CARFFG System Design and Theoretical Background: GIS and Threshold Runoff

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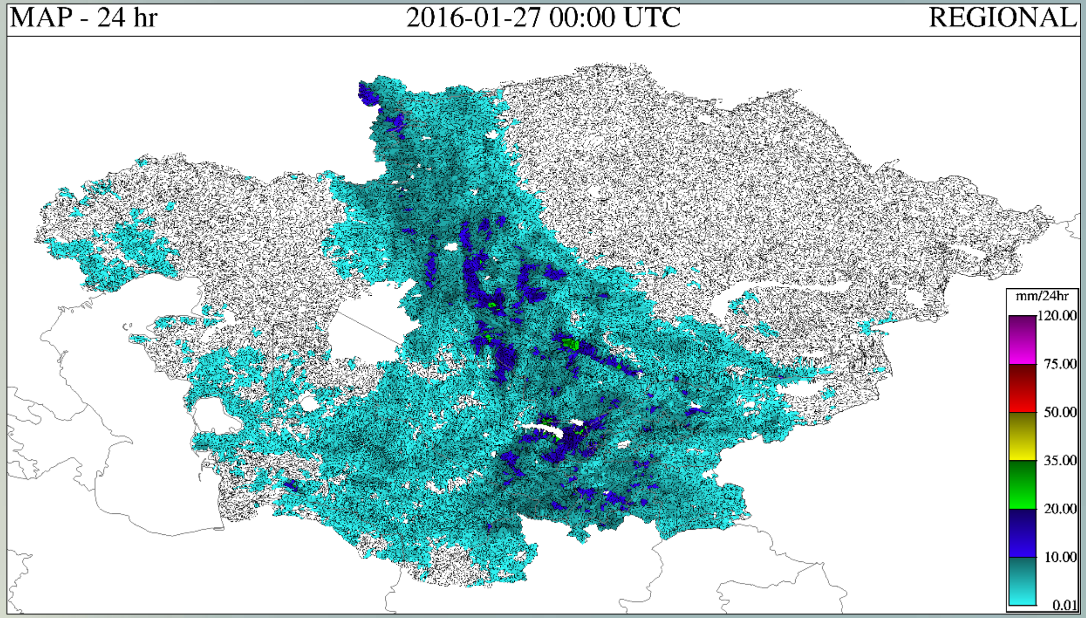
Objective of the Presentation

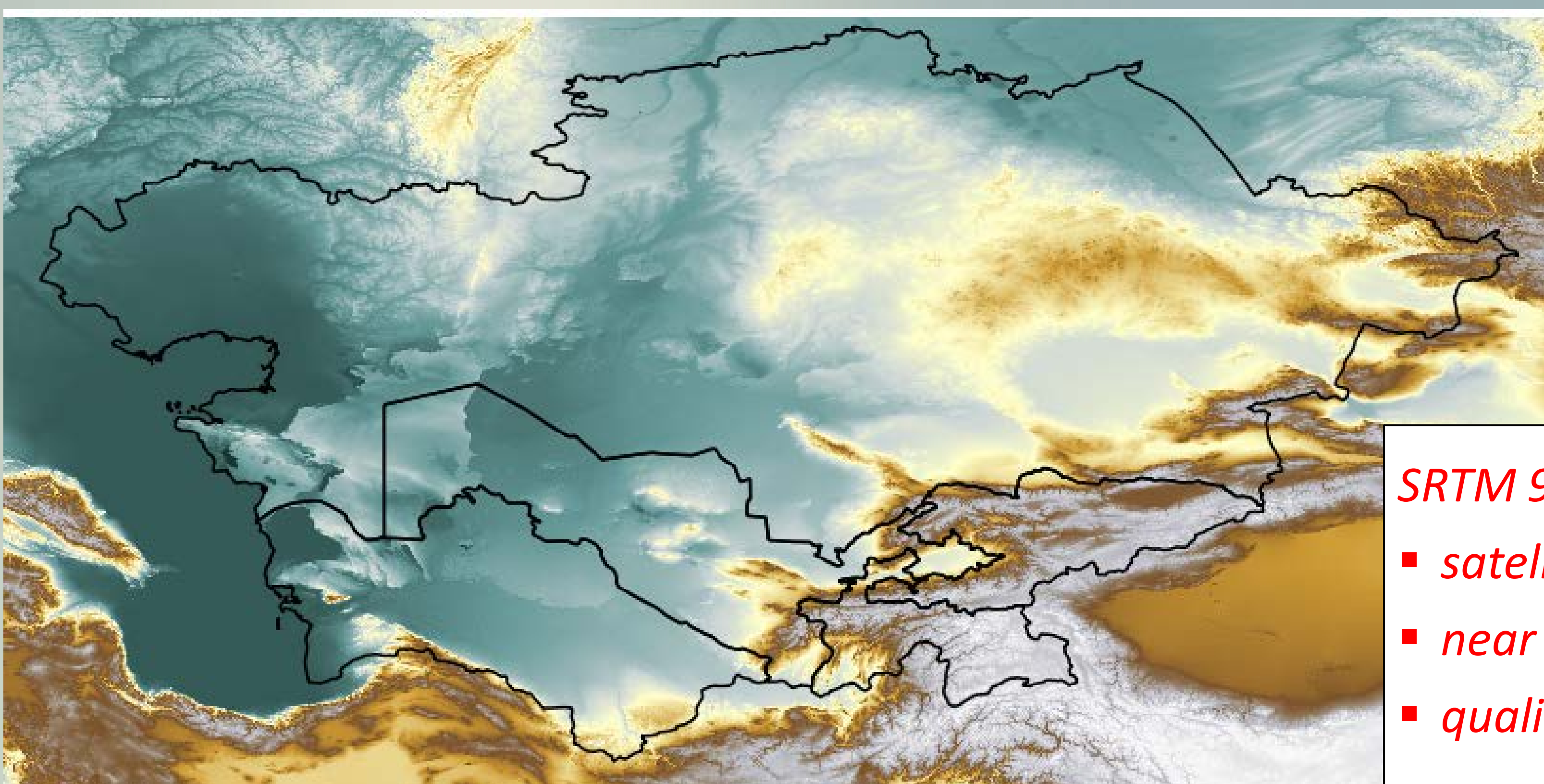
- *Describe process for delineation of flash flood-scale watersheds These are used for defining physical properties in CARFFG System*
  - *model parameterization*
  - *model computations*
  - *product displays*



- *Describe Threshold Runoff theory and estimation for CARFFG*

GIS Processing to Delineate Small Flash Flood Watersheds

- *GIS processing of digital elevation data to define watersheds*
- *GRASS GIS software utilized*
- *Estimate watershed characteristics (A, L, S) used in calculations*

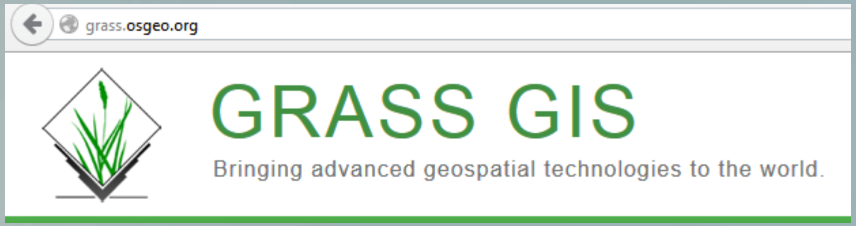


SRTM 90-m DEM

- *satellite-observed*
- *near global*
- *quality controlled*

GIS Processing to Delineate Small Flash Flood Watersheds

- *Why GRASS?*
  - *freeware*
  - *Collaboration with developer of delineation routine, r.watershed (1980s)*
  - *Evaluations of r.watershed results found superior in representing hydrologic properties of watershed.*
  - *(Also included / linked with Quantum GIS (QGIS) software)*

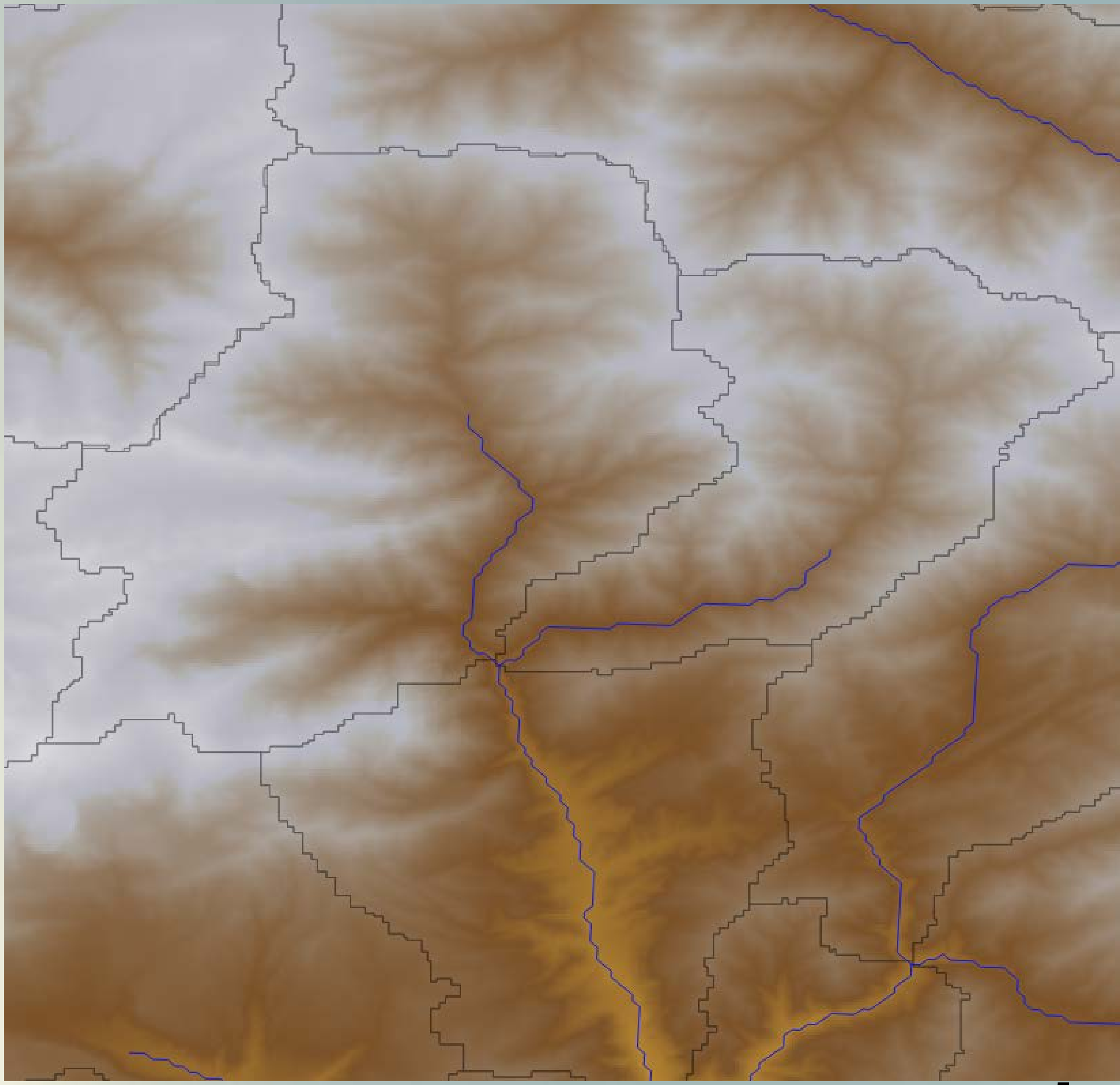


http://grass.osgeo.org

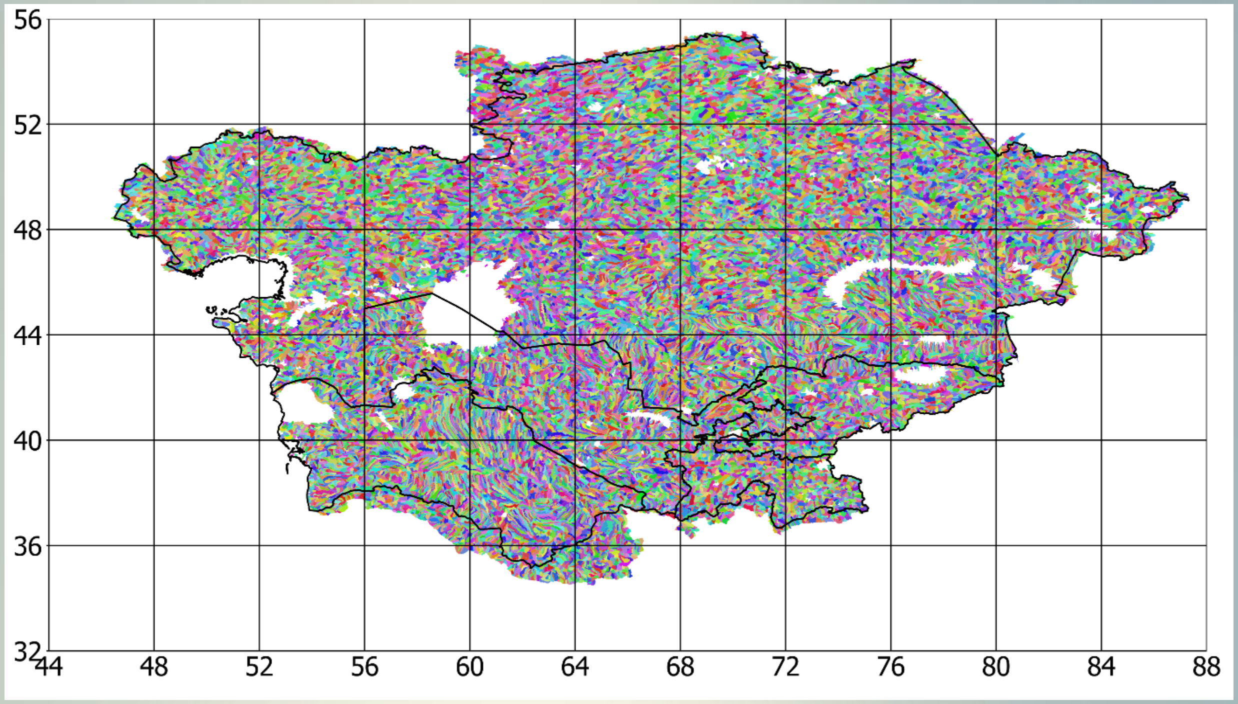
- *Routine r.watershed defines flow path and watersheds boundaries based on digital elevation data (DEM/DTM)*

GIS Processing to Delineate Small Flash Flood Watersheds

- *r.watershed determines streams and boundaries based on DEM*



CARFFG Basin Delineation

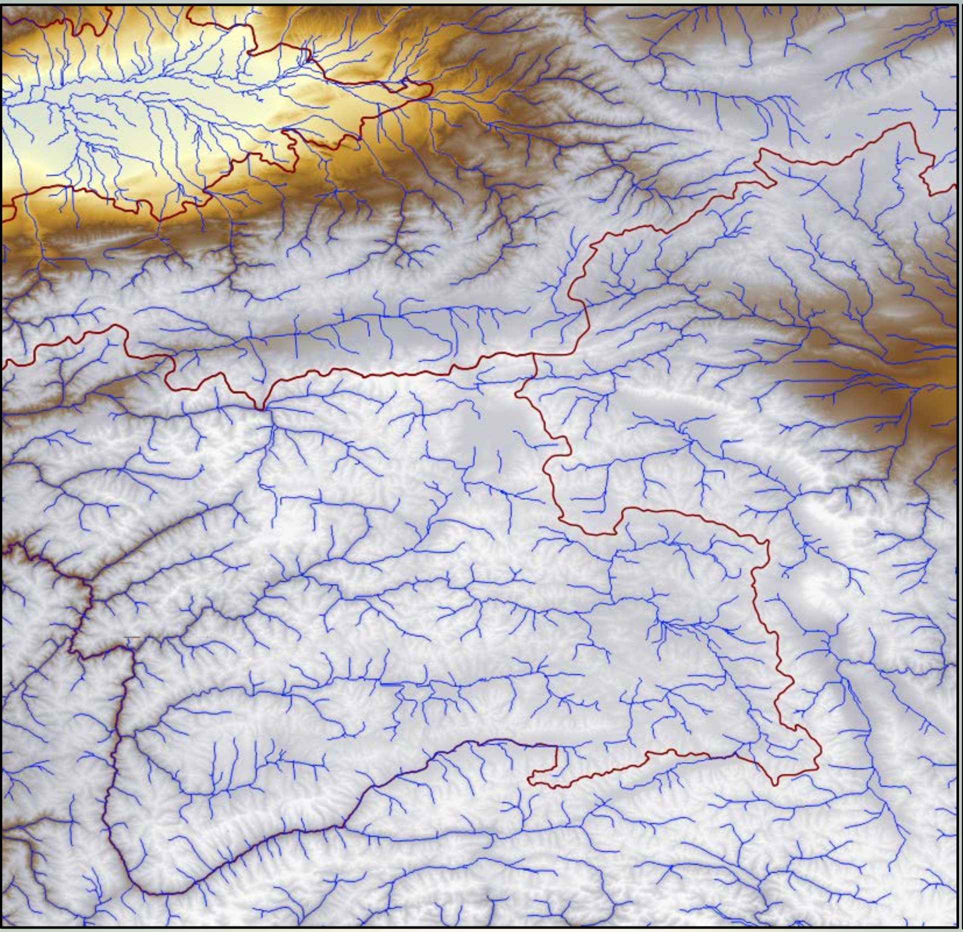


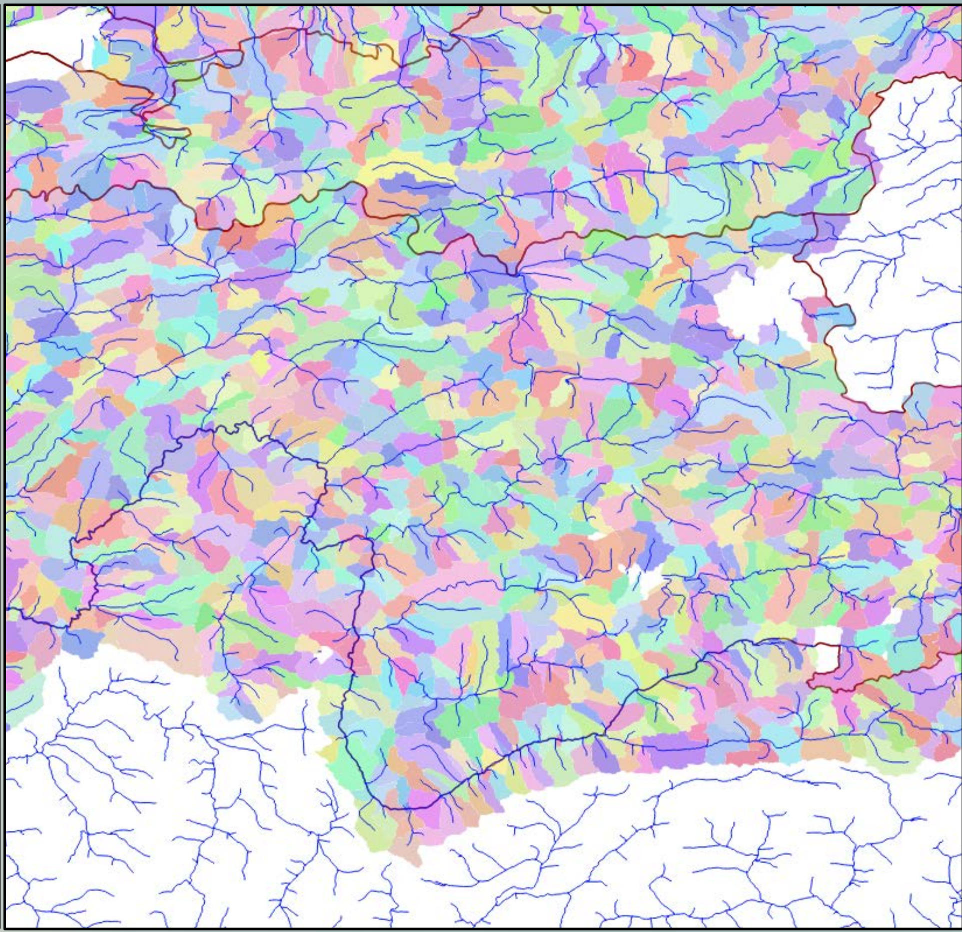
Multiple processing windows

- r.watershed parameter defines minimum headwater stream size
- Our target: average local area of ~150km^2
- Result:
  34,700 basins defined
  Average A = 120km^2
  5650 w/ A_{accum} > 2000km^2
  29050 w/ A_{accum} <= 2000km^2

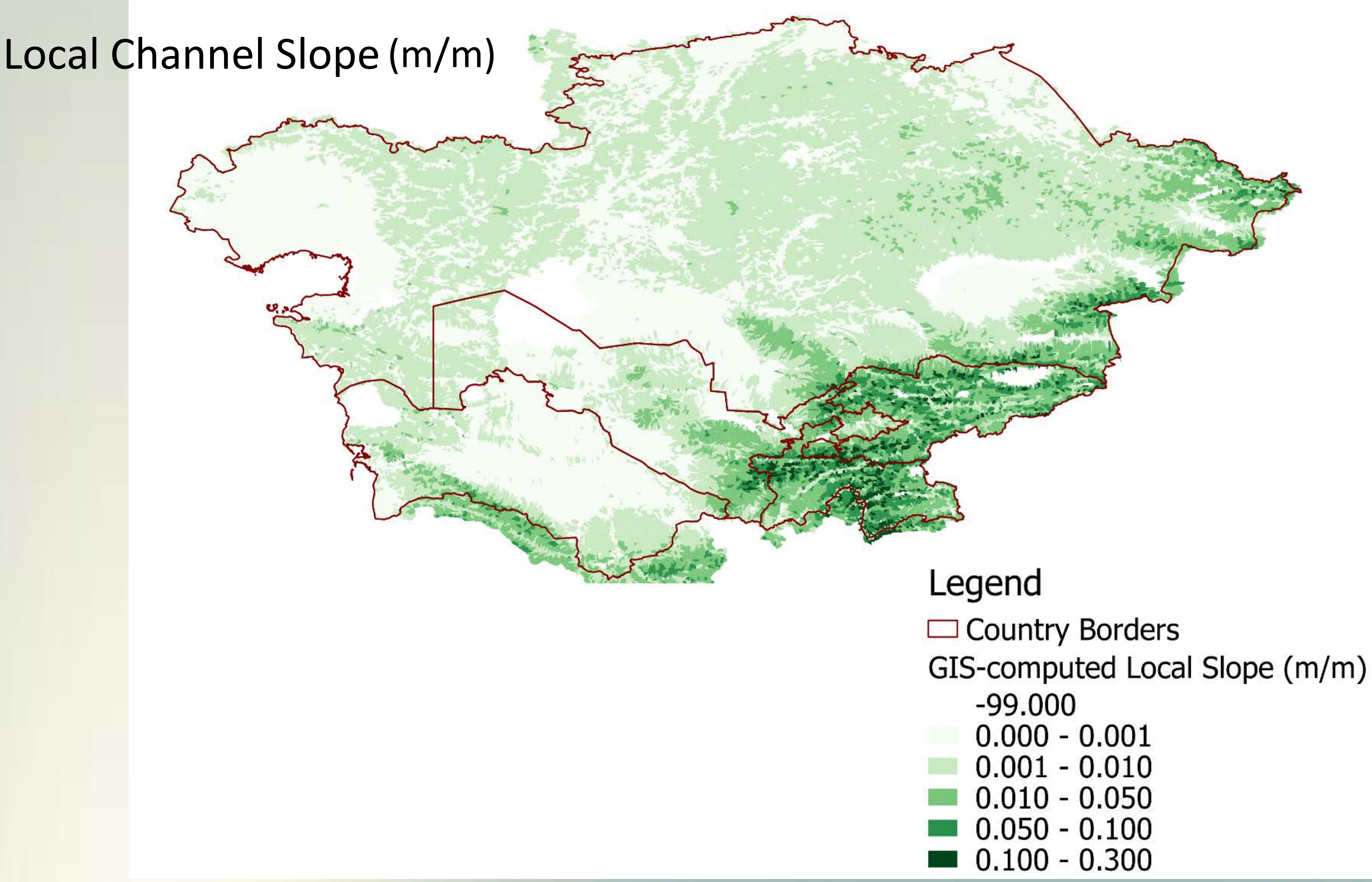
CARFFG Basin Delineation

Output is digital stream network and watershed boundaries.





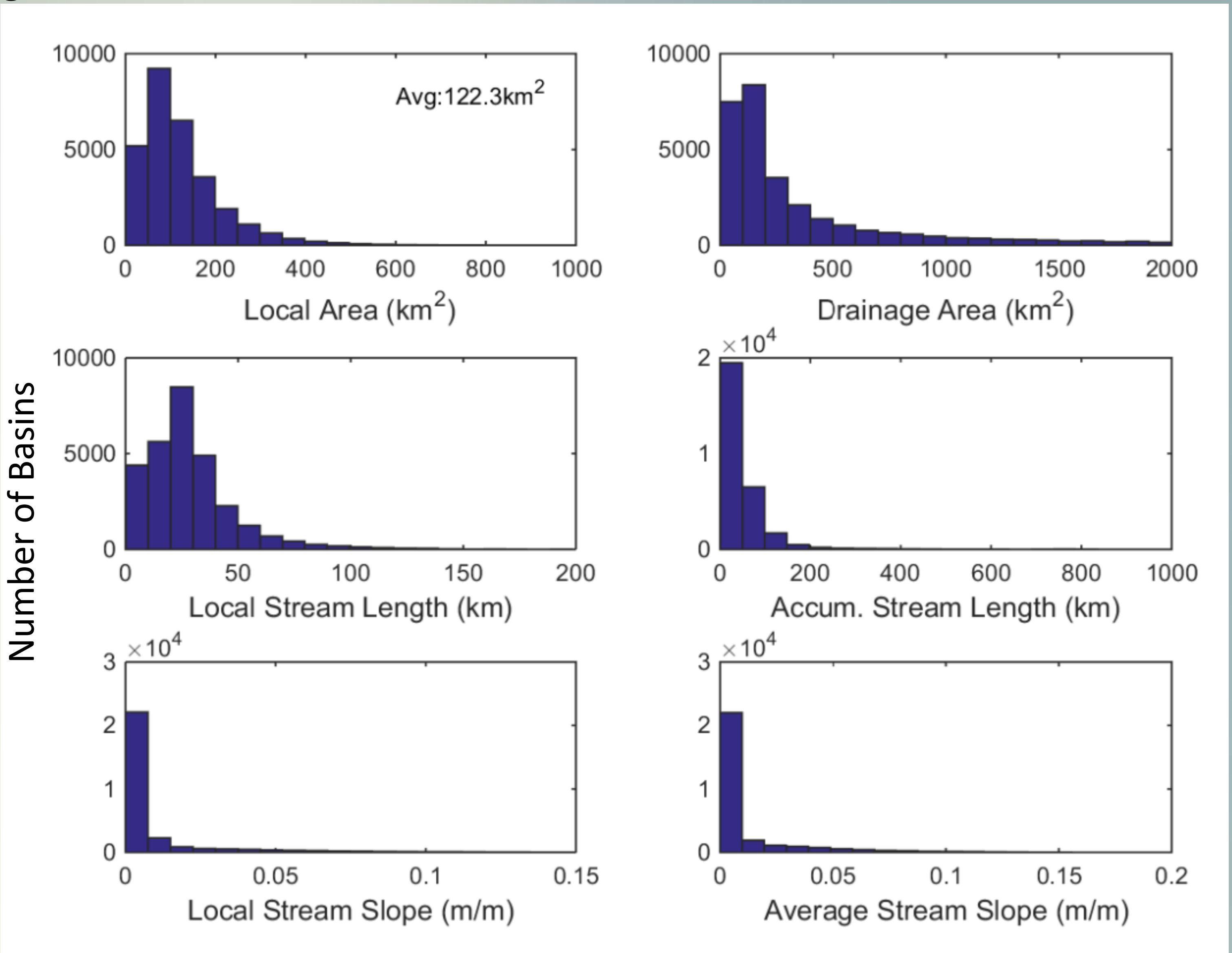
Characteristics of CARFFG Basins



Basin geometry features used to compute *threshold runoff*, a watershed characteristic and input to flash flood guidance.

Basins Geometric characteristics

For Accumulated
Drainage Area < 2000km^2



Validation of Delineation Results

(a) HRC-internal review

comparison with Digital Chart of the World (DCW) stream database

comparison with GoogleEarth Satellite Imagery

(b) Within-Country review

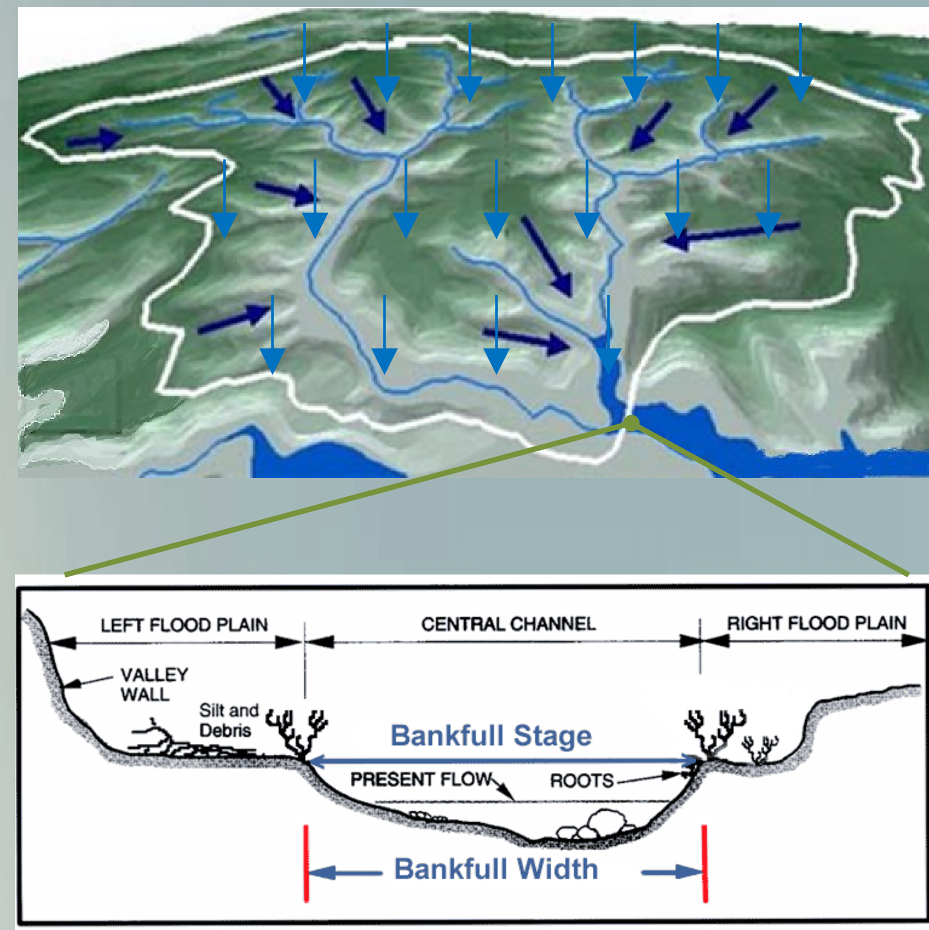
GIS layers provided to NMHSs for evaluation and comments

Comments on GIS-based Watershed Delineation

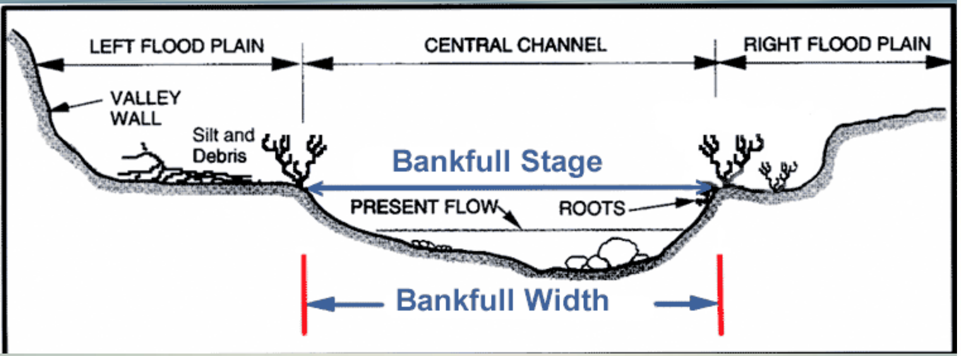
- Watershed delineation is based on topography only
  - Represents *natural* drainage system
  - SRTM “sees” top of canopy
  - Known difficulties in very mildly sloping regions and regions with small terrain undulations.
- Large regions require multiple “processing windows”, which are “patched” together to complete regional GIS file.
- Watersheds defined throughout region.
  Soil/snow models applied throughout
  FFG computed only for watersheds with cumulative area < $2000 km^2$.

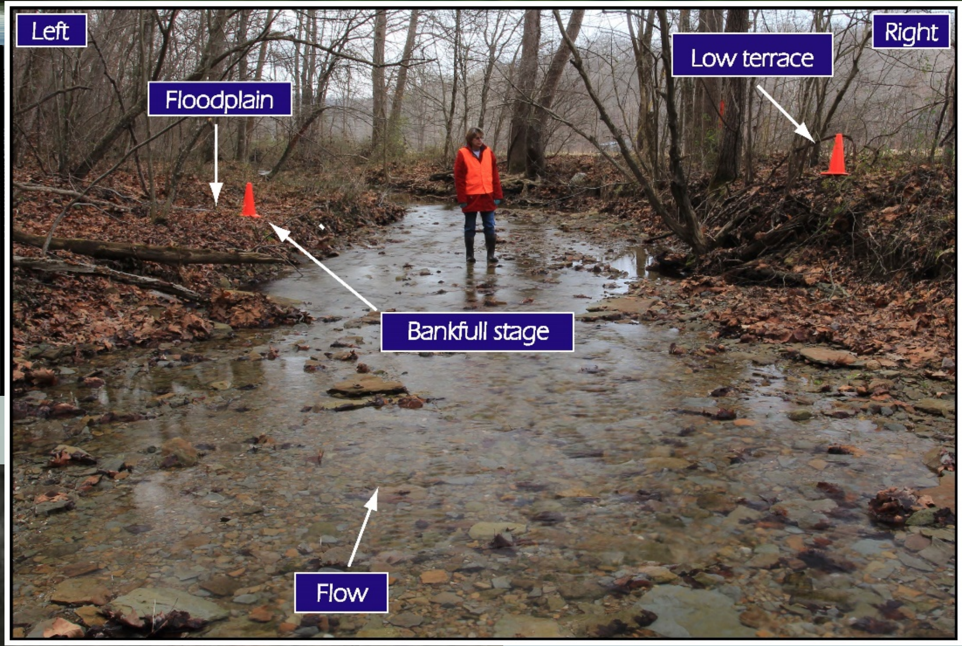
Definition of Threshold Runoff

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.



Definition of Threshold Runoff





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

Theory of Threshold Runoff Estimation

Assuming *linear response* of basins to rainfall excess, threshold runoff may be calculated under the following equality:

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

Q_p is the bankfull flow at the watershed outlet (cms) – Can be solved by Manning eqn.

q_{pR} is the peak of the unit hydrograph of duration t_R, normalized by catchment area (cms/km^2/mm) – can be estimated by GIUH

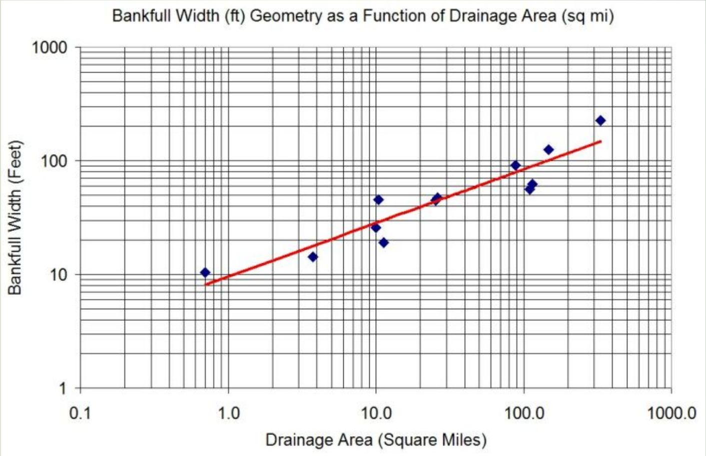
A is the catchment area (km^2) – GIS Delineation

R is the rainfall amount over the duration t_R, or the *threshold runoff* (mm)

Carpenter et al, *J. Hydrology*, 1999

Comments on Bankfull Flow

- Channel cross sections are not resolved with current (e.g., 90-m) DEM
- Bankfull condition may be identified using morphological field evidence during local stream surveys.
- Use local survey data to develop regional relationships between cross-sectional dimensions and catchment properties (e.g., A)



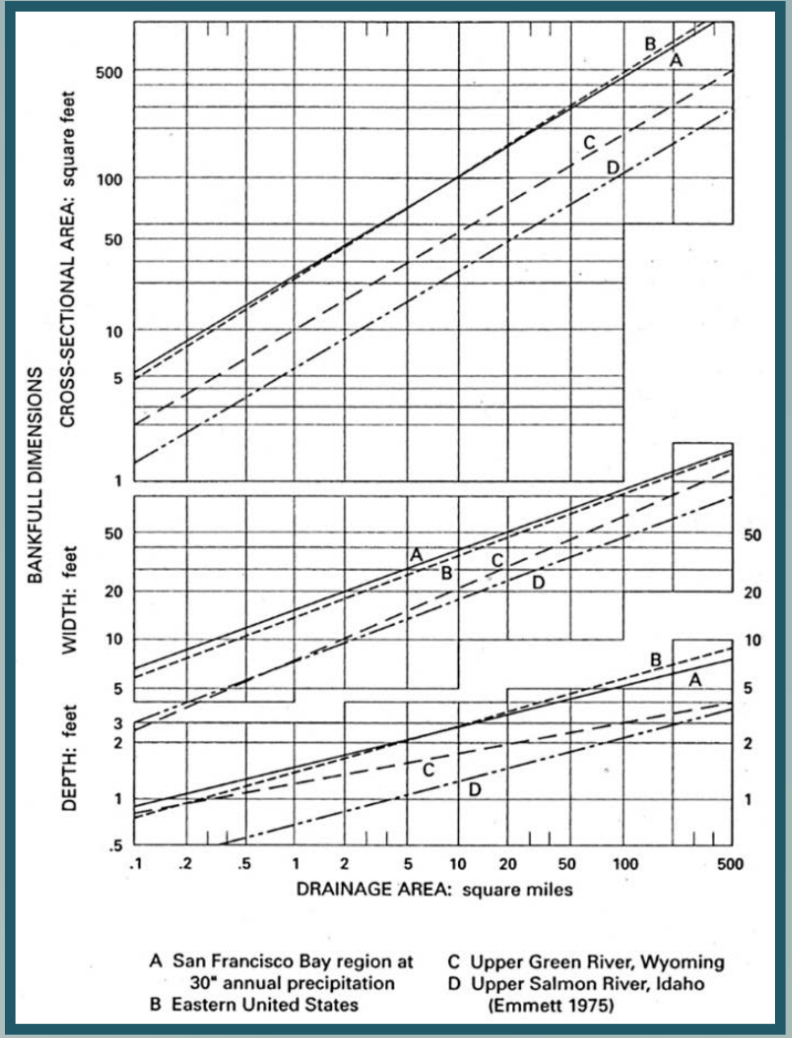
Comments on Bankfull Flow

- Bankfull cross-section dimensions (width, depth) vary with catchment size.

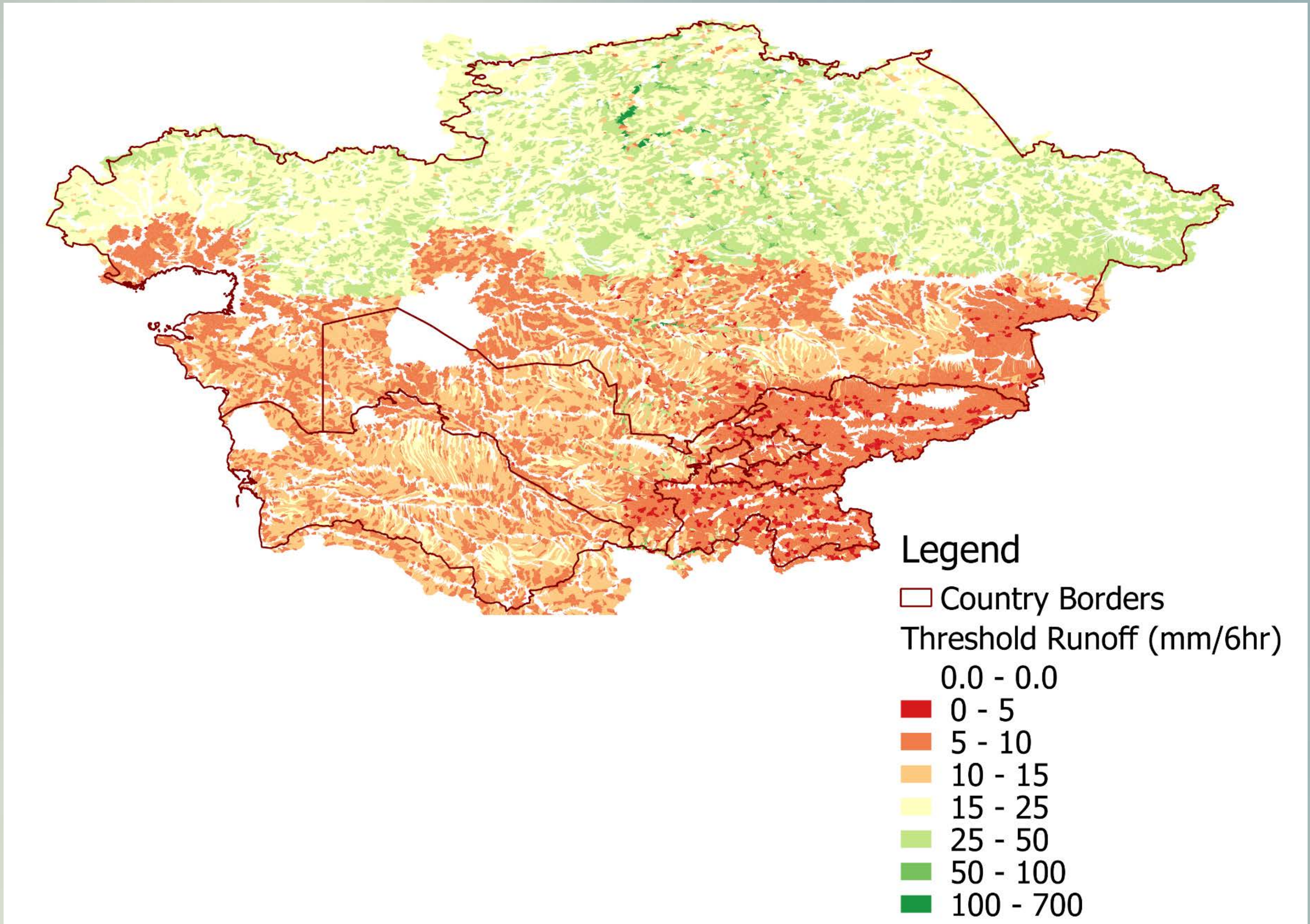
  $B_b = \alpha A^{\gamma}$ $D_b = \varepsilon A^{\lambda}$

- Use regional relationships to estimate cross-section at each outlet
- Bankfull flow is a conservative measure of flooding (little damage).

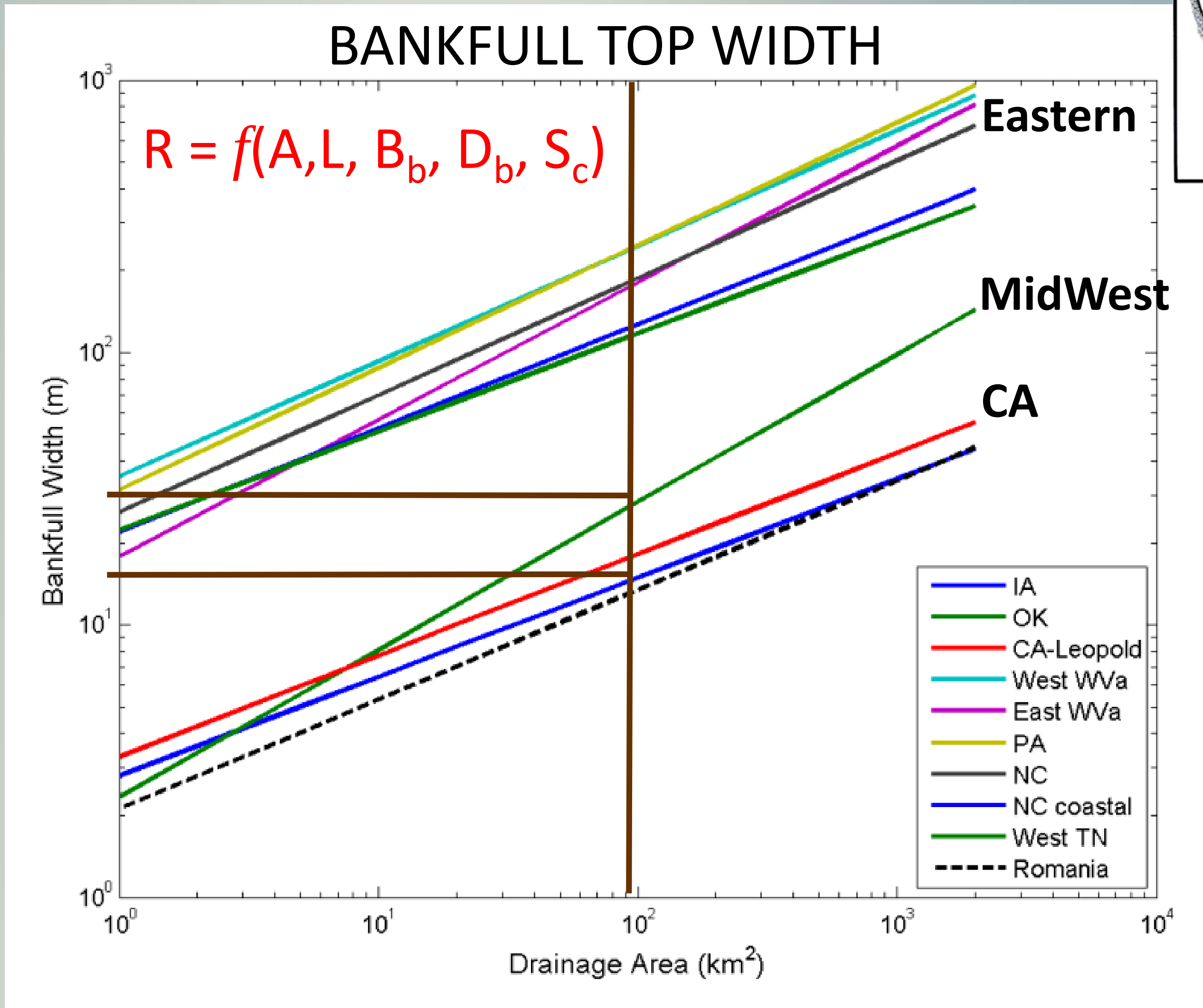
Source: L. Luna, 1994: *A View of the River*

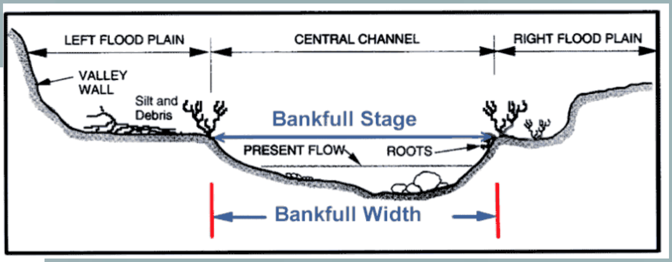


Threshold Runoff Estimates for CARFFG



Impact of Regional Relationships





Threshold Runoff (eq.1)

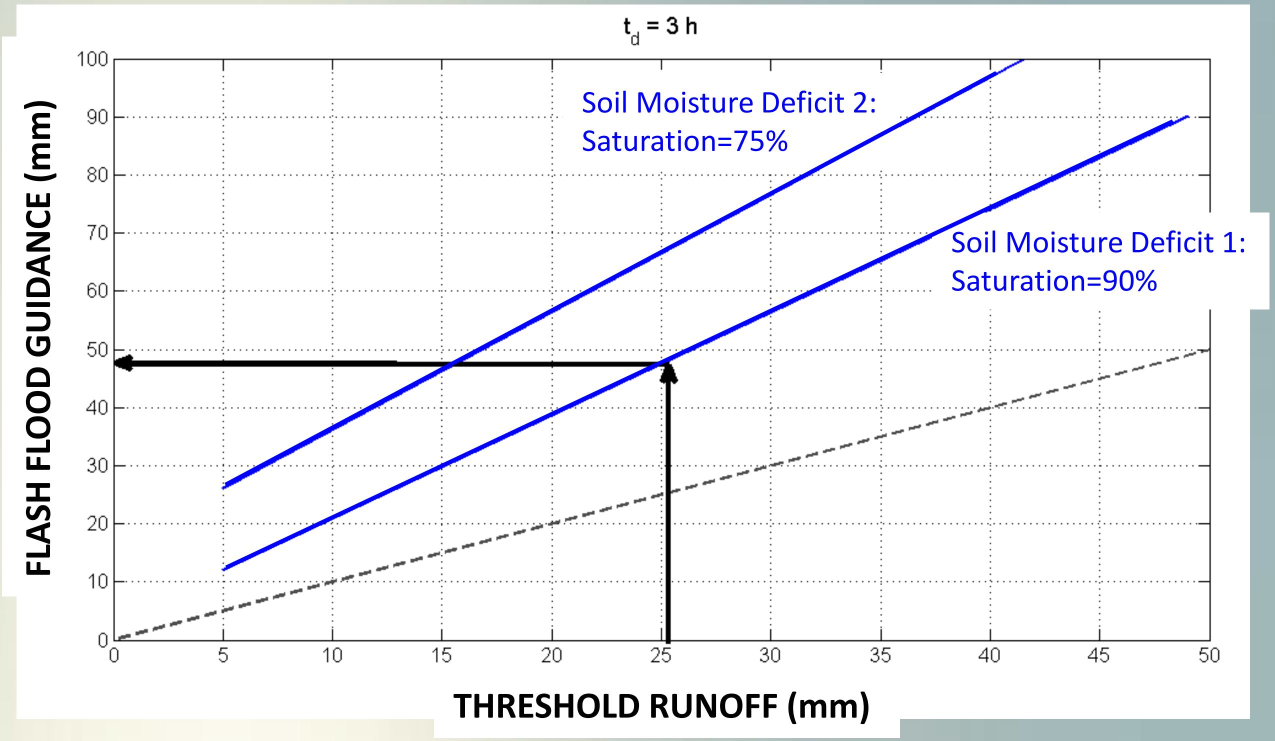
$$R = Q_p / \{q_{pR} A\}$$

Bankfull Flow:

$$Q_p = \frac{1}{n} B_b D_b^{5/3} S_c^{0.5}$$

Relationship of Threshold Runoff to FFG

*Threshold Runoff is a characteristic (non-varying) of the watershed. This is a **one-time** calculation for a given watershed. TR is computed for rainfall durations of 1-, 3-, and 6-hour to compute the 1-, 3-, and 6-hr FFG.*



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

Summary

- Delineation of flash flood watersheds for CARFFG based on GIS processing of 90-m SRTM DEM.
- ***Threshold Runoff*** (TR) is defined in a physically-based manner with hydrologic principles.
- TR employs *bankfull discharge* as flow associated with flooding conditions, and *geomorphologic unit hyd*rograph to obtain characteristic peak catchment response to uniform rainfall of given duration.
- TR formulated in terms of catchment properties (A,L), and cross-sectional dimension (B_b, D_b), which are estimated based on regional relationship with catchment properties.

References on Threshold Runoff Estimation

Carpenter, T.M., J.A. Sperfslage, K.P. Georgakakos, T. Sweeney and D.L. Fread, National threshold runoff estimation utilizing GIS in support of operational flash flood warning systems, *J. Hydrology*, 224: 21–44, 1999.

Ntelekos, A.A., Georgakakos, K.P., W.F. Krajewski, On the uncertainties of flash flood guidance, Toward probabilistic forecasting of flash floods, *J. Hydrometeorology*, 7: 896-915, 2006.

Rodriguez-Iturbe, I. and Valdes, J.B., The geomorphologic structure of hydrologic response, *Water Resources Research*, 15(6), 1409–1419, 1979.

Rodriguez-Iturbe, I., M. Gonzalez-Sanabria and R.L. Bras, A geomorphoclimatic theory of the instantaneous unit hydrograph, *Water Resources Research*, 18(4): 877-886, 1982.