# High Resolution Hydrography and Hydrologic Modeling

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# Hydrologic models are required for

- Flood forecasting
- Flood plain mapping
- Water quality assessments
- River restoration
- Setting environmental flows
- Land management

Grand challenge (NRC 2001): Better hydrologic forecasting that quantifies effects and consequences of land surface change on hydrologic processes and conditions

Floods and Droughts


Photos from Don Cline

# Hydrologic modeling

Advancing the capability for hydrologic prediction by developing models that take advantage of new information and process understanding enabled by new technology.

- A trend to more explicit physically based spatially distributed models
- Promise better prediction by better process representation

**and**

- Taking advantage of better more detailed data
- NHDPlusHR specifically, and High Resolution Topography in general are part of this trend

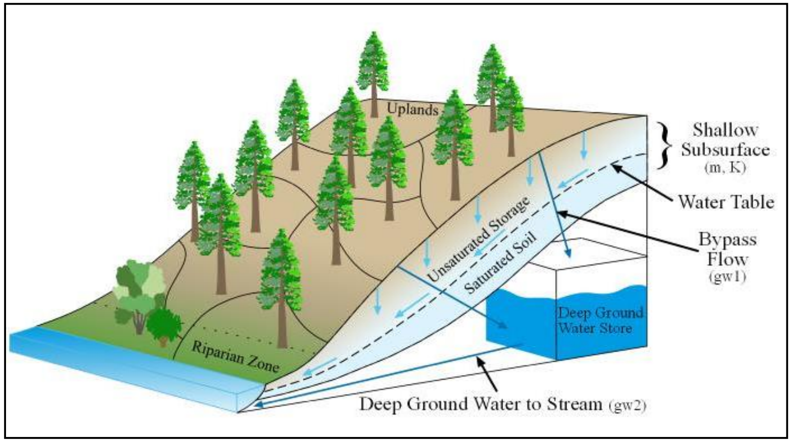
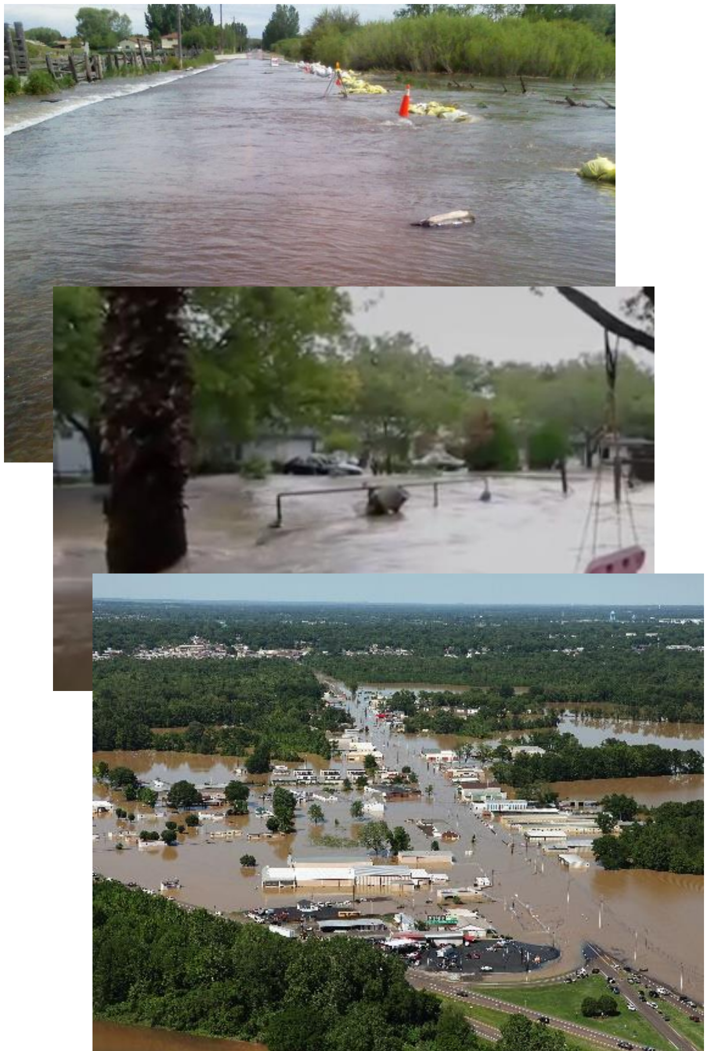
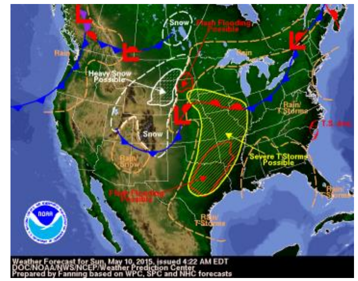



Image from Larry Band (RHESSys)

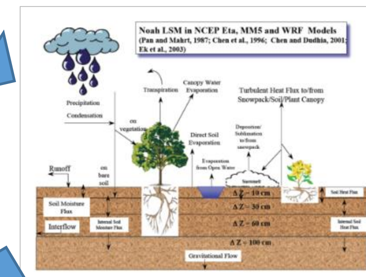
Two examples ...

# Flood plain mapping and flood forecasting as an example

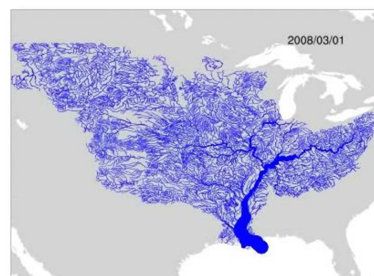




Weather




Hydrology




Hydraulics

Response

Images from David Maidment

# National Flood Interoperability Experiment (NFIE)

- Community partnership between government and academic researchers
- Includes a Summer Institute for students and faculty at the National Water Center, first in July 2015, again in 2016

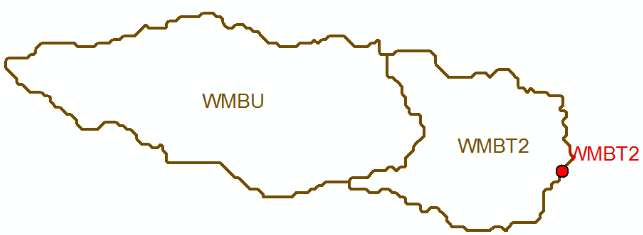
NSF CUAHSI UNIVERSITIES ALLIED FOR WATER RESEARCH NATIONAL WEATHER SERVICE USGS FEMA US Army Corps of Engineers®

From David Maidment

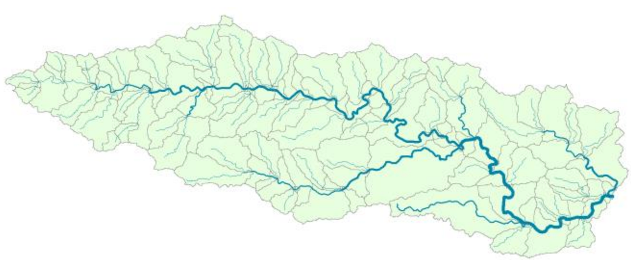
# Continental Hydrology

Blanco River at Wimberley

Two basins and one forecast point

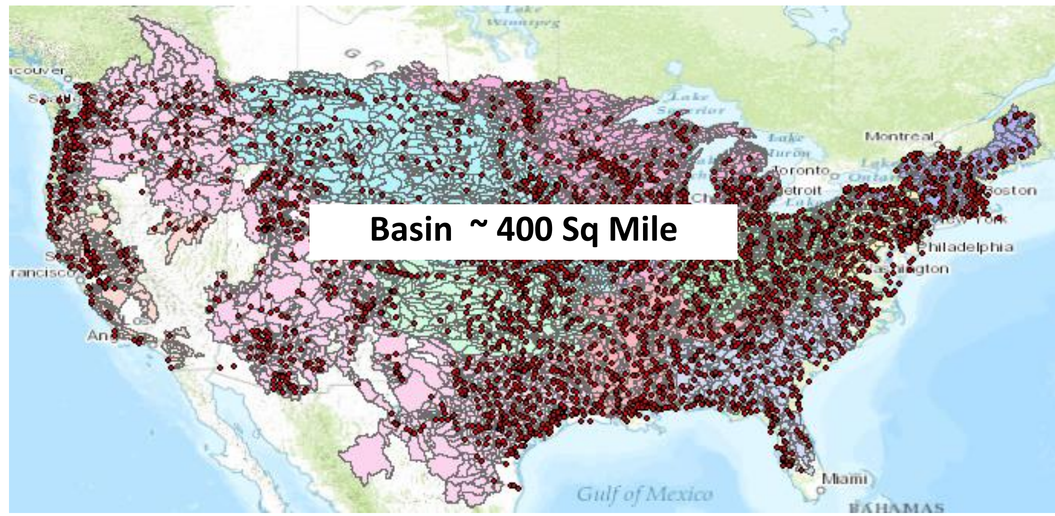



becomes

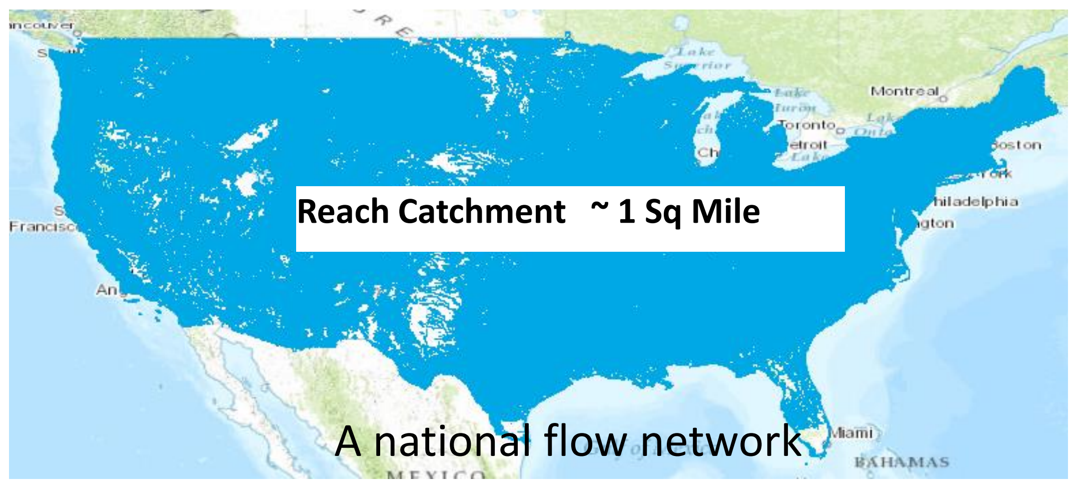


130 Catchments and Flowlines uniquely labelled

Current: 6600 basins and 3600 forecast points




NFIE: 2.7 million stream reaches and catchments from NHD Plus



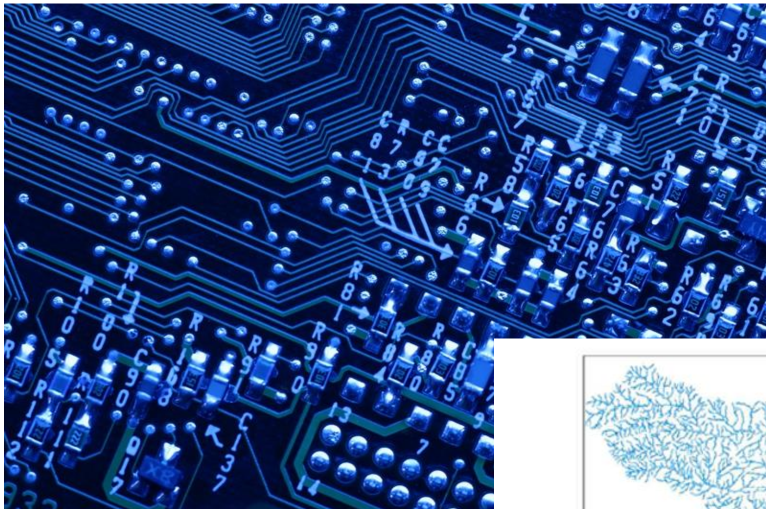

From David Maidment

# Data Requirements

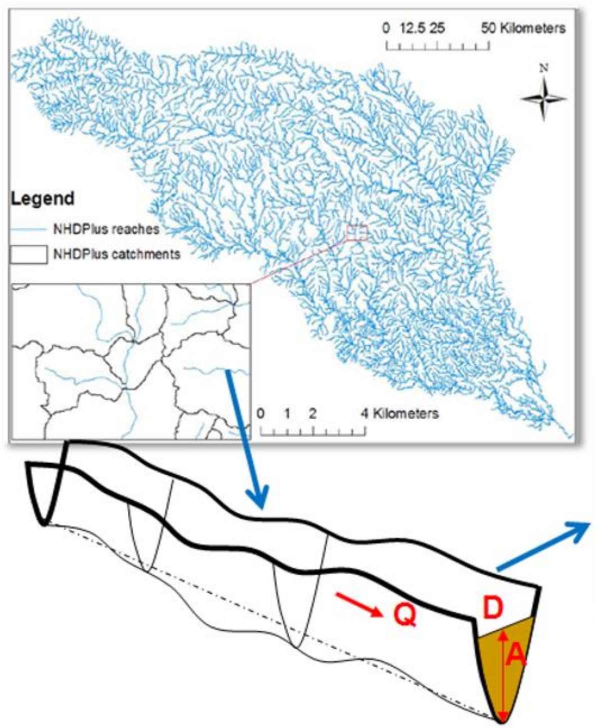
- WRF + NOAH-MP + RAPID/SPRNT produce flows at reach scale
- Need a way to obtain reach level hydraulic properties for inputs to these models
- Need a way to map from reach scale stage to flood inundation depth
- Exploit high resolution topography and 1:1 relationship between reaches (Hydro) and Catchments (Ele)

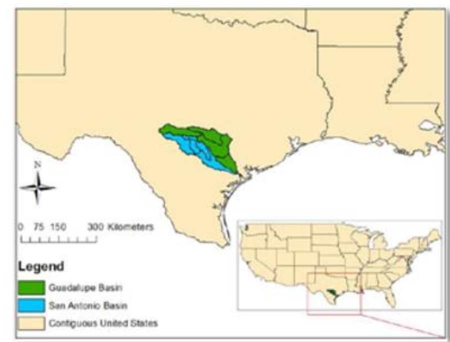
# SPRNT Model – flow and water depth on large networks

Open source code in Github



**Very Large Scale Integrated (VLSI) design of computer chips – solve 100 million equations each night to check on effects of design changes on electricity flow in chip**




**Dynamic wave routing**

**Compute water flow by analogy with electricity flow in chips**

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_l$$

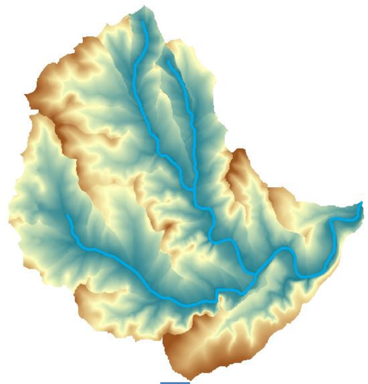
$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{\beta Q^2}{A}\right) = gA\left(S_0 - S_f\right) - gA\frac{\partial D}{\partial x}$$

St Venant Equations

Ben Hodges, Slide from David Maidment

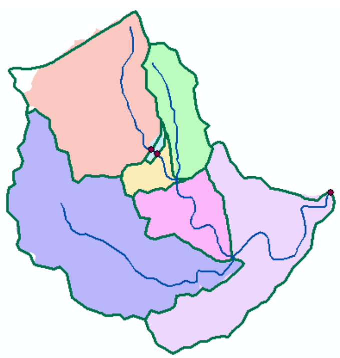
# Height above the nearest stream (HANS) flood mapping

**Height above stream**



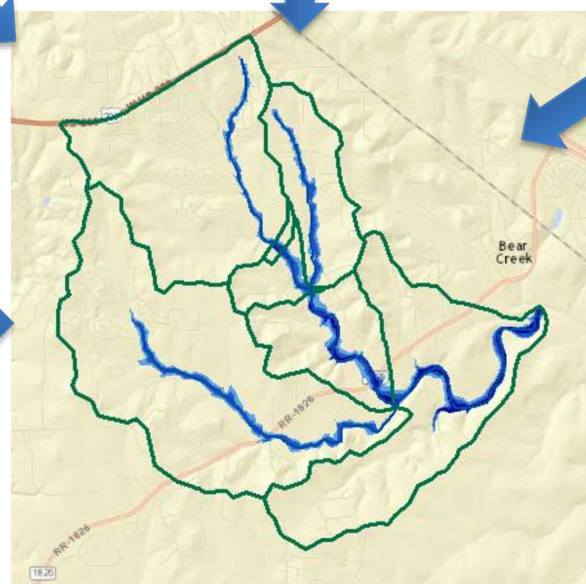
**Flowlines**

**Catchments**



**Reach Scale Flood Depth**

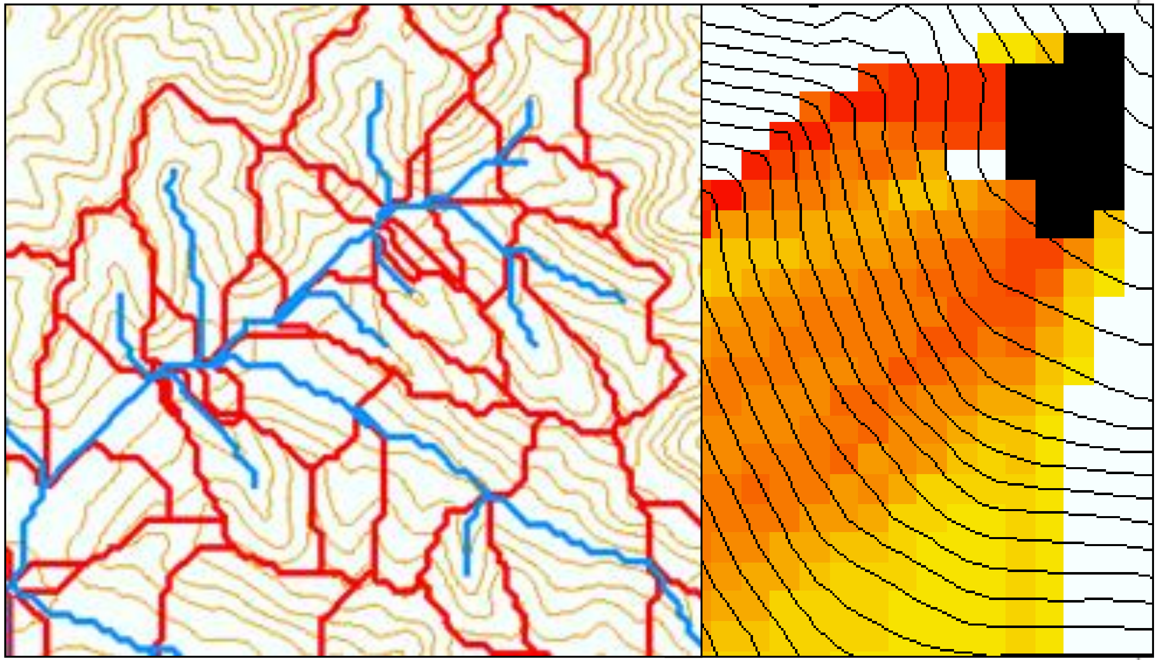
| Comid | Depth (ft) |
|---|---|
| 5781365 | 8 |
| 5781381 | 9 |
| 5781405 | 10 |
| 5781401 | 15 |
| 5781399 | 14 |
| 5781383 | 12 |
| 5781933 | 11 |



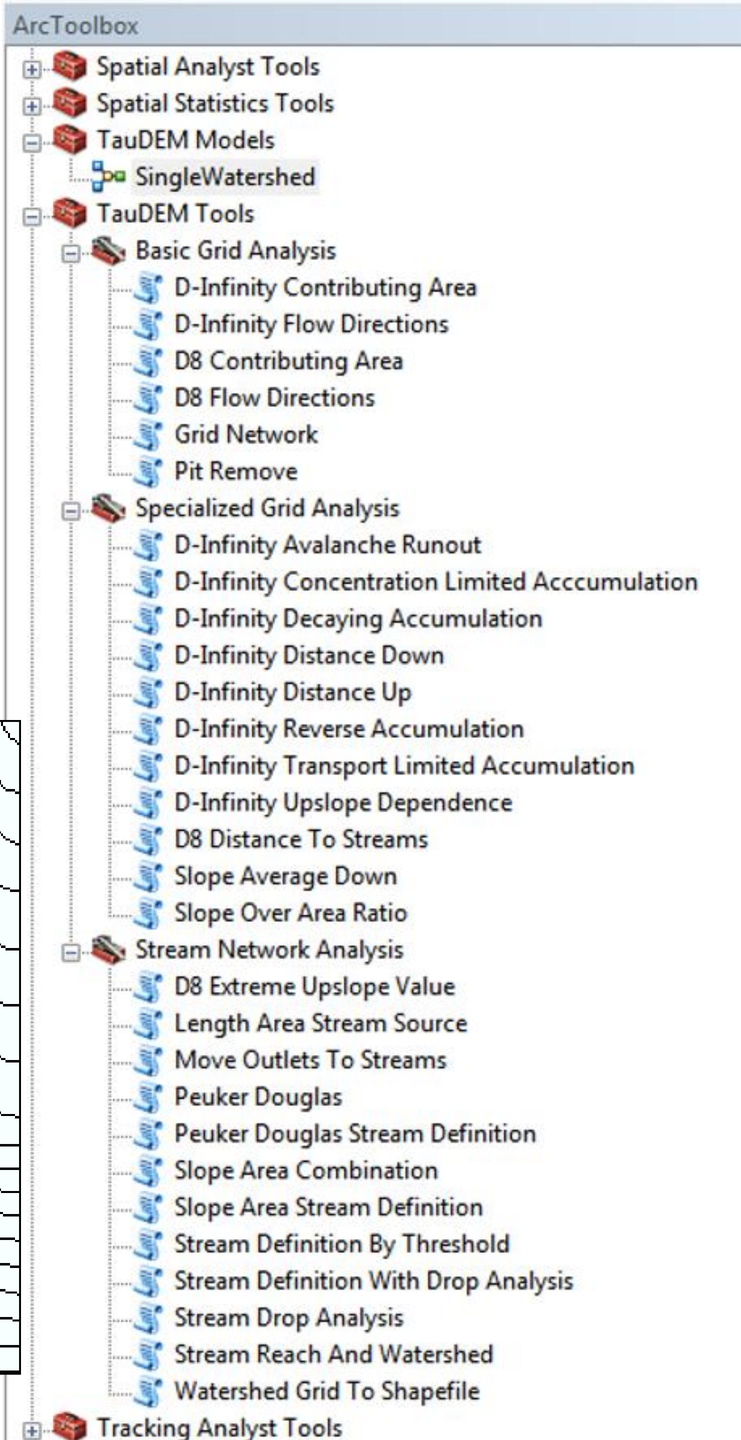

**Inundation map**

# TauDEM

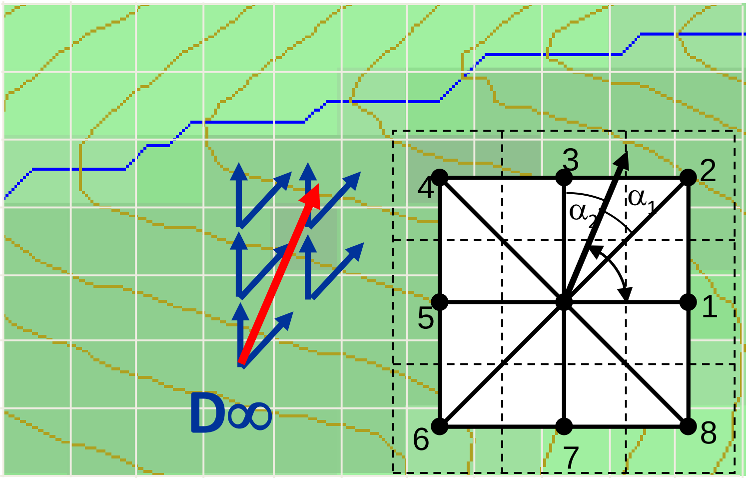
- Stream and watershed delineation
- Multiple flow direction flow field
- Calculation of flow based derivative surfaces
- MPI Parallel Implementation for speed up and large problems
- Open source platform independent C++ command line executables for each function
- Deployed as an ArcGIS Toolbox with python scripts that drive command line executables



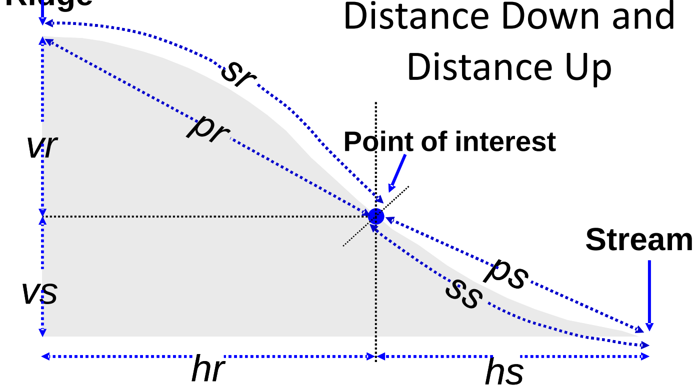
http://hydrology.usu.edu/taudem/



# TauDEM Vertical Distance to Stream

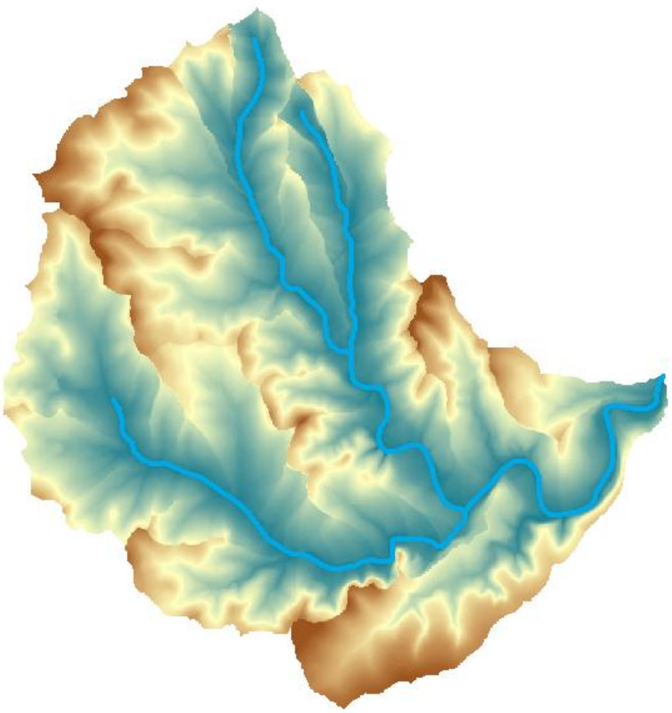



D∞ multiple direction flow field

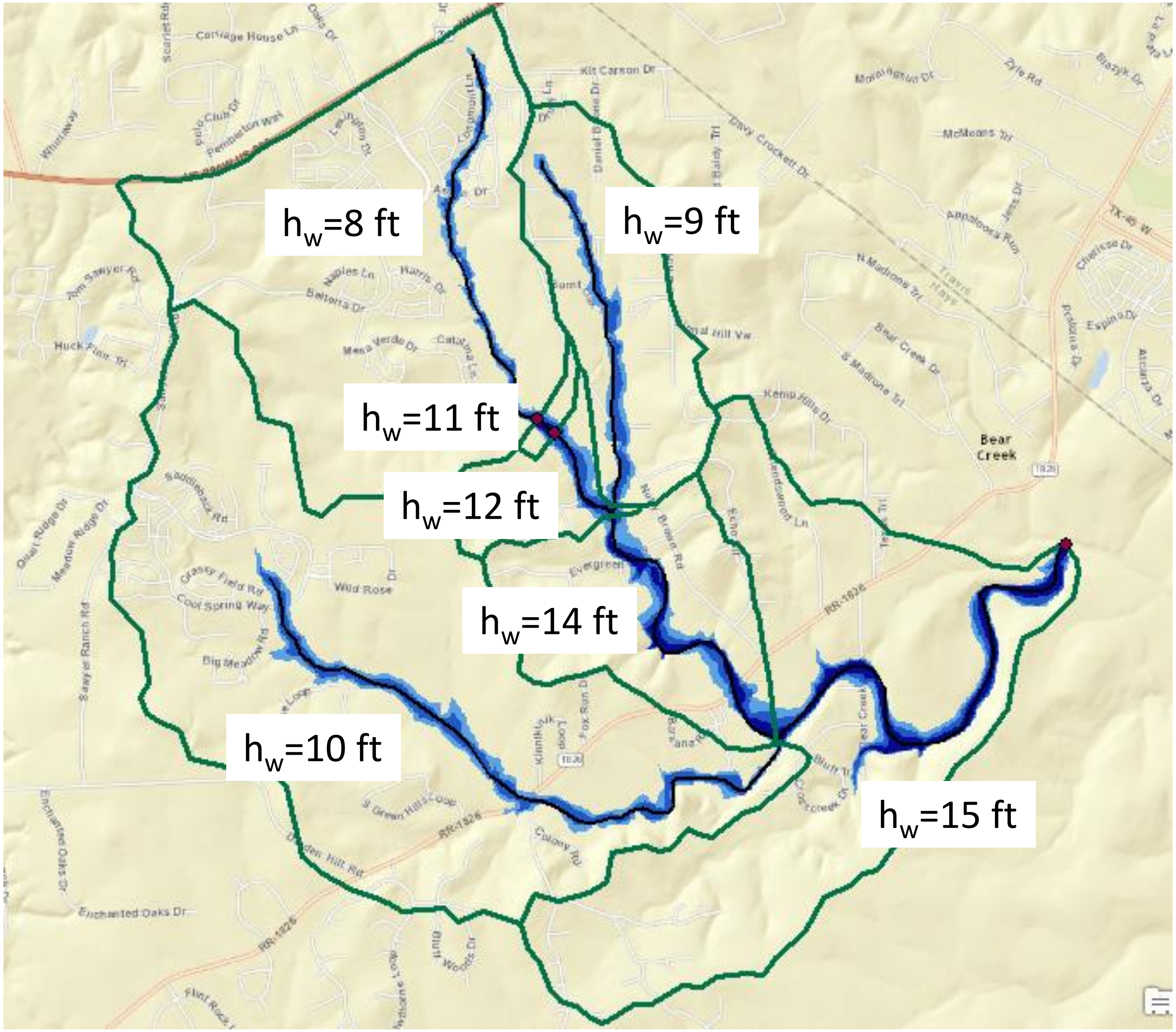



Distance Down and Distance Up

Distance to stream (vertical)



# Reach based height above nearest stream flood map example



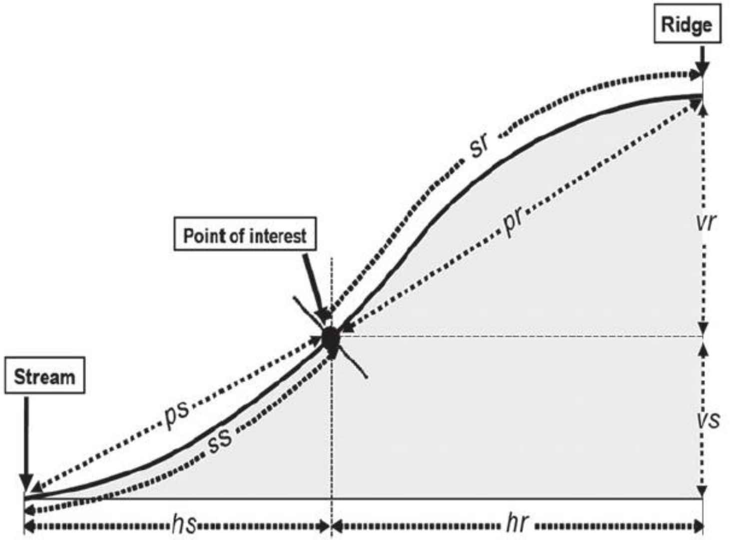
# Height above the nearest stream background

TauDEM (http://hydrology.usu.edu/taudem)

Tesfa, T. K., D. G. Tarboton, D. W. Watson, K. A. T. Schreuders, M. E. Baker and R. M. Wallace, (2011), "Extraction of hydrological proximity measures from DEMs using parallel processing," Environmental Modelling & Software, 26(12): 1696-1709, http://dx.doi.org/10.1016/j.envsoft.2011.07.018.

Nobre, A. D., L. A. Cuartas, M. Hodnett, C. D. Rennó, G. Rodrigues, A. Silveira, M. Waterloo and S. Saleska, (2011), "Height Above the Nearest Drainage – a hydrologically relevant new terrain model," Journal of Hydrology, 404(1–2): 13-29, http://dx.doi.org/10.1016/j.jhydrol.2011.03.051.

Nobre, A. D., L. A. Cuartas, M. R. Momo, D. L. Severo, A. Pinheiro and C. A. Nobre, (2015), "HAND contour: a new proxy predictor of inundation extent," Hydrological Processes, http://dx.doi.org/10.1002/hyp.10581.



# Terrain based derivation of "reach scale" hydraulic properties

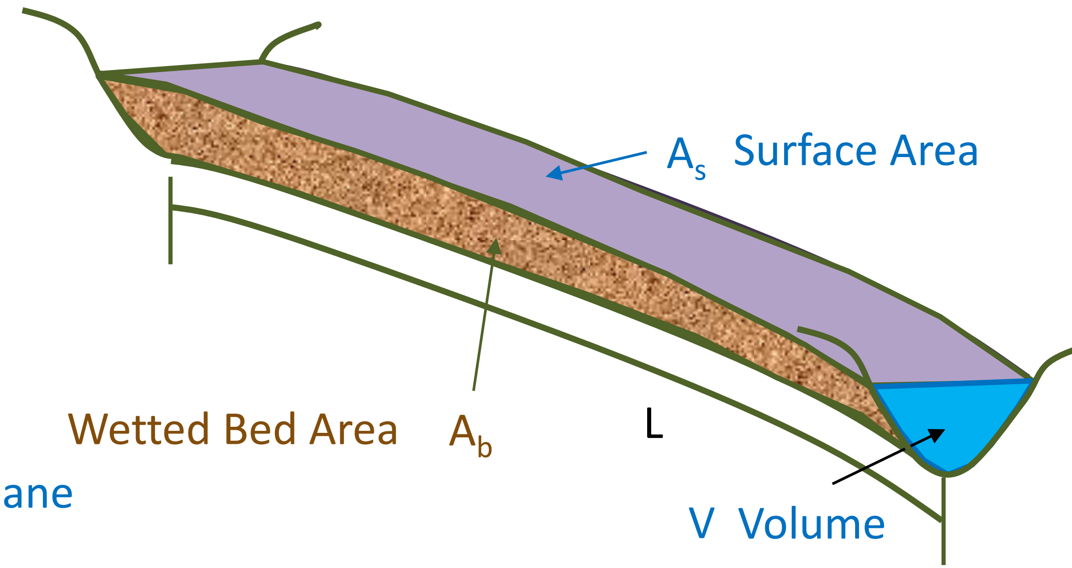
For each Catchment
For each height h
Identify cells where $h_s < h$

Single Cell Plan Area $A_c = dx * dy$

Surface area $A_s = \sum A_c$

Bed Area $A_b = \sum A_c \sqrt{1 + slp^2}$

Approximates each cell as sloping plane



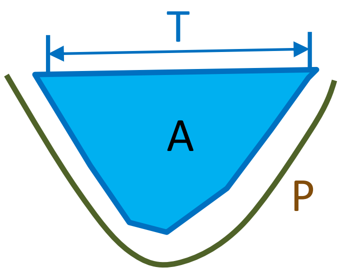

Volume $V = \sum A_c (h - h_s)$

$A = \dfrac{V}{L}$ Cross Section Area

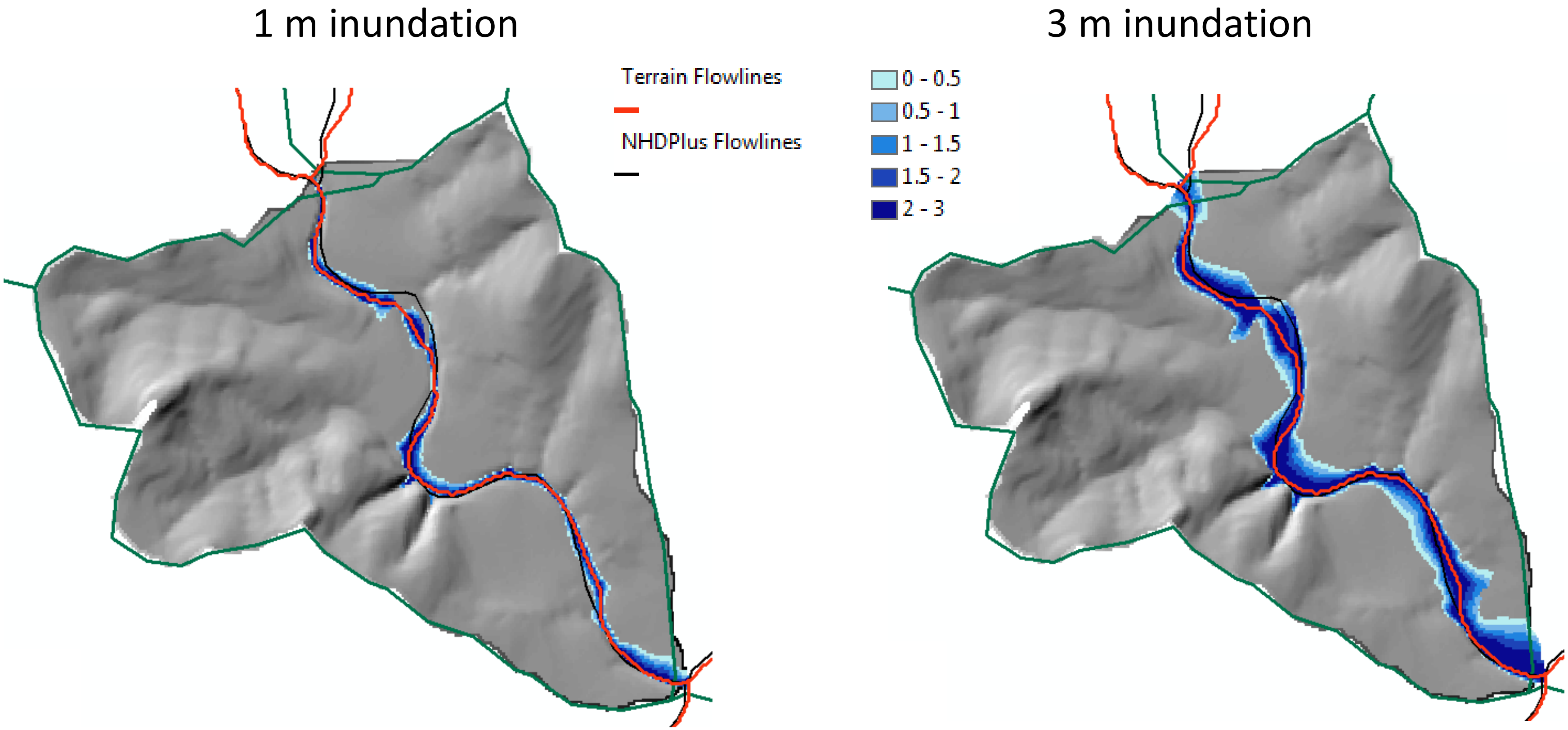
$P = \dfrac{A_b}{L}$ Wetted Perimeter

$T = \dfrac{A_s}{L}$ Top Width

$R = \dfrac{A}{P}$ Hydraulic Radius

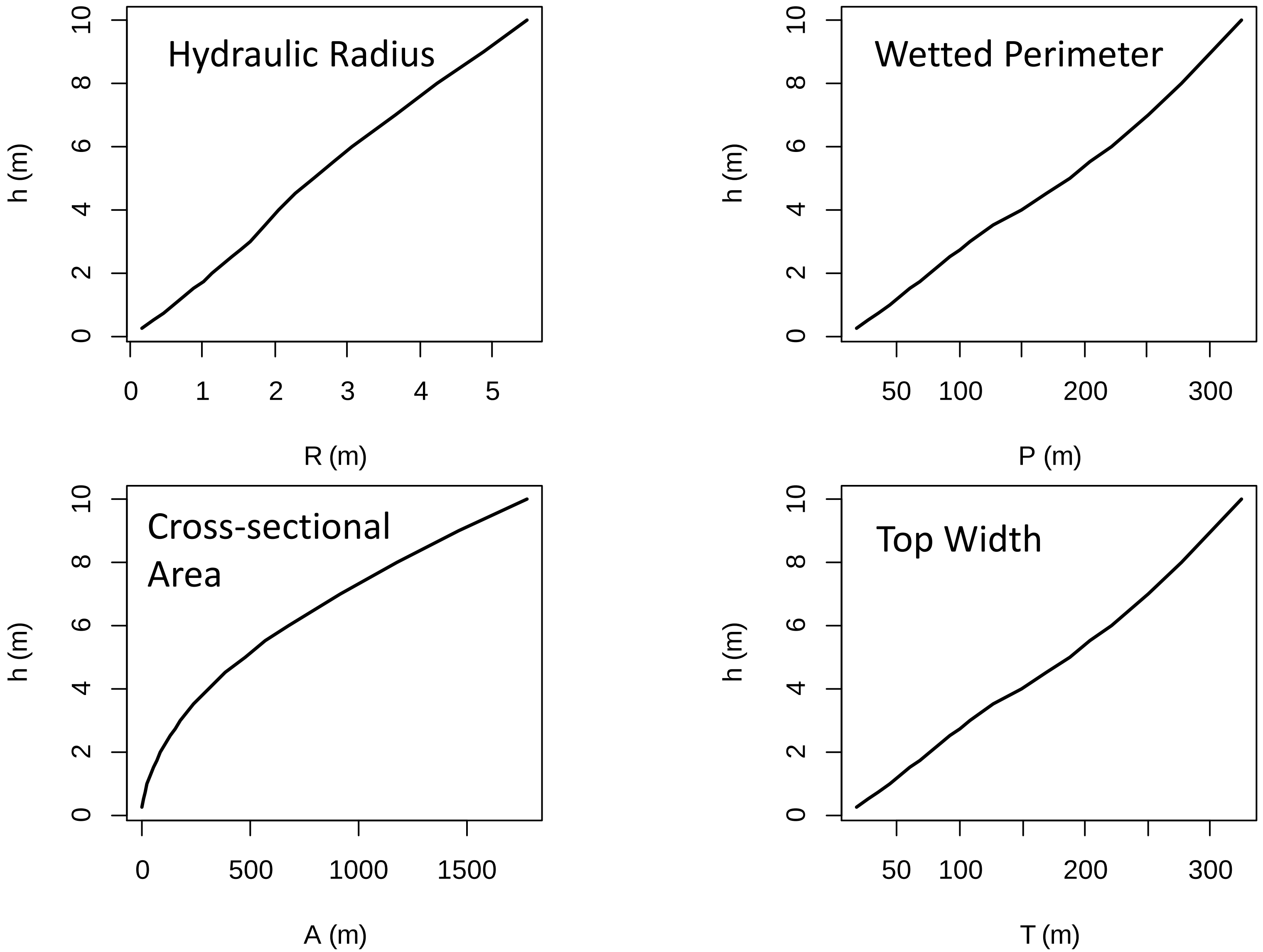


# Reach Hydraulic Properties Example



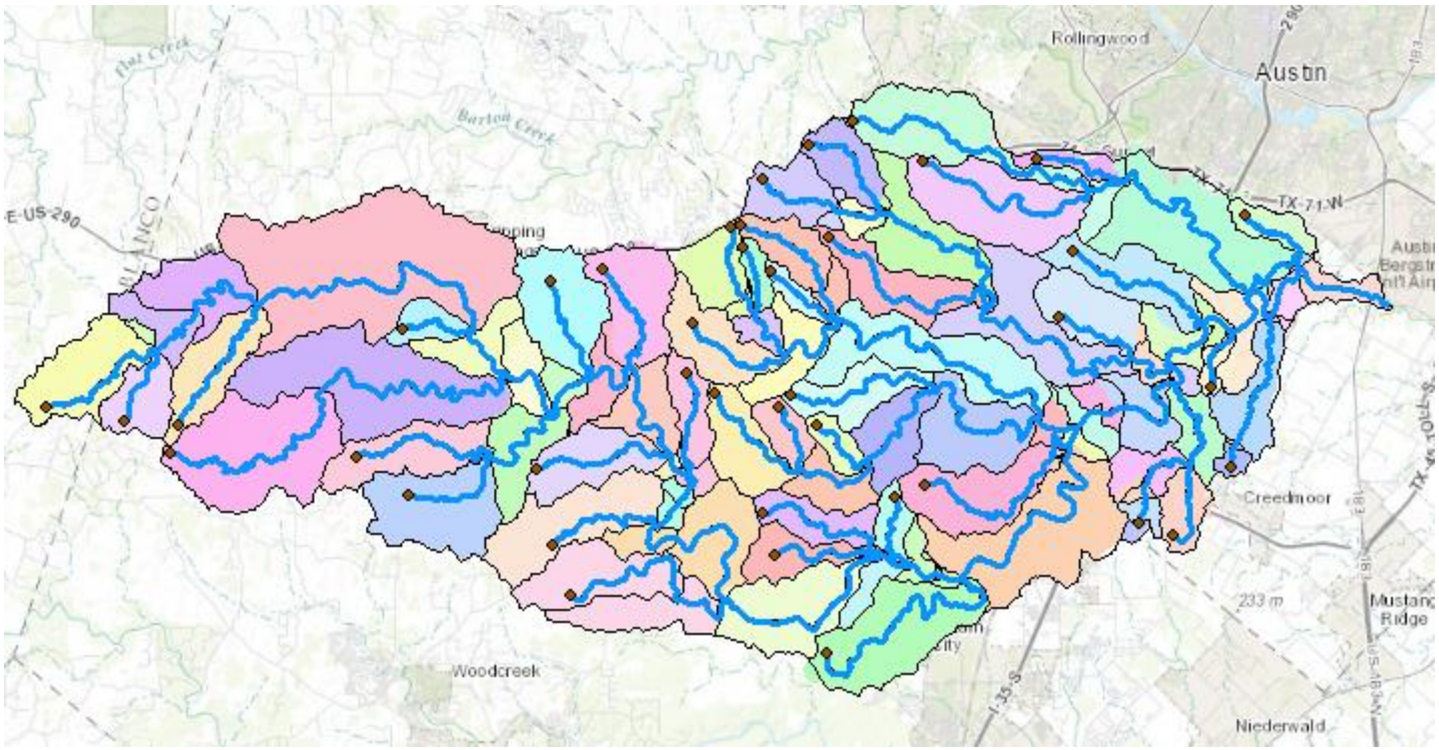

| Height (m) | $A_s$ (m²) | Vol (m³) | $A_b$ | L (m) | A=V/L (m²) | $P=A_b/L$ (m) | $T=A_s/L$ (m) | R=A/P (m) |
|---|---|---|---|---|---|---|---|---|
| 1 | 129878 | 79466 | 129948 | 2975 | 26.7 | 43.7 | 43.7 | 0.612 |
| 3 | 319877 | 530378 | 320414 | 2975 | 178.3 | 107.7 | 107.5 | 1.655 |

# Terrain Approximated Reach Average Hydraulic Properties



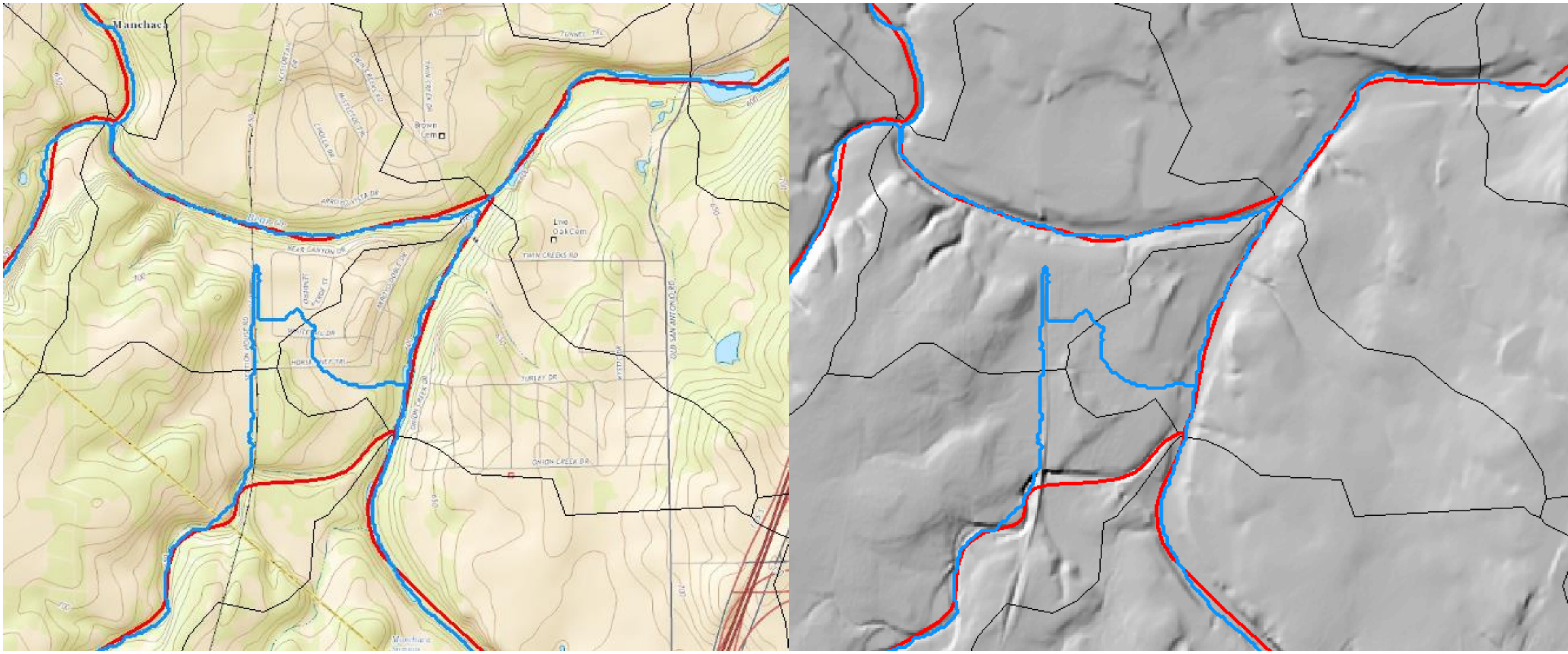

Need to evaluate in Hydraulic Model (e.g. SPRNT)

# Terrain Catchments reconciled with NHDPlus by "seeding" with stream sources




- The approach is predicated on a DEM stream raster consistent with DEM and NHDPlus reaches
- Here stream raster computed using weighted flow accumulation starting from source points

# DEM Flowlines challenged by road barriers



Need for hydrography conditioned DEM

DEM Flowlines

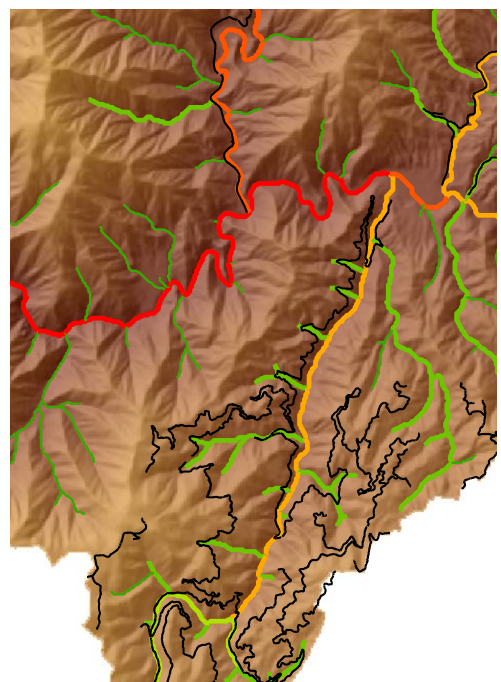
NHDPlus Flowlines

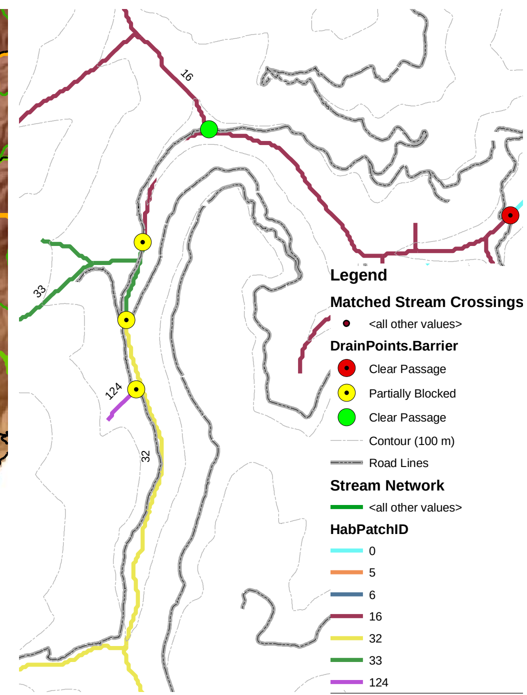
# Impact on streams from road erosion as an example

## USFS Geomorphologic Road Analysis Inventory Program (GRAIP)

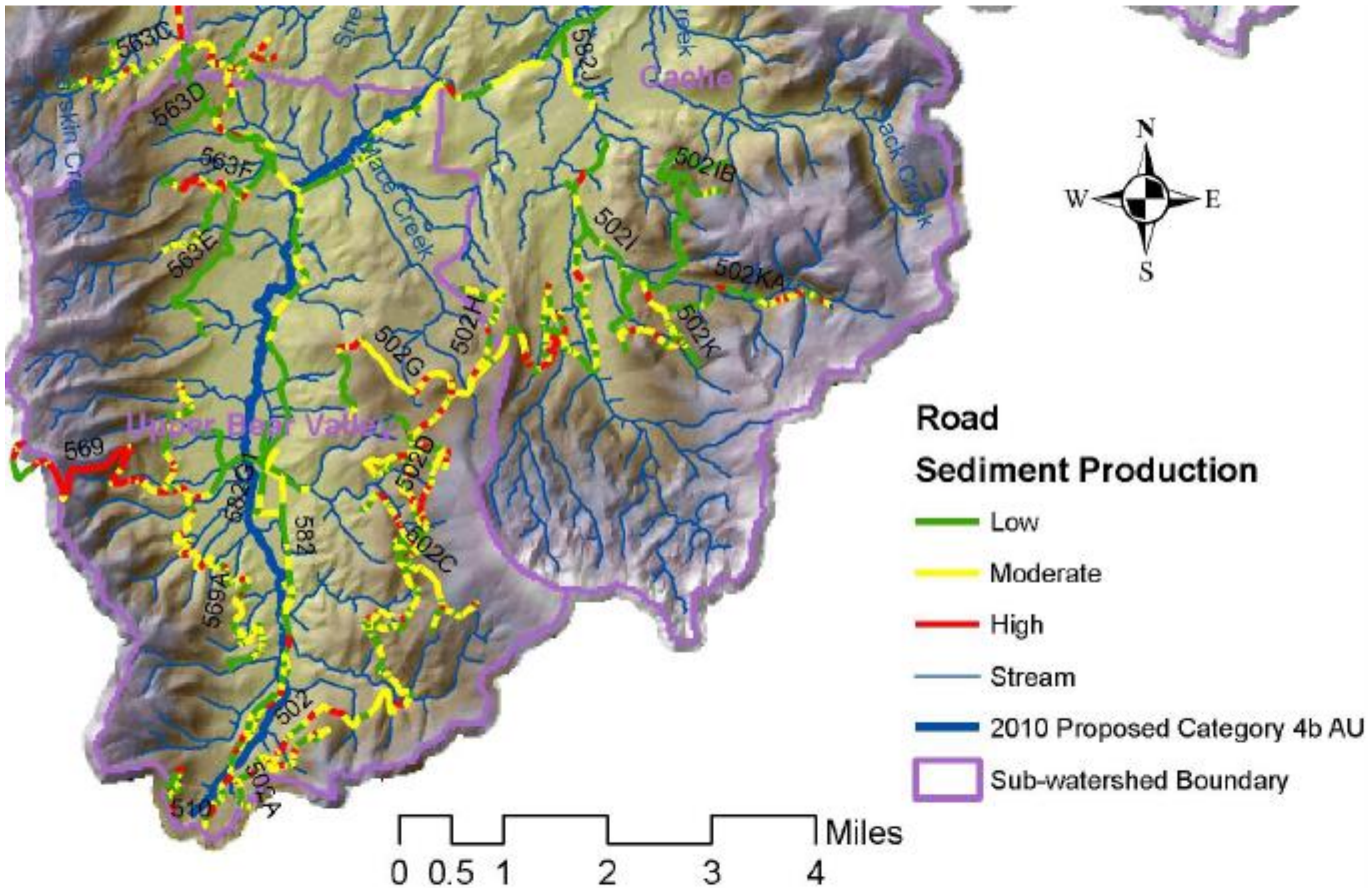
- Detailed hydrography network
- DEM derived terrain flow field
- Field surveys of road and drain point conditions
- Aggregation of sediment from roads to drain points to streams
- Road to stream connectivity
- Stream habitat fragmentation

http://www.fs.fed.us/GRAIP/



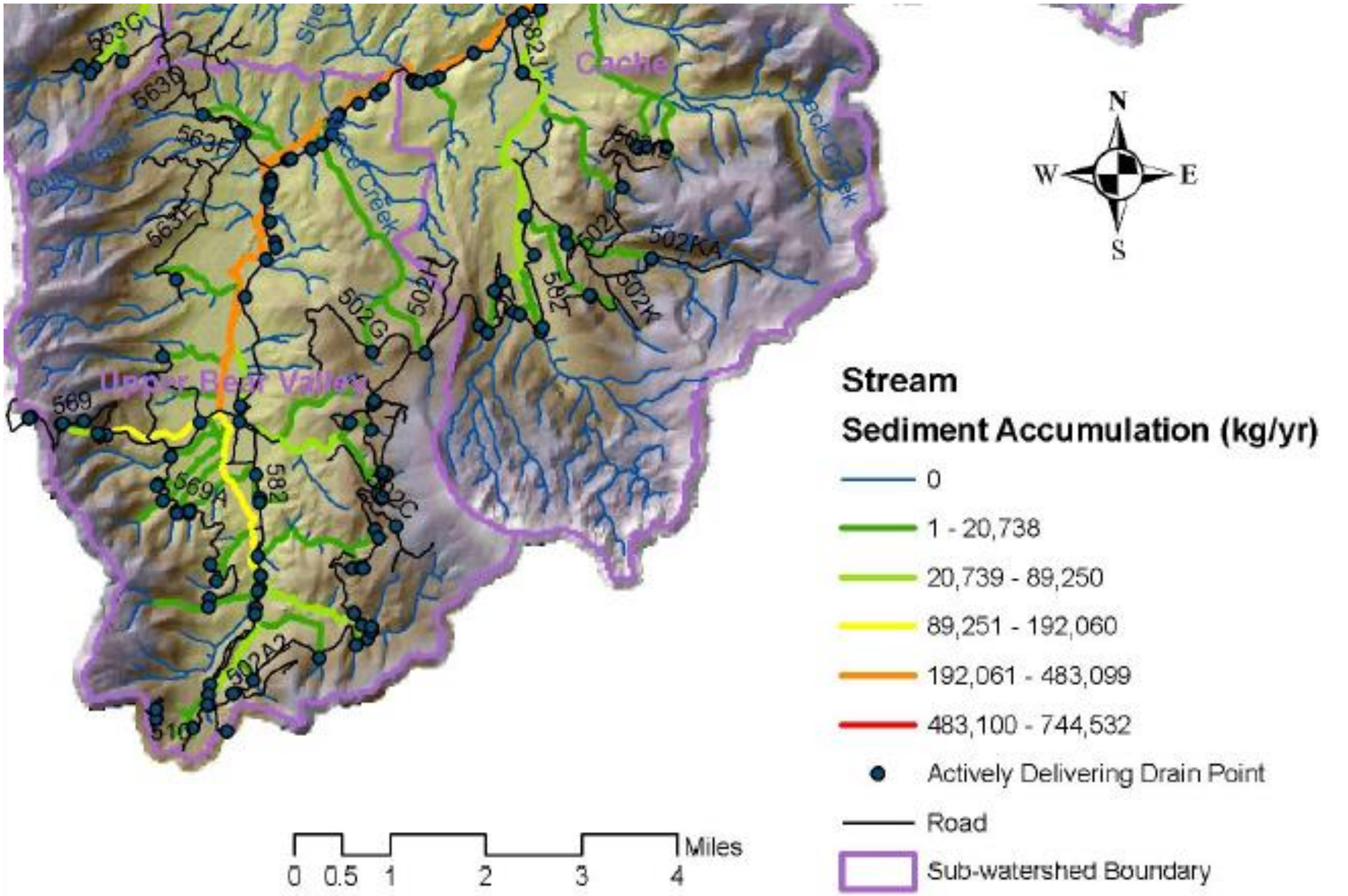


# Road Sediment Production



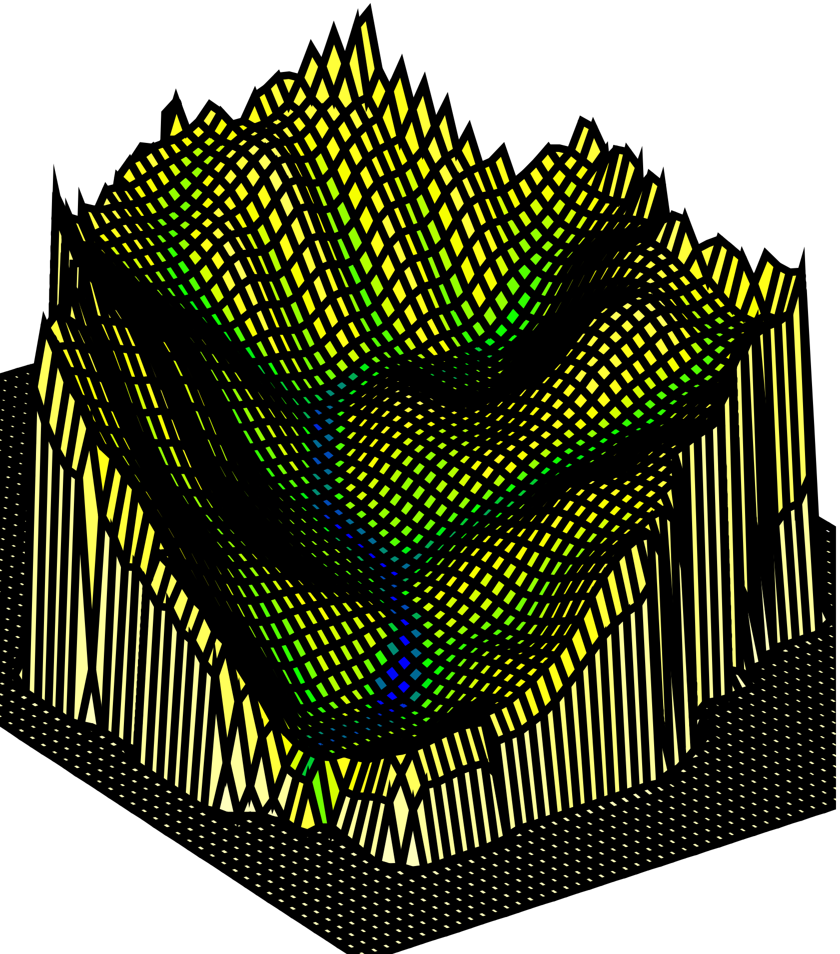

http://www.fs.fed.us/GRAIP/downloads/case_studies/BearValley2010FinalReport0210.pdf

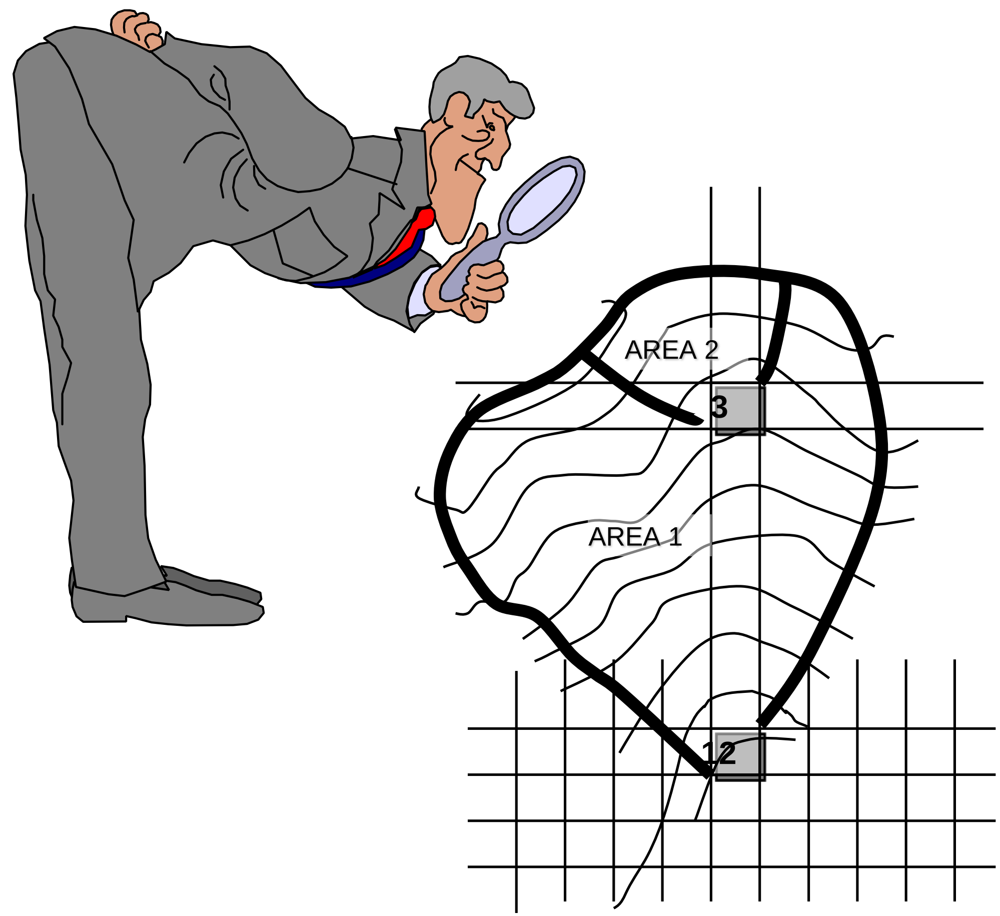
# Stream Sediment Accumulation




http://www.fs.fed.us/GRAIP/downloads/case_studies/BearValley2010FinalReport0210.pdf

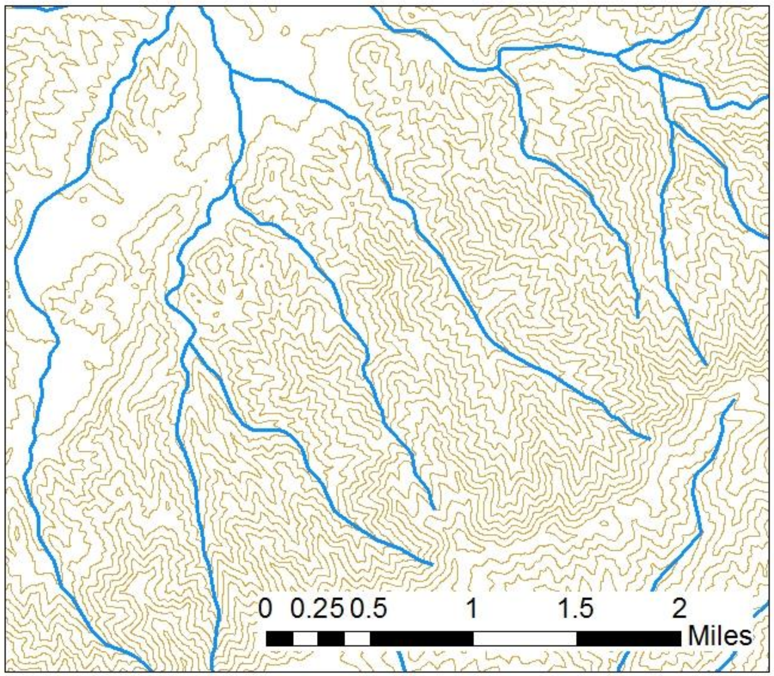
# Where do streams begin?



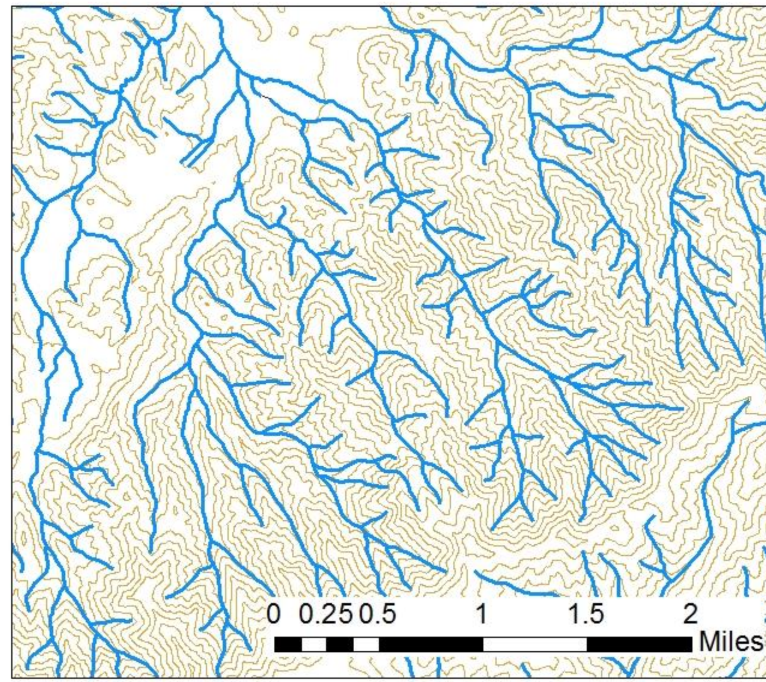


# Increasing Hydrography Resolution

NHD Plus V 2.0




NHD = NHDPlus HR




40 m contour interval

Illustration from near Andrews in SW North Carolina

# Alternative, but equally valid views

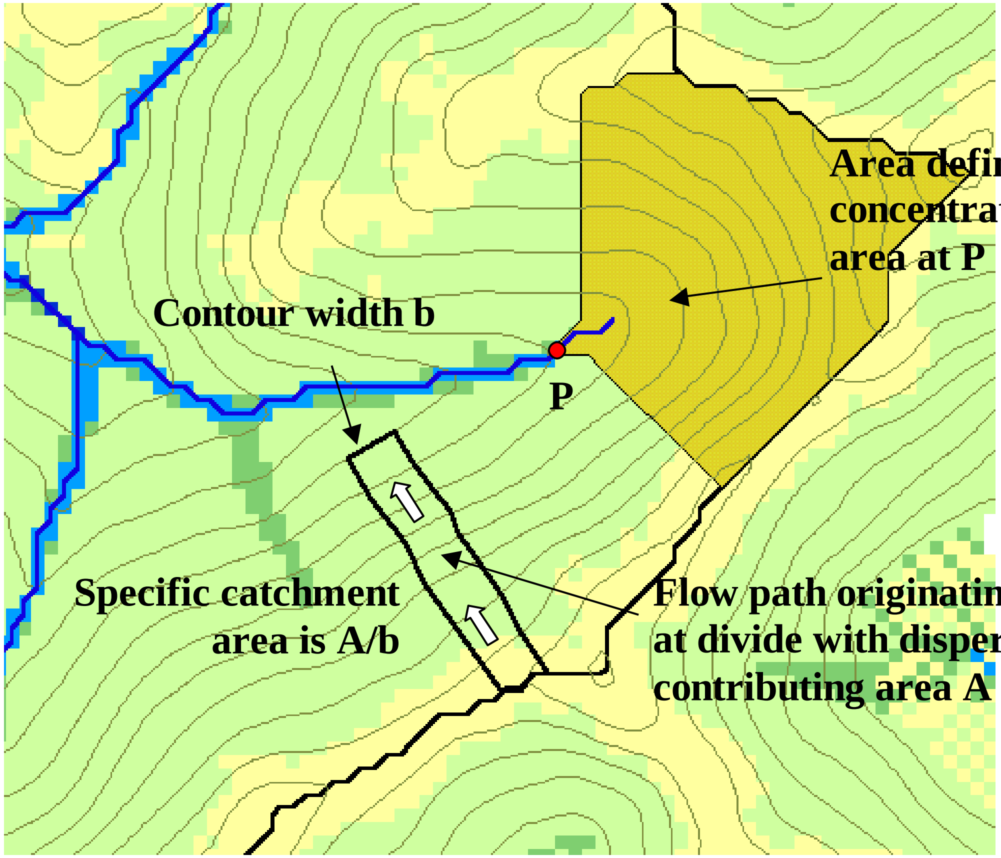
*Although the river and hill-side waste do not resemble each other at first sight, they are only the extreme members of a continuous series, and when this generalization is appreciated, one may fairly extend the "river" all over its basin and up to its very divides. Ordinarily treated, the river is like the veins of a leaf; broadly viewed it is like the entire leaf.*

Davis, W. M., (1899), "The geographical cycle," Geogr. J., 14: 481-504 (reproduced in Geographical Essays, edited by W. M. Davis, Ginn, Boston, 1909).

*landscape dissection into distinct valleys is limited by a threshold of channelization that sets a finite scale to the landscape.*

Montgomery, D. R. and W. E. Dietrich, (1992), "Channel Initiation and the Problem of Landscape Scale," Science, 255: 826-830.

# Hydrologic processes are different on hillslopes and in channels. It is important to recognize this and account for this in the delineation of streams.

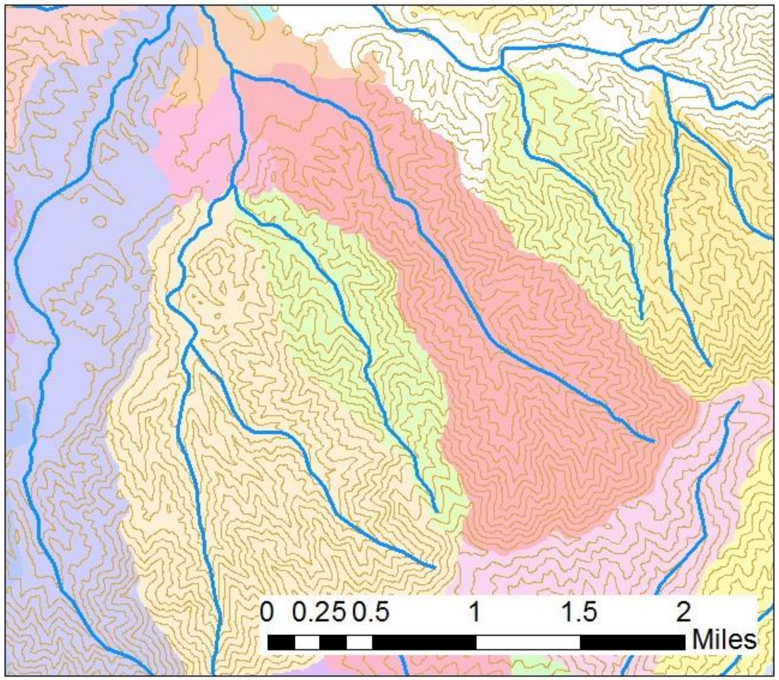



Where do streams begin?

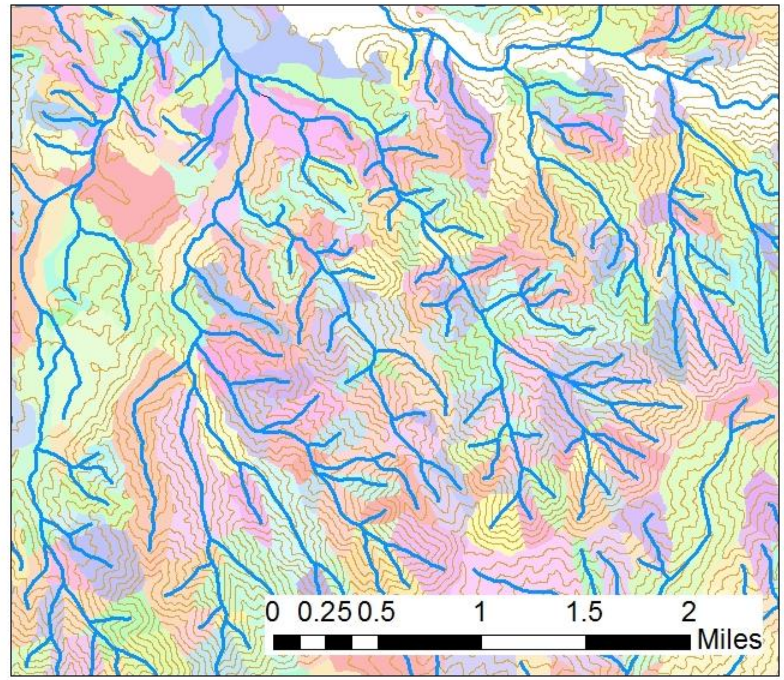
Drainage area can be concentrated or dispersed (specific catchment area) representing concentrated or dispersed flow.

# Reach Catchments

NHD Plus V 2.0




NHD = NHDPlus HR

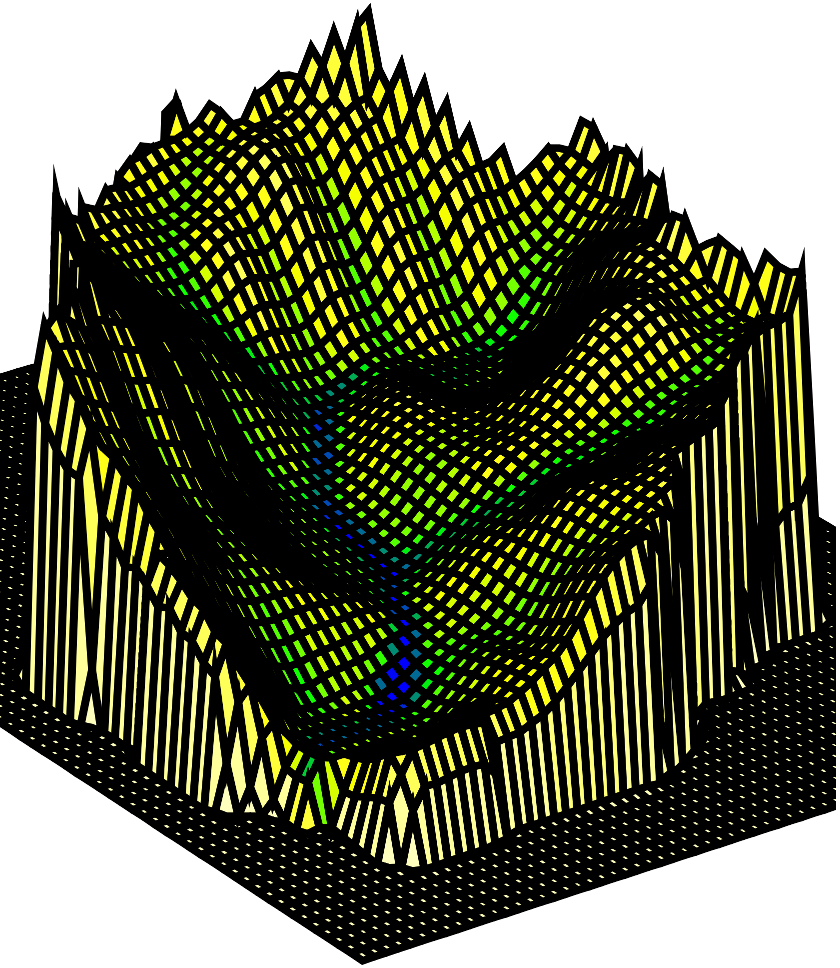


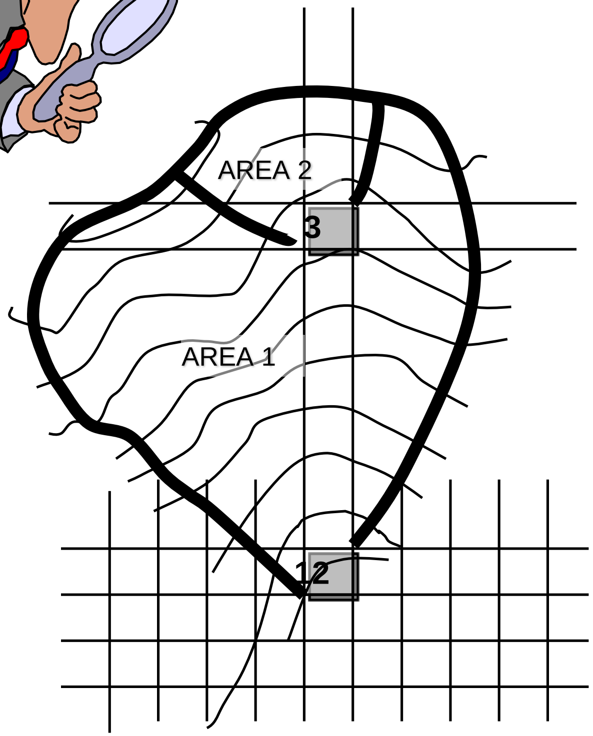

Hillslope and channel lengths across these different scale representations are different and will manifest differently in process simulations

# Conclusions

- Elevation and Hydrography should just be viewed as parts of an integrated representation for the terrestrial environment
- Integrated use demands consistency between elevation and hydrography information at high resolution
- The height above nearest stream approach suggested as way to rapidly approximate real time flood inundation and approximate reach scale hydraulic properties
- Model representations must recognize scale effects

# Are there any questions ?



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