Haiti-Dominican Republic Flash Flood Guidance (HDRFFG) System: Development of System Products

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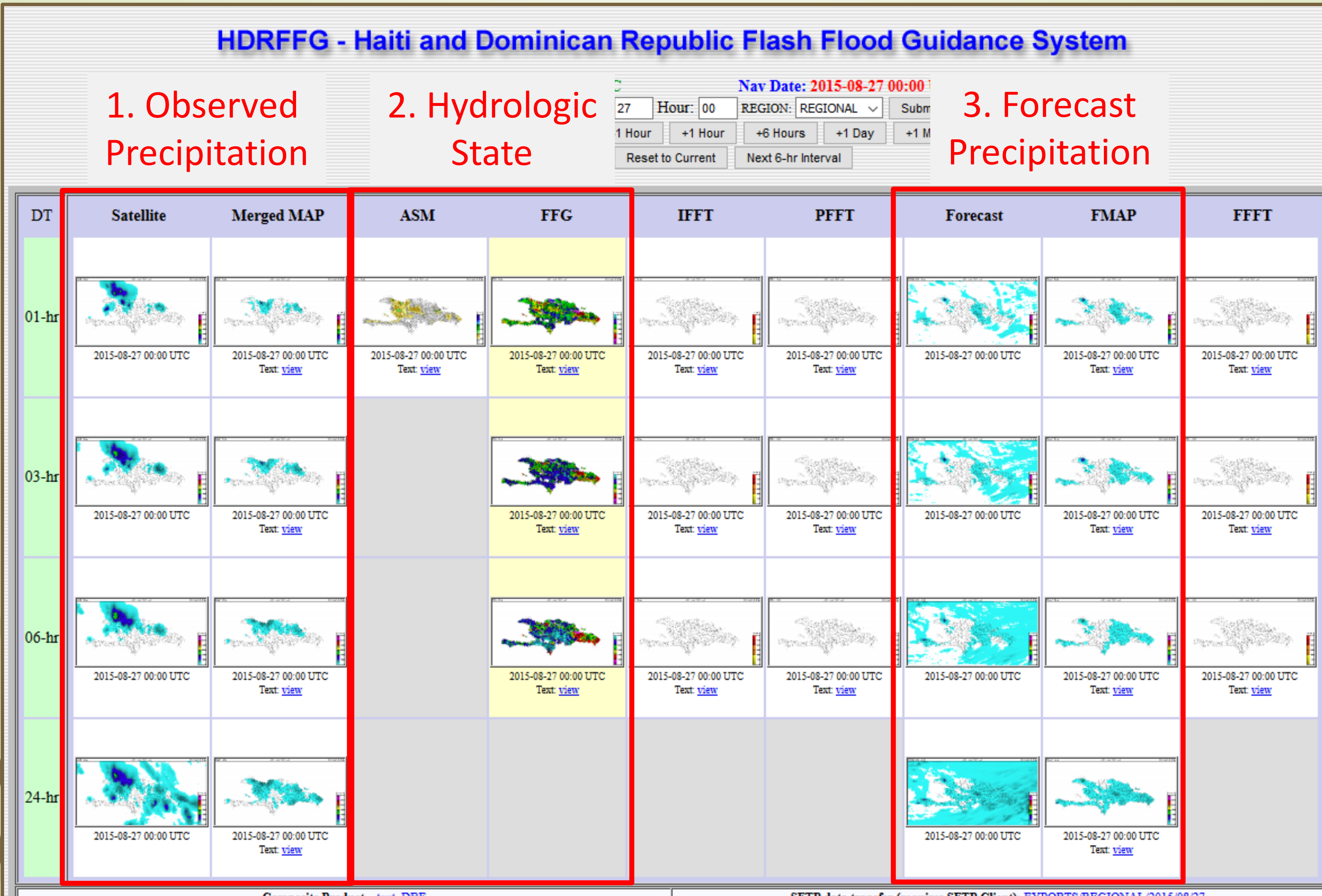
Hydrologic Research Center

HDRFFG Initial Planning Meeting 07-09 Sep 2015 Santo Domingo, DR

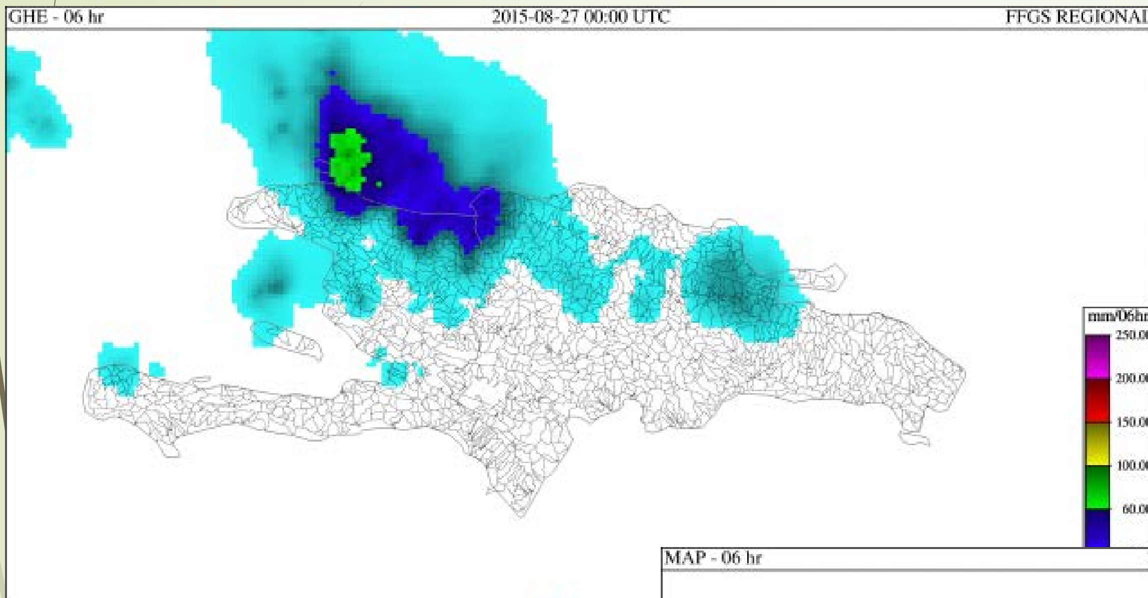
HDRFFG System Products



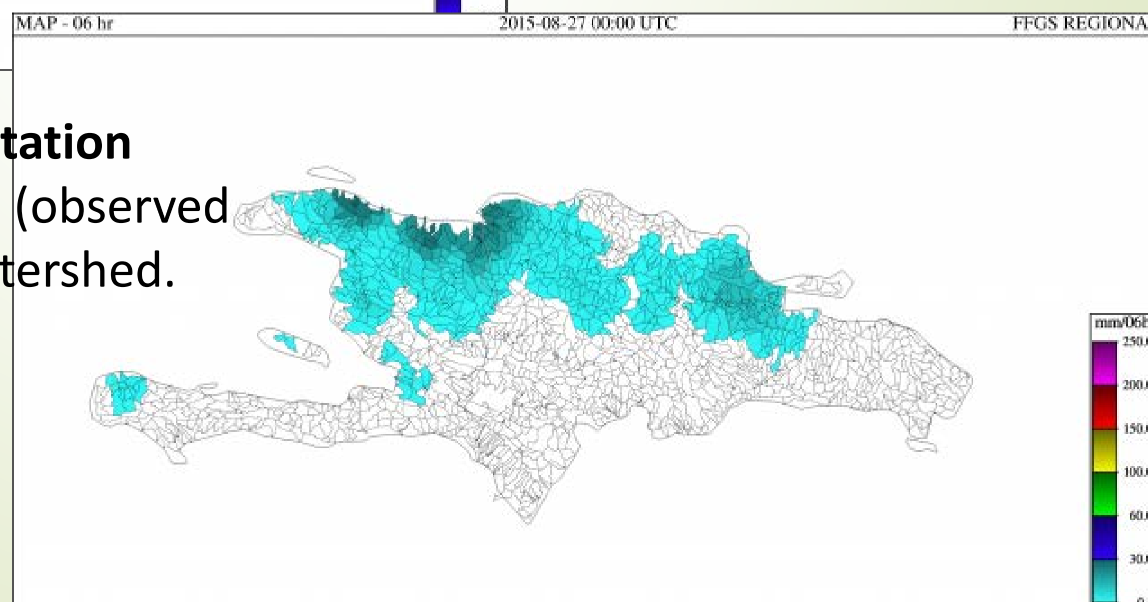
Station Identifier	Station Name	Observation Date & Time (UTC)	Precipitation (mm)	Temperature (C)	Relative Humidity (%)	Atmospheric Pressure (mb)	Solar Radiation	Wind Direction	Wind Velocity	Battery Voltage
10	Sabana Larga, Ocoa	2015-08-27 00:00:00+00	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
11	Pimentel, Duarte	2015-08-27 00:00:00+00	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
12	Las Galeras, Samana	2015-08-27 00:00:00+00	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
13	Neyba	2015-08-27 00:00:00+00	0	No Data	No Data	No Data	17	No Data	No Data	No Data
6	Valle Nuevo	2015-08-27 00:00:00+00	No Data	No Data	8	17	8	16	No Data	8

HDRFFG System Products: Precipitation

OBSERVED PRECIPITATION: How much precipitation has fallen

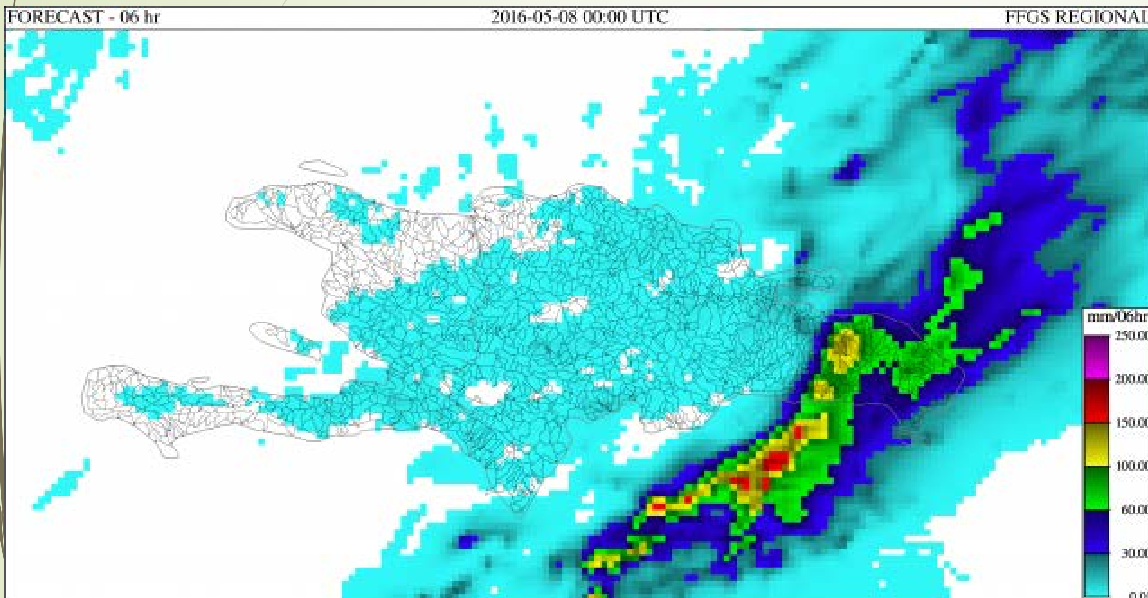


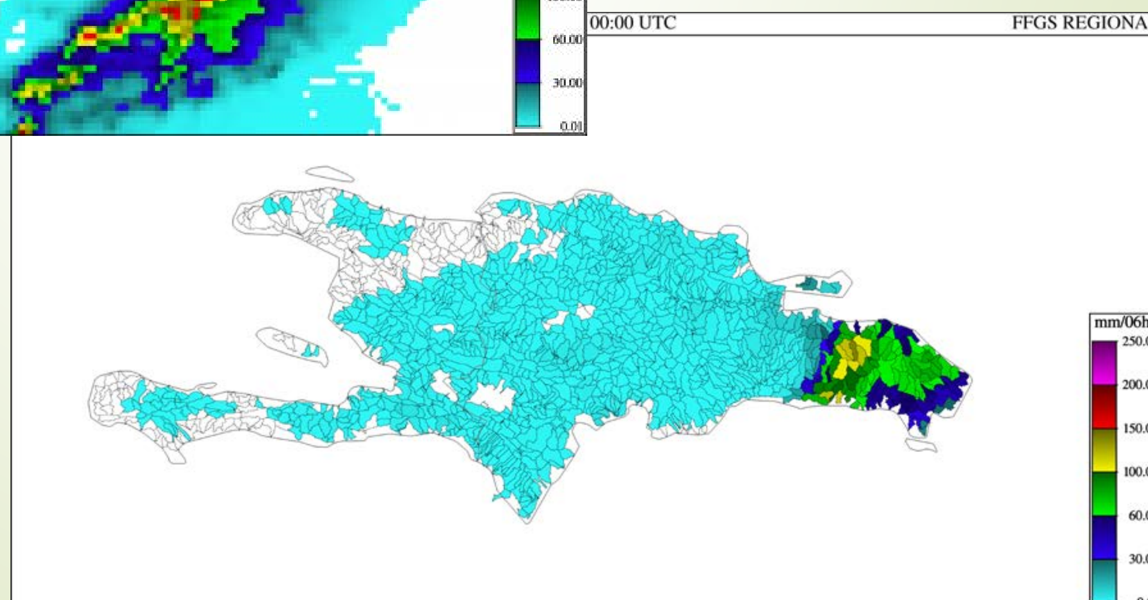
MAP: Mean areal precipitation
The average precipitation (observed or forecast) over each watershed.



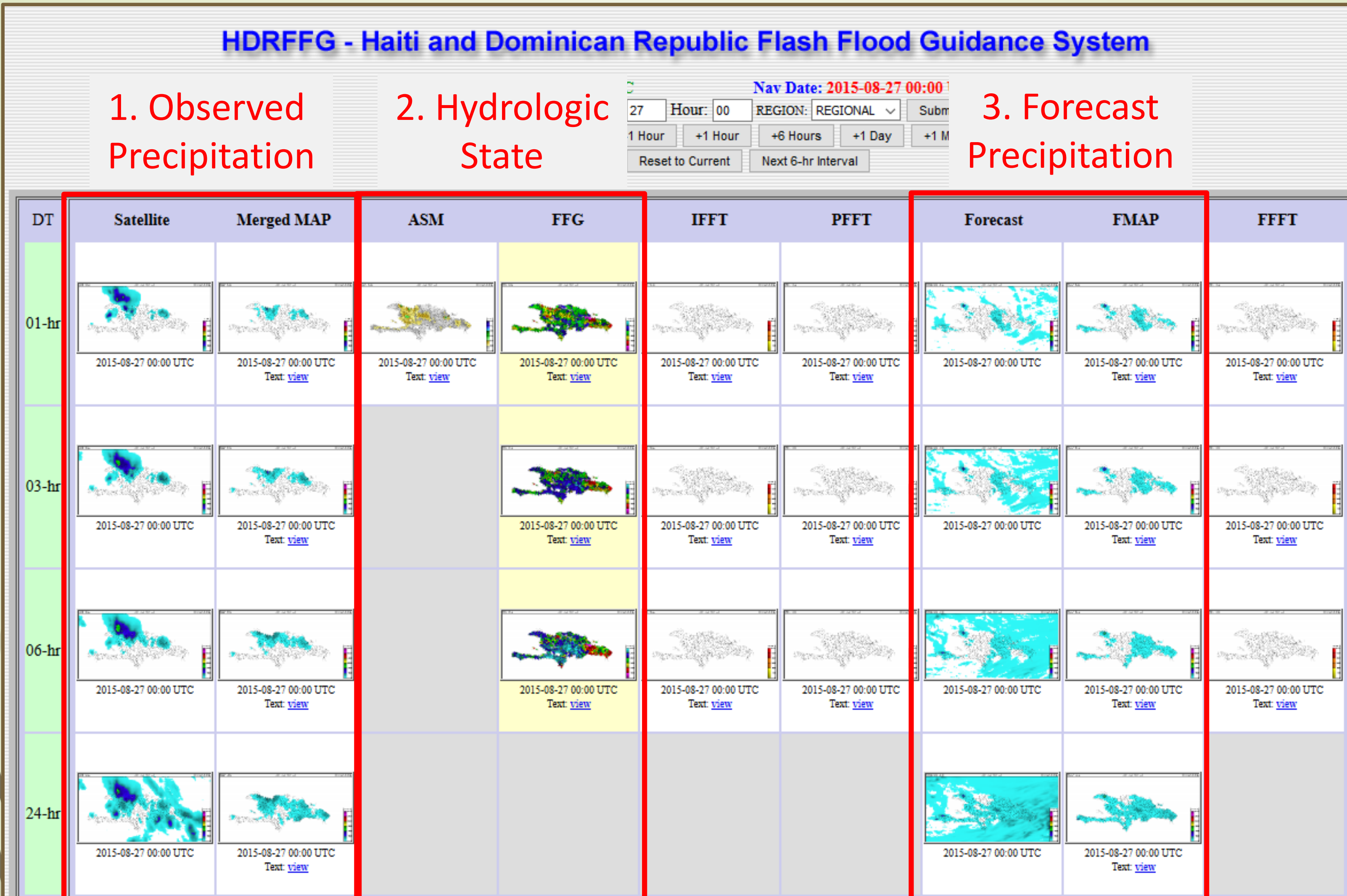
HDRFFG System Products: Precipitation

FORECAST PRECIPITATION: How much precipitation is expected based on NWP model QPF.





HDRFFG System Products



Composite Product... text, DBF | SFTP data transfer (requires SFTP Client): EXPORTS/REGIONAL/2015/08/27

Surfmet Gauge Precipitation Accumulations ending on 2015-08-27 00:00 UTC

Station Identifier	Station Name	Observation Date & Time (UTC)	Precipitation (mm)	Temperature (C)	Relative Humidity (%)	Atmospheric Pressure (mb)	Solar Radiation	Wind Direction	Wind Velocity	Battery Voltage
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7	El Pozo, Nagua	2015-08-27 00:00:00+00	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data

Why is Soil Moisture Important?

GEORGAKAKOS ET AL.: HYDROCLIMATOLOGY OF WATERSHEDS, 1

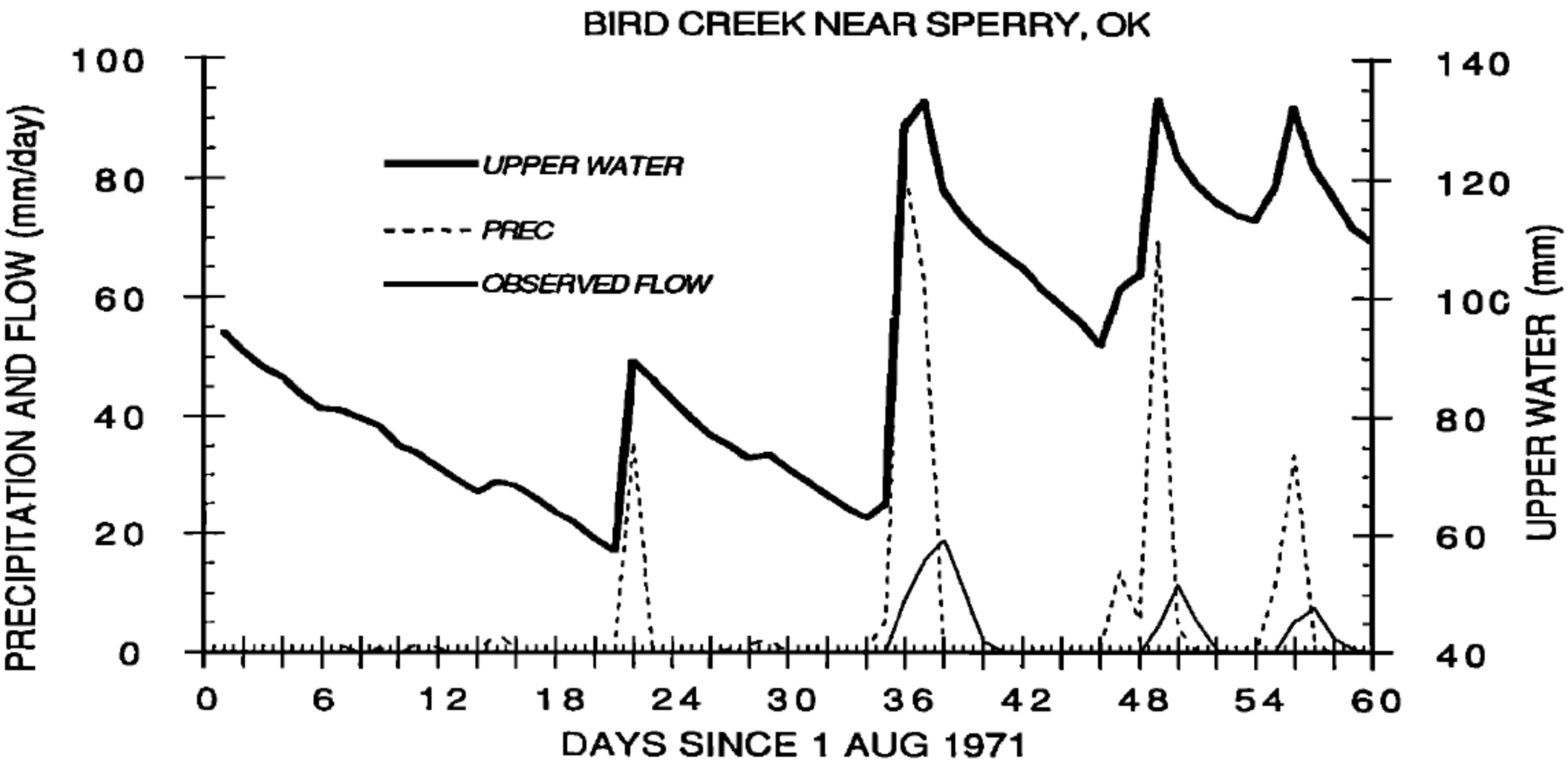


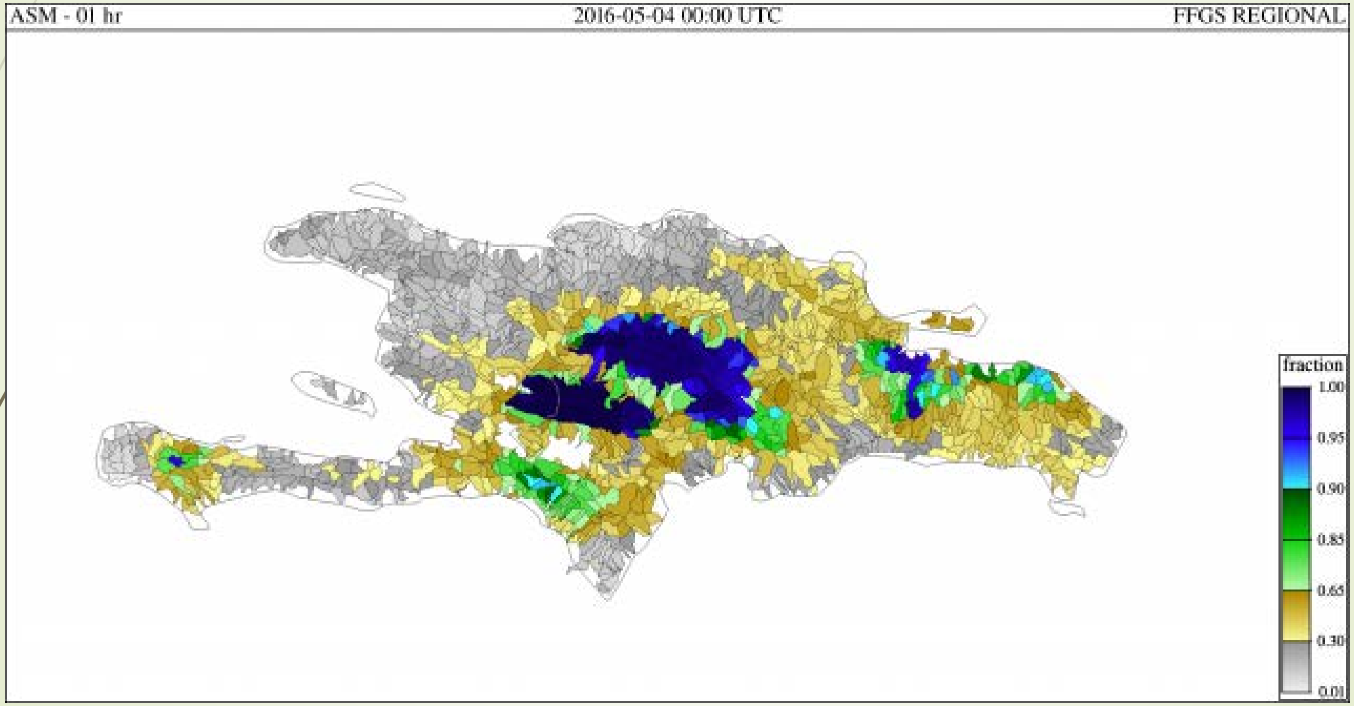
Figure 2. Daily values of rainfall rate (dashed line), flow rate (solid line), and upper soil water (heavy solid line) for Bird Creek near Sperry, Oklahoma, for August and September 1971. Rainfall and flow rates are in millimeters per day and are read on the left ordinate axis. Upper water is in millimeters and is read on the right ordinate axis. Upper water capacity is 135 mm.

Georgakakos et al., *WRR* **31**(3), 210-220, 1995.

Key Definitions

ASM: Average Soil Moisture

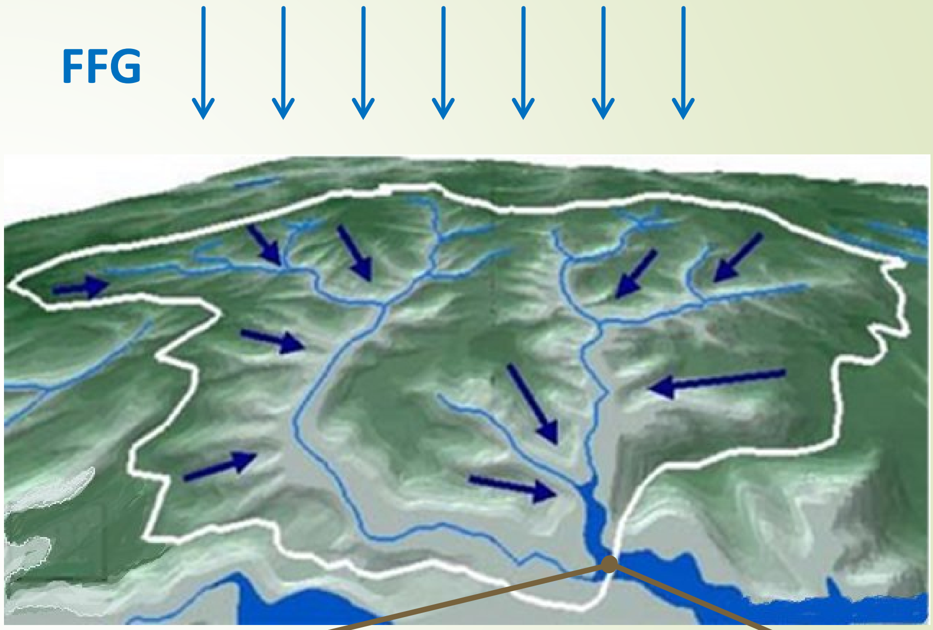
An estimate of the level of saturation (fraction) in the upper soil layer. This is computed by the model.



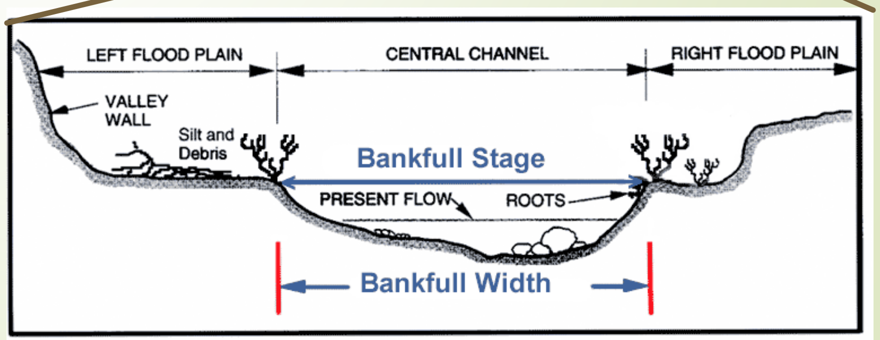
Forecasters may see changes as precipitation falls and basins (or groups of basins) become more saturated.

Key Definitions

Flash Flood Guidance (FFG): The amount of **rainfall** of a given duration and over a given catchment that is just enough to cause **bankfull conditions** at the outlet of the draining stream



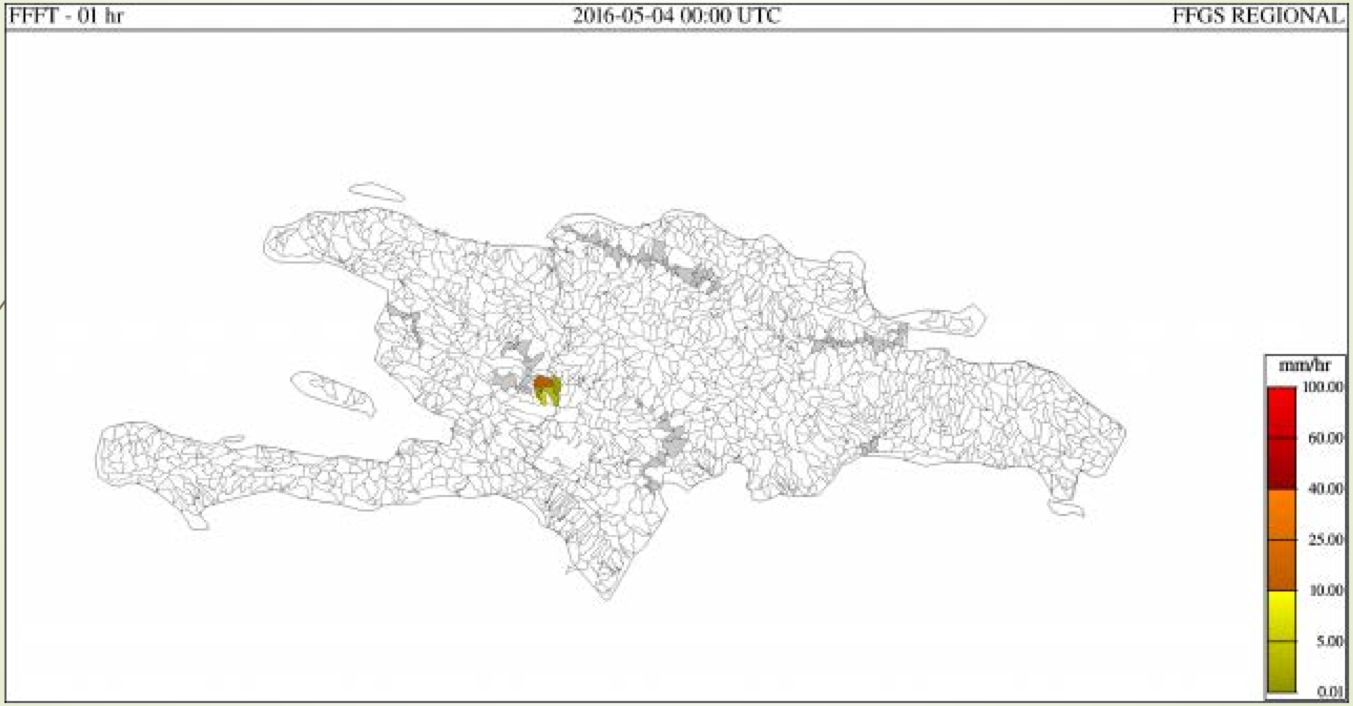
Bankfull Flow: flow level in stream associated with the transition from main/active channel to overbank or flood plain. This is level of initiation of flooding (not necessarily damage level).



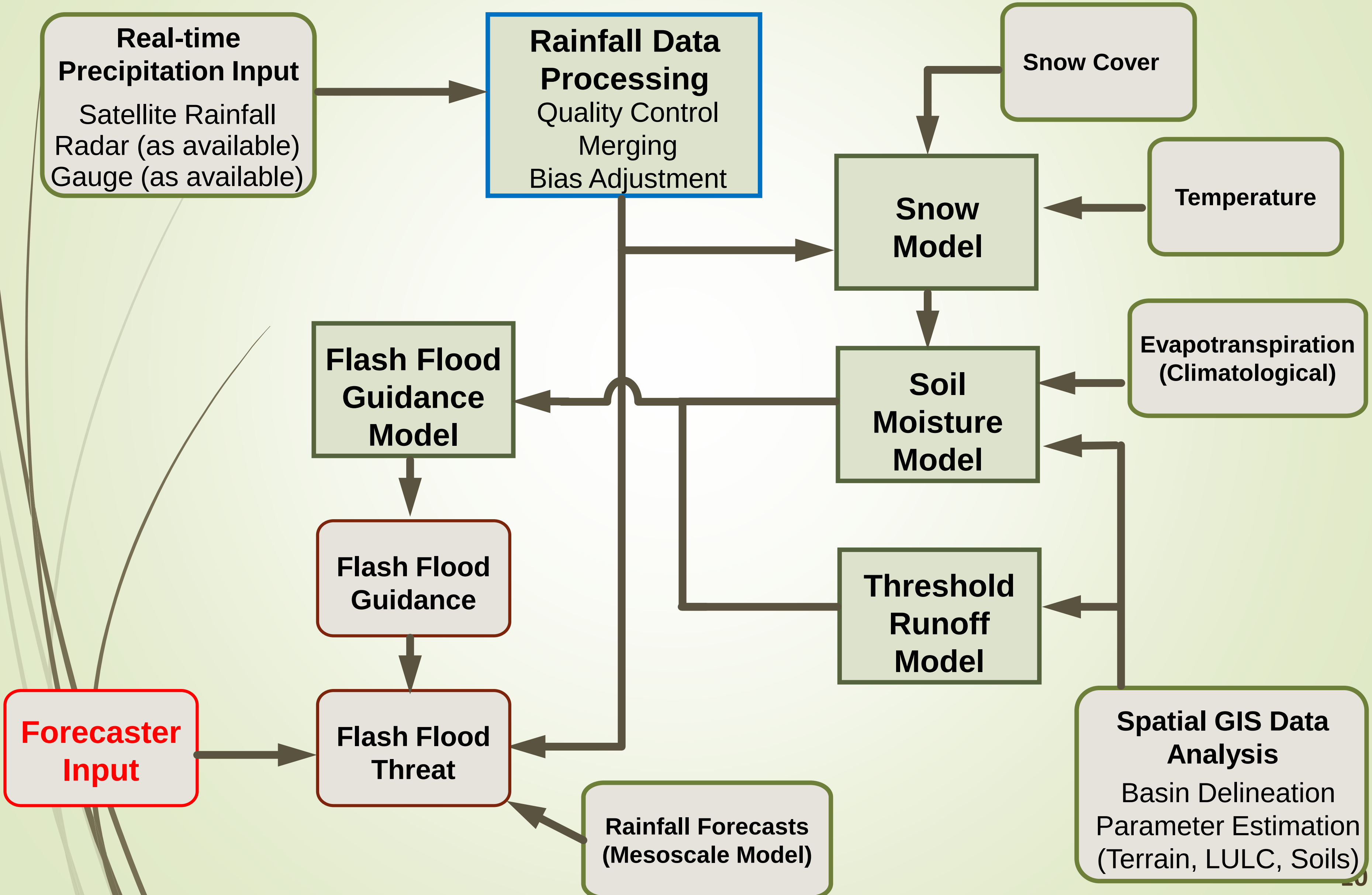
Bankfull Flow

HDRFFG System Products

Flash Flood Threat (FFT): System computed difference between the MAP and FFG values.



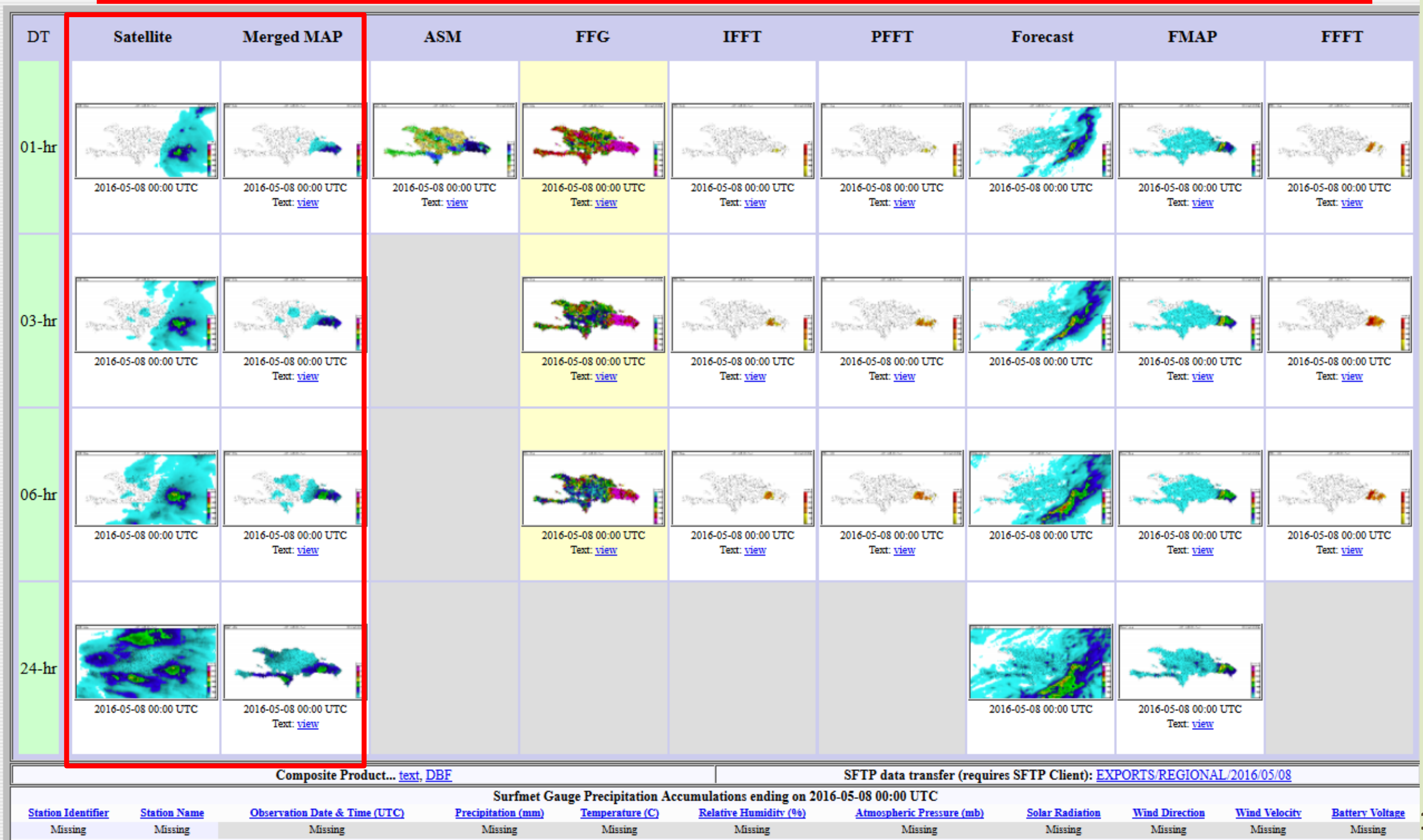
Key Technical Components for Flash Flood Guidance Systems



HDRFFG System Products

HDRFFG - Haiti and Dominican Republic Flash Flood Guidance System

Flash Flood Guidance Systems need up-to-date high-quality estimates of precipitation to assess current flash flood potential.

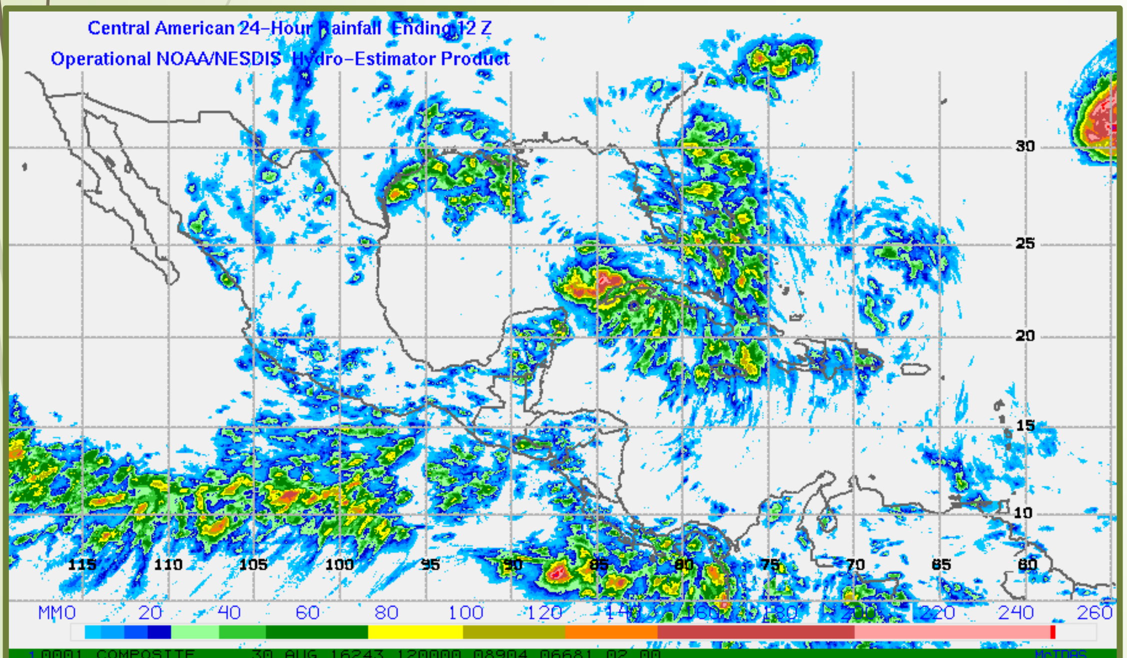


Satellite Precipitation – HydroEstimator (GHE)

Remotely-sensed precipitation estimates provide good spatial coverage and detail.

In situ observations (rain gauges) provide "ground truth" but often have sparse coverage.

NOAA/NESDIS Hydro-Estimator
24-hr rainfall ending 31-Aug-2016 @ 12 UTC

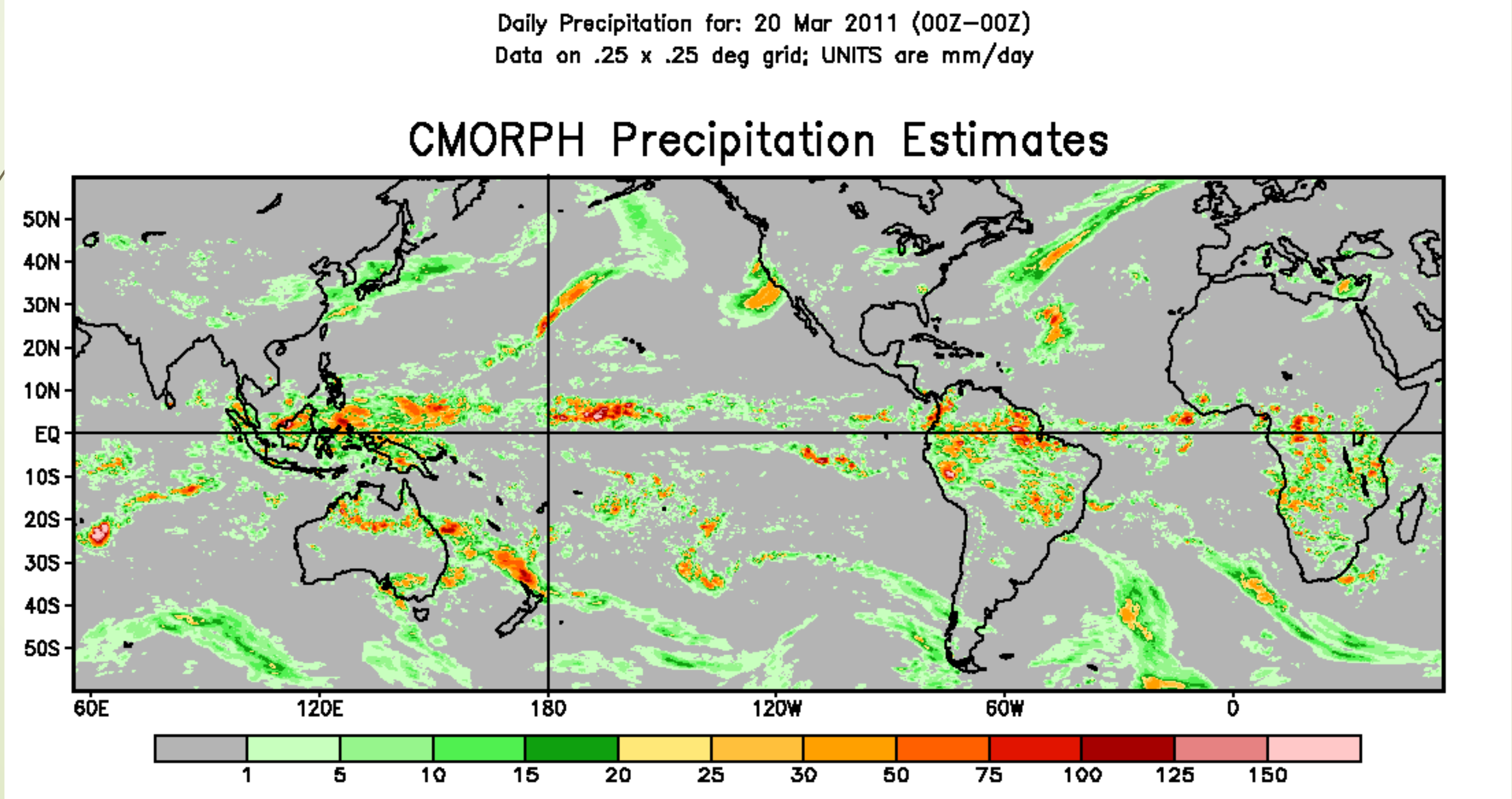


- Satellite estimates since late 1970s; Hydro-Estimator since 2002; GHE operational in 2012.
- Provide critical data in data sparse regions!
- Infrared (IR) based (10.7 μm)
- **Short latency**(< ½ hour)
- ~4 km resolution

GHE: Rainfall rate based on Cloud Top Brightness Temperature (*indirect measurement*)

Multi-Spectral Satellite Precipitation for FFG Systems

CMORPH is based on measurements of microwave scattering from raindrops.
- measure of the hydrometeors in clouds
- still not observation of rainfall at surface
- ~8 km resolution
- 18-26 hr latency in operations



Multi-Spectral Satellite Precipitation for FFG Systems

HRC effort to combine IR-based GHE rainfall with MW-based CMORPH rainfall

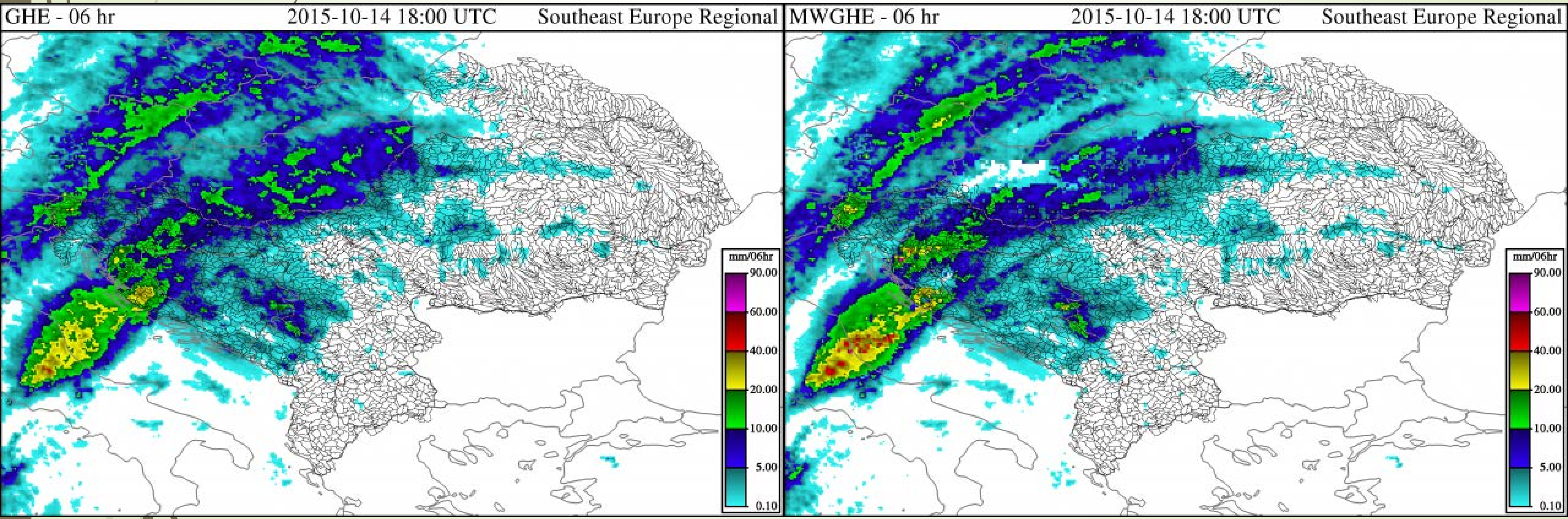
HRC-developed method which:

(a) compares IR-based GHE and MW-based CMORPH for period (2-3 days) up to last CMORPH observation,

(b) develops an adjustment factor based on differences within region,

(c) applies adjustment to GHE up to current observation.

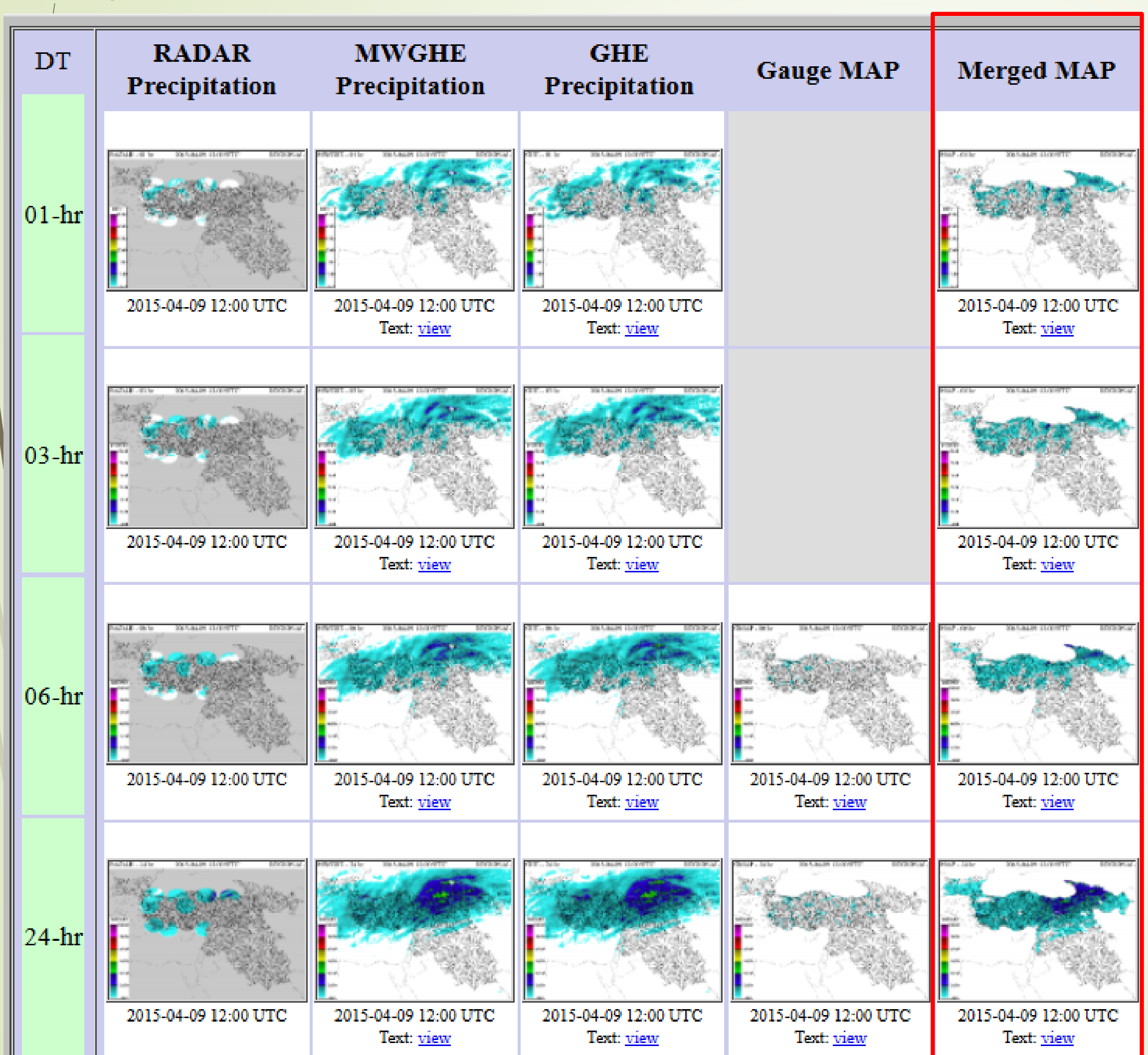
FFGS Product MWGHE



Example from South East Europe (SEEFFGS)

Merged MAP Product

Example from Black Sea Middle East (BSMEFFGS)



Merged MAP is the *best estimate* of Mean Areal Precipitation over each small watershed for previous 1-, 3-, 6- and 24- hour periods.

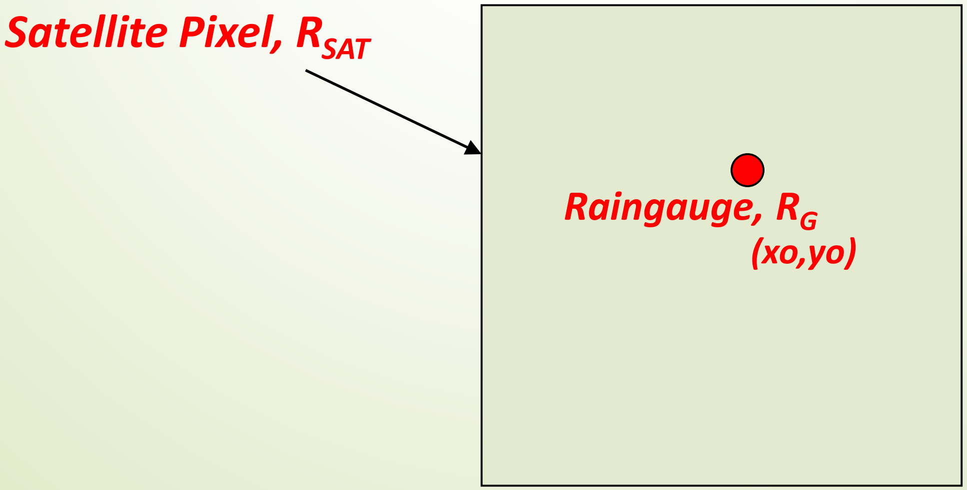
- Satellite
- Real-time gauges
- Radar (if available)

* Includes bias adjustment

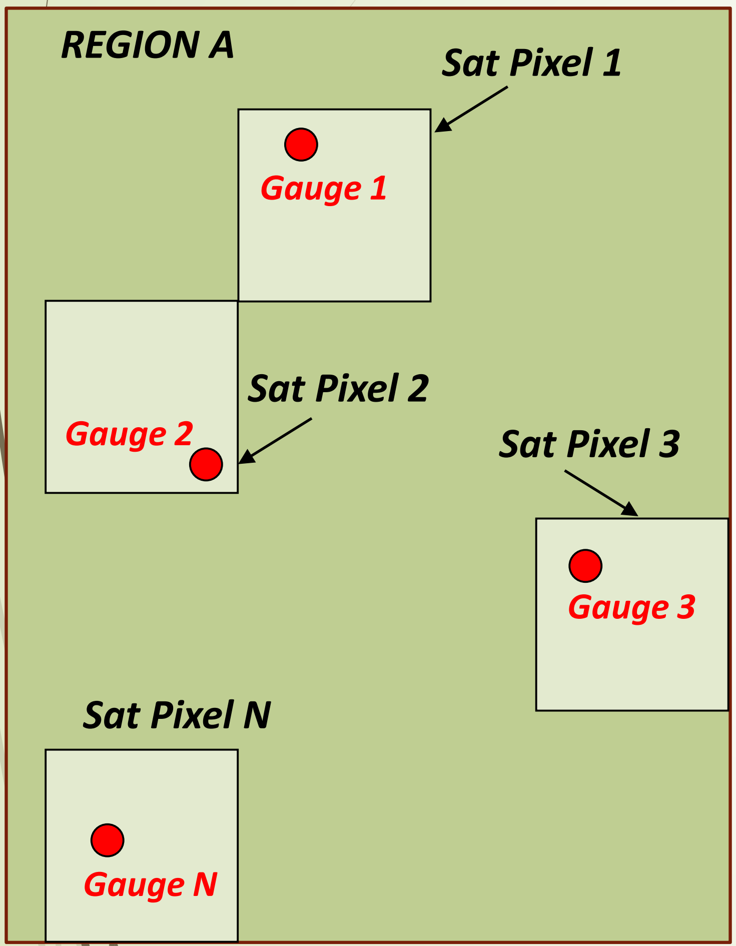
Bias Adjustment for Satellite Precipitation

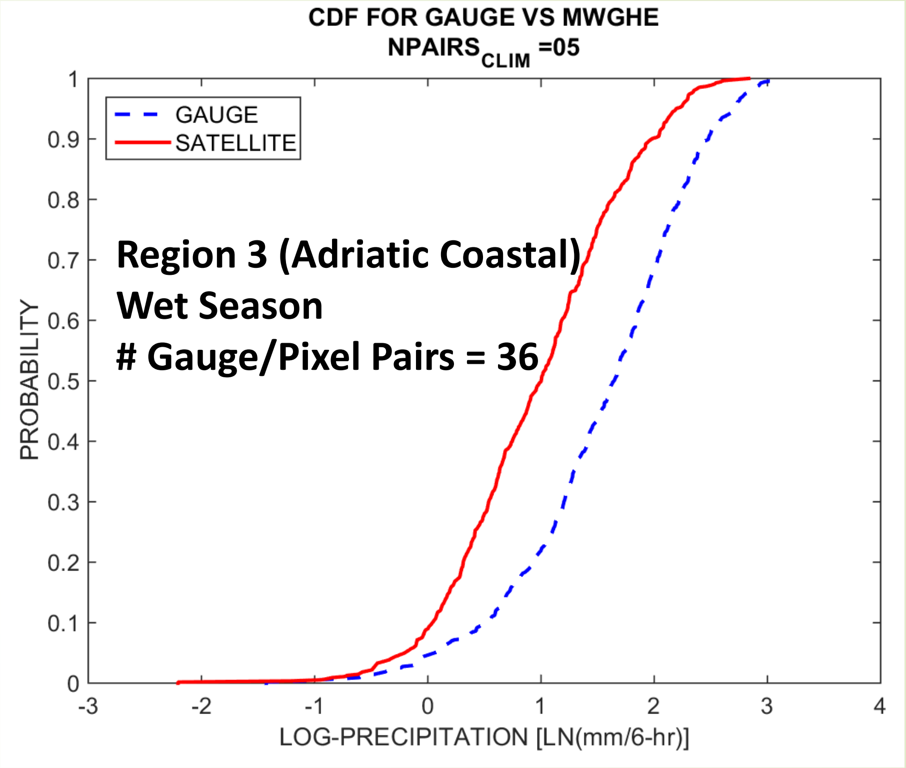
Bias may exist in the remotely sensed precipitation estimates relative to gauges. Bias should be removed before inputting to hydrologic models.

- Vastly different scales of satellite pixel and rain gauge area
- Orography organizes surface rainfall according to prevailing winds
- Satellite estimates do not directly measure rainfall at surface
- There may be significant misregistration errors in satellite data



Bias Adjustment for Satellite Precipitation





Log Bias:

$$\beta_t = \ln\left\{\frac{\sum_{j=1}^{N_G} R_G(j,t)/NG}{\sum_{j=1}^{N_G} R_{SAT}(j,t)/NG}\right\}$$

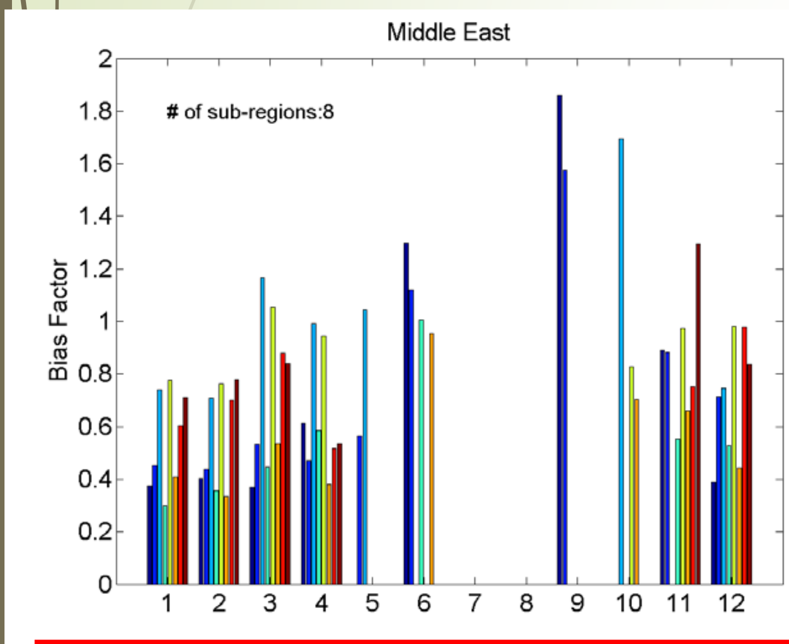
Two bias adjustments may be made: climatological and real-time.

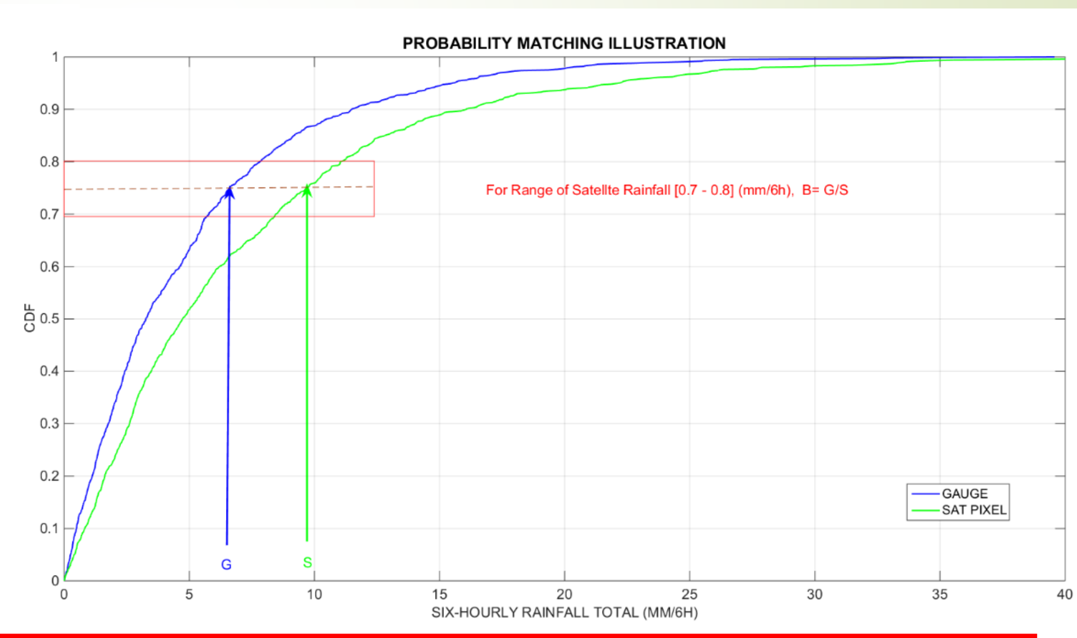
Climatological Bias Adjustment

- Considers “long-term” bias in satellite precipitation estimates based on historical data from satellite and raingauge network.
- Regions of uniform hydroclimatology, terrain and gauge density
- Analysis is done on monthly or seasonal basis (depending on data record)

Bias Factor computed from mean monthly values

Bias Factor computed based on probability matching





We gather historical raingauge data to do initial analysis, then train forecasters to do this analysis, so they may repeat as additional years of data are available.

Dynamic Bias Adjustment

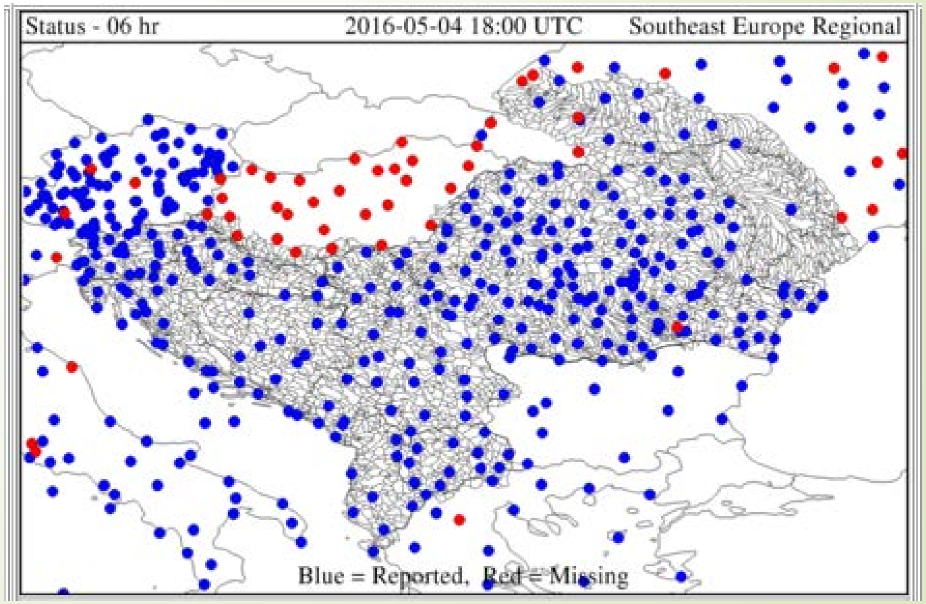
- Considers "event" (short-term) adjustment based on real-time gauge reports
- Employs Kalman Filter approach
- Minimum number of gauge/satellite pixel pairs reporting over consecutive time steps

$$\beta_t = \ell n \left[\frac{\sum_{j=1}^{N_g} R_g(t,j)}{\sum_{j=1}^{N_g} R_s(t,j)} \right]$$

$$\beta_{t+1} = \beta_t + w_{t+1}$$

$$z_{t+1} = \beta_{t+1} + v_{t+1}$$

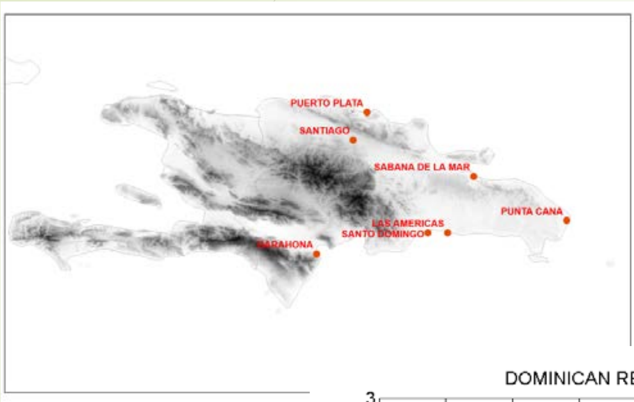
Gauge data quality control is important!

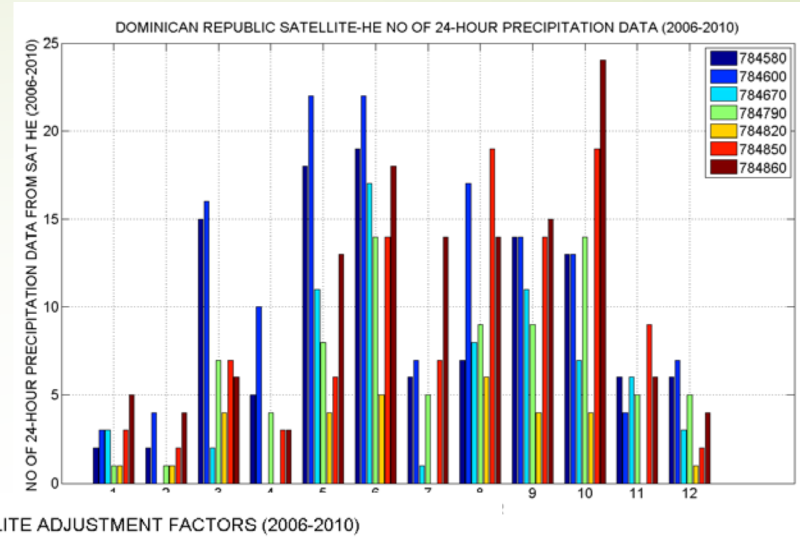


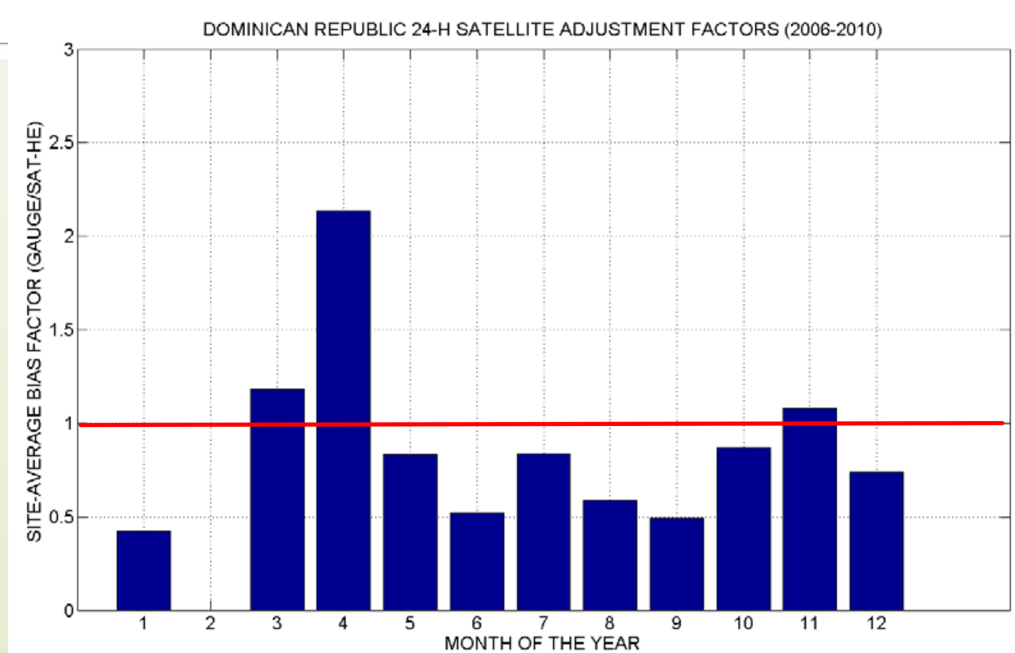
Example from South East Europe (SEEFFGS)

Bias Adjustment for HDRFFG

Historical Analysis: 2006 –2010
Limited Gauges

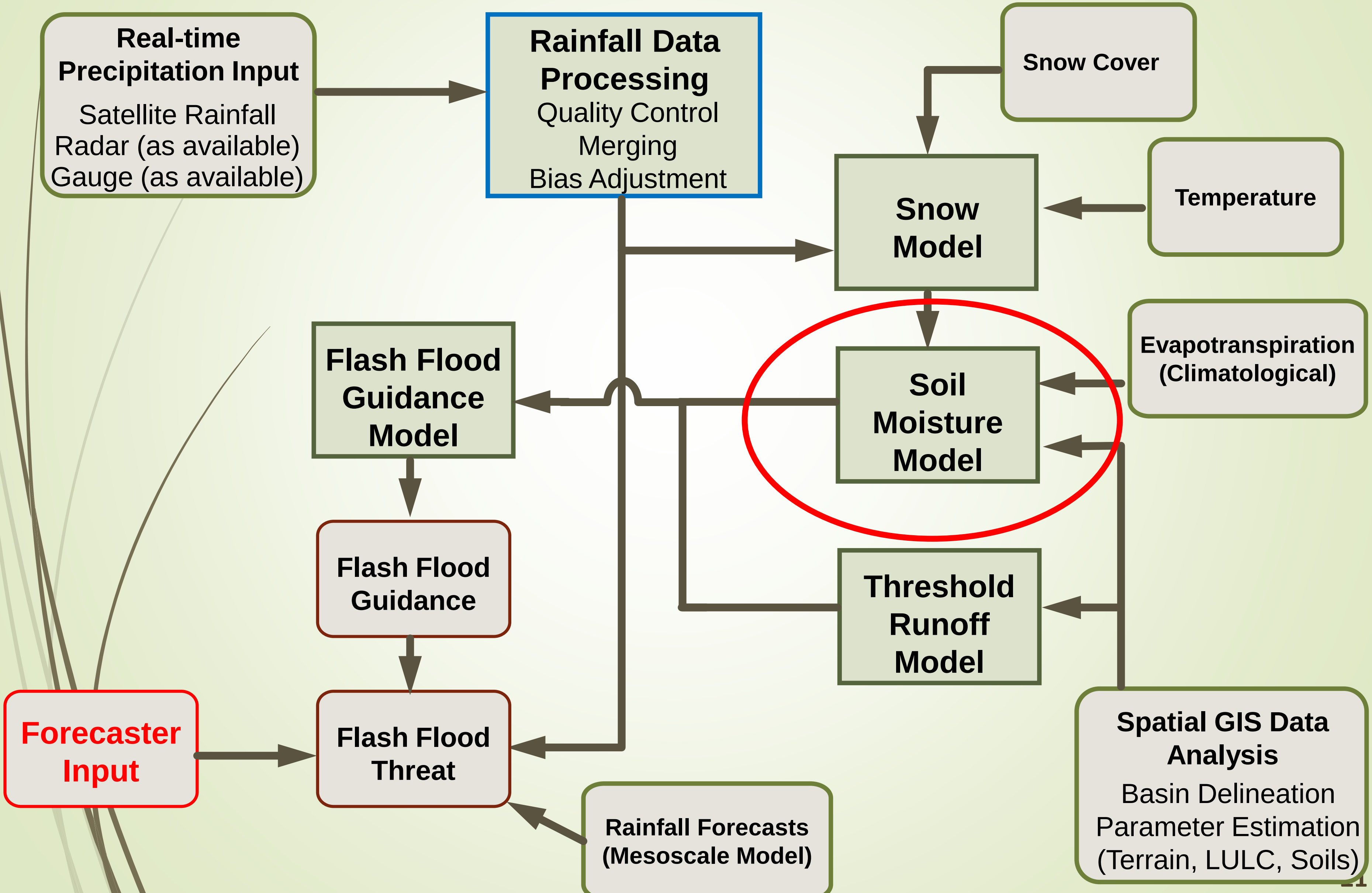






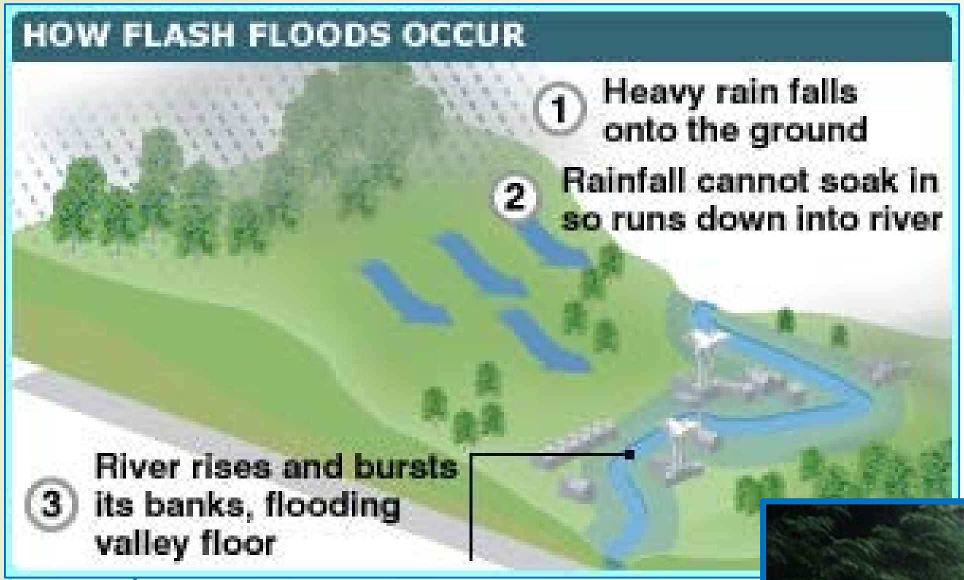
Dynamic Bias Adjustment is disengaged as real-time stations are no longer reporting.

Key Technical Components for Flash Flood Guidance Systems



Need for Soil Water Accounting

What happens after rain falls?

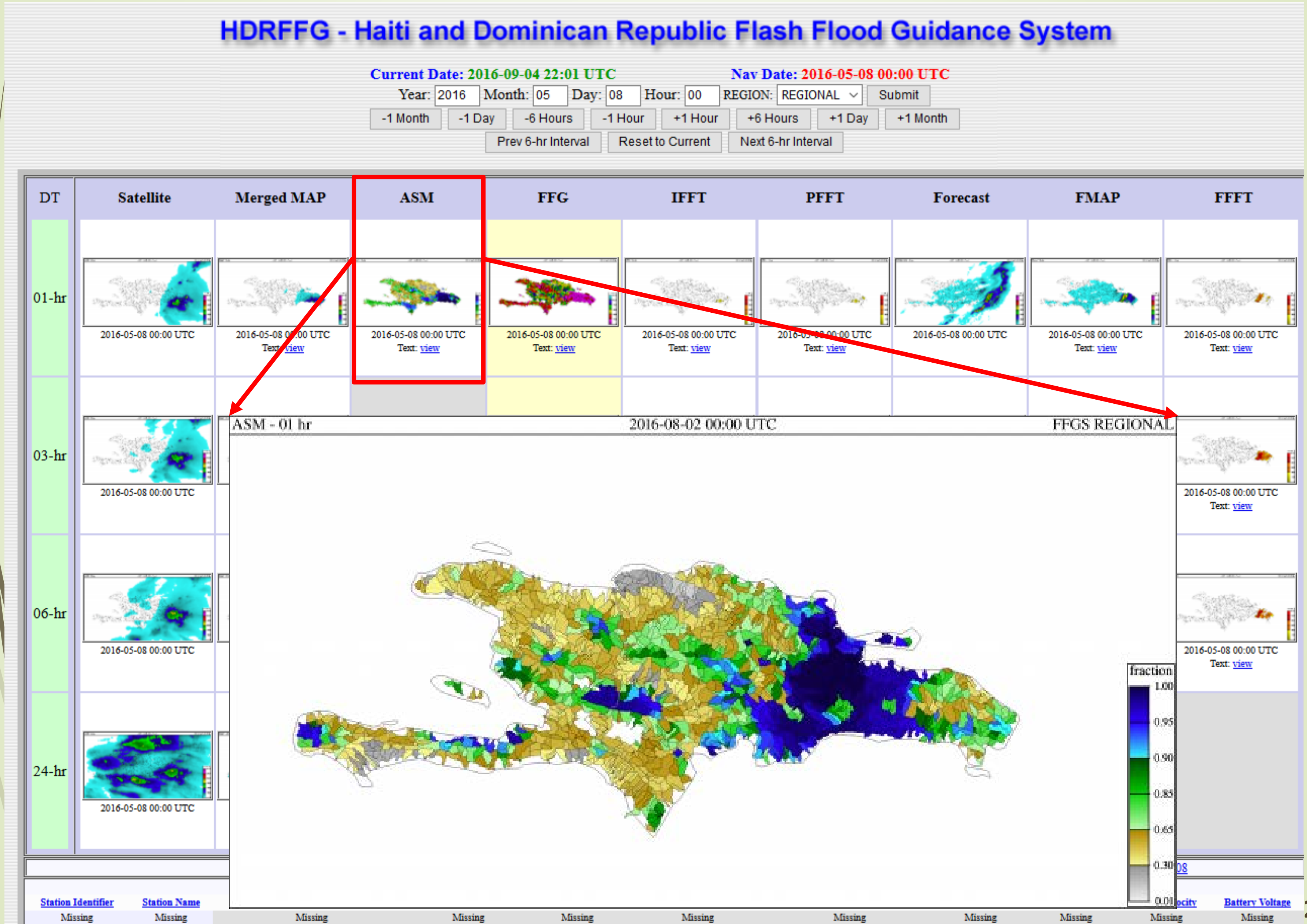


From BBC news

Hydrologic Components of FFG System account for land surface processes in production of flash floods.

- infiltration of rainfall into soil and storage of soil water
- accumulation and ablation of snow, and snow melt contribution to soil
- production of runoff into channels
- evapotranspiration

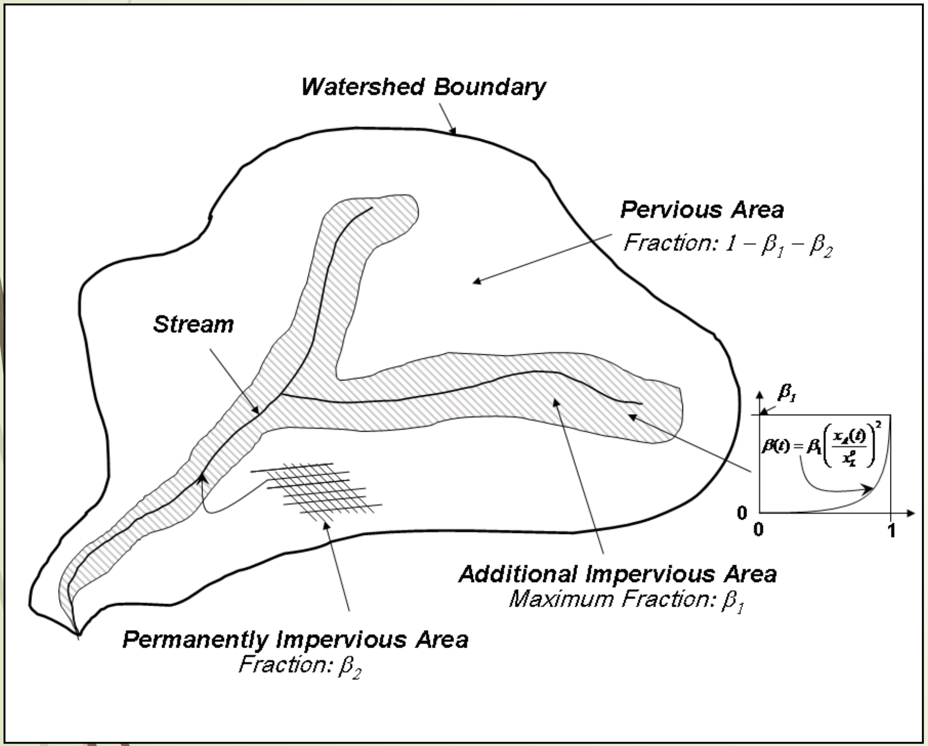
HDRFFG System Products

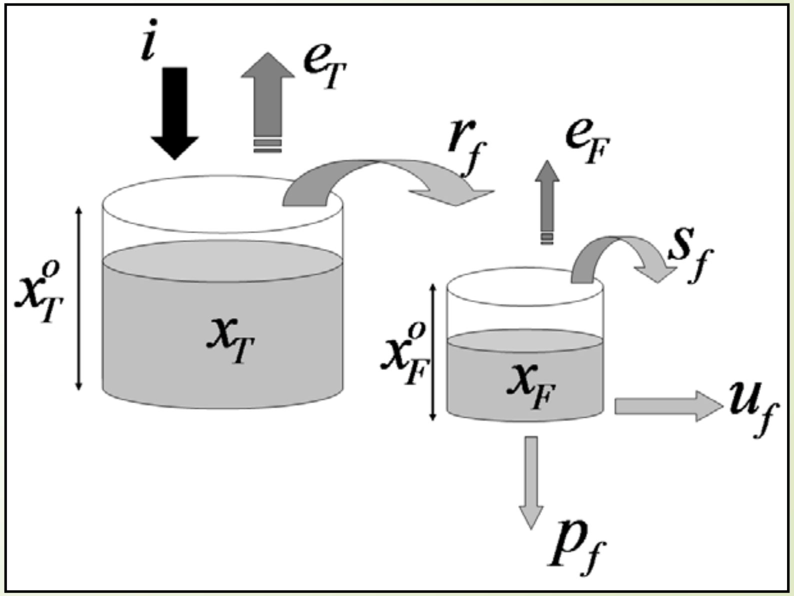


Soil Model for HDRFFG

- A conceptual hydrologic model is used for soil water modeling: Sacramento Soil Moisture Accounting Model (SAC-SMA) to estimate ability of land surface to absorb and hold moisture.

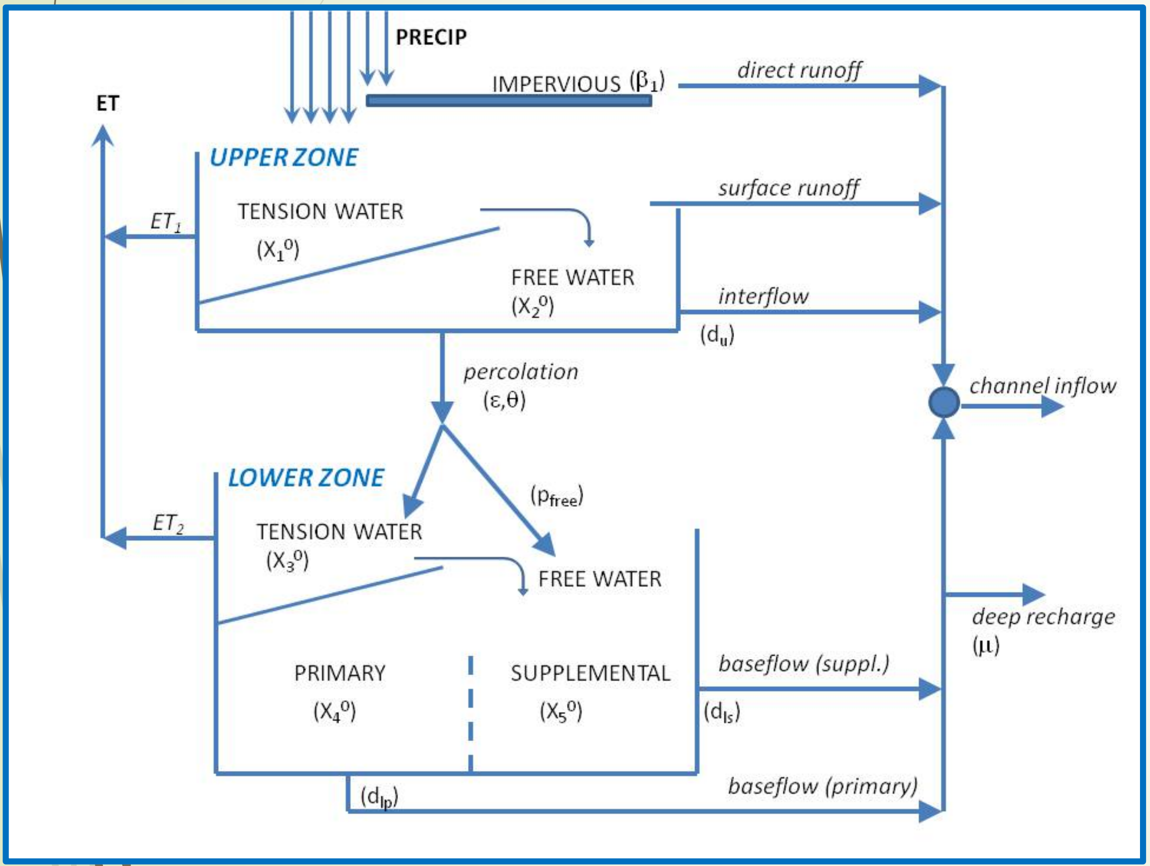
A two-layer conceptual model representing the movement of soil water through a vertical, homogeneous soil column





Soil Model for HDRFFG

Schematic of Sacramento SMA Model



INPUT:

- ❖ *Precipitation (or Rain+Snow melt)*
- ❖ *Potential Evapotranspiration*

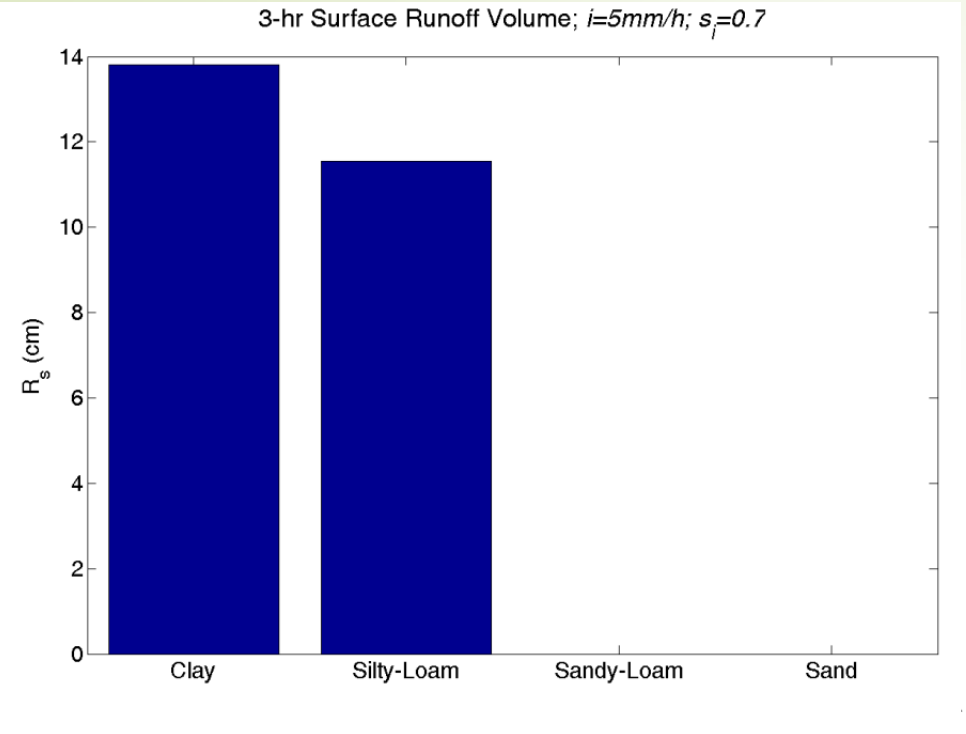
Various representations of runoff:

- ❖ *saturation excess*
- ❖ *infiltration excess*
- ❖ *combined runoff*

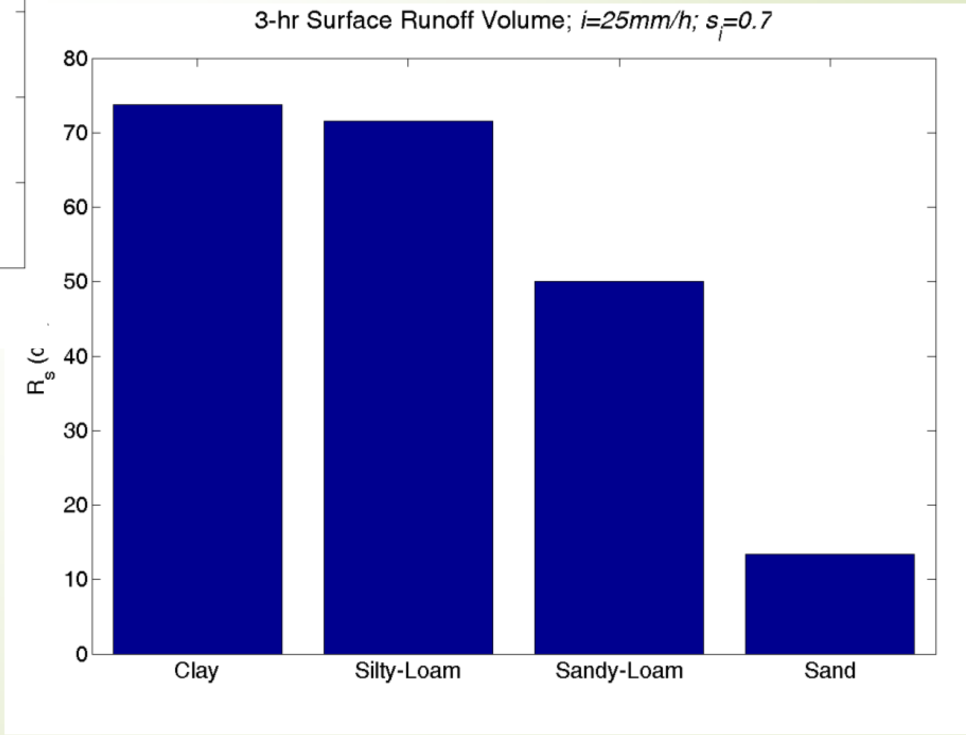
PARAMETERIZATION:

- ❖ *15 model parameters (capacities, withdrawal rates, percolation)*
- ❖ *Initial parameters based on soils and land cover*

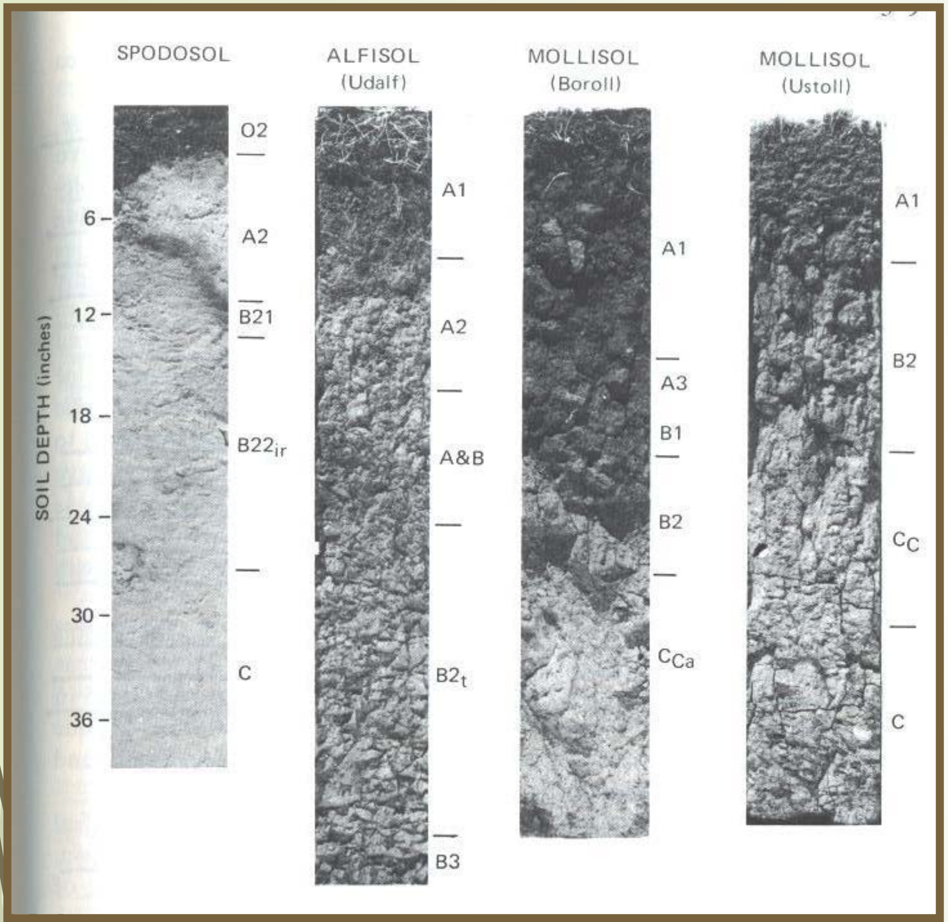
Effect of Soil Classification on Runoff Production

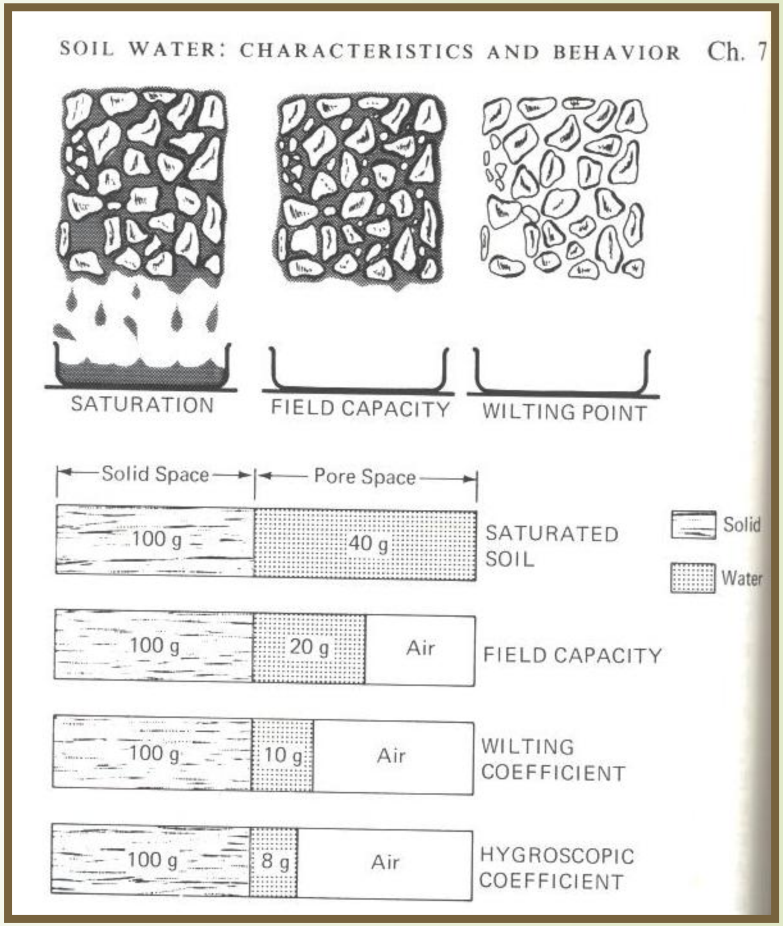


Plots of surface runoff generated over 3 hours for different soil classifications



Relating Soils Characteristics to Hydraulic Properties

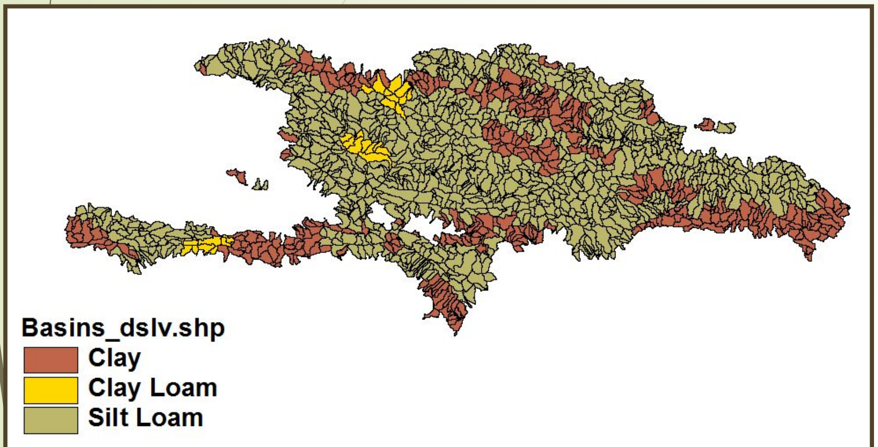




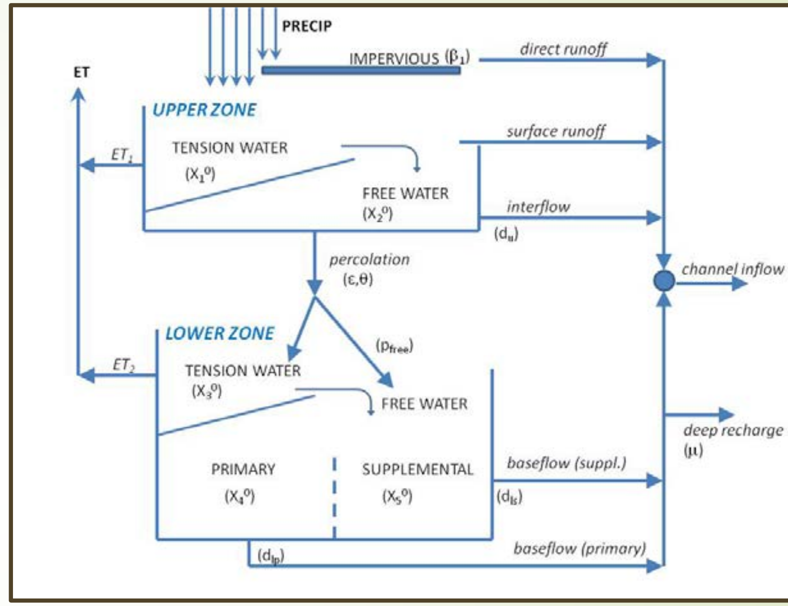
Figures from Brady, N.C., 1974: The nature and properties of soils. McMillan Publ. Co., NY

Sacramento SMA Model Parameterization

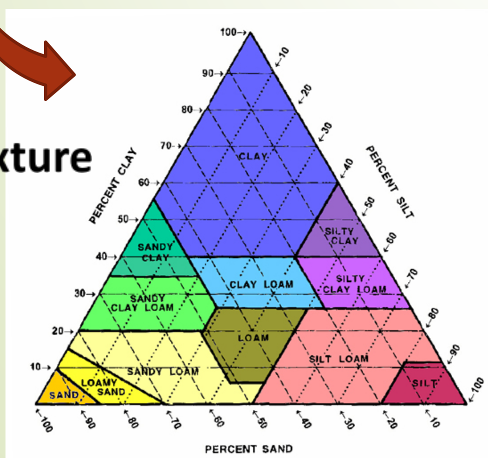
1. Soils Information



4. Parameters of SAC-SMA



2. Soils Texture

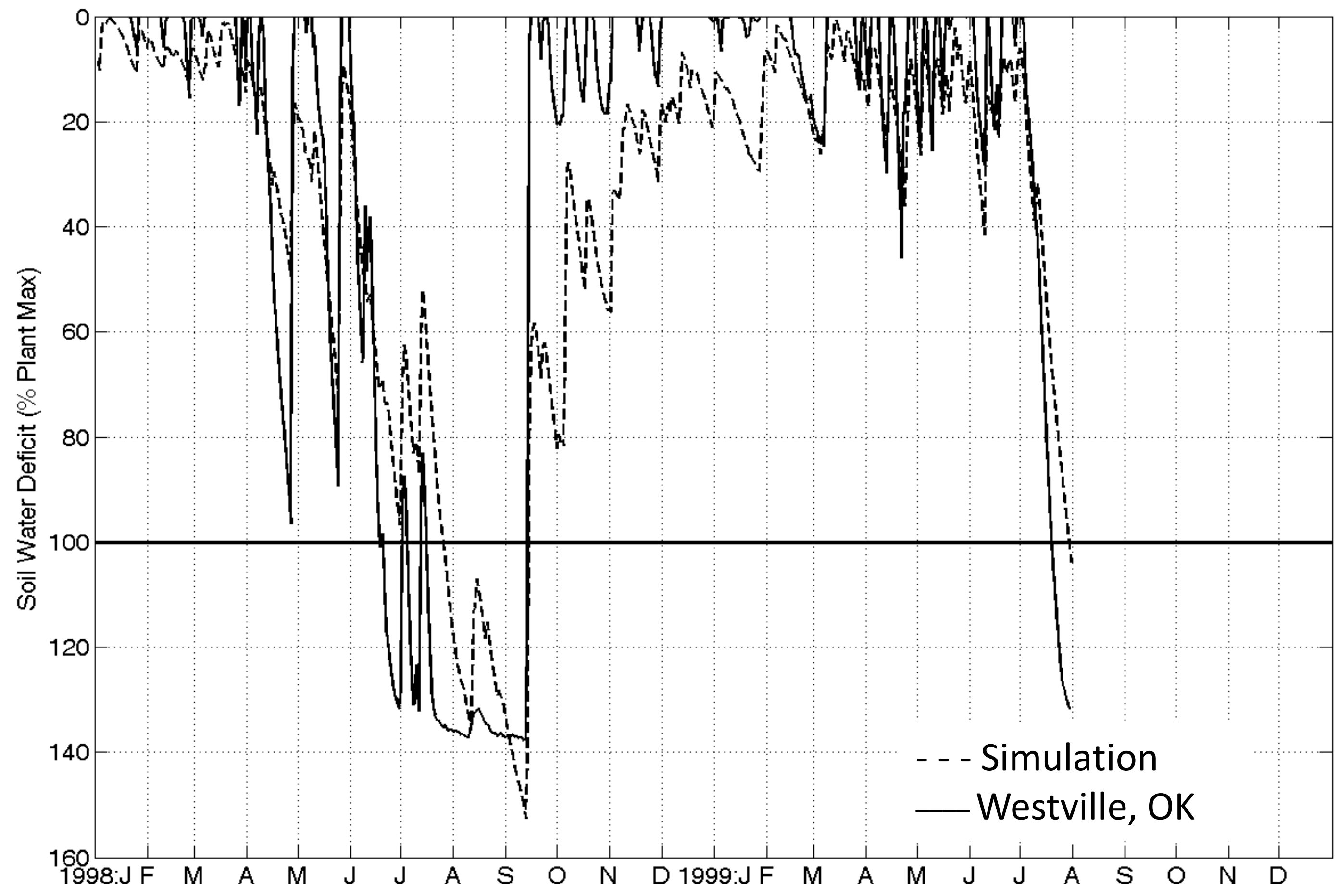


Soil Class	*$\theta_s(m^3/m^3)$*	*$\theta_f(m^3/m^3)$*	*$\theta_m(m^3/m^3)$*	*$K_s(m/h)$*	*α*	*$\sigma_{Ks}(m/h)$*
Sand	0.34	0.09	0.015	0.168	2.79	0.062
Loamy Sand	0.42	0.16	0.05	0.050	4.26	0.082
Sandy Loam	0.43	0.21	0.07	0.019	4.74	0.119
Loam	0.44	0.25	0.095	0.012	5.25	0.108
Silty Loam	0.48	0.29	0.11	0.010	5.33	0.090

3. Hydraulic Properties

Example Soil Model Output: Site-Specific Validation

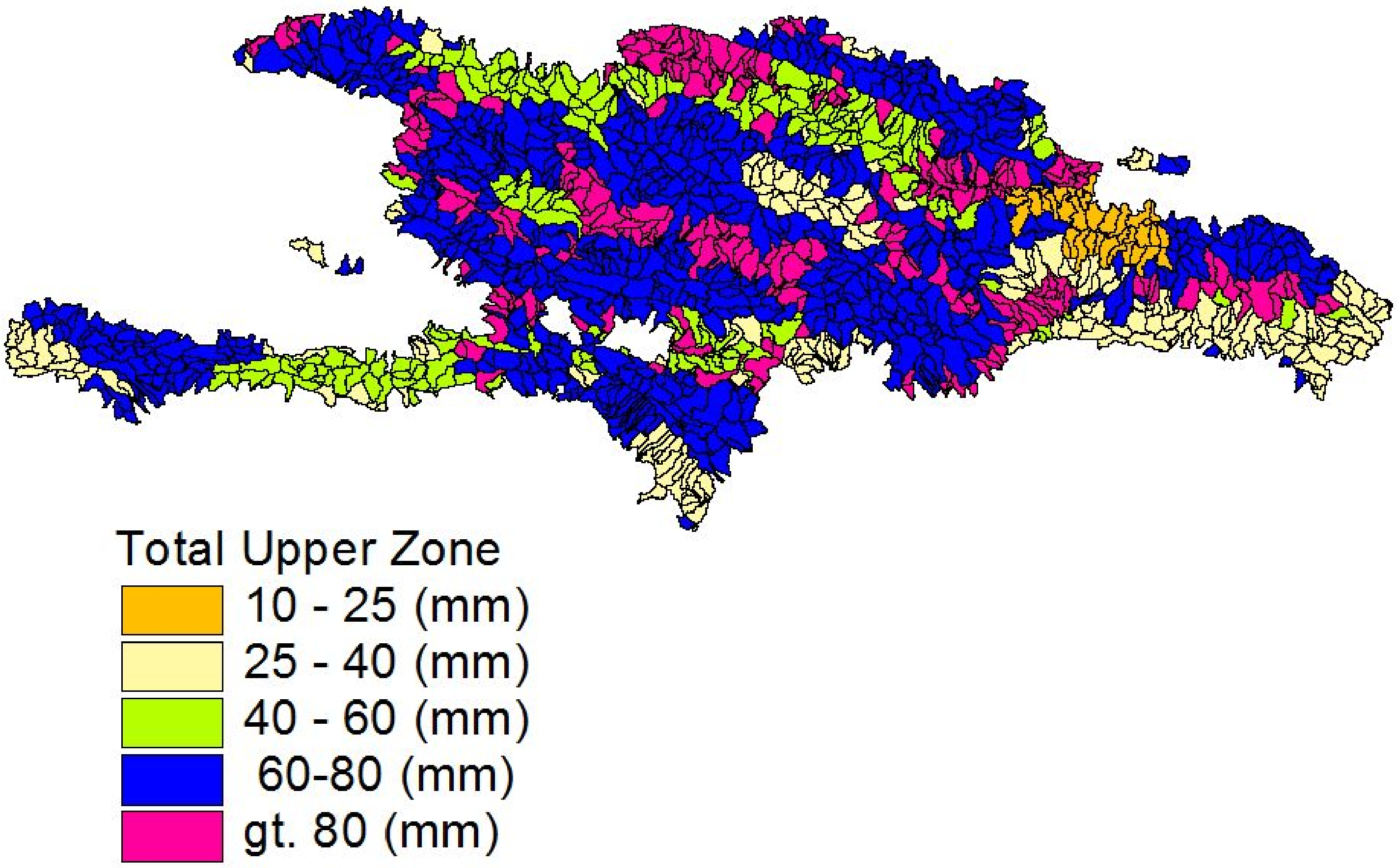
Simulation for Illinois River Basin in Oklahoma, U.S.A



Reasonably good reproduction of depth integrated soil water deficit

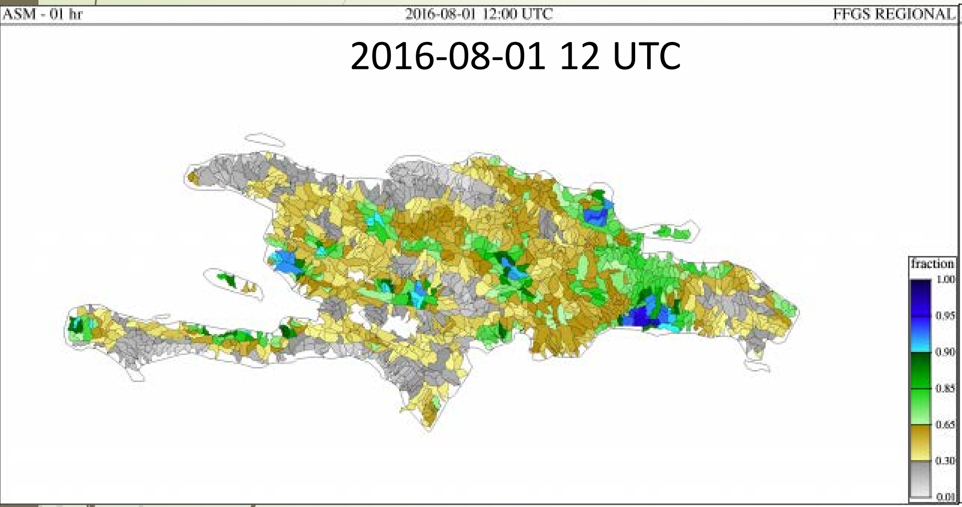
Example SAC-SMA Model Parameterization for HDRFFG

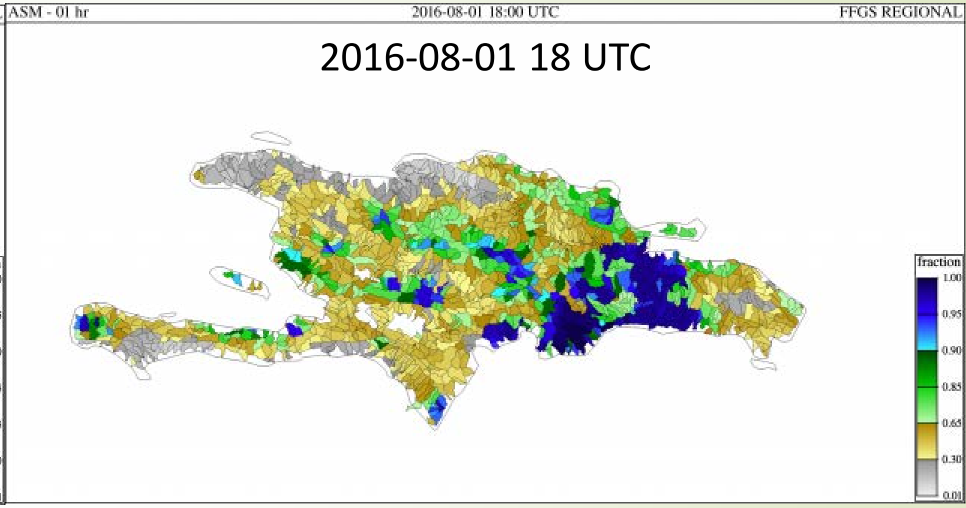
Upper Layer Capacity

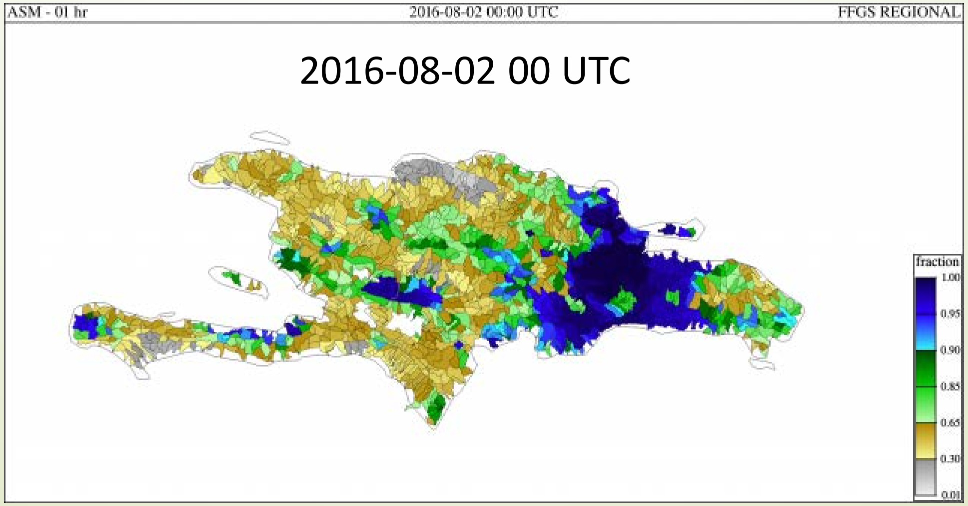


HDRFFG System Product: ASM

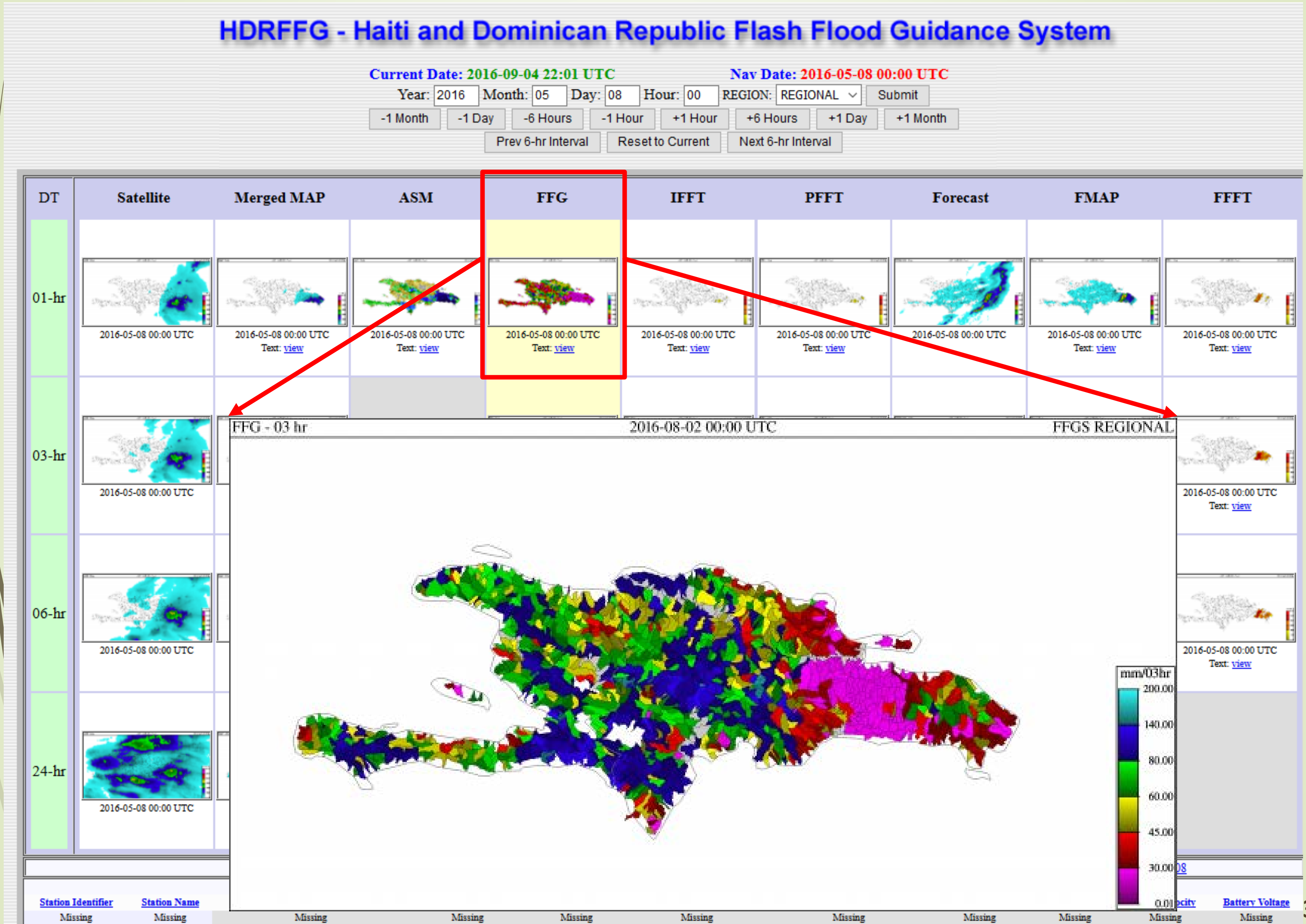
ASM: is the soil saturation fraction in the upper model soil layer (most relevant for flash flood occurrence)







HDRFFG System Products



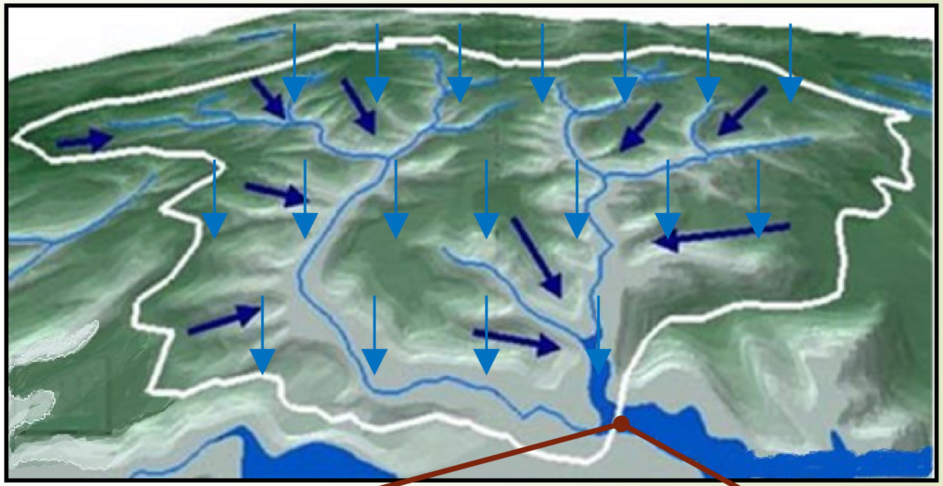
Key Concepts

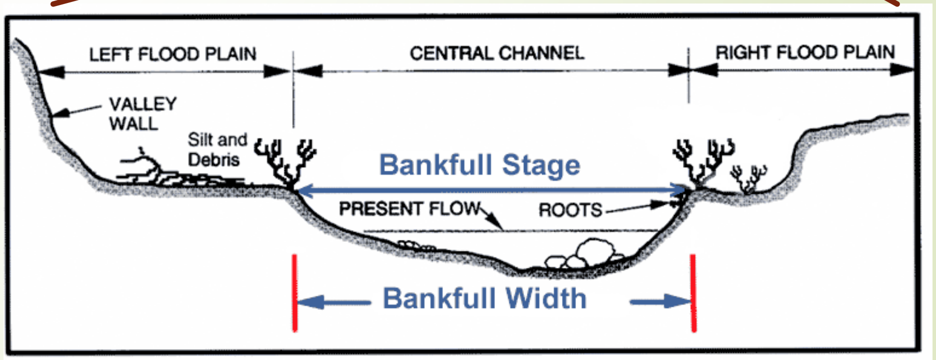
- Threshold Runoff:
  Matching of peak surface runoff to ***bankfull*** flow (as an indicator of the initiation of flooding conditions)
  → Links geomorphology to channel geometry (avoids calibration)

- Flash Flood Guidance:
  Rainfall threshold concept, familiar in operational meteorological forecasting.
  Decouples soil moisture deficit from surface runoff computations
  → Coordinated hydro-meteorologic forecast operations

Definition of Threshold Runoff

Threshold Runoff is defined as the amount of *effective rainfall* of a given duration falling over a watershed that is just enough to cause *bankfull* conditions at the outlet of the draining stream.

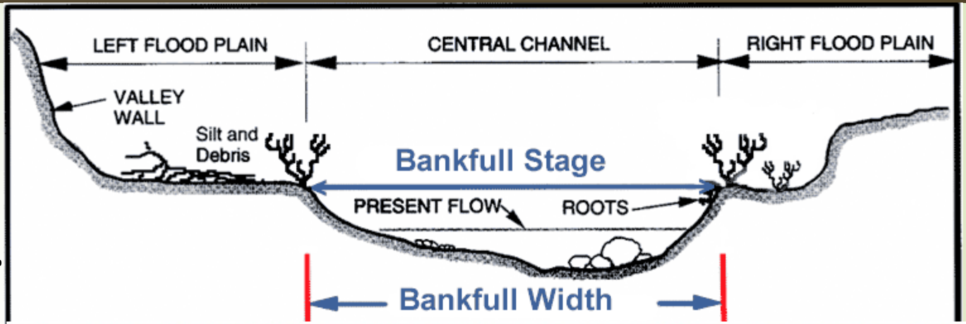


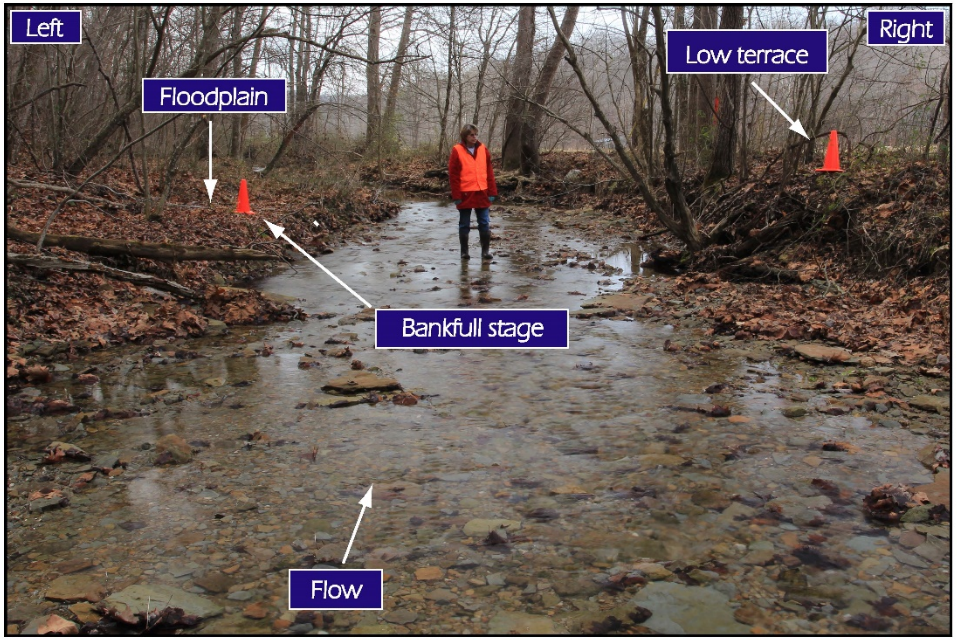


Effective rainfall is the residual amount after accounting for all losses such as interception and soil moisture storage. Effective rainfall contributes directly to runoff production.

Definition of Threshold Runoff

Threshold runoff represents the storage capacity of the stream to accept catchment runoff to a level of minor flooding defined at bankfull.



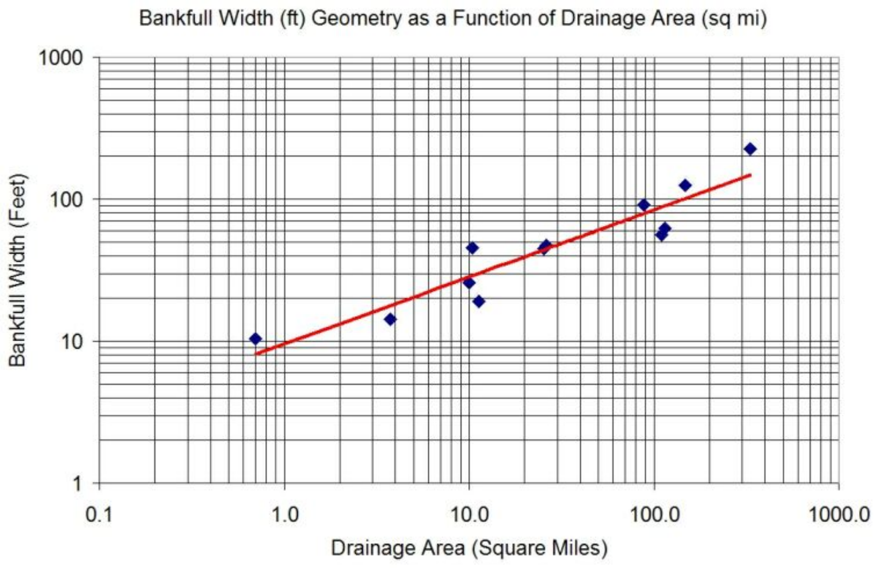


Threshold Runoff, R, = nonlinear function of catchment properties (A,L,R_L) and channel cross-section characteristics (B_b, D_b, S_c).

Estimation of Threshold Runoff

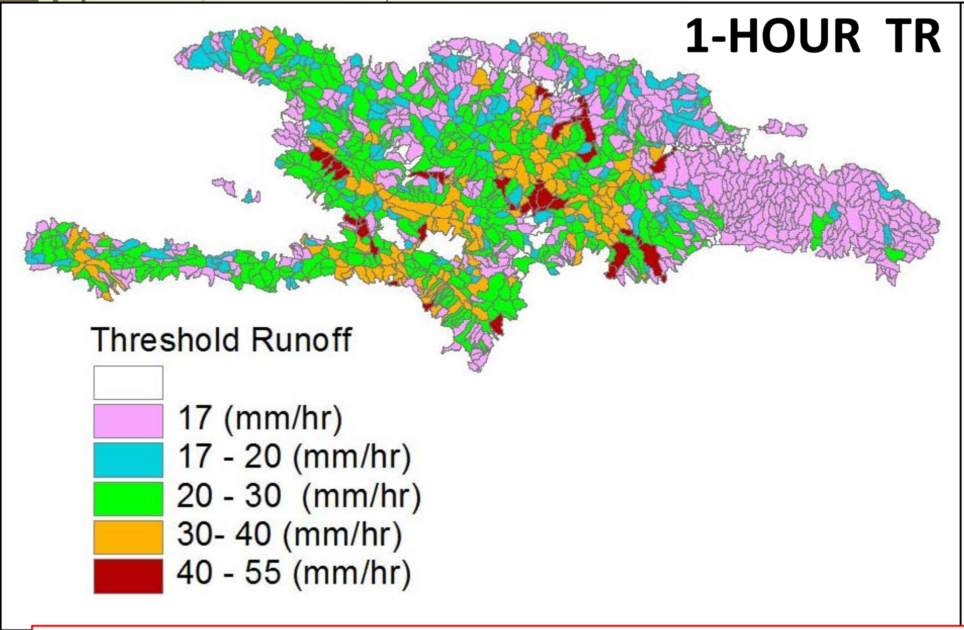
- Watershed properties (A, L) may be estimated from processing of digital elevation data (DEM).
- Channel cross sections are not resolved with current global DEMs.
- Bankfull condition may be identified using morphological field evidence during local stream surveys.
- Bankfull cross-section dimensions vary with catchment size (Luna, 1994).
  - Local survey data may be used to develop regional relationships:

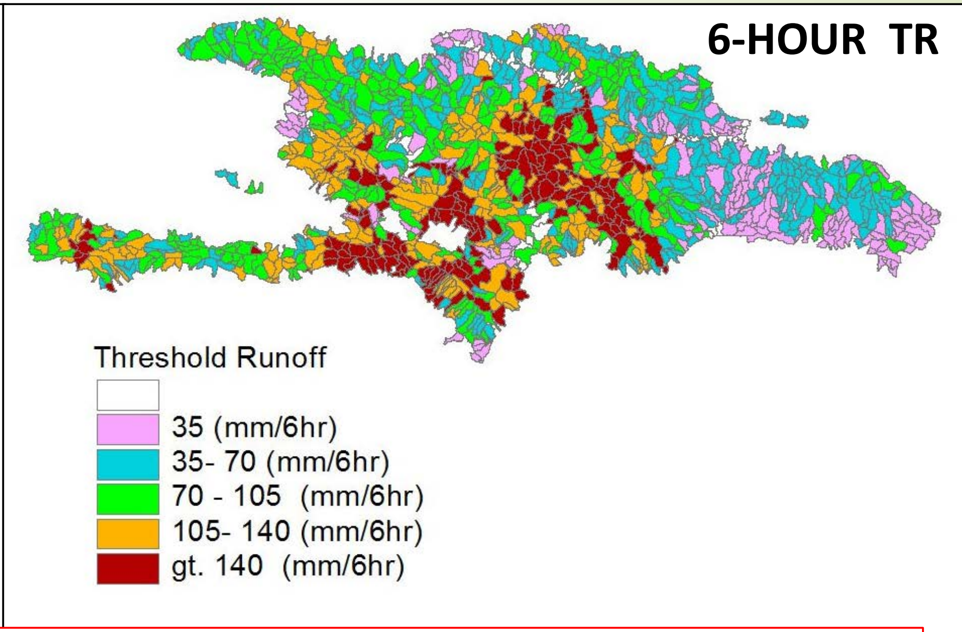
$$B_b = \alpha A^{\gamma} \qquad D_b = \varepsilon A^{\lambda}$$



Threshold Runoff Estimates for HDRFFG

(1) Define watershed boundaries (based on 90-m SRTM DEM)
(2) Compute watershed properties (A, L, S)
(3) No local channel survey data available.
Utilized satellite imagery and data from Puerto Rico to develop regional relationships for cross-section properties.
(4) Estimate channel cross-section from regional regressions
(5) Compute threshold runoff



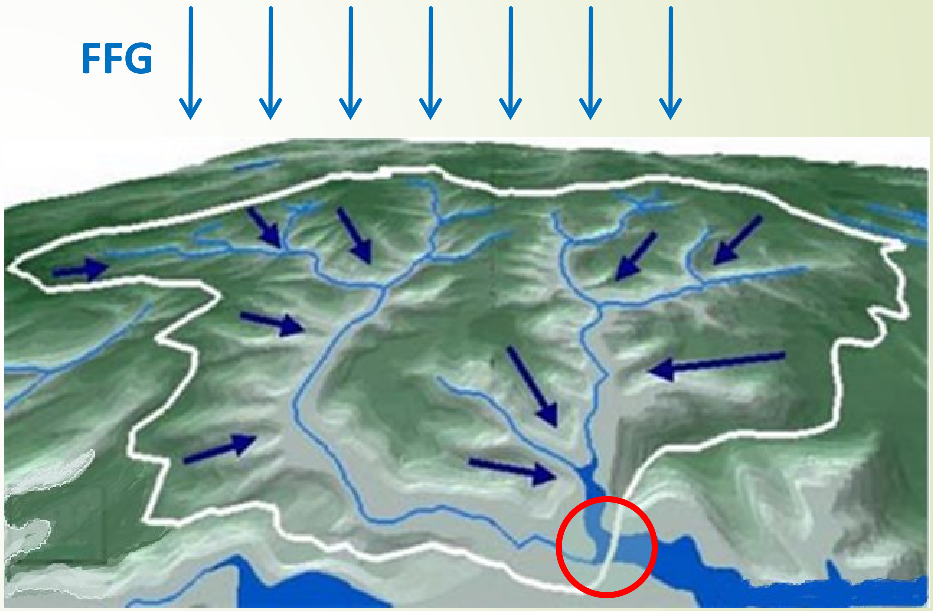


Threshold Runoff is a one-time calculation, a characteristic property, for a given watershed.

Definition of Flash Flood Guidance

Flash Flood Guidance (FFG): The amount of **rainfall** of a given duration and over a given catchment that is just enough to cause **bankfull conditions** at the outlet of the draining stream.

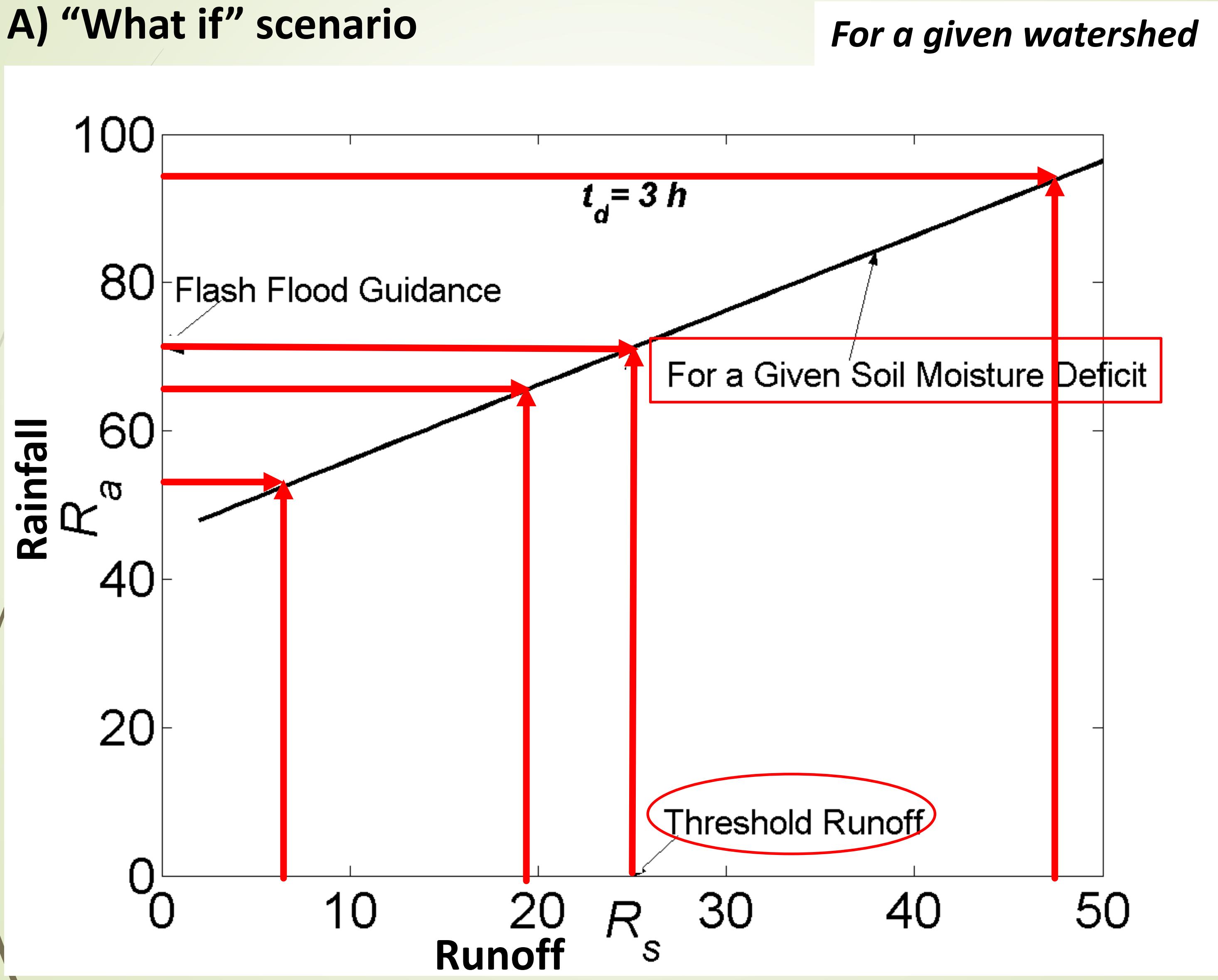
*FFG is computed on a **real-time** basis considering up-to-date soil water content.*



FFG is updated every hour in HDRFFG (currently) and computed for rainfall durations of 1-, 3-, and 6-hours.

Relationship between Threshold Runoff and FFG

A) "What if" scenario



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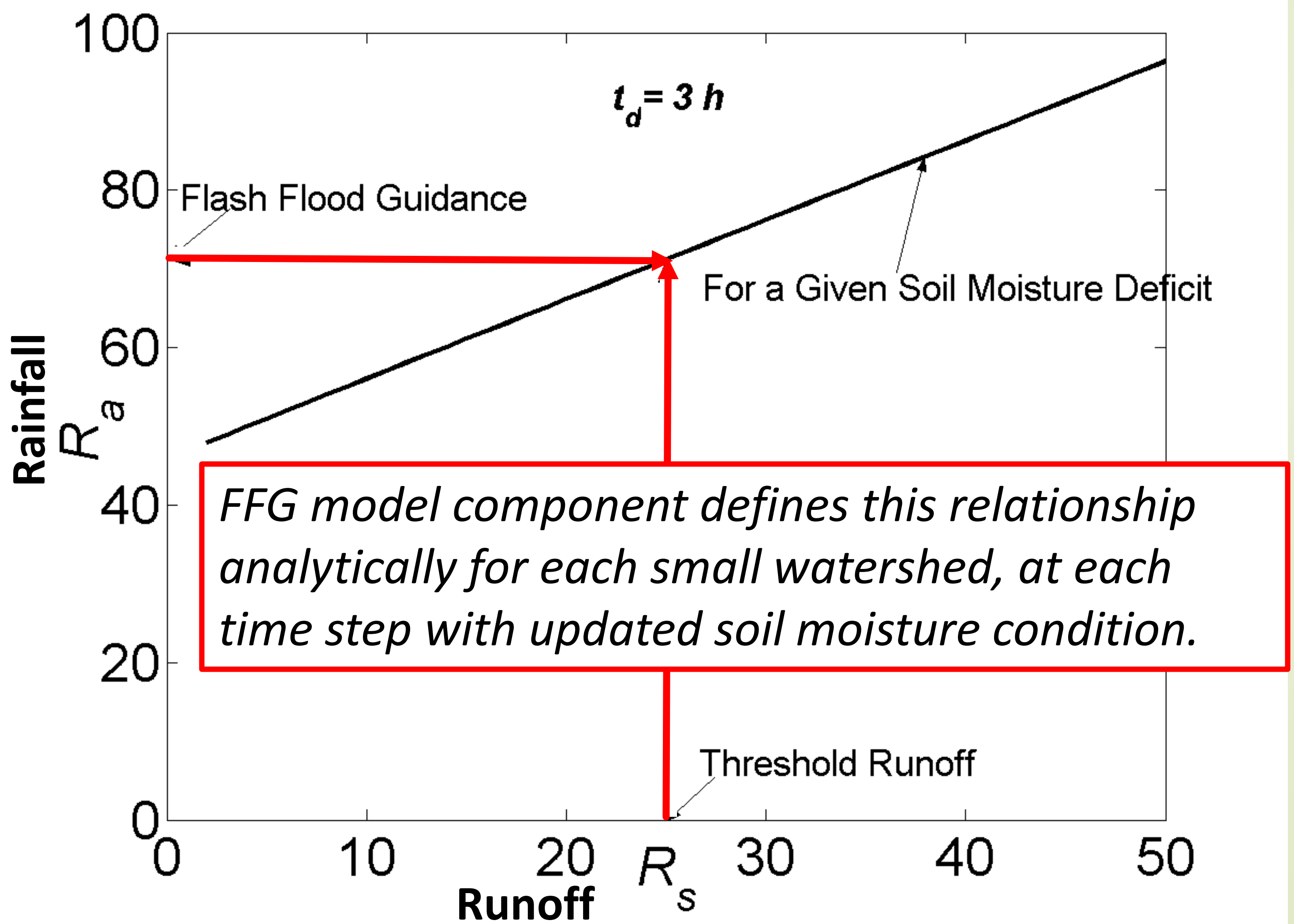
Relationship between Threshold Runoff and FFG

For a given watershed



FFG model component defines this relationship analytically for each small watershed, at each time step with updated soil moisture condition.

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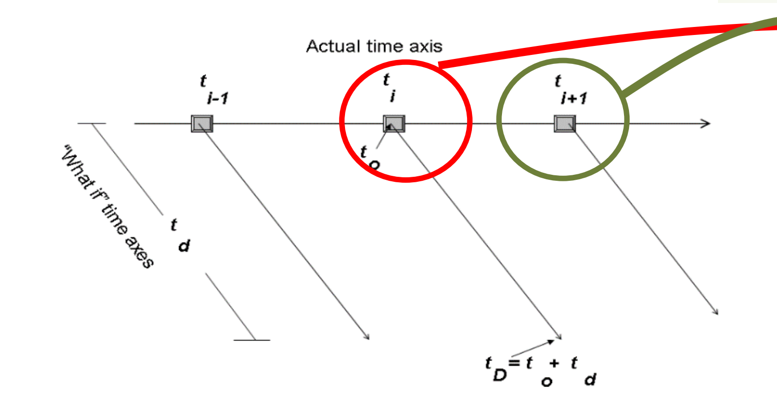
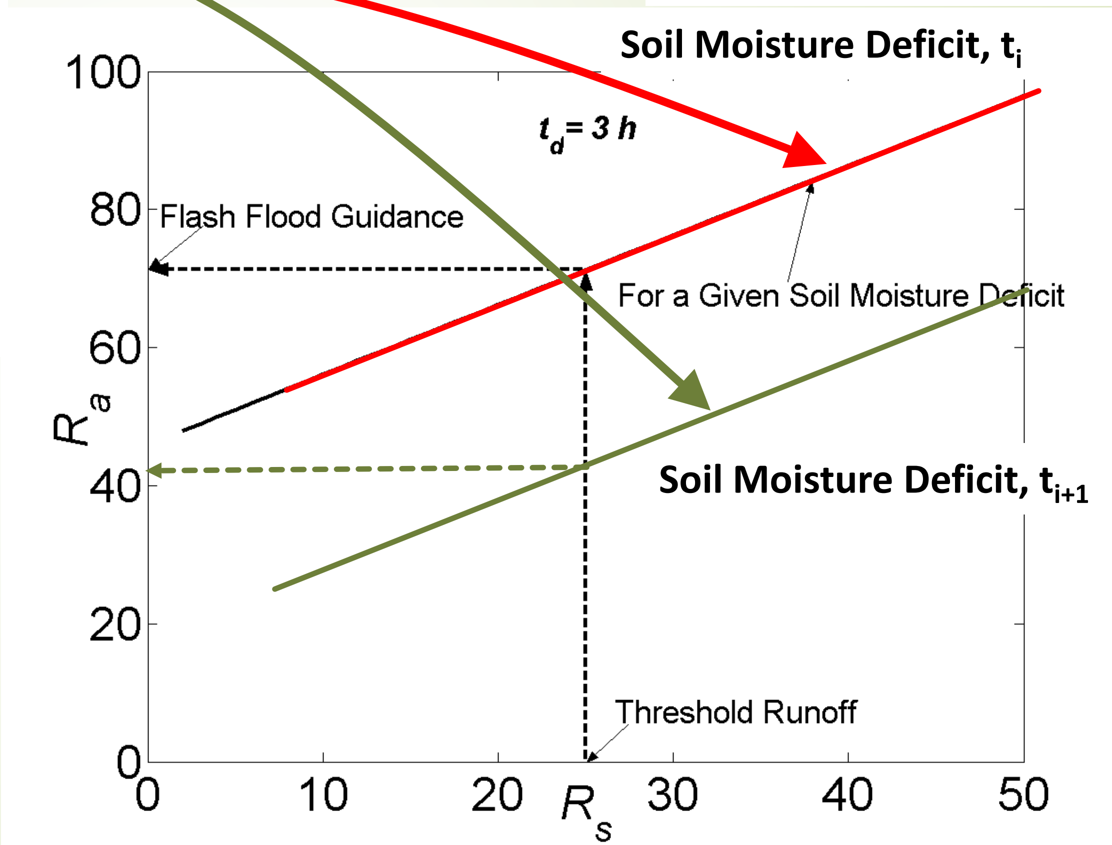
From Threshold Runoff and Soil Moisture to FFG

Model Forecast Run Time (hourly)

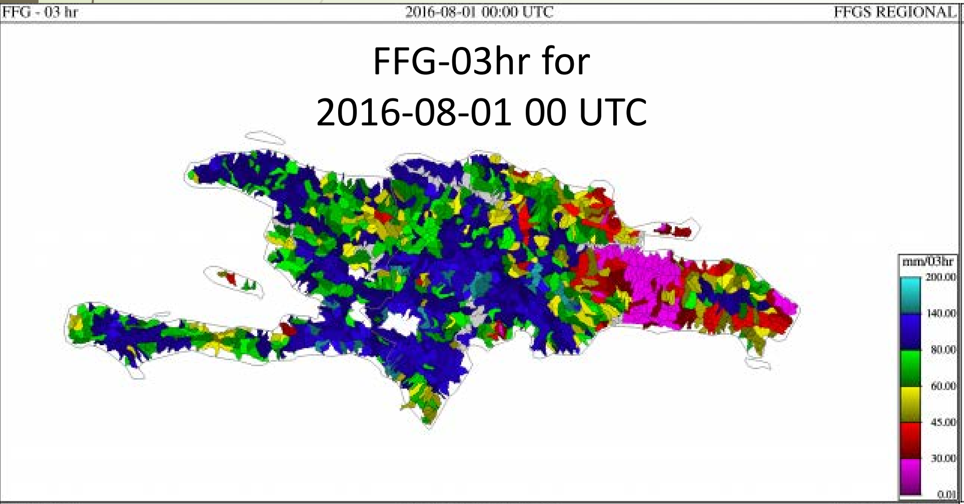


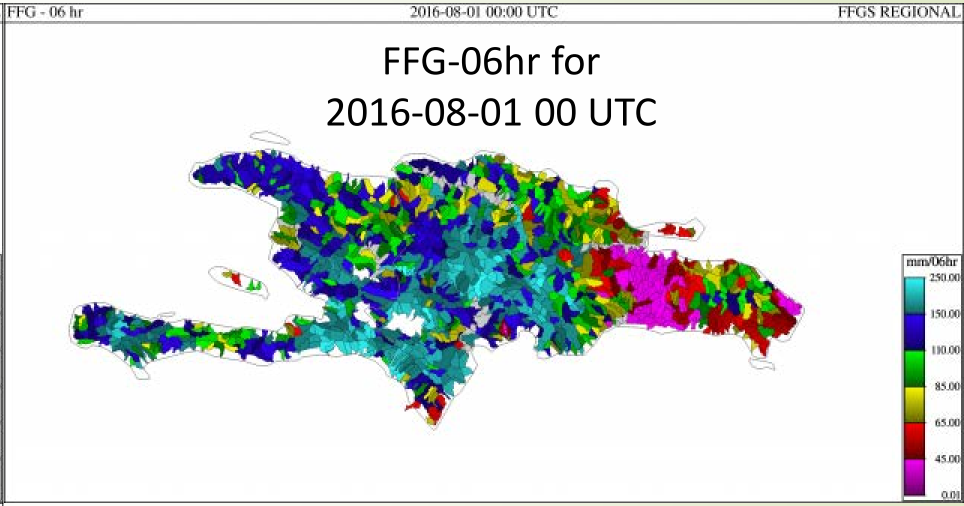
For a given watershed

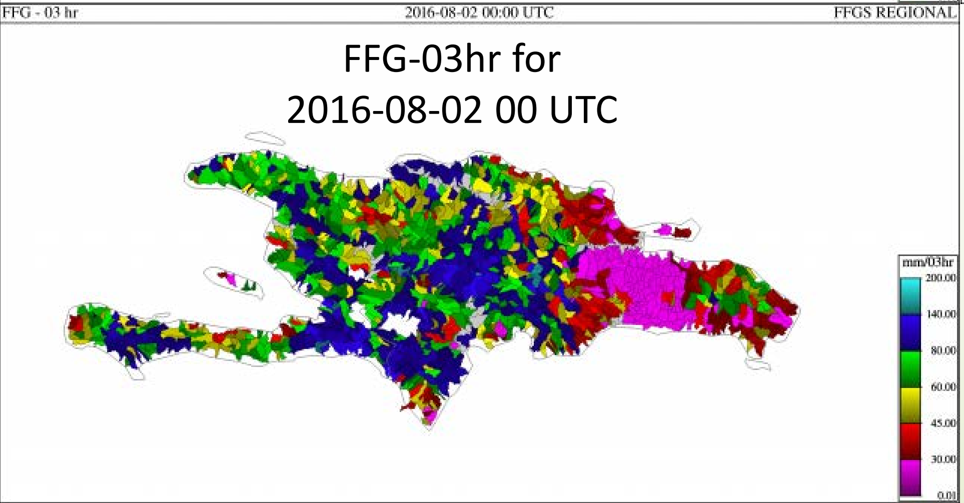


HDRFFG System Product: FFG

FFG: is the amount of precipitation of a given duration over a watershed necessary to cause bankfull conditions at the watershed outlet.
FFG is computed for rainfall durations of 1, 3 and 6-hours.

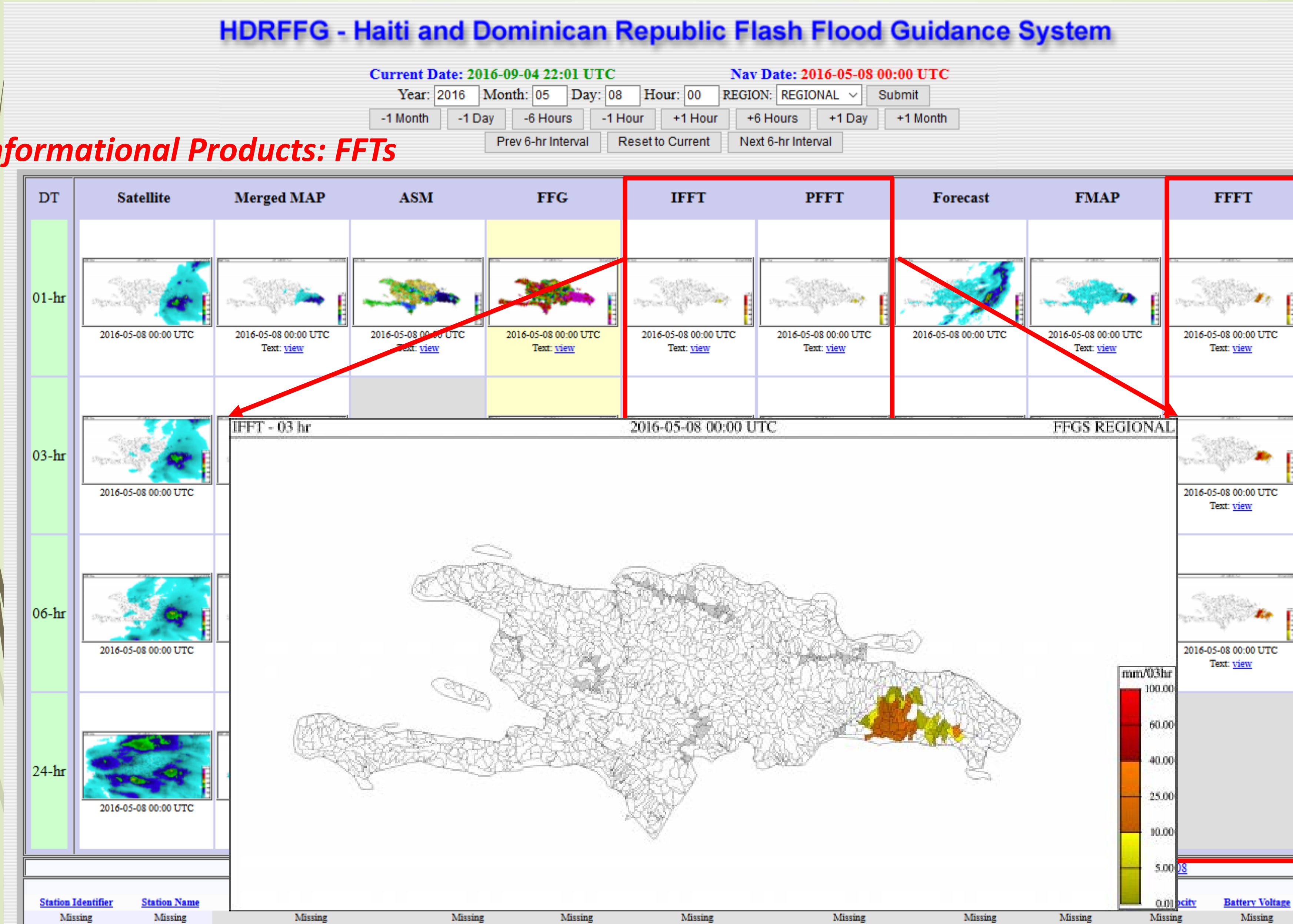






HDRFFG System Products

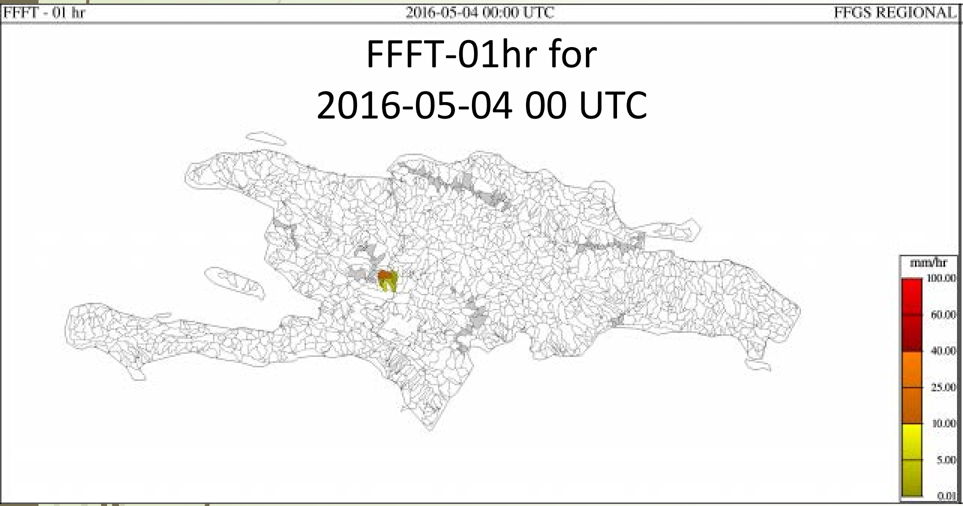
Informational Products: FFTs

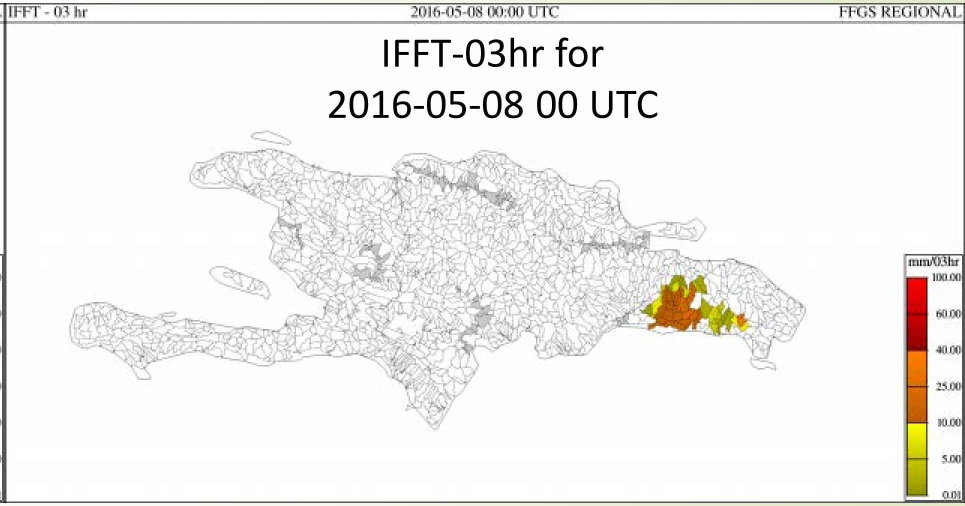


Example SAC-SMA Model Parameterization for HDRFFG

Potential for flash flooding is increased when ***PRECIPITATION > FFG***.

Flash Flood Threat, FFT, defined: ***FFT = MAP - FFG***

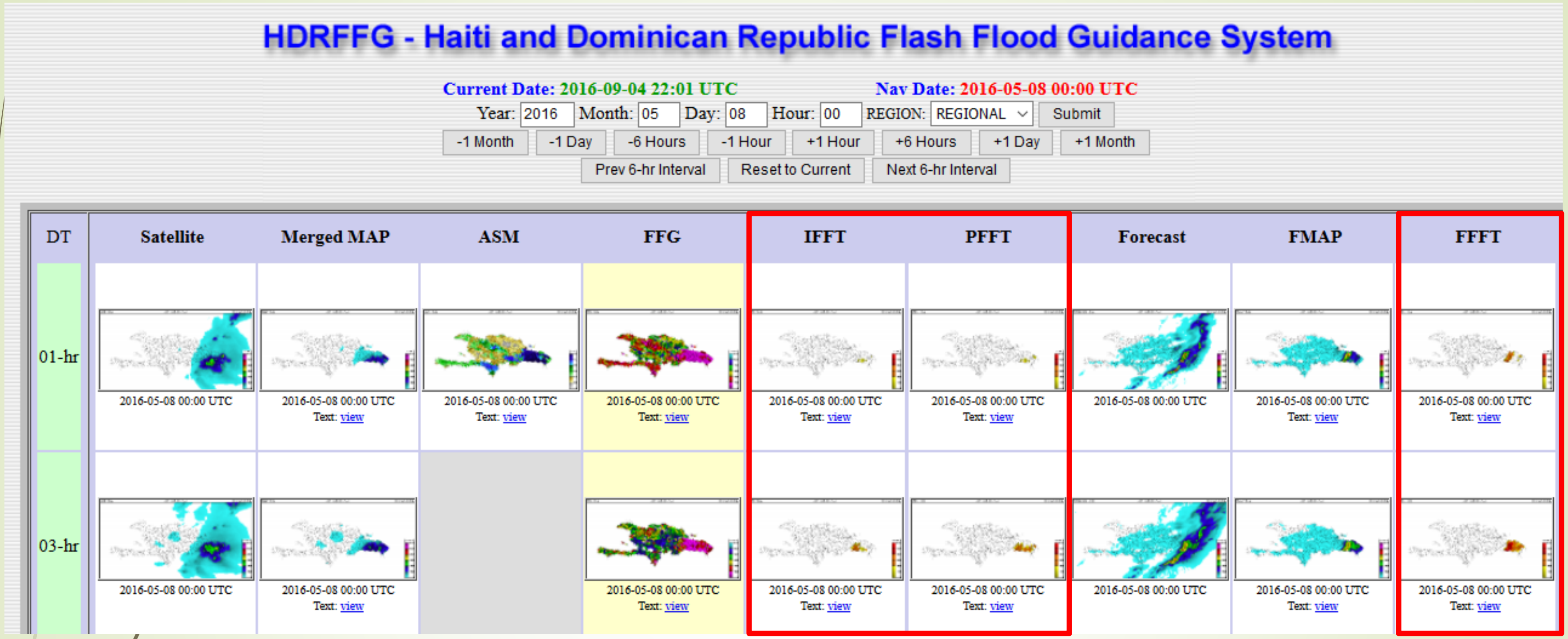




FFT provides indication of regions of potential concern. Color bar provides magnitude of FFT.

Like FFG, FFT products for computed for 1, 3, and 6-hour durations.

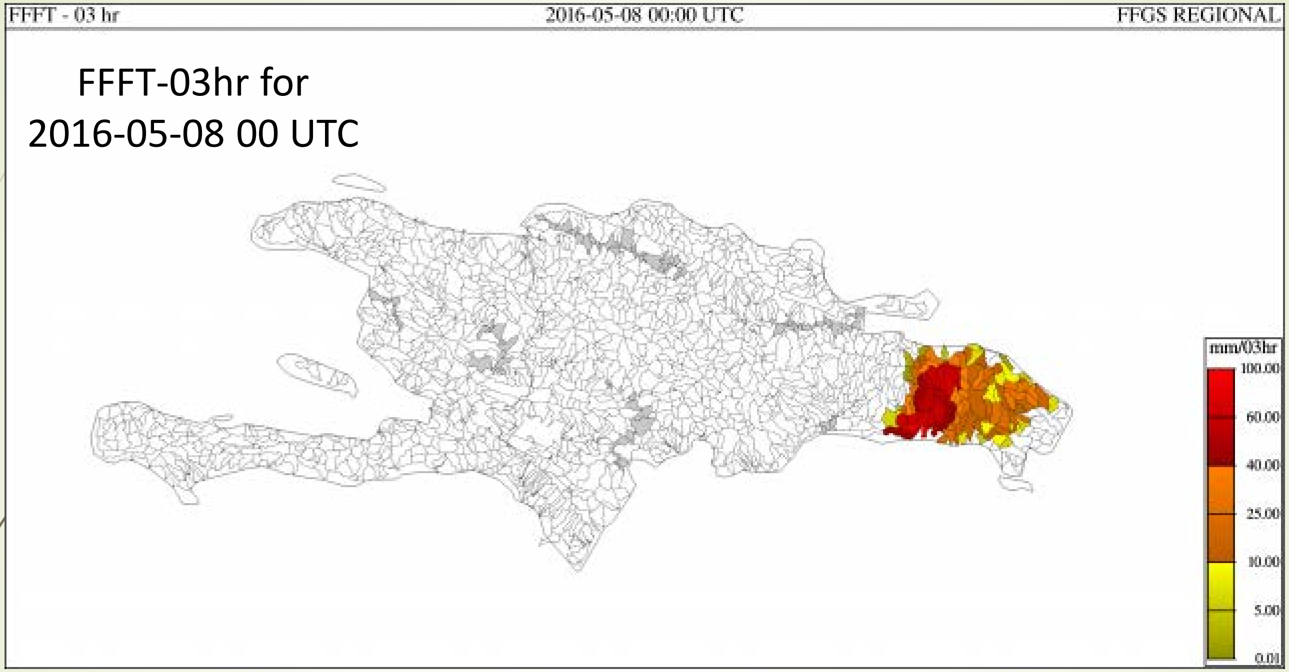
HDRFFG System Products: FFTs



Different FFT products are provided, based on observed or forecasted precipitation and timing.

- IFFT: imminent, based on observed precipitation that has fallen. *Flash flooding may be occurring!*
- PFFT: forecast of persistence – *IF* rainfall continues at current rate
- FFFT: based on forecast precipitation.

Flash Flood Threat Products



Operational forecasters recognize FFG System products and precipitation forecasts carry uncertainty, and must evaluate the current situation and forecast.

*FFT products are ****not***** intended to be the forecast, but are system indicators of potential concern. The role of the forecaster in evaluating available information is* ***critical****.*

Overview of the Development of FFG System Products

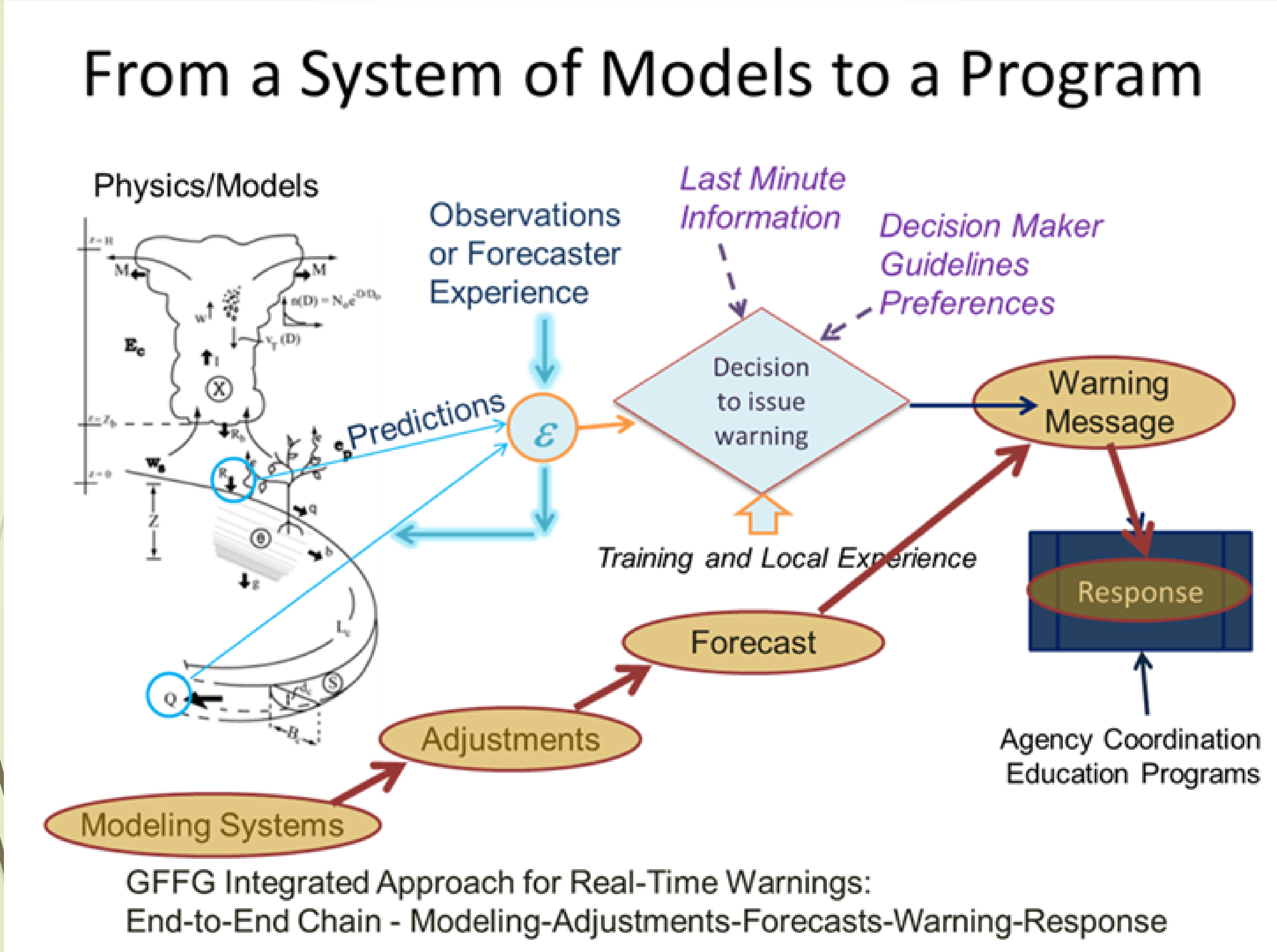
In summary:

- FFG Systems are designed to provide operational hydro-meteorological forecasters with quality information relevant to the assessment of flash flood potential toward the generation of warnings.
- Flash flood guidance concept provides estimate of the amount of precipitation necessary to produce "flooding" condition.
- FFG System ingest high resolution satellite estimates of precipitation in real time with short latency.
- Development of the technical and modeling components was reviewed. This included:
  - precipitation data ingest, quality control, and adjustment
  - accounting of the hydrologic state of the land surface and its ability to accept precipitation
  - estimation of threshold runoff as an indicator of channel storage
  - system-computed indications of regions with precipitation exceeding flash flood guidance

Overview of the Development of FFG System Products

THANK YOU

FFG System Products in Context of End-to-End Chain



Estimation of Threshold Runoff

Under assumption that watersheds respond linearly to rainfall excess, ***threshold runoff*** found by equating peak catchment runoff to flow at outlet associated with flooding. *Carpenter et al., J. Hydrology, 1999.*

$$Q_p = q_{pR} \, R \, A$$

- "Flooding flow", Q_p = bankfull flow as calculated from hydraulic principles (Mannings' steady uniform resistance formula).
  Q_p = f(channel cross-sectional characteristics: B_b, D_b, S_c)
- Peak of unit hydrograph is based on Geomorphologic Instantaneous Unit Hydrograph (GIUH) theory.
  Unit hydrograph peak response, q_{pR} = f(catchment & channel characteristics, rainfall rate)
- *Threshold Runoff, R = nonlinear function of catchment and channel characteristics (A,L, R_L, B_b, D_b, S_c)*