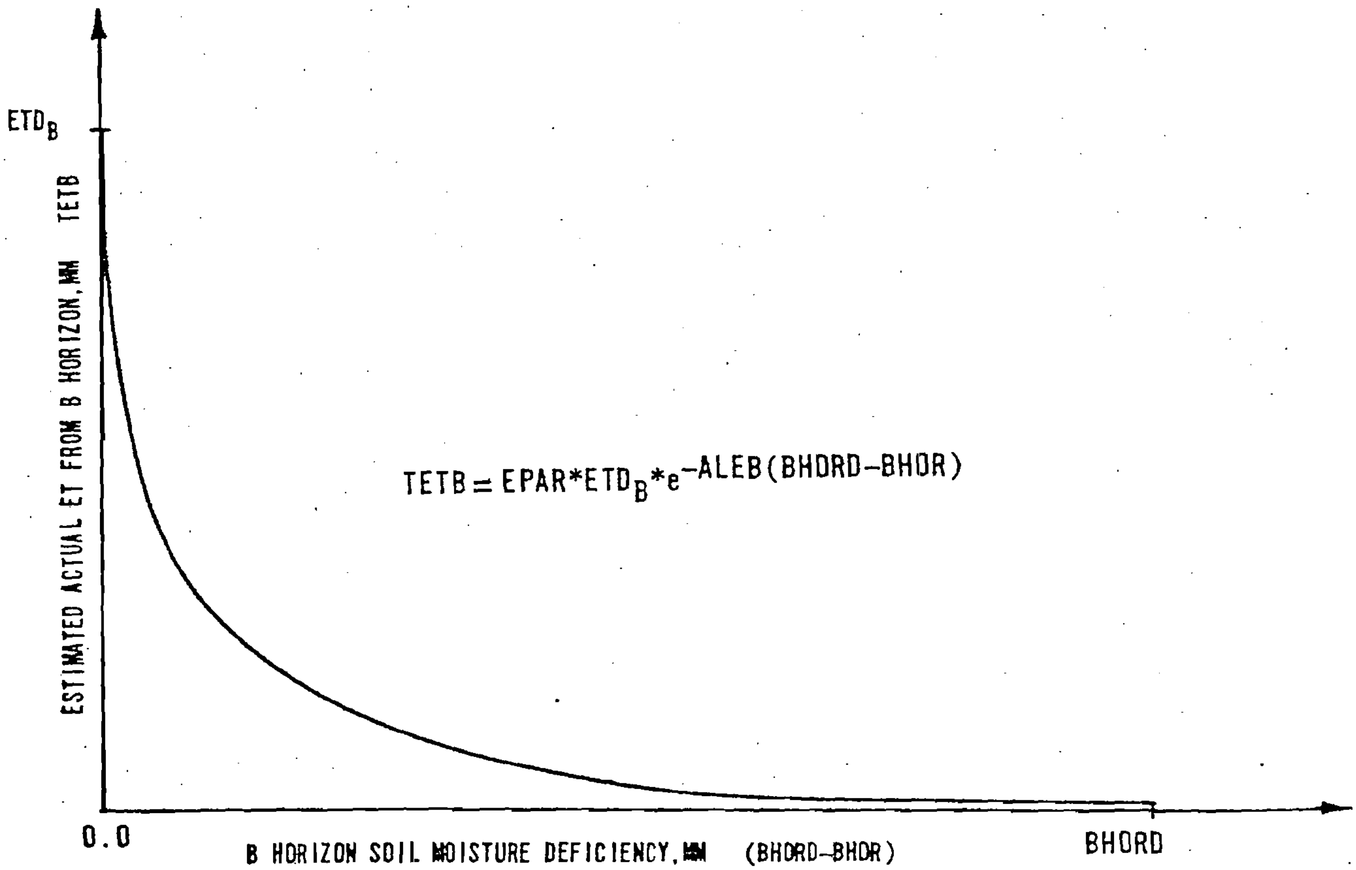

Figure 7b. B Horizon Evaporation Model.

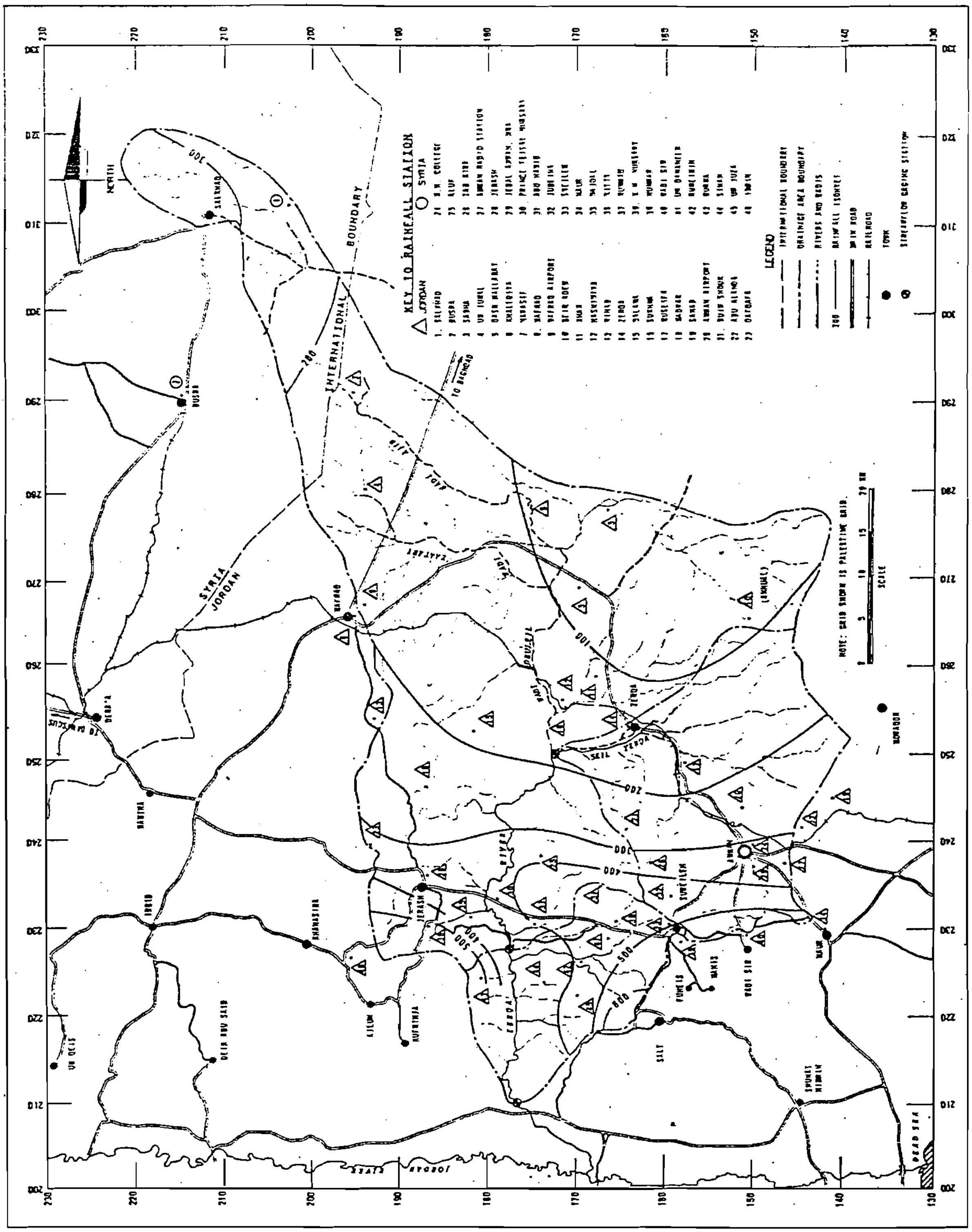

Figure 8. Rainfall Stations Network in the Zerqa River Watershed and Average Annual Rainfall.