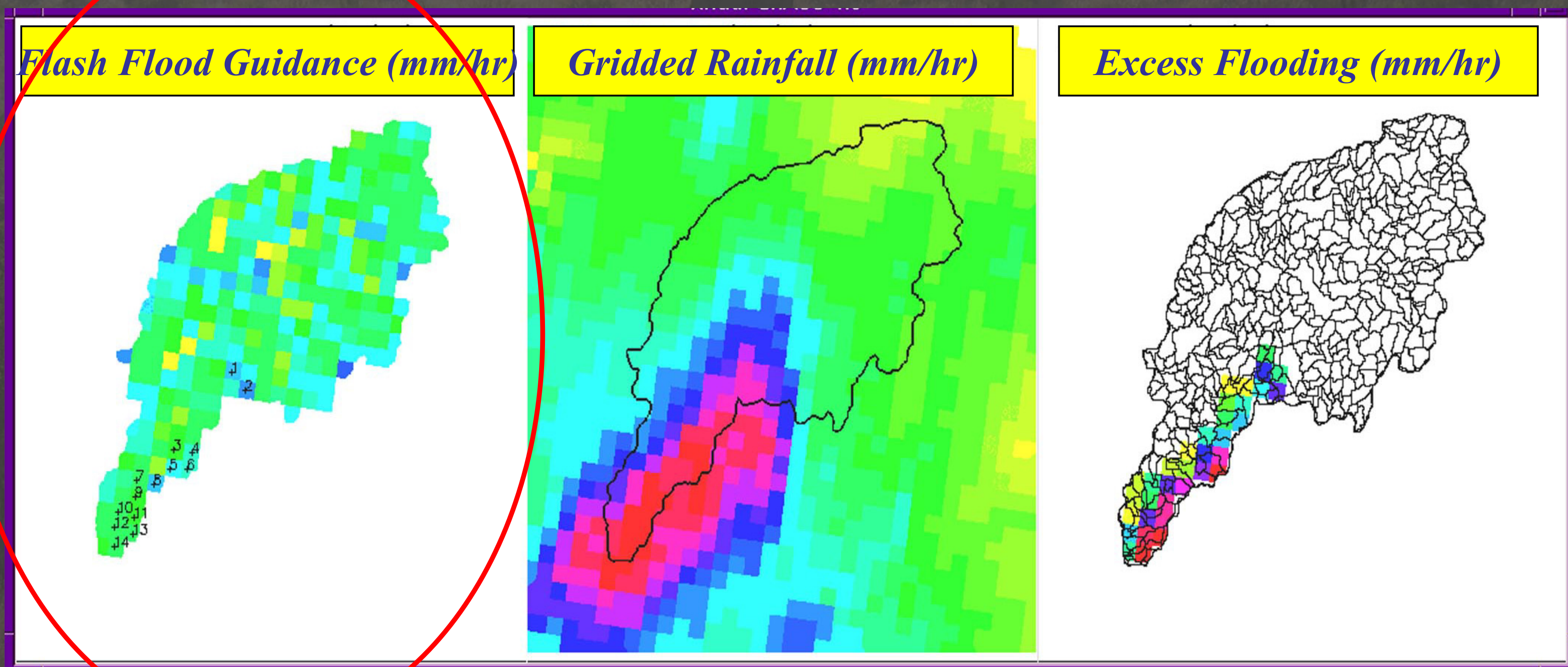
Technical Overview of FFG Models



GOAL: To present the basis of flash flood guidance estimation with a focus on input data needs and requirements.

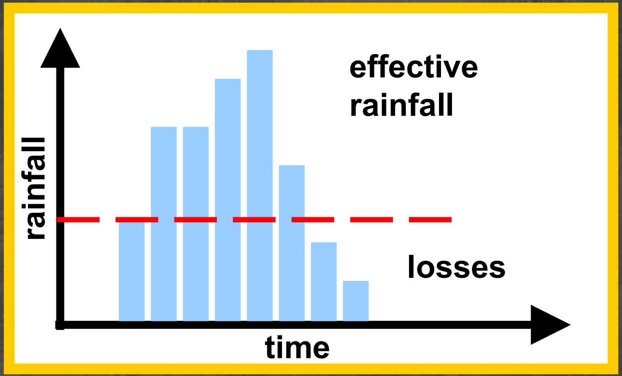
Some Definitions …

Flash Flood Guidance (FFG)

The amount of ***actual rainfall*** of a given duration required to generate bankfull flows at the outlet of a basin, under certain initial soil moisture conditions.

Threshold Runoff (TR)

The amount of ***effective rainfall*** (runoff) of a given duration capable of causing bankfull flows at the outlet of a basin.



Effective rainfall is the residual amount after accounting for all losses such as interception and soil moisture storage.

FFG is derived from TR by accounting for these losses in the transformation of rainfall to runoff.

Some Definitions …

Flash Flood Guidance (FFG)

The amount of ***actual rainfall*** of a given duration required to generate bankfull flows at the outlet of a basin, under certain initial soil moisture conditions.

FFG is computed on a real-time basis considering the current soil moisture conditions within the basin and additional precipitation of 1-, 3-, and 6-hour durations.

Threshold Runoff (TR)

The amount of ***effective rainfall*** (runoff) of a given duration capable of causing bankfull flows at the outlet of a basin.

Threshold Runoff formulated with physical basis on hydrologic principles. It is a one-time calculation for a given basin, based on catchment and stream channel characteristics.

Threshold Runoff Estimation

We estimate threshold runoff by equating the *peak runoff* generated from a catchment, as defined by the catchment unit hydrograph, with the *bankfull flow* in the stream at the outlet of the catchment.

$$Q_{bf} = q_{pR} * R * A$$

where: Q_{bf} is the bankfull flow at the catchment outlet

q_{pR} is the catchment unit hydrograph peak (cms/km^2/mm)

A is the catchment area

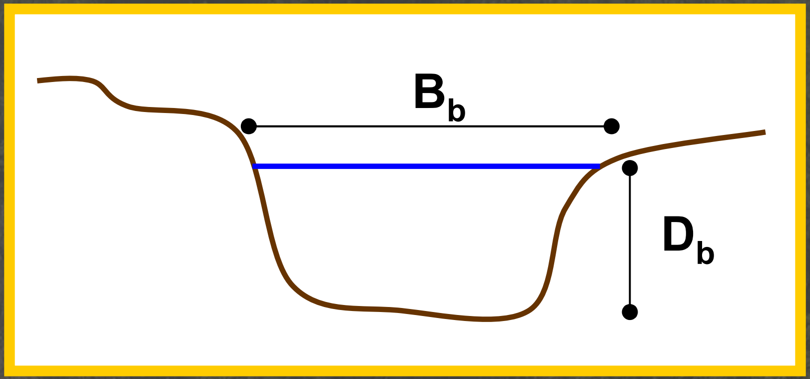
and R is the effective rainfall of given duration of interest or "threshold runoff"

Threshold Runoff Estimation

Bankfull Flow

"Flooding" occurs when a stream overflows its banks. Thus bankfull flow is a physically-based definition of the flow associated with flash flooding.

Bankfull flow may be estimated using hydrologic principles based on stream cross-sectional properties based.



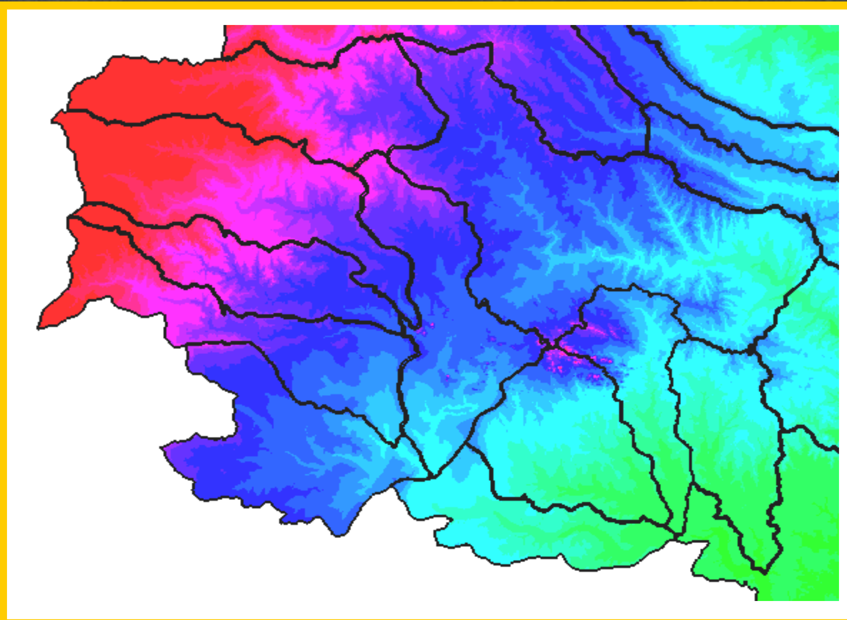
Unit Hydrograph Peak Response

The unit hydrograph represents the response of a catchment to a unit input (mm) of rainfall uniformly falling over the catchment over a given duration. The physically-based geomorphologic instantaneous unit hydrograph (GIUH) is used, and can be computed using catchment-scale (e.g., drainage area, stream length) and channel-scale properties (e.g., cross-sectional characteristics).

Data Requirements for Threshold Runoff Estimation

The variables (Q_{bf}, q_{pR}, A) must be defined in terms of known or readily determined quantities.

(1) GIS processing of digital elevation data provides delineation of catchment areas with computed characteristics such as drainage area, stream length and channel slope.



Data Required:

* Digital elevation data (DEM)
* Digital stream network & watershed boundaries for guidance/verification

Data Requirements for Threshold Runoff Estimation

The variables (Q_{bf}, q_{pR}, A) must be defined in terms of known or readily determined quantities.

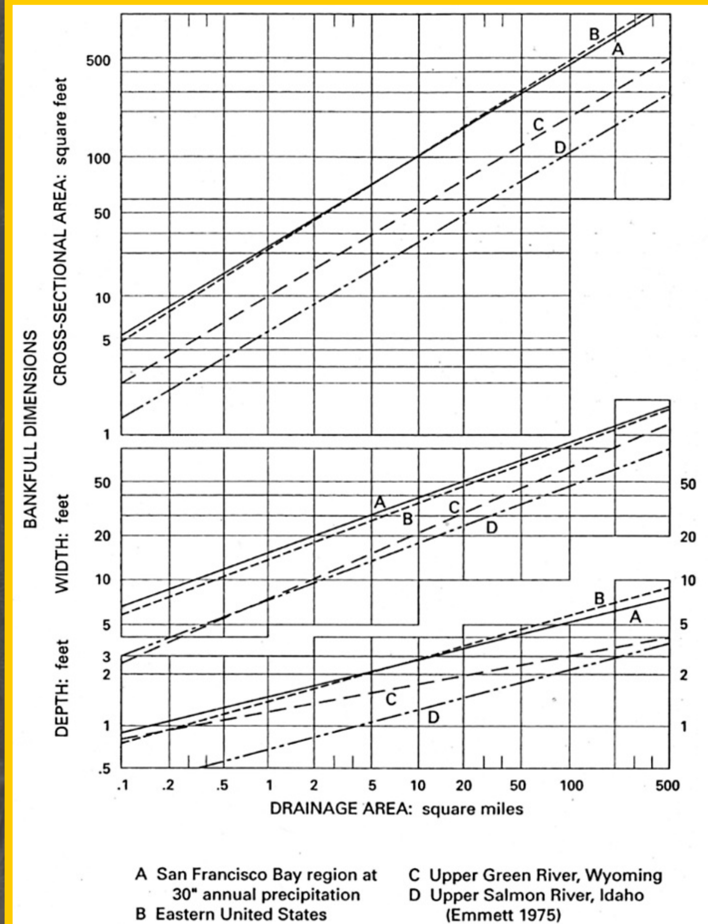
(2) Channel cross-sectional characteristics can not be resolved with current DEMs nor measured at every location of interest.

Regional relationships between cross-sectional properties and catchment characteristics may be derived from high-quality channel surveys.

$B_b = \alpha A^{\gamma}$ $D_b = \varepsilon A^{\lambda}$

Data Required:

* High-quality channel survey data



Source: L. Luna, 1994: *A View of the River*

Some Comments on Threshold Runoff Estimation

- **"The devil is in the details"**

  While equating of catchment response with the bankfull flow results in a "simple" expression, the solution is in a non-linear relationship for R.

  The primary reference for threshold runoff estimation is:

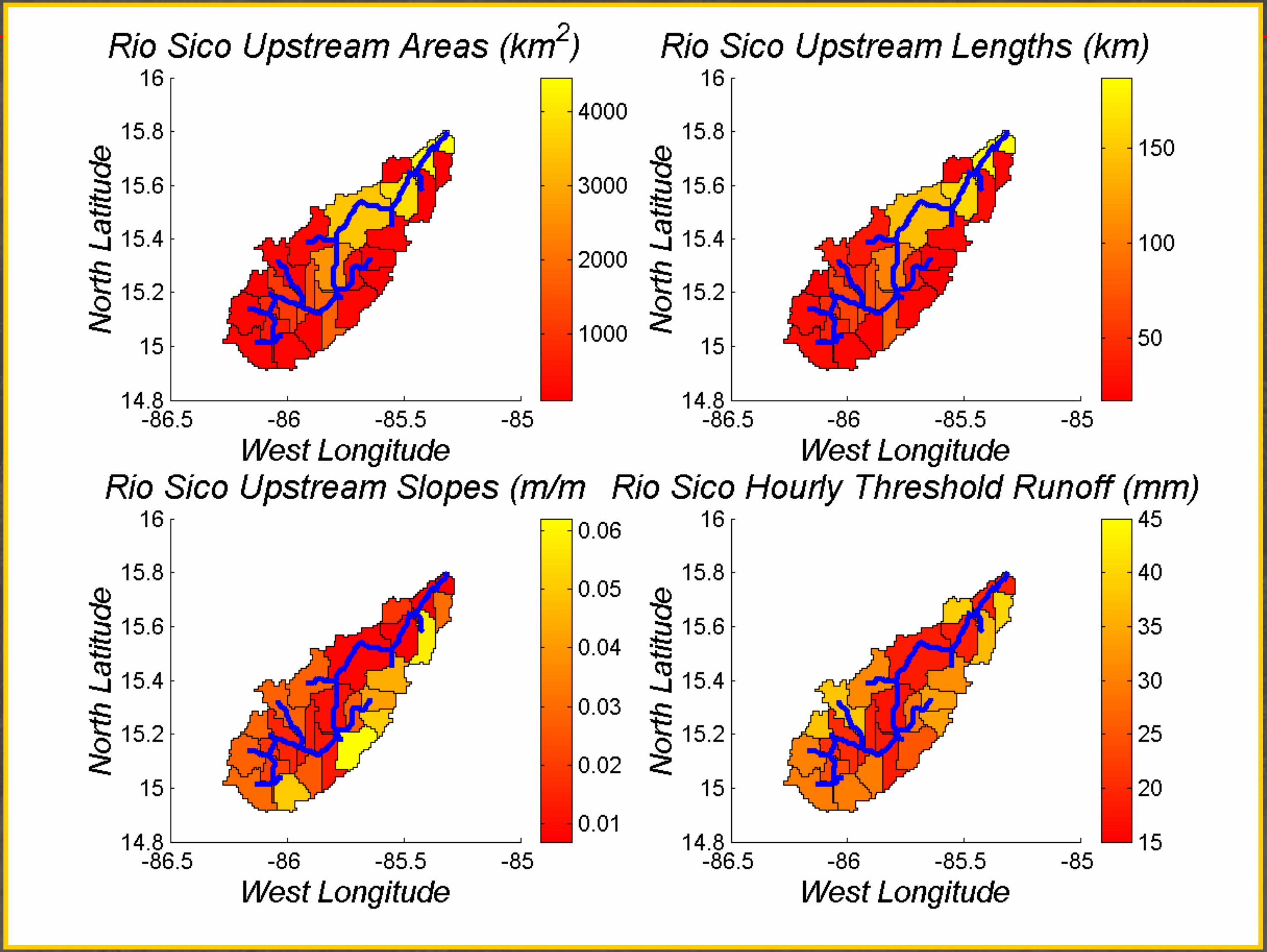
  Carpenter, T.M., et al., 1999: National threshold runoff estimation utilizing GIS in support of operational flash flood warning systems, J. Hydrology, 224 (1-2), 21-44.

- **Bankfull Flow** is typically associated with a return period of 1½-5 yrs.

  This may not be associated with significant flood damage and thus a "conservative" threshold for flash flooding.

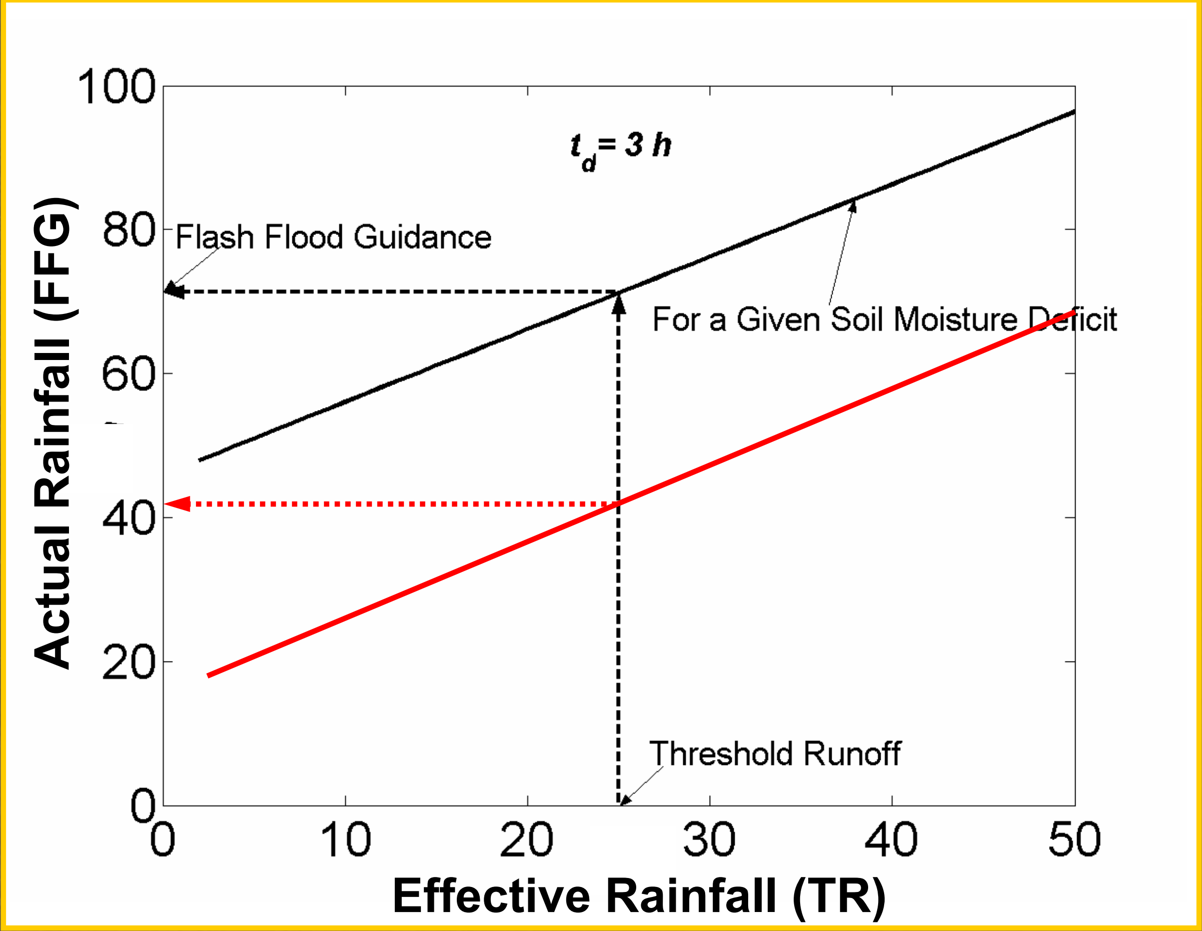
- **The assumptions of unit hydrograph theory** limit application to catchments with cumulative drainage area < 2000km^2.

Example of Threshold Runoff Estimation



Flash Flood Guidance Estimation

FFG is derived from threshold runoff using the current soil moisture deficit.



Soil Moisture Modeling

Soil moisture model represents the top 1-1.5 m of soil depth.

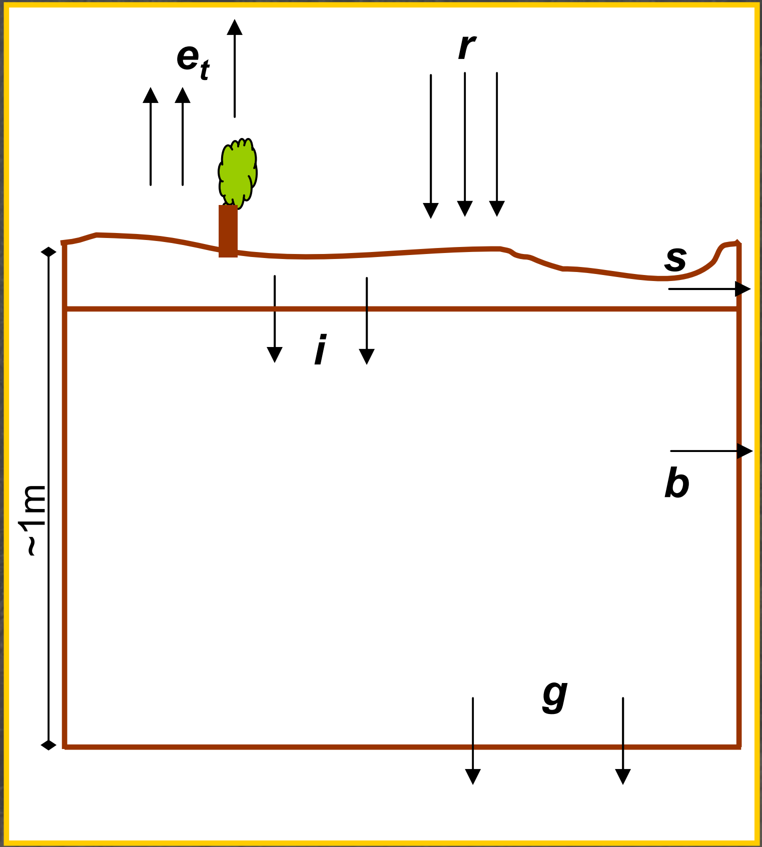
1) Infiltration excess at surface layer

2) Soil moisture accounting

$$Z_T \frac{d(\theta(t)-\theta_w)}{dt} = r(t)-e_t(t)-s(t)-b(t)-g(t)$$

$$s(t) = \begin{cases} 0 & ;\ \theta(t)-\theta_w < \theta_s-\theta_w \\ r(t) & ;\ \theta(t)-\theta_w \geq \theta_s-\theta_w \end{cases}$$

$$K=Ks\left(\frac{\theta(t)-\theta_f}{\theta_s-\theta_f}\right)^{2\alpha+3}$$



Data Required:

* Rainfall input

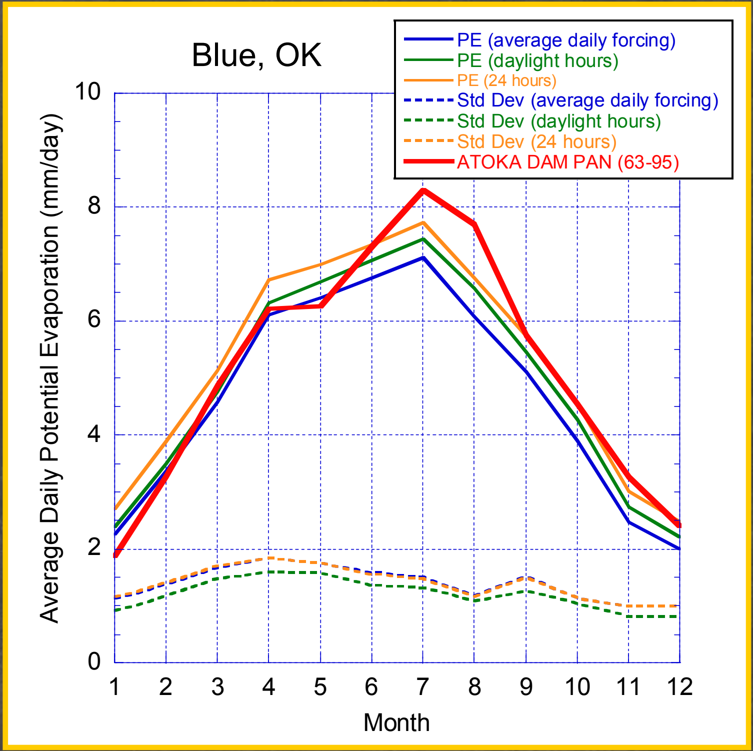
*Surface soil texture, soils properties and soil depth

* land surface cover

Evapotranspiration Estimation

Penman-Monteith equation may be used to estimate the potential evapotranspiration.

$$\lambda E_T = \frac{\Delta(R_n - G) + \rho_a c_p\left(\frac{e_s - e_a}{r_a}\right)}{\Delta + \gamma(1 + r_s/r_a)}$$



where: λ = the latent heat of vaporization,

E_T = the volumetric rate of potential ET,

R_n = the net radiation,

G = the soil heat flux,

ρ_a = the mean air density at constant pressure,

$(e_s - e_a)$ represents the vapor pressure deficit,

c_p = the specific heat of the air under constant pressure,

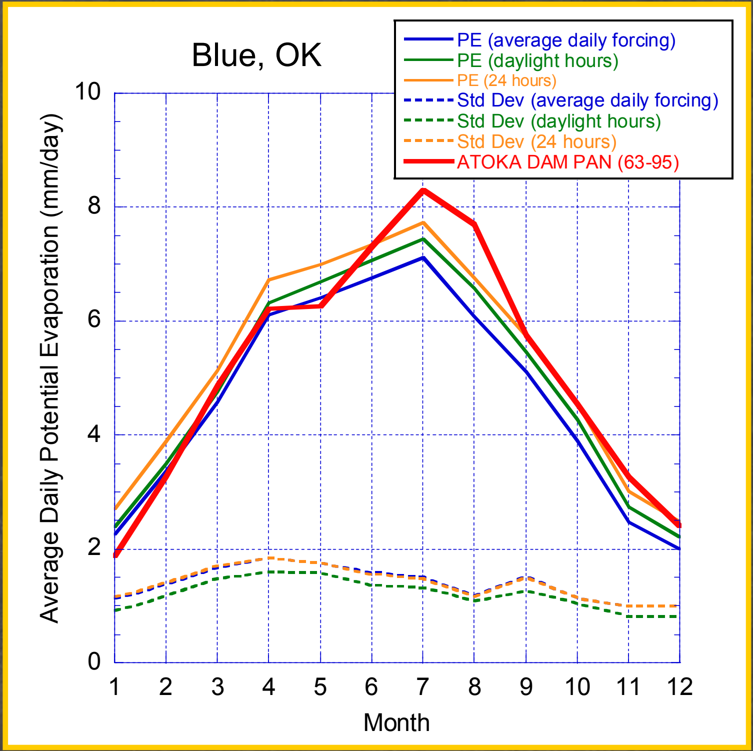
Δ represents the slope of the saturation vapor pressure vs. temperature relationship,

γ = the psychrometric constant,

and r_s and r_a = the (bulk) surface and aerodynamic resistances

Evapotranspiration Estimation

Penman-Monteith equation may be used to estimate the potential evapotranspiration.



$$\lambda E_T = \frac{\Delta(R_n - G) + \rho_a c_p\left(\frac{e_s - e_a}{r_a}\right)}{\Delta + \gamma(1 + r_s/r_a)}$$

Data Required:

- * Surface met variables (radiation, winds, etc)
- * Land surface cover

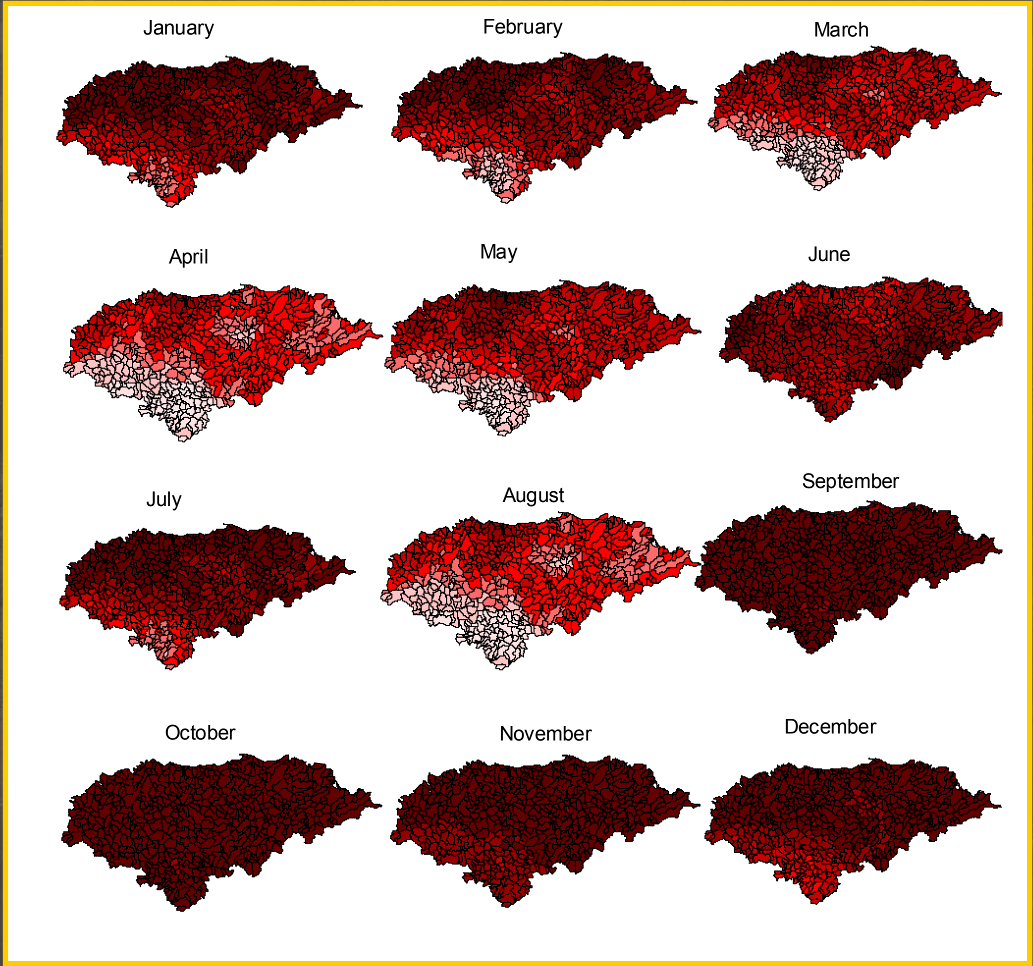
Depth Integrated Soil Moisture

Climatology: 1989-1998

Honduras

Soil Moisture (%)

- 0.9 - 1
- 0.8 - 0.9
- 0.7 - 0.8
- 0.6 - 0.7
- 0.5 - 0.6
- 0.4 - 0.5
- 0.1 - 0.4
- 0 - 0.1



Soil Moisture Model Validation

Example validation for region with soil moisture measurements:

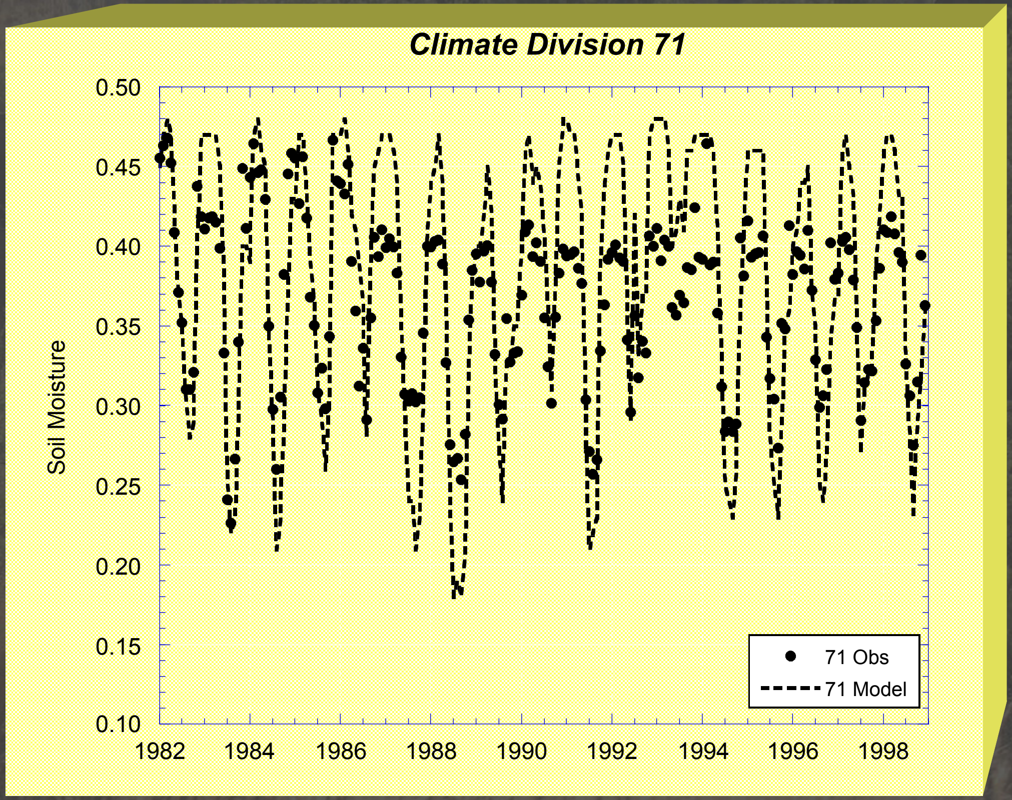
Climate Division in U.S.

~ O[3000km^2]

3 neutron probes

Saturation excess model

Model matches both the range and the timing of fractional soil moisture content.

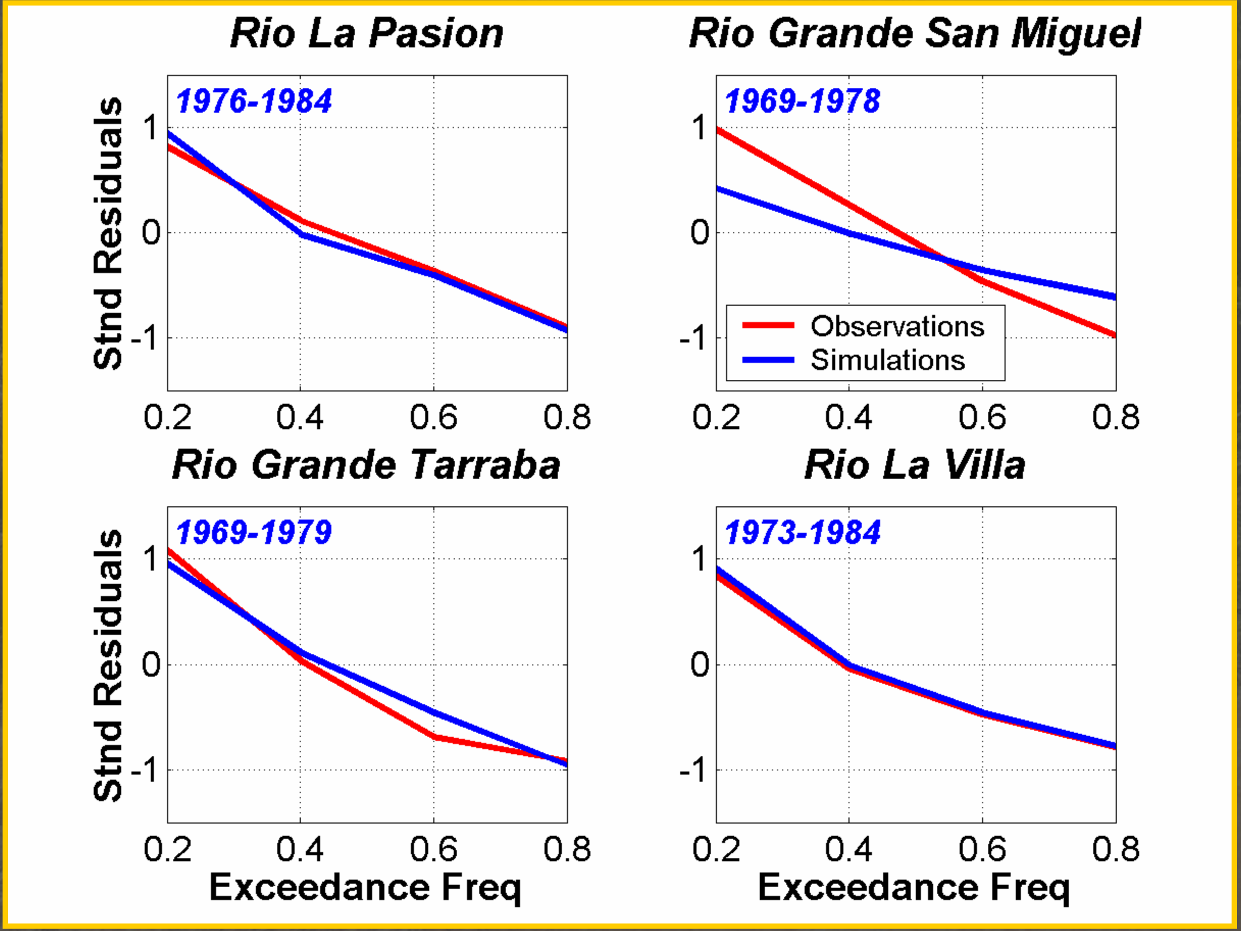


Data Required:

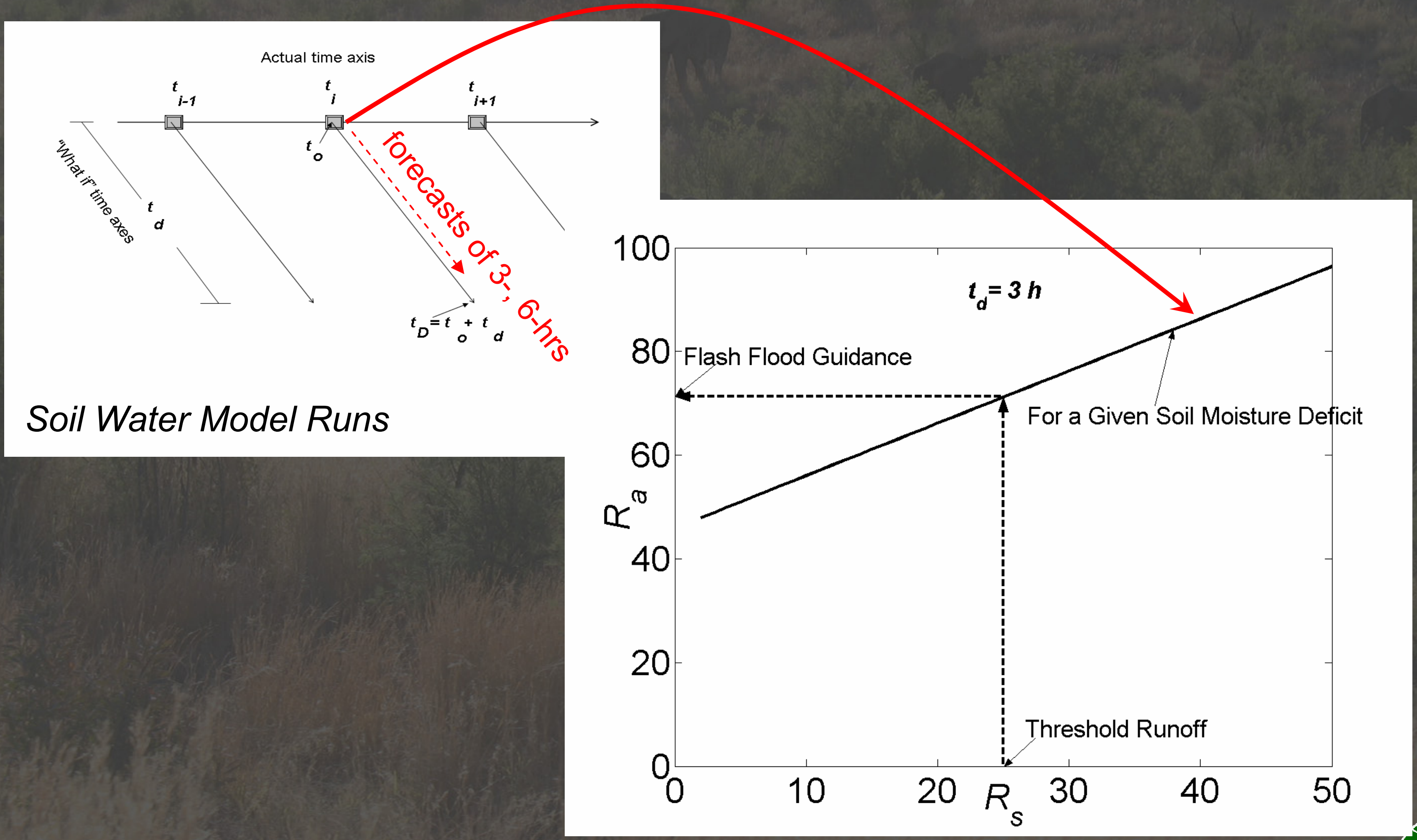
* Historical rainfall and surface met data, pan evaporation
* Historical soil moisture measurements

Soil Moisture Model Validation

In the absence of soil moisture measurements, stream flow may be compared with model-generated runoff.



Real-Time Flash Flood Guidance Estimation



Summary

- **Threshold Runoff and FFG defined in physically-based manner with sound hydrologic principles**
- **Threshold Runoff data requirements:**
  DEM, digital stream network and watershed boundaries, channel cross-sectional survey data
- **FFG estimated in real time by estimating soil moisture deficit at time of forecast through soil moisture accounting**
- **Soil Moisture Model data requirements:**
  Soil texture and soil properties information, land cover data, surface met variables, soil moisture measurements, stream flow.
- **Model components to be validated for South Africa applications regions with local data**