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Importance of Spatial Distribution in Small Watersheds

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I was here before ...

- 1982 – 1983: Dip. Hydraulic Engineering
- 1987 – 1988: M. Sc. Hydraulic Engineering

Definitions

- ***Spatial distribution***: location of land uses, soil types and precipitation within the watershed.

- ***Small watershed***: a drainage area with a time of concentration shorter than the model's computational time step.

> *Rule of thumb: If it is larger than 3,500 km^2, it will take more than one day to drain; if it is smaller than 350 km^2, it will take less than one day to drain.*

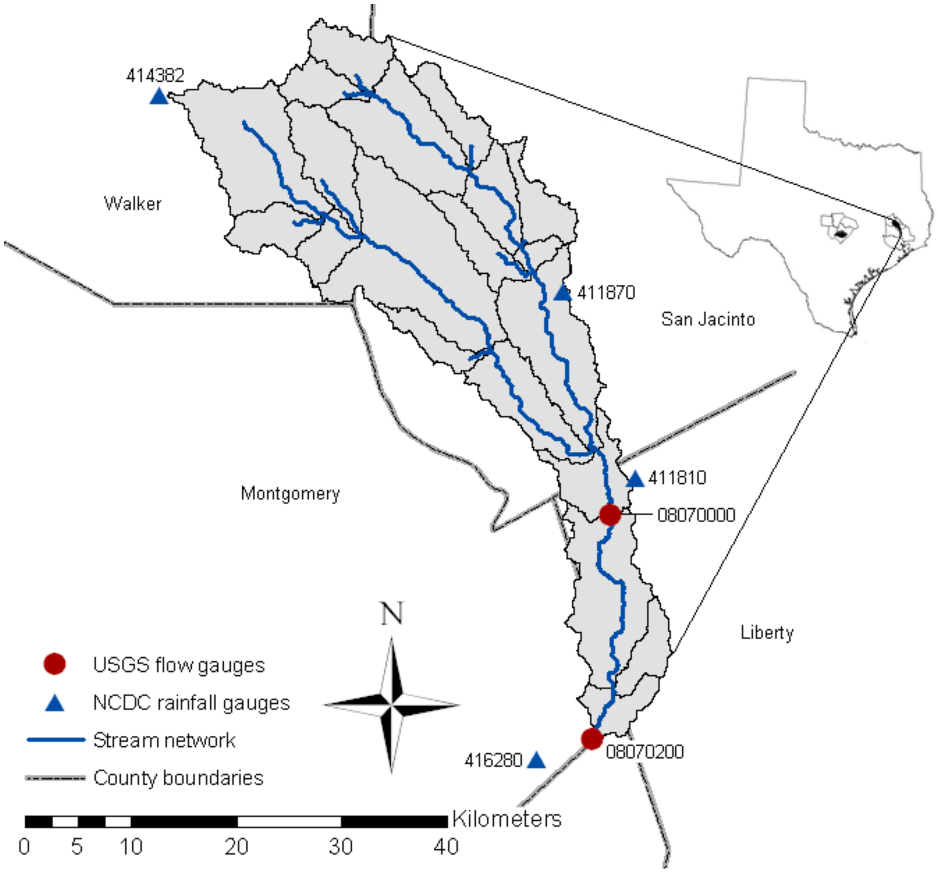
- Other spatial issues not addressed here: ***data resolution*** and ***subbasin size / network density***.

Research Question

- **Is the spatial distribution really important in small watersheds?**
- Doesn't all surface runoff drain within one time step? Do we need a model to capture that? Does it matter where the runoff was generated?
- Is the baseflow significant in small watersheds?
- Do we really need to know where things take place in a small watersheds?

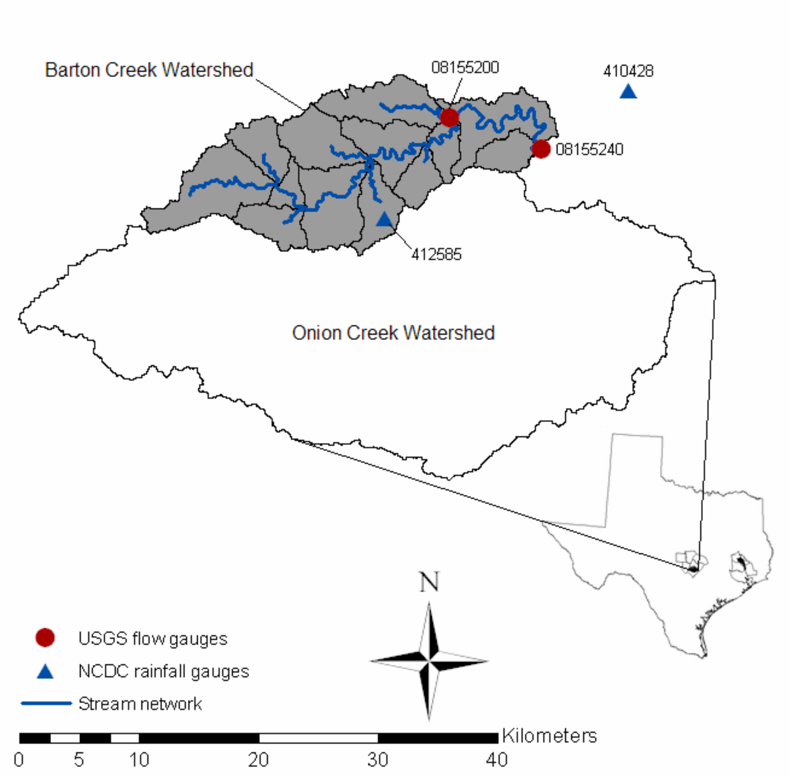
San Jacinto River Watershed

- **East Fork of the San Jacinto River watershed.**
  - Area: 1,005 km^2
  - Land use: 72% forest and 23% rangeland.
  - Soil texture: 62% sand.
  - Precipitation: 1400 mm/yr.
  - Number of subbasins: 20



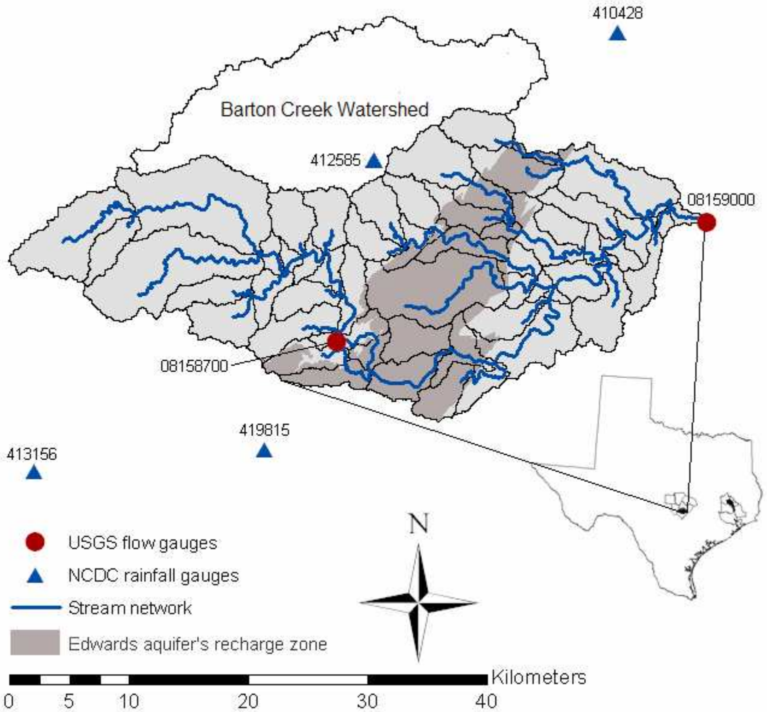
Barton Creek Watershed

- **Barton Creek watershed.**
  - Area: 277 km^2
  - Land use: 51% forest and 42% rangeland.
  - Soil texture: even (sand/silt/clay).
  - Precipitation: 1020 mm/yr.
  - Number of subbasins: 16



Onion Creek Watershed

- **Onion Creek watershed.**
  - Area: 831 km^2
  - Land use: 45% forest and 42% rangeland.
  - Soil texture: even (sand/silt/clay).
  - Precipitation: 1020 mm/yr.
  - Number of subbasins: 61



Hydrologic and Terrain Data

- **Land use/cover**: USGS National Land Cover Dataset (NLCD).
- **Soil type**: NRCS State Soil Geographic Dataset (STATSGO).
- **Precipitation**: NWS-NCDC rain gauges.
- **Topography**: USGS National Elevation Dataset (NED).
- **Flow**: USGS flow gauges.

Watershed Models

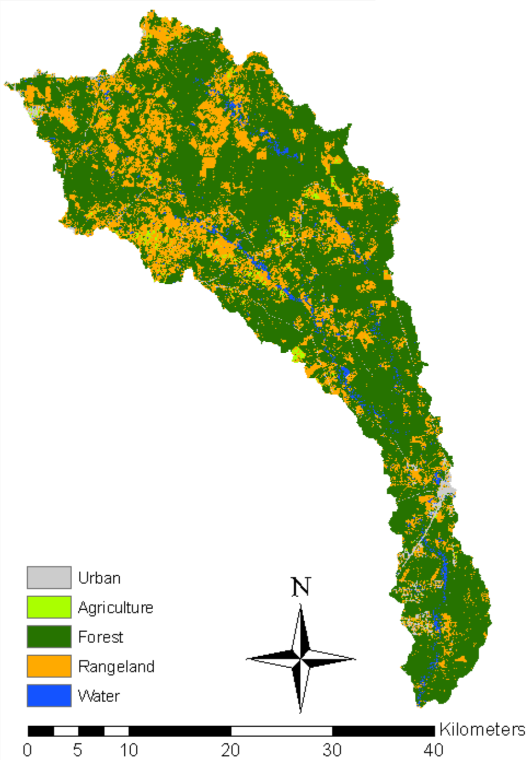
- A total of 54 models were developed as unique combinations of:
  - three watersheds: East Fork of San Jacinto Rv., Barton Ck. and Onion Ck;
  - three land use distributions: original, random and single;
  - three soil type distributions: original, random and single;
  - two precipitation distributions: multiple and single rain gauge.

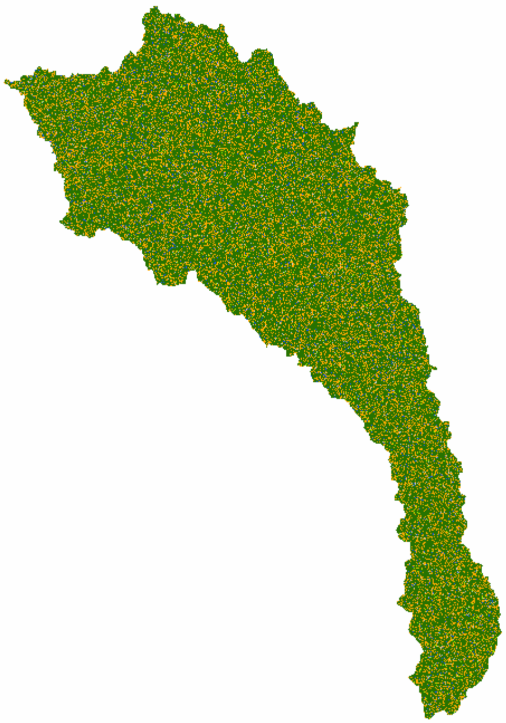
$$3 \times 3 \times 3 \times 2 = 54$$

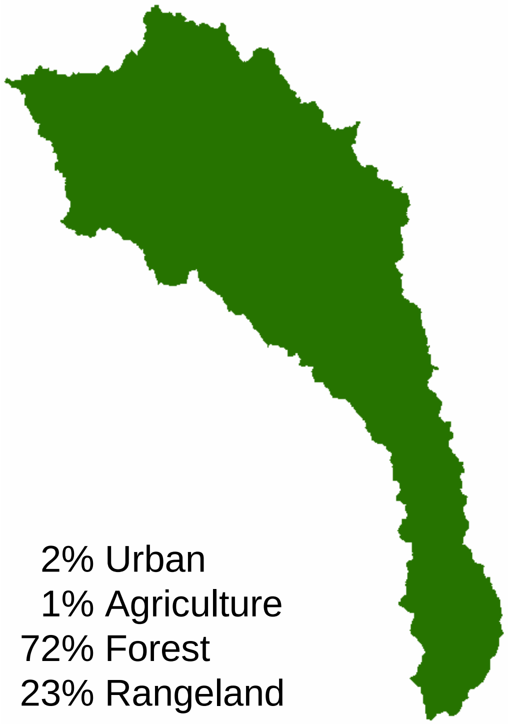
Simulation Periods

- Calibration period
  - 2 years of stabilization: January 1, 1989 to December 31, 1990
  - 4 years of simulation: January 1, 1991 to December 1994
- Validation period
  - 2 years of stabilization: January 1, 1995 to December 31, 1996
  - 4 years of simulation: January 1, 1997 to December 31, 2000

East Fork San Jacinto River





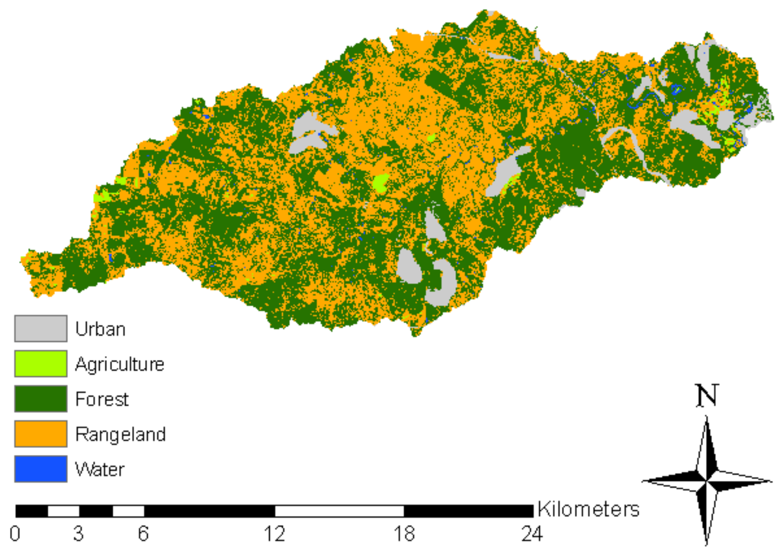


2% Urban
1% Agriculture
72% Forest
23% Rangeland
2% Water

Land use / cover

Barton Creek

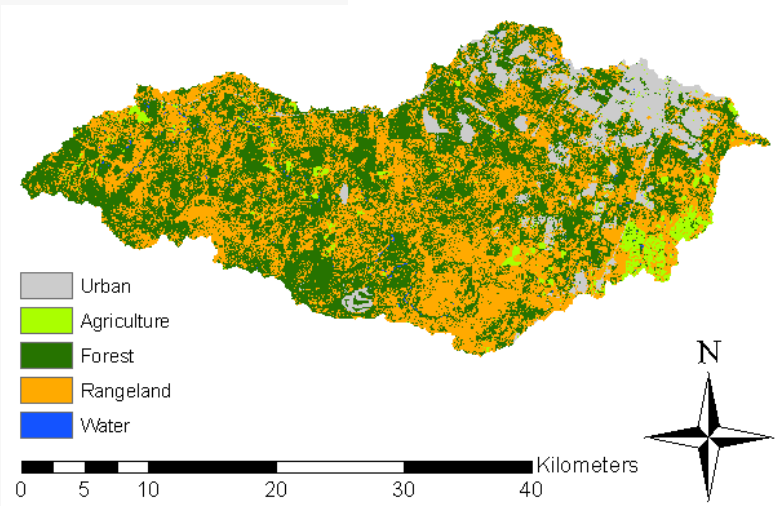
6% Urban
1% Agriculture
51% Forest
41% Rangeland
1% Water

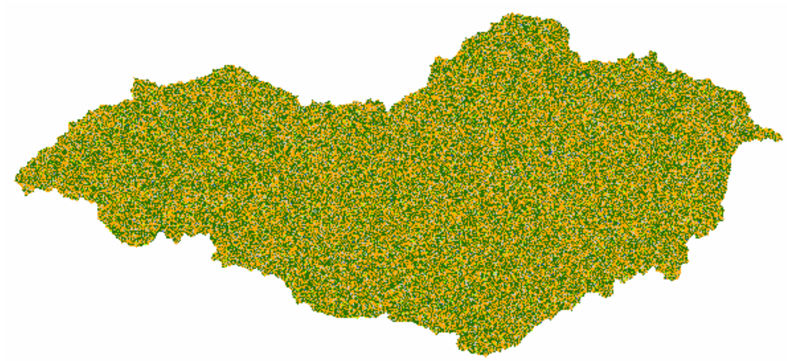


Land use / cover

Onion Creek

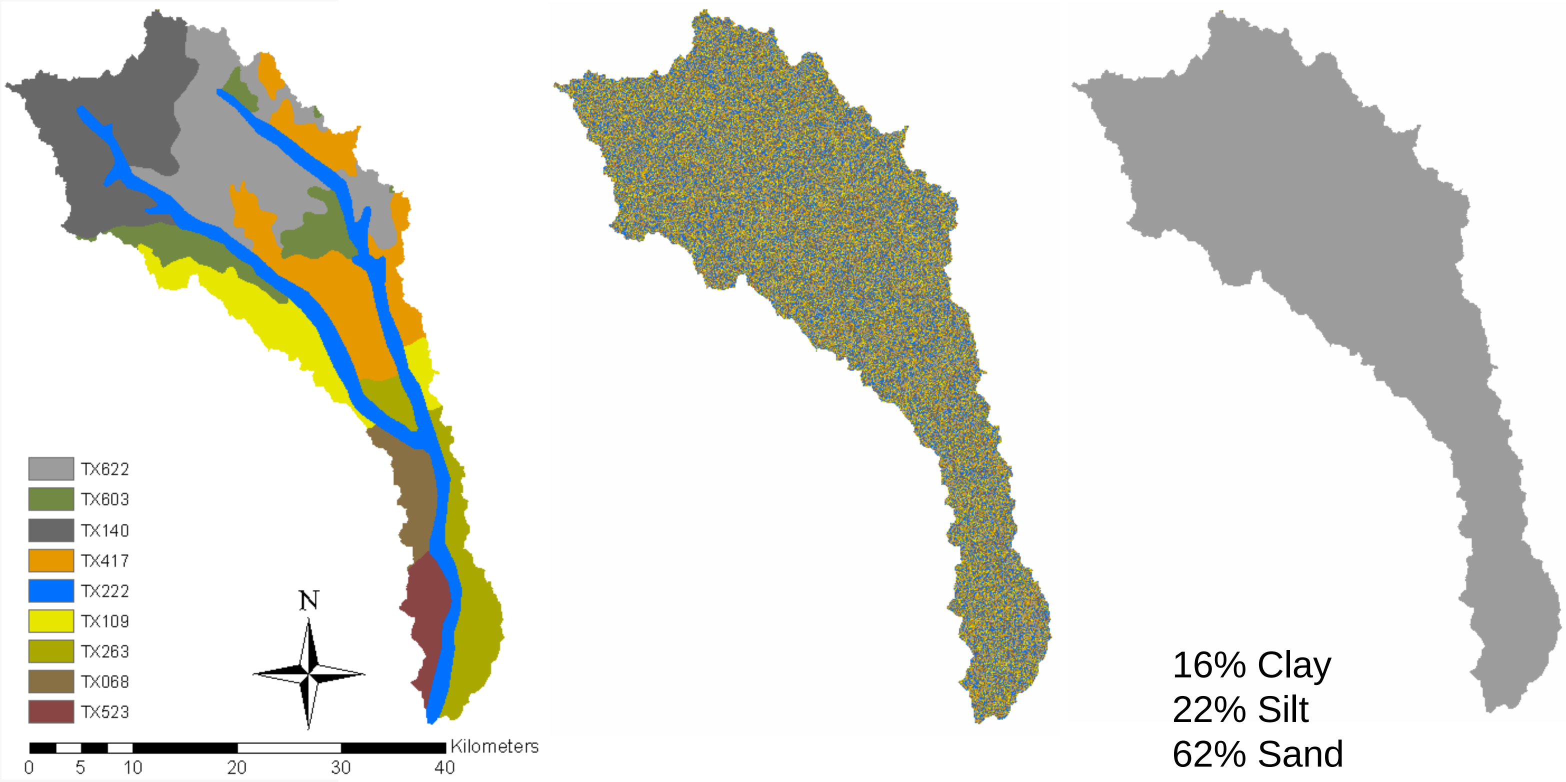
9% Urban
3% Agriculture
45% Forest
42% Rangeland
1% Water





Land use / cover

East Fork San Jacinto River

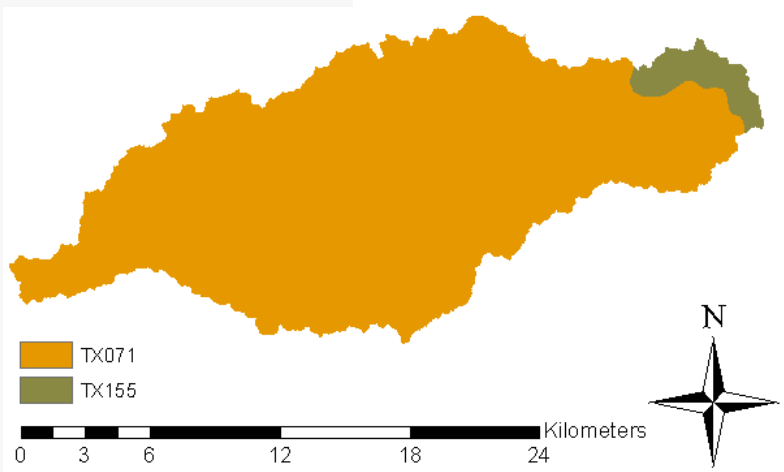


16% Clay
22% Silt
62% Sand

Soil type

Barton Creek

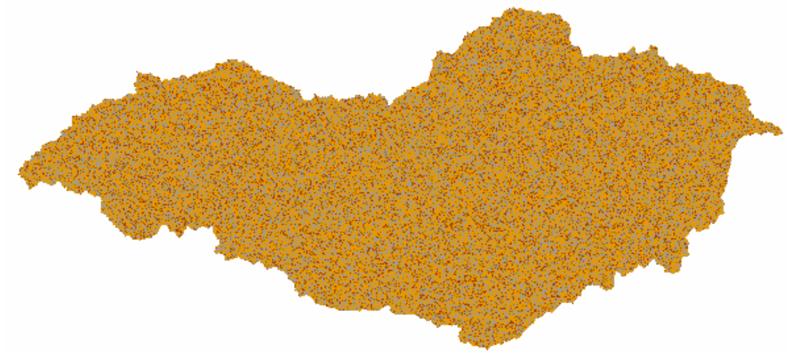
28% Clay
38% Silt
34% Sand

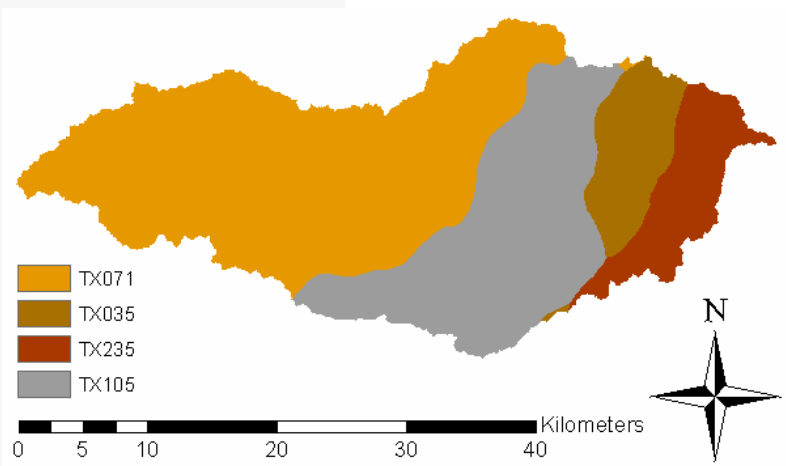


Soil type

Onion Creek

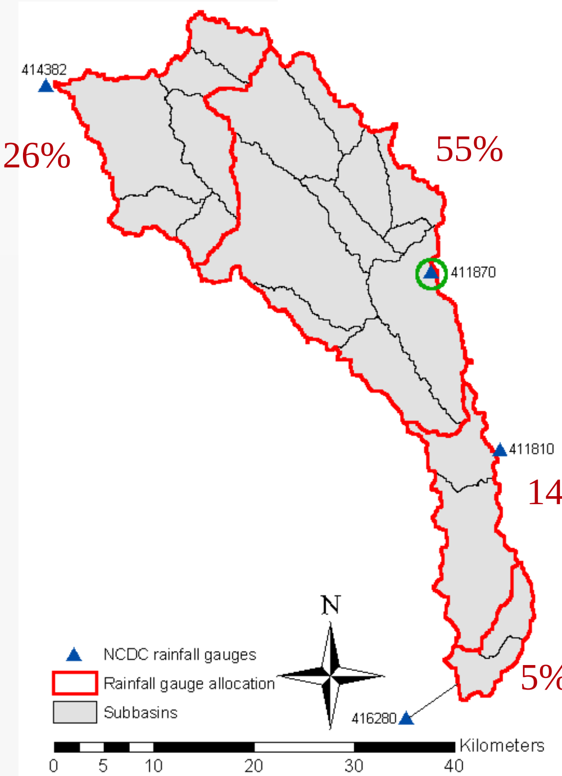
36% Clay
35% Silt
29% Sand

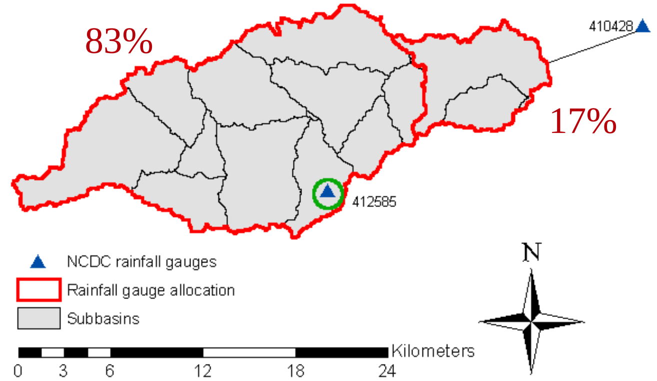


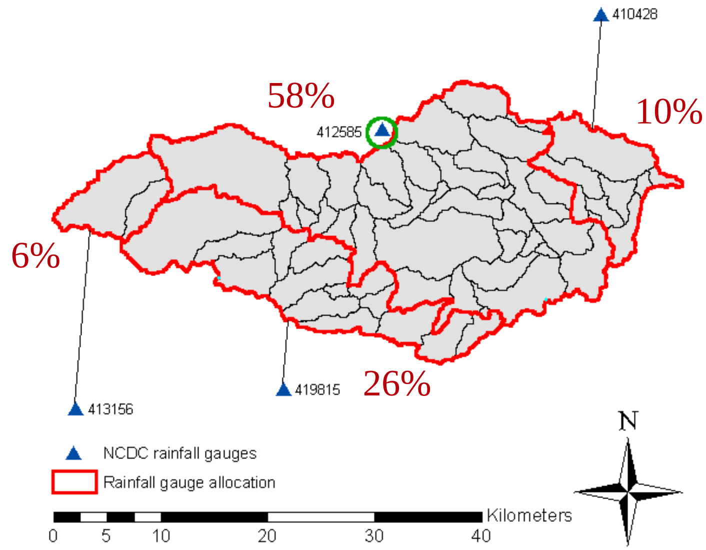


Soil type

Precipitation – Multi/Single Gauge







Calibration Objective Function

- Objective function:

$$\sum_{i=1}^{n}(Q_{obs} - Q_{sim})^2$$

  - Tends to stress the matching of peak flows more than the matching of low flows… perhaps too much! The entire calibration might be driven by a few extremely high-flow days.

- Method used to minimize the objective function: Shuffle Complex Evolution (SCE).

Calibration Parameters

Parameter	Description (Neitsch et al., 2002) **COPY&PASTE**	Range
CN2	Initial NRCS runoff curve number for moisture condition II	35 – 99
SOL_AWC	Available water capacity of the soil layer (mm H_2O/mm soil)	0.0 – 1.0
ESCO	Soil evaporation compensation factor	0.01 – 1.0
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm H_2O)	0 – 5000
GW_REVAP	Groundwater revap coefficient	0.02 – 0.20
REVAPMN	Threshold depth of water in the shallow aquifer for revap or percolation to the deep aquifer to occur (mm H_2O)	0 – 500
GW_DELAY	Groundwater delay time (days)	0 – 200
RCHRG_DP	Deep aquifer percolation fraction	0.0 – 1.0
CH_K2	Effective hydraulic conductivity in main channel alluvium (mm/hr)	0.025 – 250
ALPHA_BF	Baseflow alpha factor (days)	0.0 – 1.0
OV_N	Manning's n value for overland flow	0.01 – 1.0
GW_DELAY	Groundwater delay time (days)	0 – 200
RCHRG_DP	Deep aquifer percolation fraction	0 – 1.0

Calibration Decision Variables

- Parameter change rule:

$$p_{\text{adjusted-x}} = p_{\text{initial-x}} + \alpha_p \left(p_{\text{b}} - p_{\text{initial-x}} \right)$$

  - $p_{\text{initial-x}}$: parameter value at location x before calibration;
  - $p_{\text{adjusted-x}}$: parameter value at location x after calibration;
  - p_b: upper/lower parameter limit; and
  - α_p: decision variable for parameter p.

- There are 13 calibration parameters *p* and, therefore, 13 decision variables α_p.

Model Assessment

- The Nash-Sutcliffe coefficient was used to assess the model efficiency.

$$NS = 1 - \frac{\sum_{i=1}^{n} (Q_i - \hat{Q}_i)^2}{\sum_{i=1}^{n} (Q_i - \bar{Q})^2}$$

- Note that NS compares the model with the “no model” (long-term average value). High NS might indicate a good model or a bad no-model.

Results - Calibration

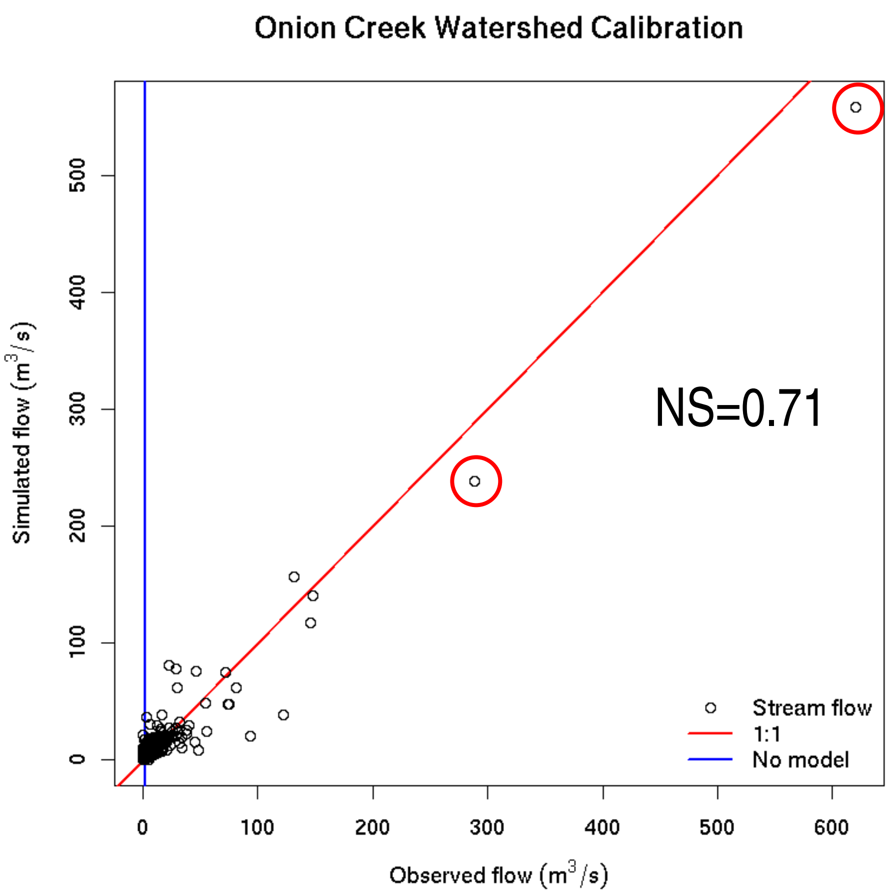
Calibration		Multiple rain gauges			Single rain gauge		
		Soil type: Original	Soil type: Single	Soil type: Random	Soil type: Original	Soil type: Single	Soil type: Random
East Fork San Jacinto River	Land use: Original	0.44	0.45	0.44	0.42	0.34	0.25
	Land use: Single	0.43	0.50	0.46	0.37	0.42	0.41
	Land use: Random	0.39	0.37	0.39	0.39	0.37	0.35
Barton Creek	Land use: Original	0.86	0.88	0.86	0.83	0.85	0.84
	Land use: Single	0.83	0.88	0.88	0.79	0.85	0.85
	Land use: Random	0.86	0.87	0.88	0.82	0.84	0.86
Onion Creek	Land use: Original	0.92	0.91	0.91	0.92	0.91	0.87
	Land use: Single	0.92	0.90	0.91	0.91	0.90	0.89
	Land use: Random	0.91	0.91	0.90	0.92	0.90	0.88

Nash – Sutcliffe Coefficient

Why is it so good?

- Onion Creek: original land use distribution, original soil type distribution and multiple rain gauges.

  NS = 0.92



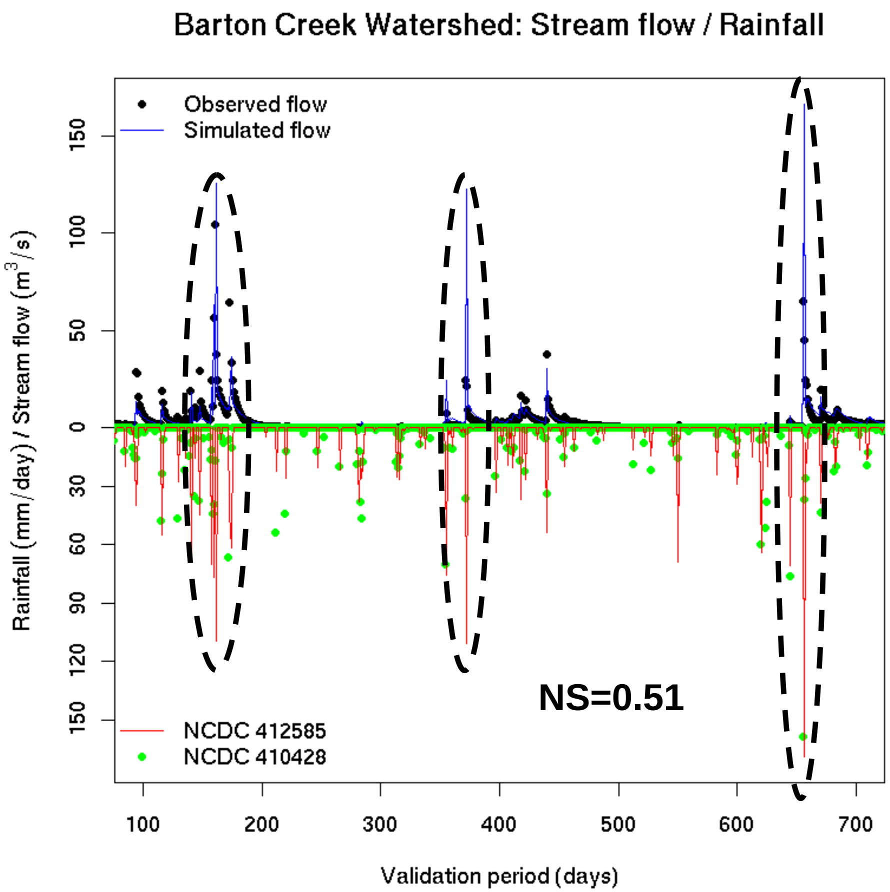
Results – Temporal Validation

Temporal validation		Multiple rain gauges			Single rain gauge		
		Soil type: Original	Soil type: Single	Soil type: Random	Soil type: Original	Soil type: Single	Soil type: Random
East Fork San Jacinto River	Land use: Original	0.43	0.58	0.50	0.26	0.37	0.25
	Land use: Single	0.31	0.62	0.49	0.23	0.47	0.31
	Land use: Random	0.33	0.43	0.41	0.30	0.27	0.23
Barton Creek	Land use: Original	-0.22	-0.20	-0.22	-0.22	-0.28	-0.01
	Land use: Single	-0.44	-0.20	-0.19	-0.39	-0.10	-0.35
	Land use: Random	-0.28	-0.32	-0.15	-0.22	-0.10	-0.20
Onion Creek	Land use: Original	0.27	0.31	0.31	0.03	0.07	0.04
	Land use: Single	0.19	0.27	0.31	0.06	0.05	0.09
	Land use: Random	0.21	0.24	0.29	0.12	0.01	0.11

Why is it so bad?

- Barton Creek: original land use distribution, original soil type distribution and multiple rain gauges.

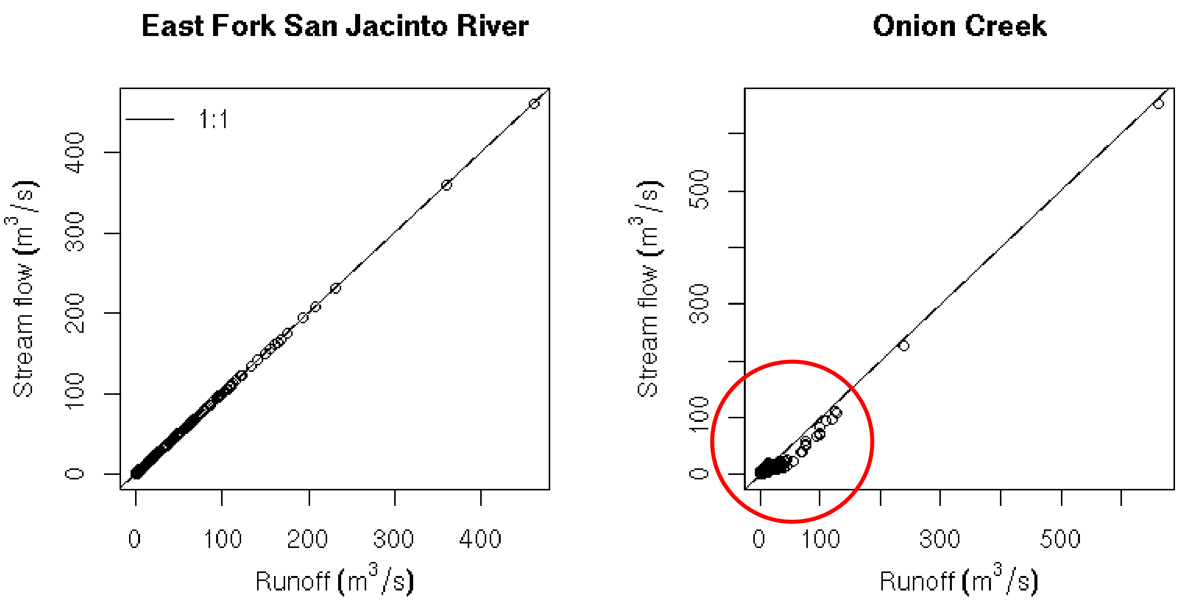
NS = -0.22



Results – Spatial Validation

Spatial validation		Multiple rain gauges			Single rain gauge		
		Soil type: Original	Soil type: Single	Soil type: Random	Soil type: Original	Soil type: Single	Soil type: Random
East Fork San Jacinto River	Land use: Original	0.48	0.38	0.47	0.53	0.36	0.36
	Land use: Single	0.47	0.49	0.44	0.47	0.48	0.45
	Land use: Random	0.48	0.35	0.46	0.47	0.56	0.49
Barton Creek	Land use: Original	0.69	0.72	0.68	0.70	0.75	0.72
	Land use: Single	0.65	0.73	0.73	0.67	0.74	0.74
	Land use: Random	0.66	0.71	0.73	0.70	0.73	0.75
Onion Creek	Land use: Original	0.72	0.76	0.58	0.52	0.55	0.38
	Land use: Single	0.70	0.73	0.65	0.45	0.45	0.22
	Land use: Random	0.57	0.70	0.43	0.54	0.34	0.46

Effect of Flow Routing



Conclusions

- In small watersheds, lumped models might do as well as distributed models.
- In small watersheds, it does not matter where runoff is generated with respect to the outlet, provided the correct combinations of land use/cover, soil type and precipitation depth are defined.
- There is a need to define subbasins to capture the precipitation spatial variability.
- The Nash-Sutcliffe coefficient is not a good metric to compare model performance. It is good only to compare models of the same watershed over the same period.

Questions?