MRCFFG System Development and Theoretical background
Soil Moisture & FFG Modeling

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San Diego, California

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Phnom Penh, Cambodia
FFGS Terminology

Flood - occurrence of a flow event that overtops the natural or artificial banks in a reach of river channel.

Flash Flood – a flood that follows shortly after rainfall event.

Bankfull Flow - a flow in which the water level is at the top of its banks and further rise would result in inundation of the flood plain.

Flash Flood Guidance (FFG) – the volume of spatially uniform precipitation of a given duration (1-6 hours) over a certain small catchment that is required to cause minor flooding in the draining outlet of the catchment.

Threshold Runoff – rainfall depth in a given duration that is needed for the flow at the basin outlet to exceed bankfull flow when the basin is in near saturation conditions.

Flash Flood Threat – rainfall of a given duration in excess of the corresponding Flash Flood Guidance value.
# Large River Flooding vs. Flash Flooding

<table>
<thead>
<tr>
<th><strong>LRF</strong></th>
<th><strong>FF</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchments response affords long lead times</td>
<td>Catchment response is very fast and allows short lead times (&lt;12 hour)</td>
</tr>
<tr>
<td>Entire hydrograph can be produced with low uncertainty given that a good quality data is available</td>
<td>Prediction of occurrence is of interest</td>
</tr>
<tr>
<td>Local information is less valuable</td>
<td>Local information is valuable</td>
</tr>
<tr>
<td>A hydrologic forecasting problem, primarily</td>
<td>A truly hydro-meteorological forecasting challenge</td>
</tr>
<tr>
<td>Affords time for coordination of flood response and damage mitigation</td>
<td>Coordination of forecasting and response is challenging over short times</td>
</tr>
</tbody>
</table>
The Components of the Flash Flood Guidance System

- Satellite Rainfall
- Rain gauge
- Forecast Rainfall
- Rainfall Data
- Potential ET
- Flash Flood Guidance Model
- Soil Moisture Model
- Spatial GIS Data Analyses: Basin delineation, Parameter Estimation
- Threshold Runoff

Flash Flood Guidance
Soil Moisture Modeling
Basin Delineation

Data: DEM, stream network
Quality Control.

Shuttle Radar Topography Mission (SRTM)
Consultative Group for International Agriculture Research (CGIAR-CSI).

90-m resolution processed to a resolution of ~360-m

- 6372 sub-basins
- mean area 182 km²
- s.d. area 140 km²
- Mean channel length 25 km
### Basin Delineation

<table>
<thead>
<tr>
<th></th>
<th>Cambodia</th>
<th>Lao PDR</th>
<th>Thailand</th>
<th>Vietnam</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. basins</td>
<td>1113</td>
<td>1424</td>
<td>2900</td>
<td>2074</td>
</tr>
<tr>
<td>No. basins sm. 2000 km²</td>
<td>968</td>
<td>1115</td>
<td>2242</td>
<td>1633</td>
</tr>
<tr>
<td>Average basin local area (km²)</td>
<td>174 (179)</td>
<td>180 (187)</td>
<td>183 (193)</td>
<td>186 (193)</td>
</tr>
<tr>
<td>S.D basin Area (km²)</td>
<td>125 (122)</td>
<td>136 (139)</td>
<td>141 (139)</td>
<td>148 (141)</td>
</tr>
<tr>
<td>Average Channel Length (km)</td>
<td>27 (28)</td>
<td>23 (26)</td>
<td>25 (28)</td>
<td>25 (28)</td>
</tr>
<tr>
<td>Average slope</td>
<td>0.007 (0.0075)</td>
<td>0.017 (0.012)</td>
<td>0.01 (0.012)</td>
<td>0.017 (0.021)</td>
</tr>
</tbody>
</table>

![Basin Area Distribution](chart-cambodia-lao-erd.png)

- **Cambodia**: Distribution of basin areas.
- **Lao PDR**: Distribution of basin areas.
- **Thailand**: Distribution of basin areas.
- **Vietnam**: Distribution of basin areas.
Example of the delineation verification: comparison of the delineated streams (light green) and DCW stream network (black) for a region in northern Laos.
Sacramento Soil Moisture Accounting
SAC-SMA Model

- Process based conceptual model
  - A simplified description of physical processes:
    Mass balance - soil profile as a series of connected reservoirs with capacities and release coefficients

- Areal Lumped – basin scale
  - Mean areal fluxes
  - Effective time invariant parameters
Three general types of soil water content that influence the runoff

**Tension water**
- The part that can be separate from the soil and returned to the atmosphere through ET
- Water that is held against gravity due to force attraction by the soil molecules
- Depend on soil climate and land cover

**Free water**
- Water in the liquid state that is free to travel
- This is the water that will supply all the deficiencies in the model compartments (i.e., tension, percolation into the lower zone)
- The lateral flow is generated from the free water
- When rainfall intensity is larger than the percolation rate than the excess rain will generate surface flow.

**Interception**
- The portion of rain that is remained on the vegetation
- A moisture storage that affect the rainfall-runoff regime
- The intercepted water is temporarily interfere with the ET from the tension water storage.
- Form modeling perspective the intercepted water is included in the tension storage.
- Problem might occur in areas with large annual variability in interception

In general:
- Smaller soil particles (clay) have larger tension water storage
- Large soil particles (sand) have larger free water storage

References:
Burnash, R.J.C., 1995
1) Tension water storages in the SAC-SMA model are related to available soil water estimated as the difference in volumetric water content between field capacity (θfld) and wilting point (θwlt).

2) The model free water storages are related to gravitational soil water estimated as the difference between porosity (θsat) and field capacity (θfld).

3) The depth of the model upper and the lower zones combined are equal to the soil profile depth (Zmax).

4) During common average soil moisture conditions the model upper tension water storage is full and the upper free water storage is empty. Thus, during rainfall events the initial losses to the soil before surface runoff is generated satisfy the upper free water storage requirements.
Upper Zone Soil Moisture

\[ ASM = \frac{XT + XF}{XTo + XFo} \]
Free
Lower Zone

ET
Rain
Surface-flow

Tension
Free

Interflow

Percolation

Lower Zone
Fig. 2. Model relationship (solid line) between a given volume of rainfall, $R_a$, of duration $t_d$ and the model-generated runoff $R_s$ for a given soil moisture deficit. The relationship is used to translate the surface runoff that is just enough to cause flooding of the draining stream at the watershed outlet (called threshold runoff) to the required volume of rainfall over a given duration $t_d$ (called flash flood guidance of duration $t_d$).
Effective rainfall is the residual amount after accounting for all losses such as interception and soil moisture storage.

FFG is the amount of actual rainfall of a given duration falling over the watershed that causes flooding at the outlet of the drainage stream.

FFG is derived from threshold runoff through soil moisture modeling and accounting for all losses in the transformation of rainfall to runoff.

Threshold Runoff is a one-time calculation for a given watershed whereas FFG is computed on a real-time basis.
Relating Channel Cross-Sectional Properties To GIS-Computed Quantities

Channel cross-sectional properties needed can not be resolved with current digital elevation models (DEM).

Bankfull cross-section dimensions (top width and hydraulic depth) vary with catchment size due to sediment carrying characteristics of bankfull flow:

\[ B_b = \alpha A^\gamma \quad \text{and} \quad D_b = \varepsilon A^\lambda \]

Develop such relationships based on channel survey data.

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

Oklahoma to basins with slopes gentler than 3%.
Iowa to basins with slopes between 3-6%.
California for basins that are steeper than 6%.
Evapotranspiration Demand ETD
Jensen-Haise: Radiation-based method with two parameters

For basin scale hydrologic models and operational environments, ETD procedures that are based on extraterrestrial radiation and climatic surface temperature outperform more complex models (e.g., Penman Monteith).

J-H Evapotranspiration Demand in a given location (mm/day):

\[ PE = \frac{[Re (Ta - K2)]}{K1(\lambda \rho)} \]

for \( Ta > K2 \)

- \( Re \) - Daily potential Incoming extraterrestrial radiation (Mj m\(^{-2}\) d\(^{-1}\));
  - \( f \{ \text{latitude, Julian date} \} \)
- \( Ta \) - Long term daily averages of surface temperature (\( \text{minT+maxT}/2 \));
  - \( f \{ \text{Julian date, elevation} \} \)
- \( K2 \) (°C) – minimum temperature for which PE=0 (~5 °C)
- \( K1 \) (°C) – scale parameter (75-130) (assigned to 90)
- \( \lambda \) – Latent heat of water (Mj kg\(^{-1}\))
- \( \rho \) - density of water (kg m\(^{-3}\))

CRU-U of East Anglia, UK
Monthly climatology of mean daily
Ta and diurnal Ta range
(1961-1990; 10 min scale)
New et al. 2002

Jensen & Haise 1963
McGuinness & Borden 1973
Oudin et al 2005
PET Interpolated from DSF Surface Temperature Data

- **PET (mm/day) January 1st**
  - 1 - 1.5
  - 1.5 - 2
  - 2 - 2.5
  - 2.5 - 3
  - 3 - 3.5
  - 3.5 - 4

- **DSF-Daily Temperature Data**

- **Mekong Station Data: Long-Term Average of Mean Daily Temperature**

- **Annual PE vs. Elevation for SE Asia Stations**

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Hydrologic Research Center www.hrc-lab.org
Soil Moisture Accounting Model A priori Parameter Estimation

Soil Texture and Hydraulic Properties

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>( \theta_w ) (m³/m³)</th>
<th>( \theta_f ) (m³/m³)</th>
<th>( \theta_s ) (m³/m³)</th>
<th>( K_s ) (m/s)</th>
<th>( n )</th>
<th>( c_s ) (m/v)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>0.34</td>
<td>0.09</td>
<td>0.015</td>
<td>0.168</td>
<td>2.79</td>
<td>0.062</td>
</tr>
<tr>
<td>Loamy Sand</td>
<td>0.42</td>
<td>0.16</td>
<td>0.05</td>
<td>0.050</td>
<td>4.26</td>
<td>0.082</td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>0.43</td>
<td>0.21</td>
<td>0.07</td>
<td>0.019</td>
<td>4.74</td>
<td>0.119</td>
</tr>
<tr>
<td>Loam</td>
<td>0.44</td>
<td>0.25</td>
<td>0.095</td>
<td>0.012</td>
<td>5.25</td>
<td>0.108</td>
</tr>
<tr>
<td>Silty Loam</td>
<td>0.48</td>
<td>0.29</td>
<td>0.11</td>
<td>0.010</td>
<td>5.33</td>
<td>0.090</td>
</tr>
<tr>
<td>Sandy Clay Loam</td>
<td>0.60</td>
<td>0.24</td>
<td>0.11</td>
<td>0.016</td>
<td>6.77</td>
<td>0.088</td>
</tr>
<tr>
<td>Clay Loam</td>
<td>0.47</td>
<td>0.32</td>
<td>0.17</td>
<td>0.009</td>
<td>8.17</td>
<td>0.059</td>
</tr>
<tr>
<td>Silty Clay Loam</td>
<td>0.46</td>
<td>0.33</td>
<td>0.19</td>
<td>0.007</td>
<td>8.72</td>
<td>0.105</td>
</tr>
<tr>
<td>Sandy Clay</td>
<td>0.41</td>
<td>0.29</td>
<td>0.18</td>
<td>0.026</td>
<td>10.73</td>
<td>0.054</td>
</tr>
<tr>
<td>Silty Clay</td>
<td>0.47</td>
<td>0.33</td>
<td>0.21</td>
<td>0.065</td>
<td>10.59</td>
<td>0.124</td>
</tr>
<tr>
<td>Clay</td>
<td>0.47</td>
<td>0.36</td>
<td>0.24</td>
<td>0.004</td>
<td>11.55</td>
<td>0.106</td>
</tr>
</tbody>
</table>

Values are from Cosby et al. 1984.
FOOD AGRICULTURE ORGANIZATION [FAO]
Harmonized Soil Texture
Land Cover Database is derived from the U.S. Geological Survey's (USGS) Global Land Cover Characteristics (GLCC) database at 30 arc second resolution in a common grid for the entire globe.
Upper Zone Parameters
Percolation Equation Parameters

- **REXP**: 1.8, 2, 2.5, 3.1, 3.5
- **ZPERC**: 50, 90, 120, 150
Lower Zone Parameters
Huai Bang Sai (Thailand)

Observed = instantaneous
Simulation = mean Daily

Daily time step 1990-1995

STREAMFLOW
Rain
Soil Moisture

Mm/Day
Model States
FFT Evaluation

1-Hr FFT

3-Hr FFT

6-Hr FFT

millimeter $\rightarrow$ [Rain(t+1) - FFG(t)]
Product Description

- MODIS Instrument onboard Terra & Aqua satellites
- Daily product
- 250m grid resolution
- 10X10 degree tiles
- False detections eliminated by requiring the 3 last consecutive days and Terrain shadow masking, to designate as inundated
- [http://oas.gsfc.nasa.gov/floodmap/home.html](http://oas.gsfc.nasa.gov/floodmap/home.html)
- NRT Staff (esp. Dr. Dan Slayback & Frederick Policelli) generated historic products for analysis
Basin Case Studies

Basin ID: 31245
Location: Bangkok
Soil Texture: Silty Clay
Soil Depth: V. Deep
LU/LC: Cropland/Woodland/Grassland
Elevation (m): 6
Area (km²): 162
Channel Length (km): 32.2
Channel Slope (%): 0.31
Many basins in Southeast Asia experience large inundation extents. Does soil saturation fraction (ASM) reflect actual conditions, when inundation occurs?