HMG-IITM

Survey on modeling of spatial soil moisture variability in the Xinanjiang model and its derivatives

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and

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Xinanjiang model, Zhao R. J., 1980

- Widely used in the humid and semi-humid regions of China as a basic tool for rainfall-runoff simulation and flood forecasting
- Runoff occurs only when on repletion of the soil moisture storage at a particular point
- Structure of the Xinanjiang model has been divided into four modules
  - Evapotranspiration
  - Runoff production
  - Runoff separation
  - Routing

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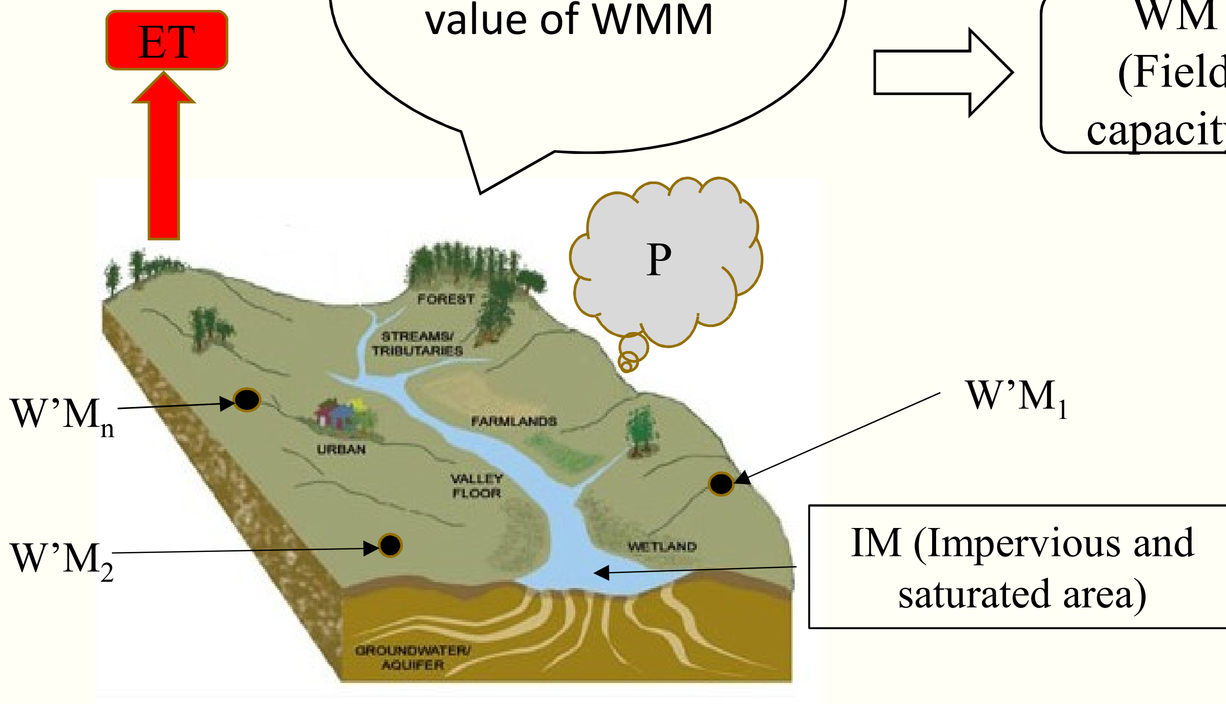
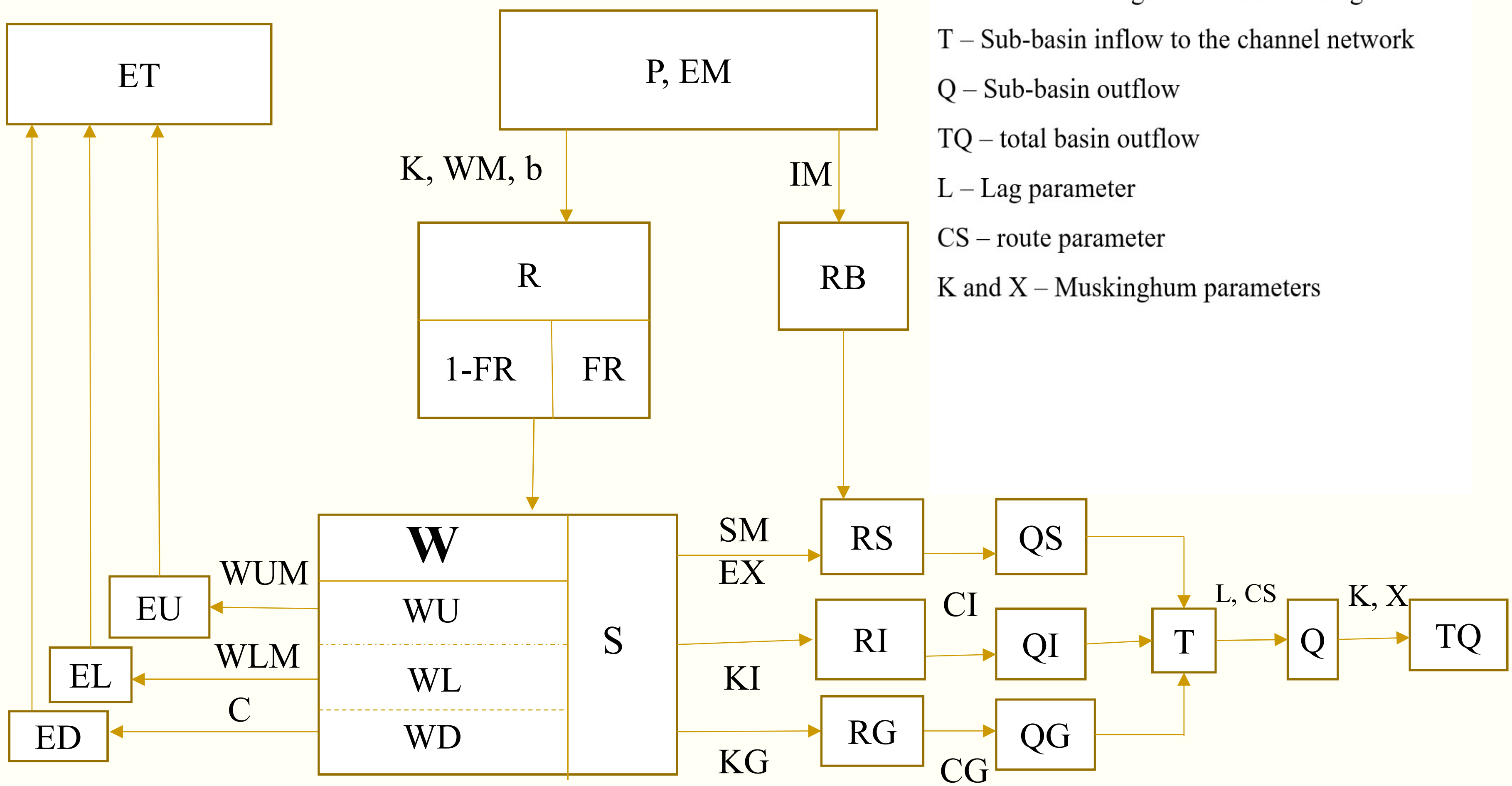
f is fraction of pervious area and F is the total pervious area

W'M varies from 0 to a maximum value of WMM

WM (Field capacity)



Flow Chart



QS, QI, and QG – surface, interflow, and groundwater discharge

T – Sub-basin inflow to the channel network

Q – Sub-basin outflow

TQ – total basin outflow

L – Lag parameter

CS – route parameter

K and X – Muskinghum parameters

Evapotranspiration Module

- Evaporation occurs at the potential rate until the storage of the first layer is exhausted

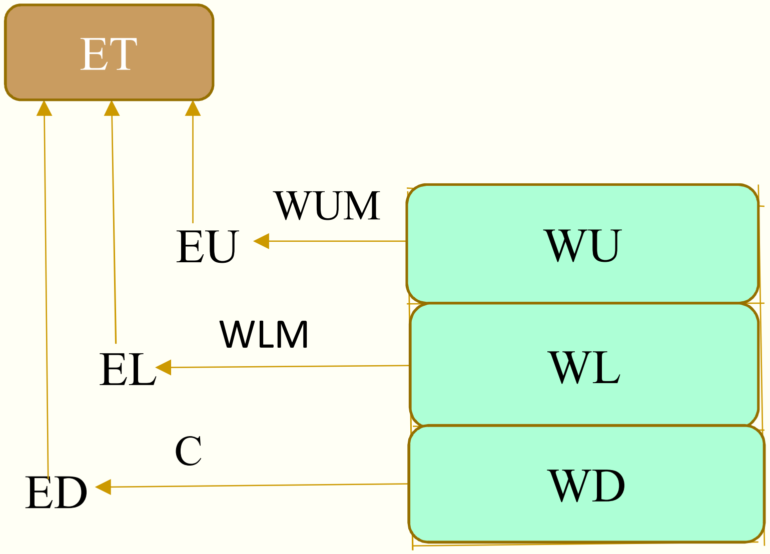
$$EU = K \times EM$$

- After exhaustion of the upper layer remaining potential evapotranspiration is applied to the lower layer, but the efficiency is modified

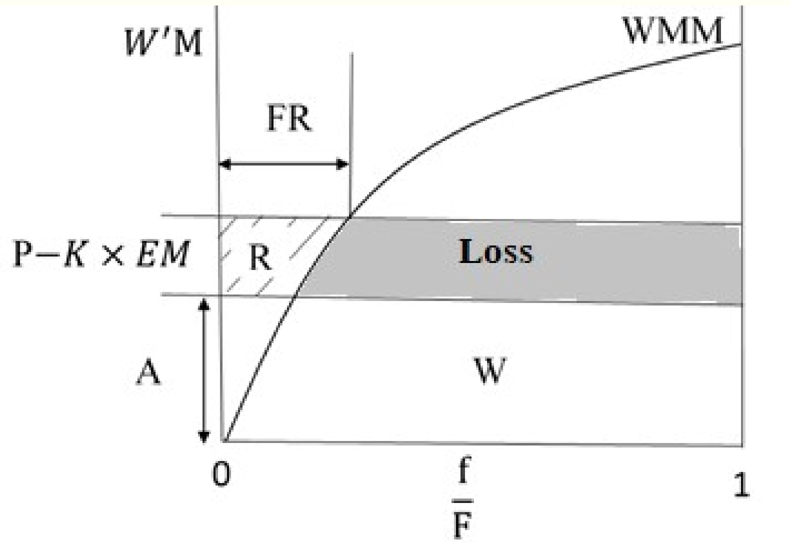
$$EL = (K \times EM - EU) \times \frac{WL}{WLM}$$

- When the total evapotranspiration in the upper and lower layers is less than a pre-set threshold, evapotranspiration continues to the deep layer to keep the pre-set minimum value.

$$ED = C \times (K \times EM - EU) - EL$$



Runoff Production Module



$$1-\frac{f}{F}=\left(1-\frac{W'M}{WMM}\right)^{b}$$

$$WM=\int_{0}^{WMM}\left(1-\frac{W'M}{WMM}\right)^{b}dW'M$$

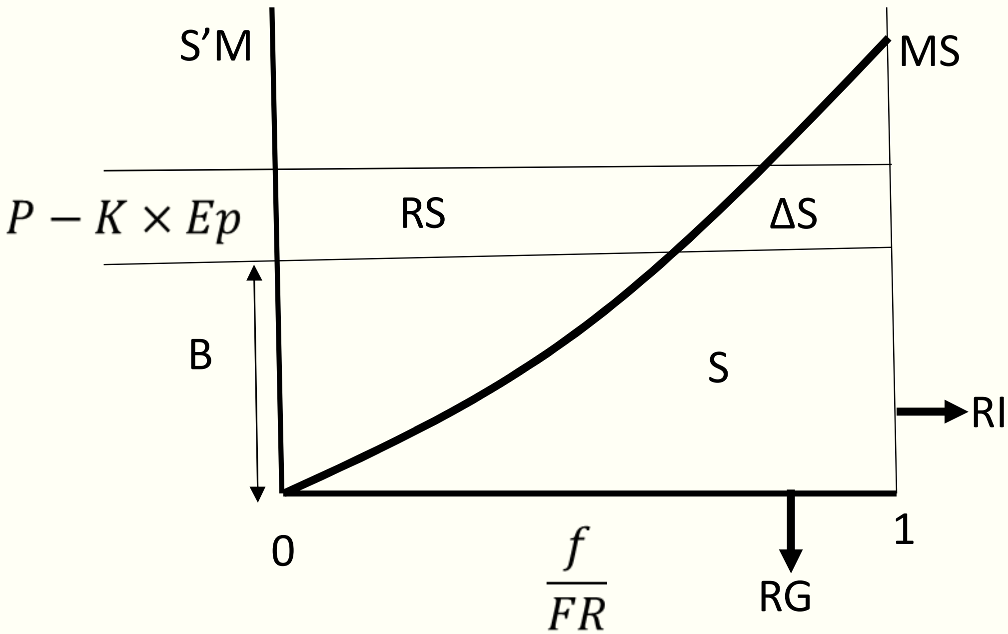
$$WM=\frac{WMM}{1+b}$$

$\frac{f}{F}$ = Proportion of the pervious area of the basin whose soil moisture storage capacity is less than or equal to W'M

$$R=P-PET-Loss$$

$$R=\begin{cases}P-PET-\displaystyle\int_{A}^{P-PET+A}\left(1-\frac{W'M}{WMM}\right)^{b}dW'M, & \text{for } P-PET+A<WMM\\ P-PET-(WM-W), & \text{Otherwise}\end{cases}$$

Separation of Runoff Component



$$\left(1 - \frac{f}{FR}\right) = \left(1 - \frac{S'M}{MS}\right)^{EX}$$

$$SM = \int_0^{MS} \left(1 - \frac{S'M}{MS}\right)^{EX} dS'M = \frac{MS}{EX + 1}$$

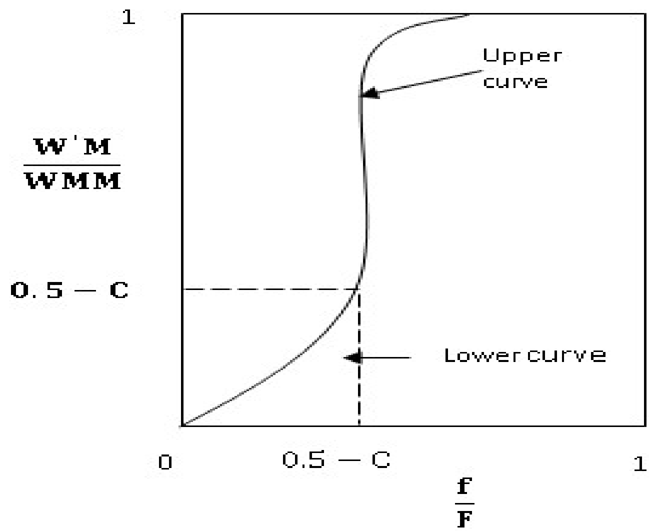
$$RS = \begin{cases} \mathrm{P - PET - SM + S + SM} \times \left[1 - \frac{\mathrm{P - PET + B}}{\mathrm{MS}}\right]^{1+\mathrm{EX}}, & \text{for } P - PET + B < MS \\ \mathrm{P - PET - (SM - S)}, & \text{Otherwise} \end{cases}$$

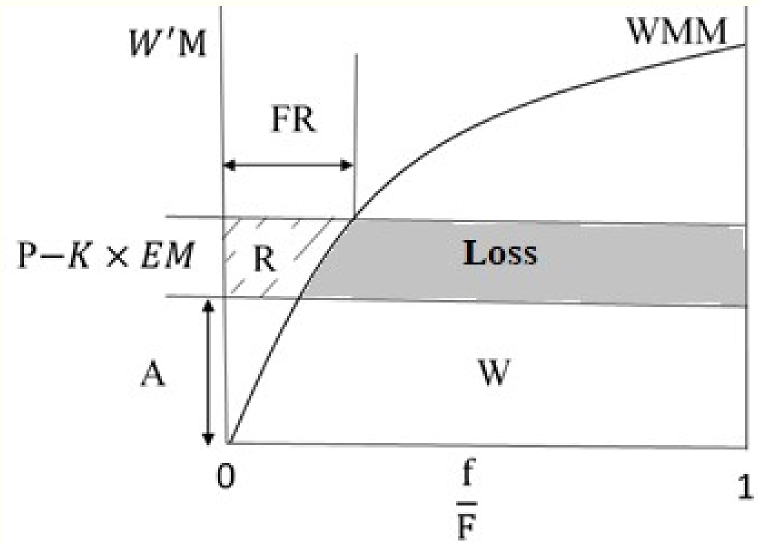
Routing Module

- The sub-basin outflow is produced by an empirical Unit hydrograph or by lag and route method

- Flood routing from the sub-basin outlets to the total basin outlet is achieved by applying Muskingum method to each reaches.

Jayawardene, 2000

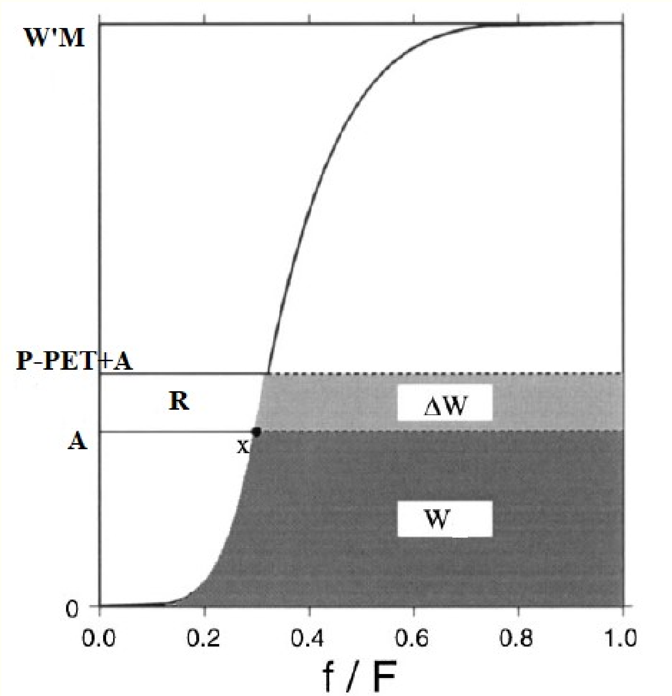


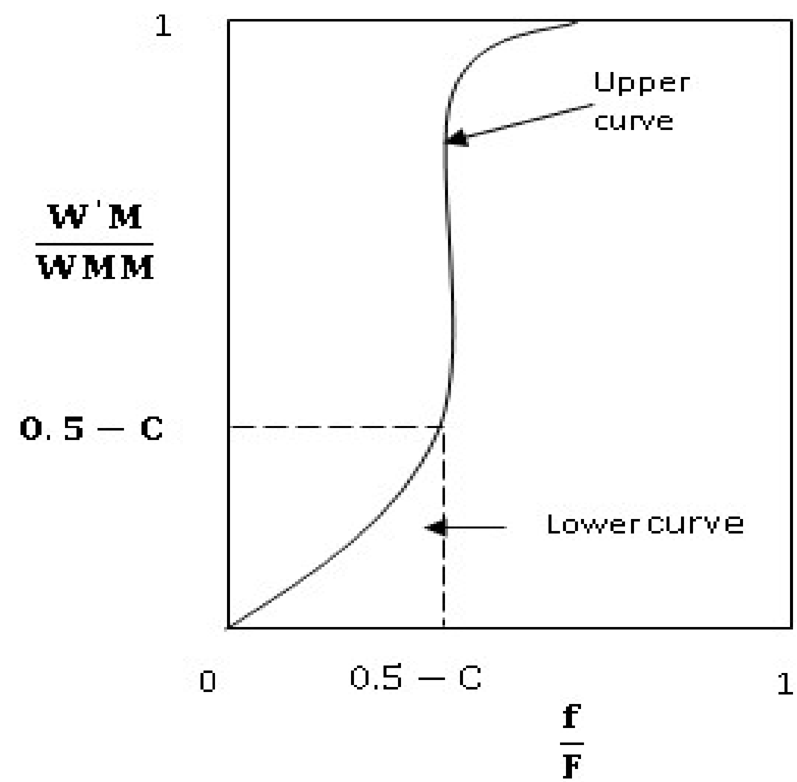


Distribution of soil moisture storage capacity curve

$$\frac{f}{F} = \begin{cases} (0.5 - c)^{1-b}\left(\frac{W'M}{WMM}\right)^{b} & \text{for } 0 \leq \frac{W'M}{WMM} \leq (0.5 - c) \\ 1 - (0.5 + C)^{1-b}\left(1 - \frac{W'M}{WMM}\right)^{b} & \text{for } (0.5 - C) < \frac{W'M}{WMM} \leq 1 \end{cases}$$

Runoff Generation

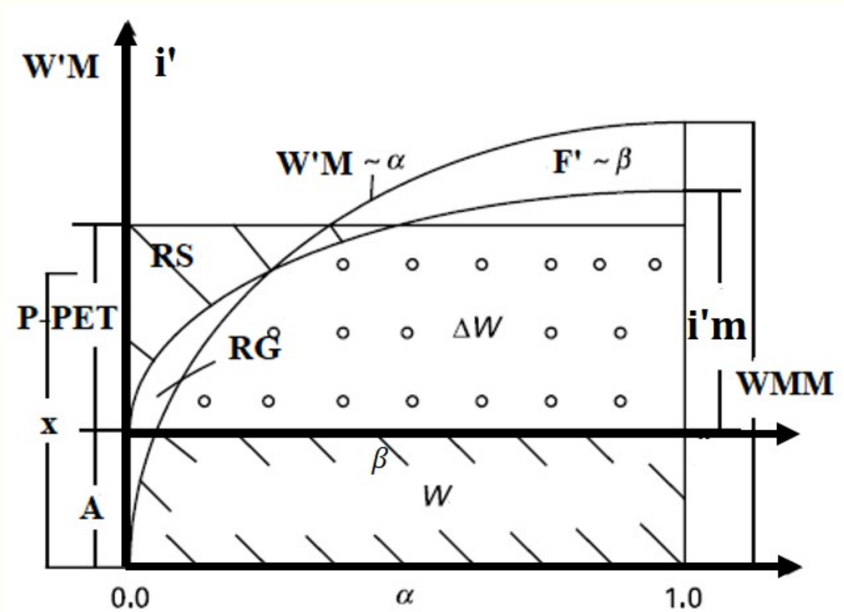




$$R = \int_{A}^{P-PET+A} \left(\frac{f}{F}\right) dW'\mathrm{M}$$

Hu et al., 2005

- Considers both Horton and saturation overland flow mechanisms simultaneously
- Rainfall excess runoff occurs if rainfall intensity is greater than infiltration rate, while saturated overland flow occurs if the soil moisture reaches the field capacity

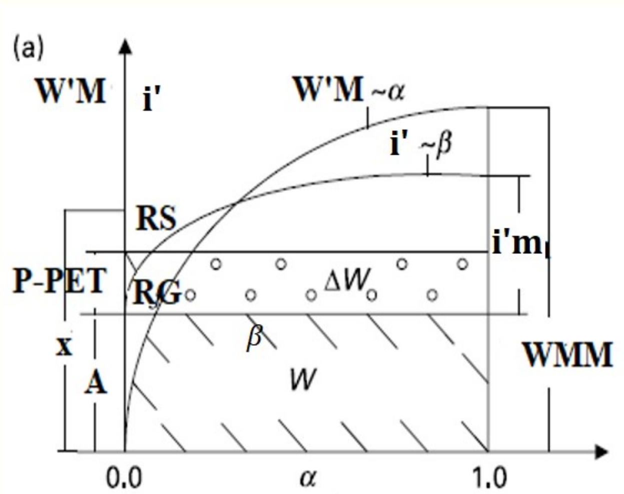


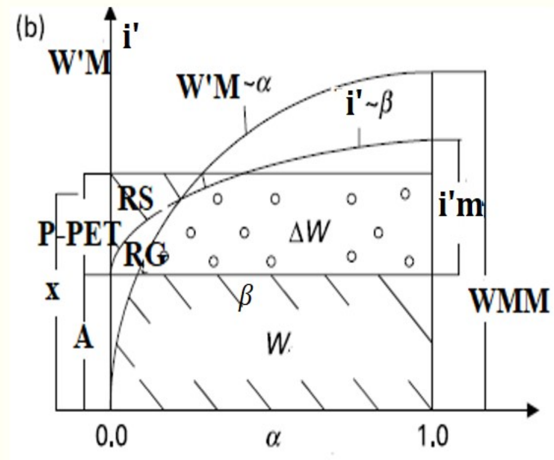
$$\frac{n}{N} = 1 - \left(1 - \frac{i'}{i'm}\right)^{m}$$

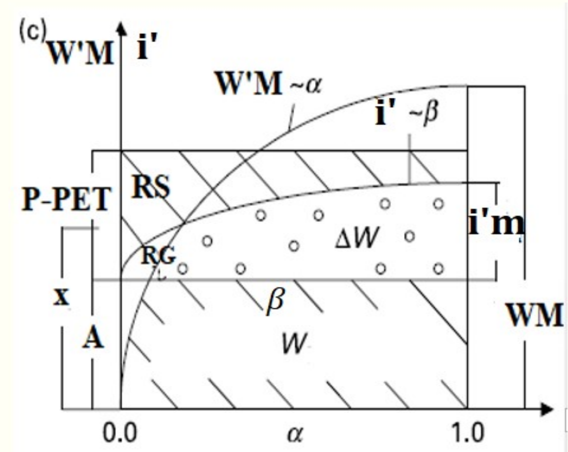
$$\alpha = \beta = \frac{f}{F}$$

Runoff Generation

$$\boxed{\text{When, } A + i'_m \leq WMM}$$







$$\mathrm{P - PET + A \leq x}$$

$$RS = \int_0^{P-PET} \left(\frac{f}{F}\right) di'$$

$$RG = \int_A^{A+P-PET} \frac{f}{F}\, dW'\mathrm{m} - \int_0^{P-PET} \left(\frac{f}{F}\right) di'$$

$$\mathrm{x \leq P - PET + A} \leq i'_m$$

$$RS = \int_0^{P-PET} \left(\frac{f}{F}\right) di'$$

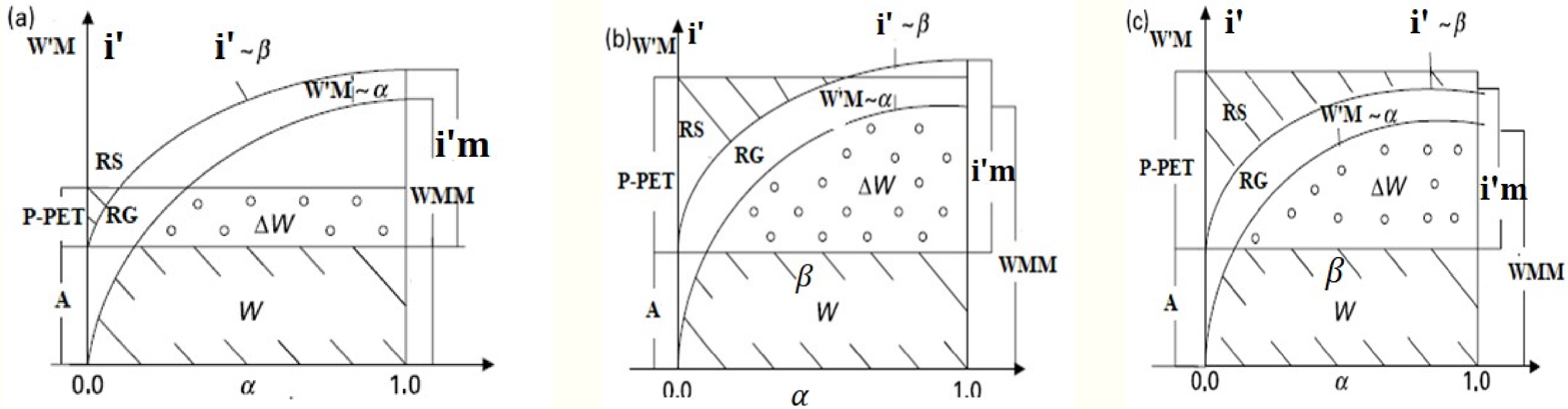
$$RG = \int_A^{x} \frac{f}{F}\, dW'M - \int_0^{x-A} \left(\frac{f}{F}\right) di'$$

$$\mathrm{P - PET + A} \geq W + i'_m$$

$$RS = P - PET - \int_0^{i'_m} \left(1 - \frac{f}{F}\right) di'$$

$$RG = \int_A^{x} \frac{f}{F}\, dW'M - \int_0^{x-A} \left(\frac{f}{F}\right) di'$$

$$\text{When, } A + i'_m > WMM$$



$$\mathrm{P-PET+A \leq wmm}$$

$$\mathrm{WMM \leq P-PET+A} \leq A + i'_m$$

$$\mathrm{P-PET+A} \geq A + i'_m$$

$$RS = \int_0^{P-PET} \left(\frac{f}{F}\right) di'$$

$$RG = \int_A^{A+P-PET} \frac{f}{F} dW'\mathrm{m} - \int_0^{P-PET} \frac{n}{N} di'$$

$$RS = \int_0^{P-PET} \left(\frac{f}{F}\right) di'$$

$$RG = \int_0^{P-PET} \left(1 - \frac{f}{F}\right) di' - (WM - W_0)$$

$$RS = P - PET - \int_0^{i'_m} \left(1 - \frac{f}{F}\right) di'$$

$$RG = \int_0^{i'_m} \left(1 - \frac{f}{F}\right) di'$$

Fang et al., 2017

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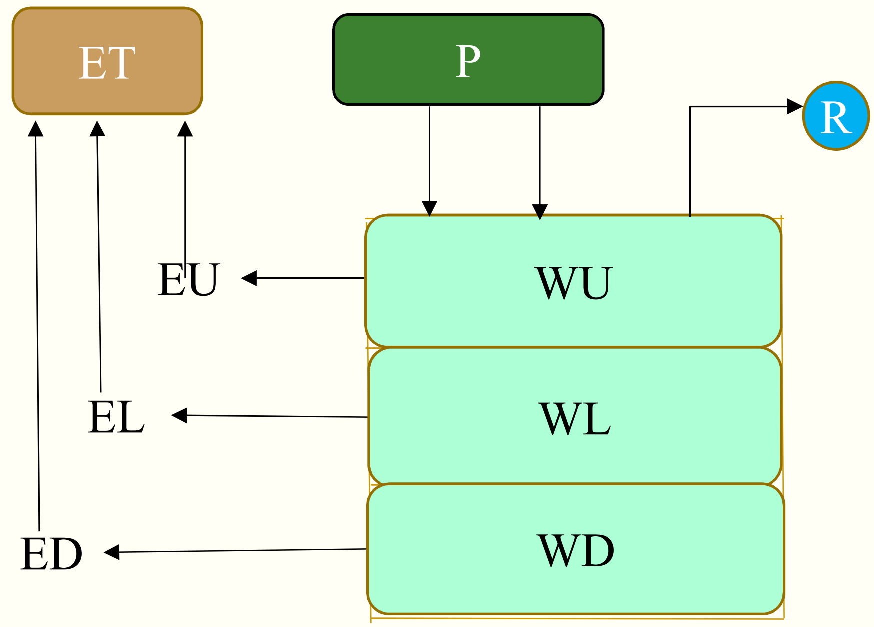
- $\Delta W = P - R - ET$

- $\Delta S = R_n - G - H - LE$

- $ET = \frac{LE}{\lambda \rho_w}$



VIC Model., 1992

- The VIC model is a macroscale hydrologic model
- Runoff generation based on the concept of series of buckets of soil moisture storage with variable infiltration capacities
- This model and its variants use the same modular structure of the Xinanjiang model based on the variable infiltration capacity concept

$$\mathbf{1-\frac{A_S}{A_T}=\left(1-\frac{i}{i_m}\right)^{b}}$$

$$R = P - PET - WM + (1+K_b)\mathrm{W} \qquad \text{for } i_0 + \mathrm{P} - \mathrm{PET} \geq i_m$$

$$R = P - PET - WM + (1+K_b)\mathrm{W} + \mathrm{WM}\left(1-\frac{i_0+P-PET}{i_m}\right)^{b+1}$$

$$\text{For } i_0 + \mathrm{P} - \mathrm{PET} < i_m$$

Arno Model., 1996

- Semi-distributed conceptual rainfall-runoff model
- Uses the basic structure of the Xinanjiang model, with added features accounting for drainage and percolation losses
- Based on a spatial probability distribution of soil moisture capacity and of dynamically varying saturated contributing areas

$$\frac{\mathbf{S - S_I}}{\mathbf{S_T - S_I}} = \mathbf{1} - \left(\mathbf{1} - \frac{\mathbf{W'M}}{\mathbf{WMM}}\right)^{\mathbf{b}}$$

$$R = P - PET + \frac{S_T - S_I}{S_T}\left[(WM - W) - WM\left[\left(1 - \frac{W}{WM}\right)^{\frac{1}{1+b}} - \frac{P - PET}{(1+b)WM}\right]^{1+b}\right] + D + B_f$$

$$\text{for } 0 < P - PET < (b+1)WM\left(1 - \frac{W}{WM}\right)^{\frac{1}{b+1}}$$

$$R = P - PET + \frac{S_T - S_I}{S_T}(WM - W) + D + B_f$$

$$\text{for } P - PET \geq (b+1)WM\left(1 - \frac{W}{WM}\right)^{\frac{1}{1+b}}$$

Conclusions

- Many researchers have tried to modify the basic structure of the Xinanjiang model to incorporate the soil moisture dynamics in a conceptual framework

- Some models seem to be simple and flexible to represent the soil moisture water capacity curve

- However, some are having a complex modular structure with the addition of more and more conceptual component processes i.e., increasing the number of model parameters

- All these models (Xinanjiang) are not well tested in varied real world basins

- Only statistical power distribution function is used to express the model structure, however, its physical basis has not been verified yet


THANK YOU