Impacts of Watershed Delineation on Modeled Runoff from Summer Storms

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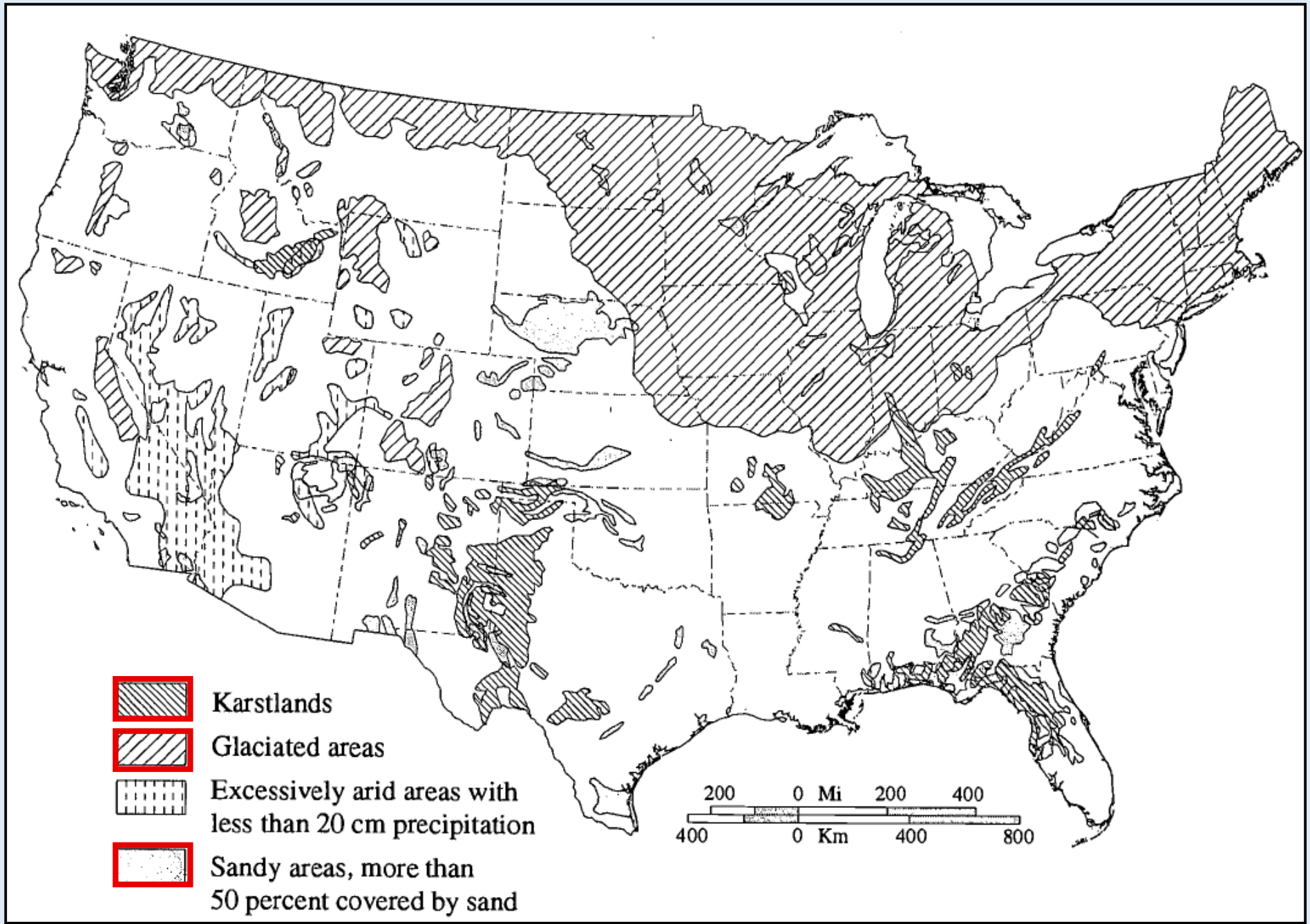
Rationale

- Modeled Runoff after storms is used to:
  - Determine regulatory limits
  - Plan for storm events
- Watershed Delineation Determines Modeled Area*
- Are watersheds containing Internal Drainage being delineated correctly?

*Jensen 1988

Filled-Sink Delineation Problem Areas

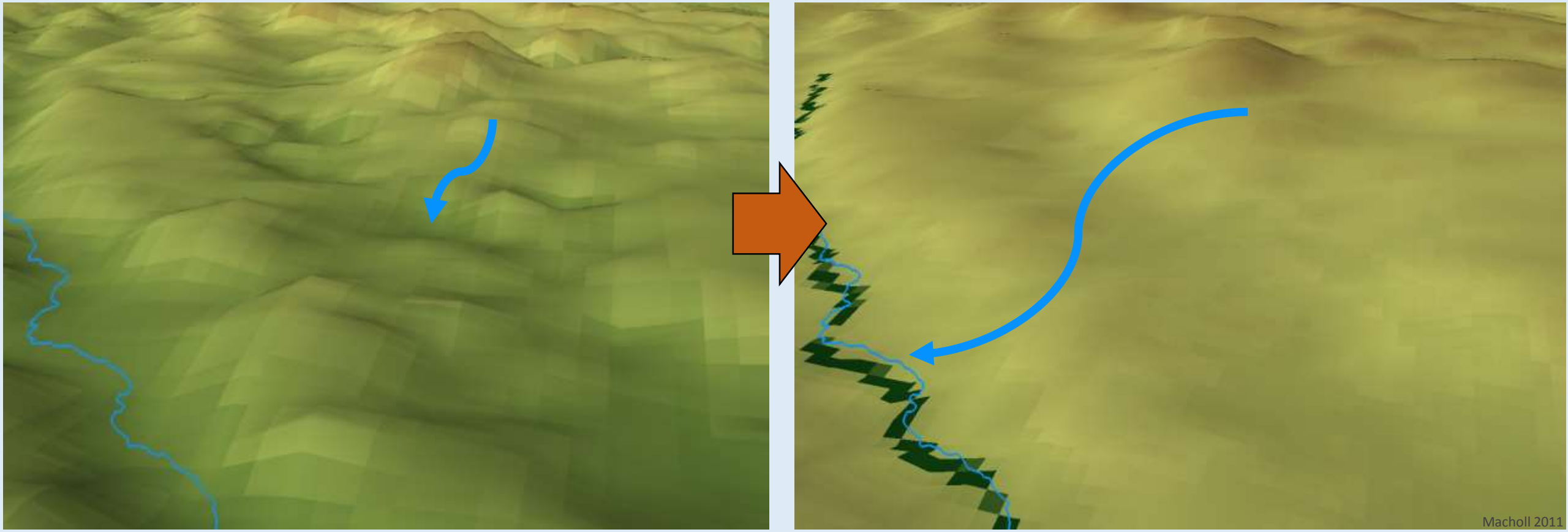


Study Objectives

- How do different delineation methods perform?

- Watersheds in North WI & MN
  - Uneven Topography
  - Internal Drainage
    - Wetlands & Bogs
  - Low Agriculture & Development

Filling Sinks in the Digital Elevation Model



Unfilled

Filled

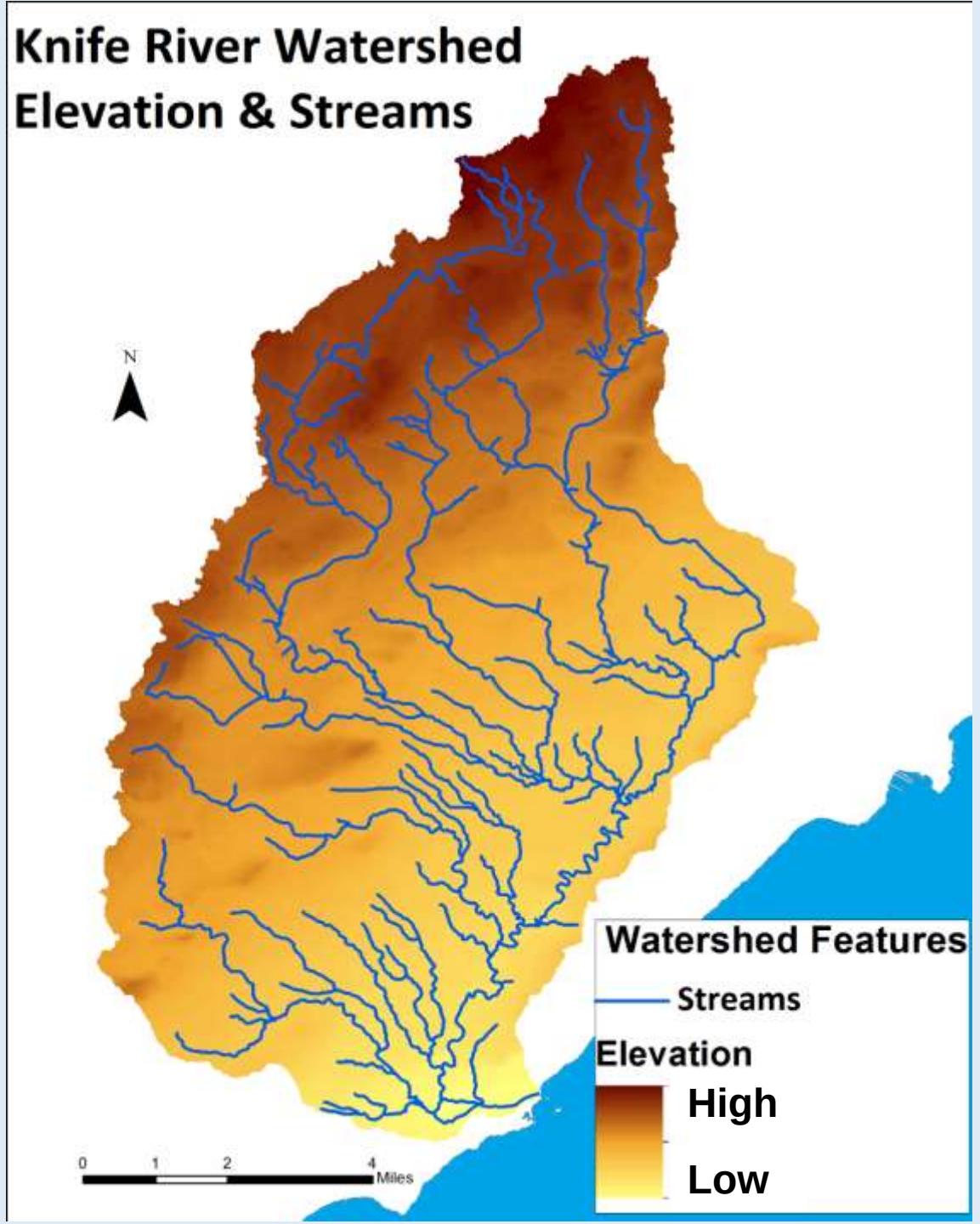
Filled Sink Delineation

Works well with:

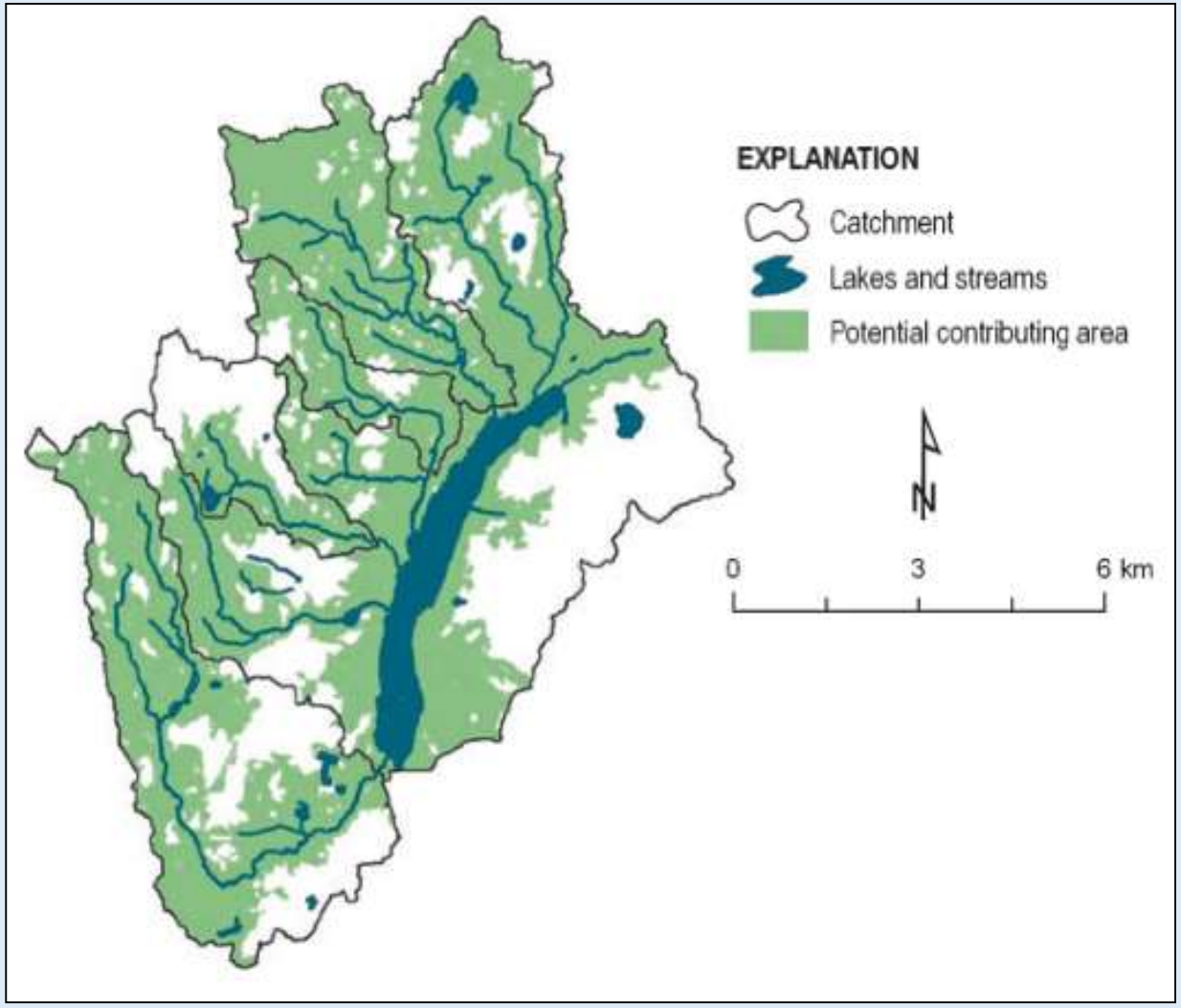
- High drainage density
- High relief

Problematic:

- Low drainage density
- Low relief
- Internal Drainage



Internally Drained Areas in Watersheds



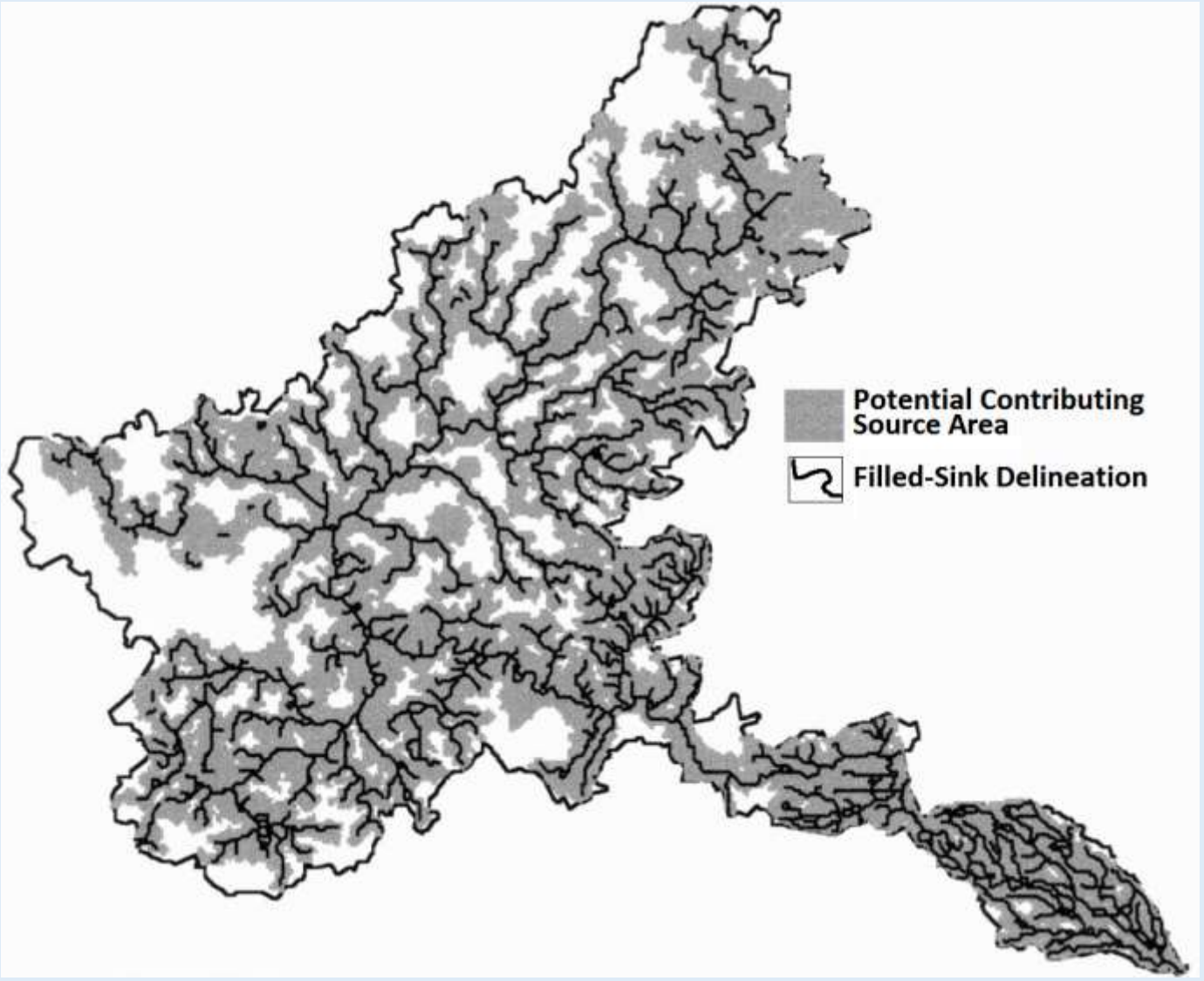
Macholl 2011

- Isolated from drainage networks
  - Can lead to Error in GIS runoff models*
  - Common in upper Midwest **
  - May contain bogs, lakes, internal drainage networks

*Taylor 2012 **Richards 2004

Richards 2004: Potential Contributing Source Areas

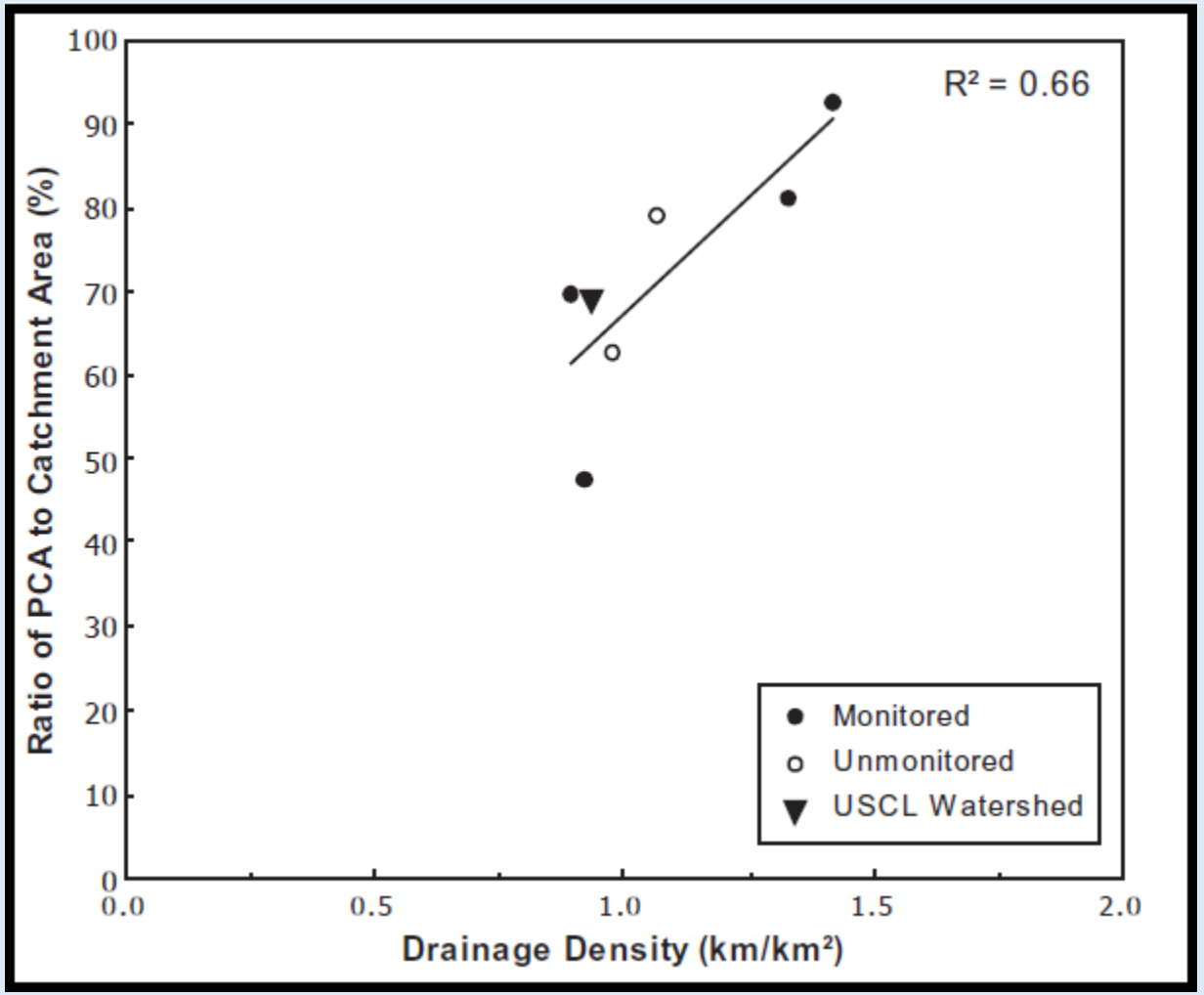
- Huron River Watershed, Michigan
  - Internal Drainage
    - 37% smaller than filled sink delineation
  - Unfilled DEM
  - Delineates outward from drainage network



Previous Studies

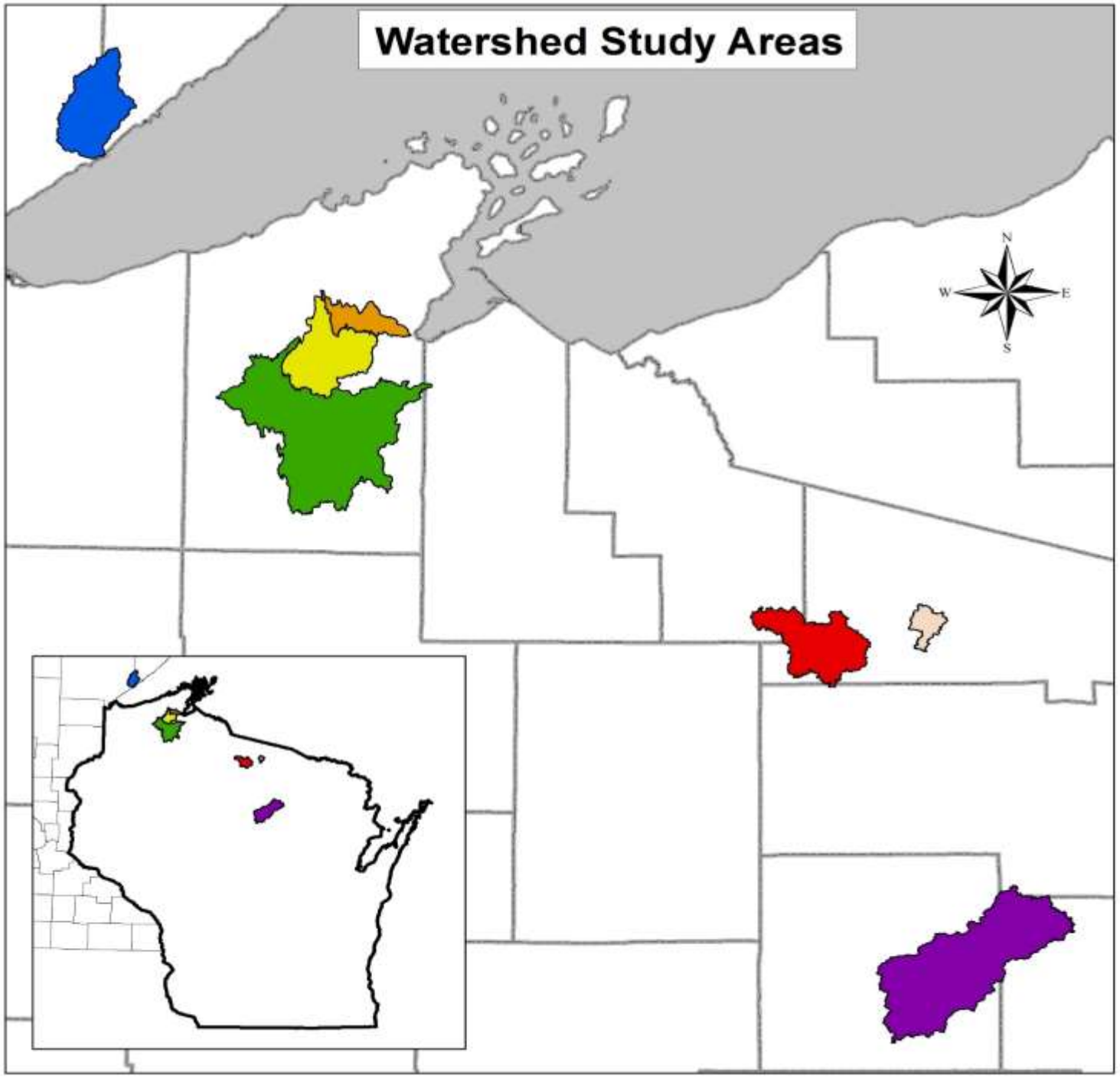
Macholl 2011 – PCSA in Wisconsin

- Four small watersheds in northwest WI
- PCSA performed better than filling sinks
- Few storms occurred during study

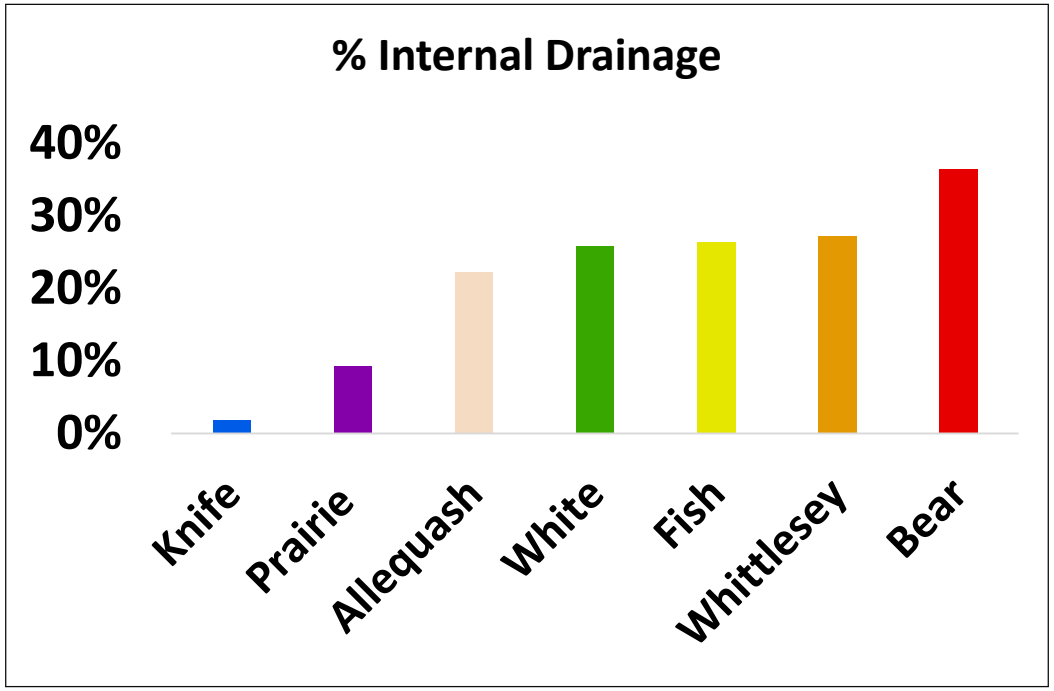


Methods

- 3 Watershed Delineation Methods:
  - Filling Sinks
  - Cutting Sinks
  - Potential Contributing Source Areas (PCSA)
- Modeling Runoff: NRCS Curve Number
- Observed Runoff - USGS



- 7 Watersheds
- 10 mi² - 300 mi²
- Internal Drainage



Bear River
Knife River
Whittlesey Creek
Fish Creek
Allequash Creek
White River
Prairie River

0 5 10 20 30 40
1:1,000,000 Miles

Sources: WI-DNR, MN-DNR, USGS

Created by: Bill Troolin

Data Inputs & Sources

Spatial Data

• **Elevation – 10m DEM**	NED-10m (USGS), LIDAR 1m (MN-DNR)
• **Land cover – NLCD**	(USGS)
• **Hydric Soils**	(NRCS)
• **Streams and Lakes**	(WI-DNR, MN-DNR)
• **Roads and Borders**	(WI-DNR, MN-DNR)

Tabular Data

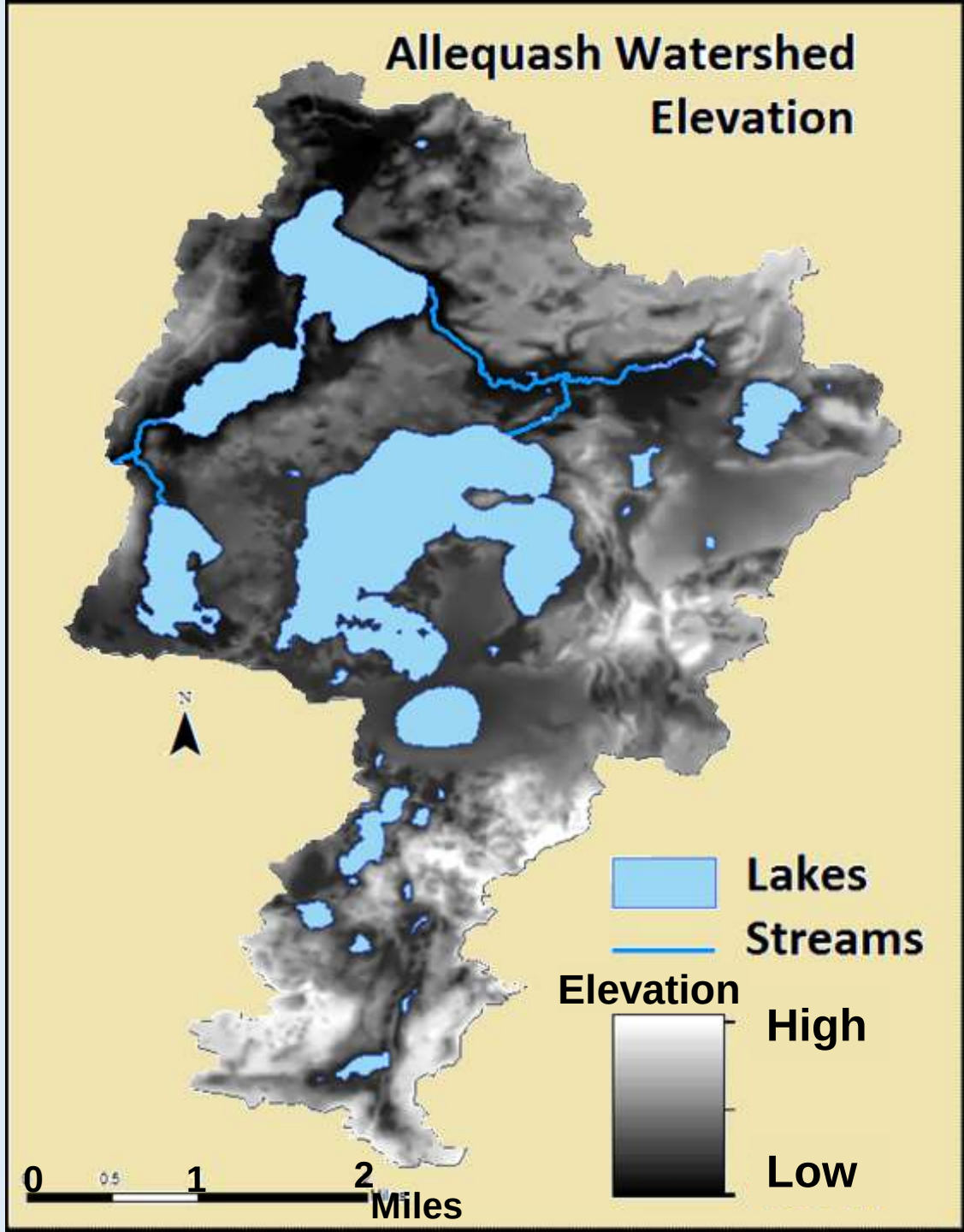
• **Precipitation**	(NCDC, NWS)
• **Discharge**	(USGS)

Delineation Method 1 : Filled Sinks

- Fast & Easy
- Boundaries may include Internal Drainage

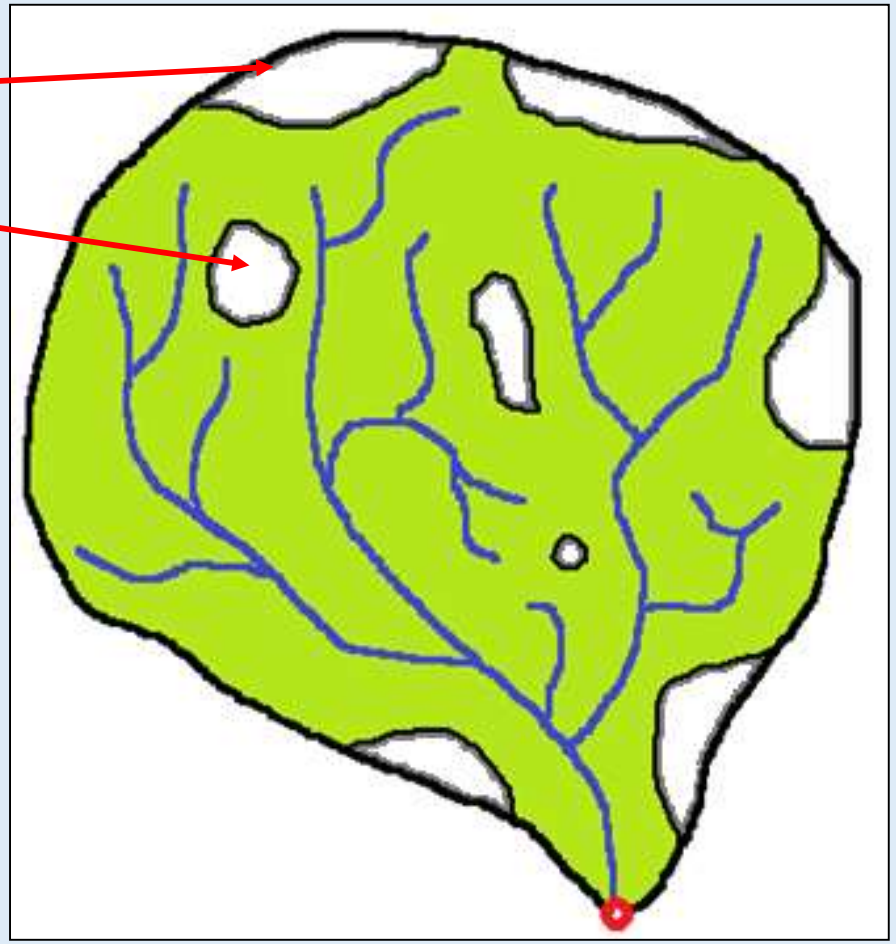
<u>Problem factors</u>:

- Low Drainage Density
- Internal Drainage
- Low Relief



Delineation Method 2: Cut Sinks

- Where were Sinks filled?
  - Identify sinks
  - Remove sinks
    - Filled cells reclassified as NoData
- Model runoff using modified watershed area

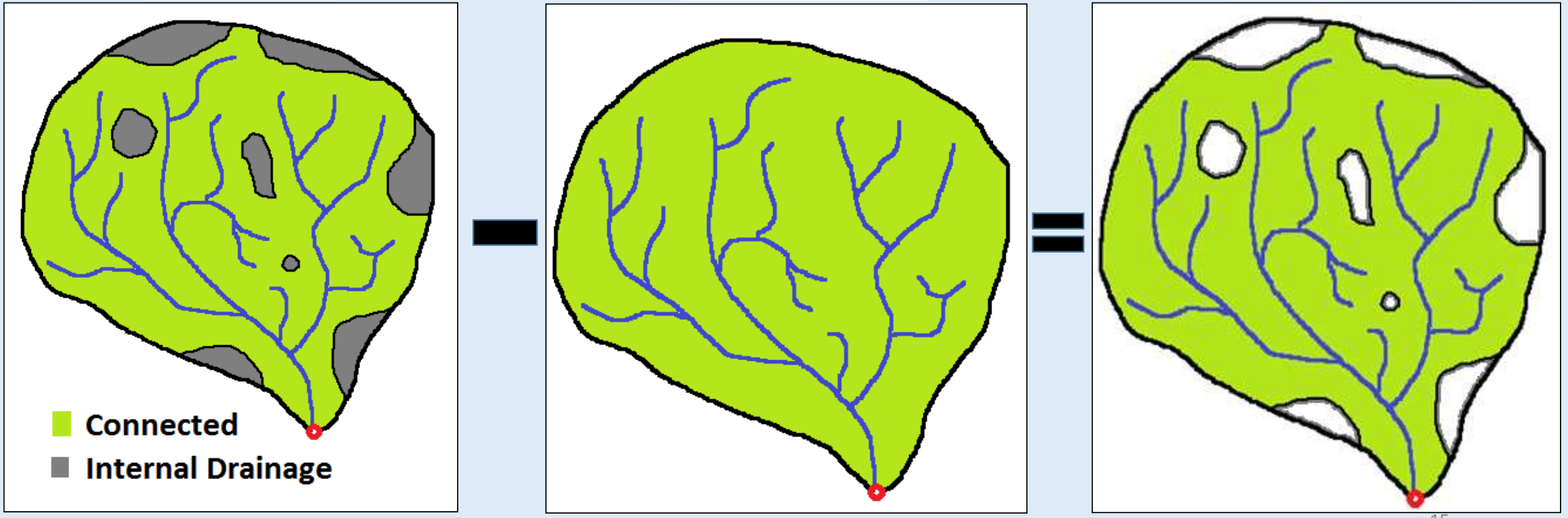


Filled delineation watershed with internal drainage colored white.

Identifying Internally Drained Areas

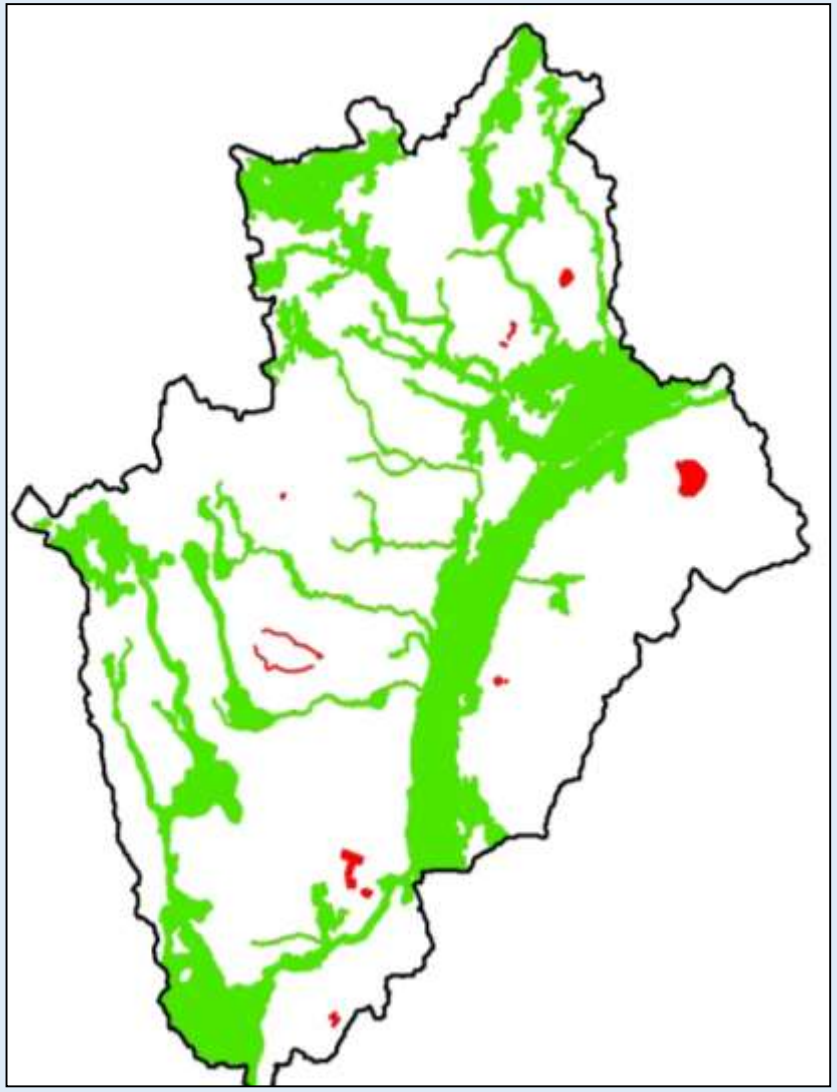
- ArcMap Raster Calculator
- Reclassify cells with elevation change as No Data

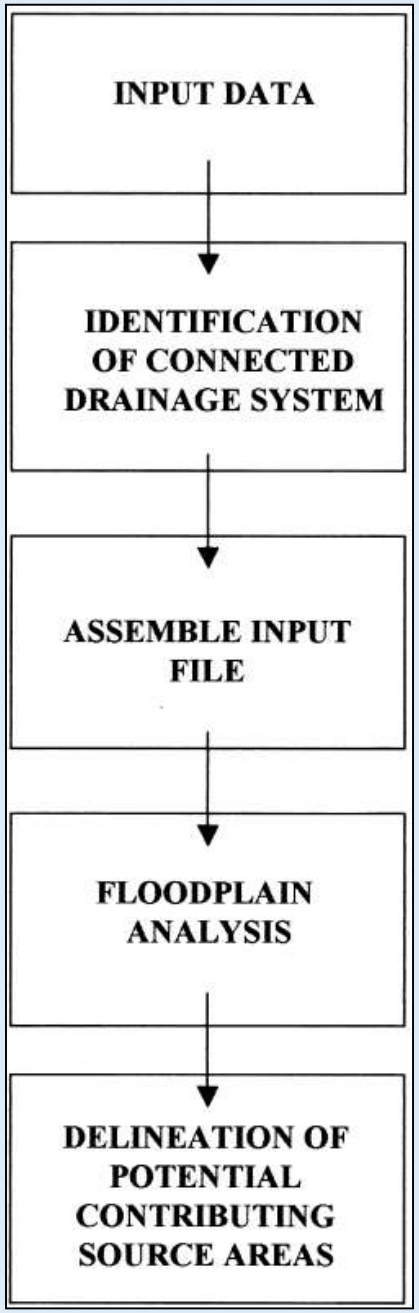
Filled DEM | **Unfilled DEM** | **Cut Watershed**



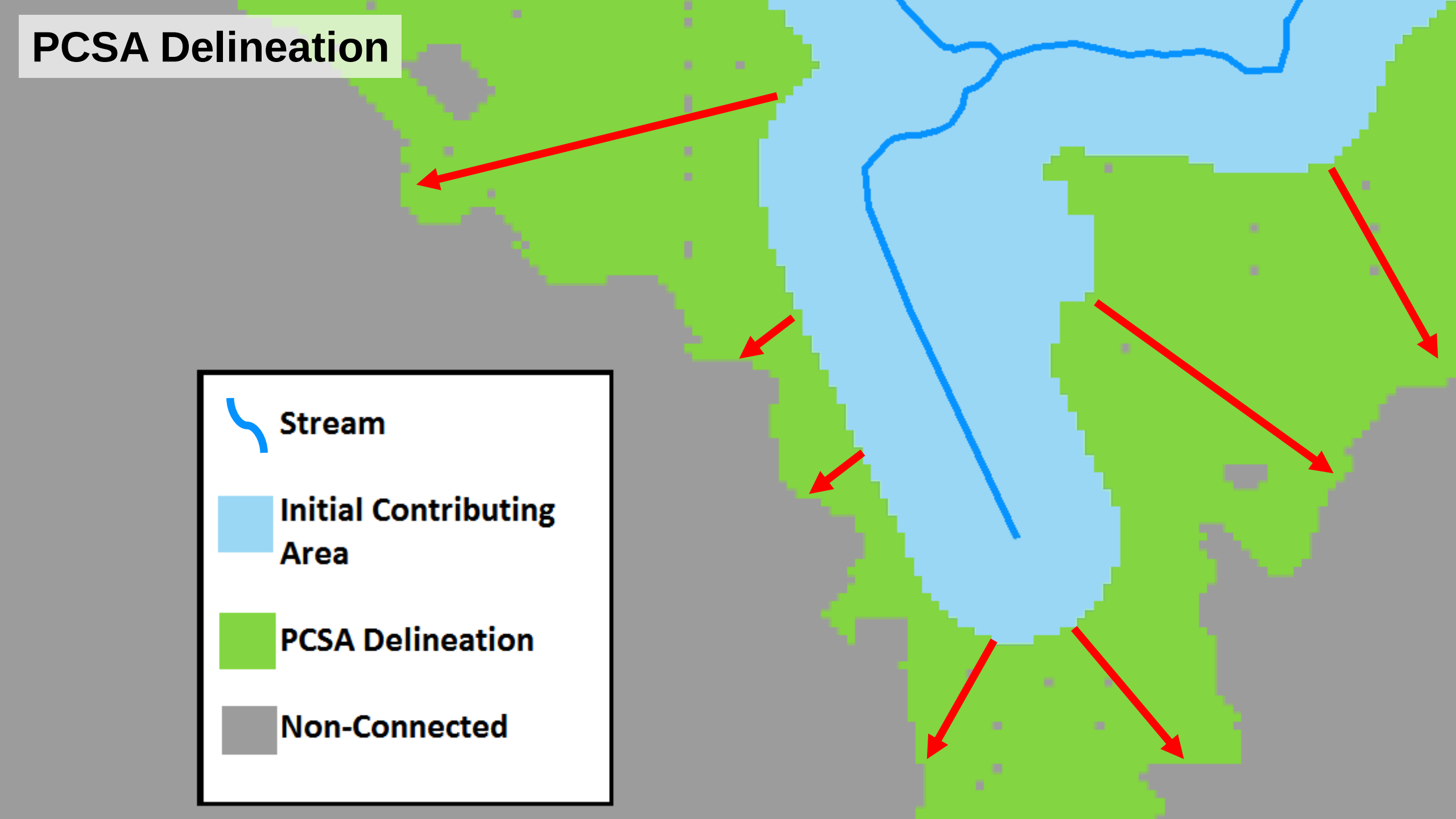
Method 3: Potential Contributing Source Areas

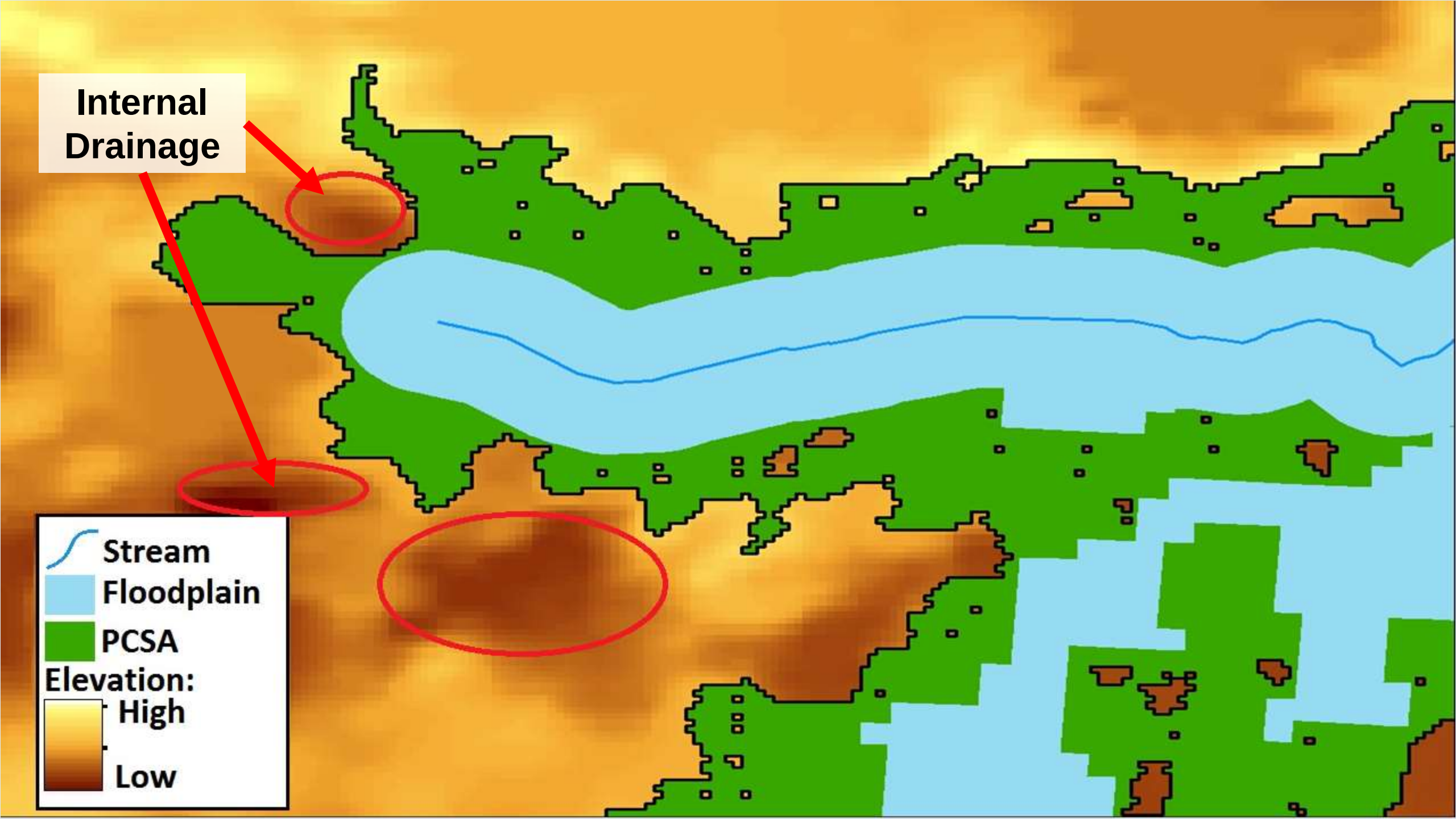
- Initial Input :
  - Streams and Lakes
  - Floodplains, Wetlands
- Delineates outward from Initial Input
- Increased accuracy
- More data & time intensive

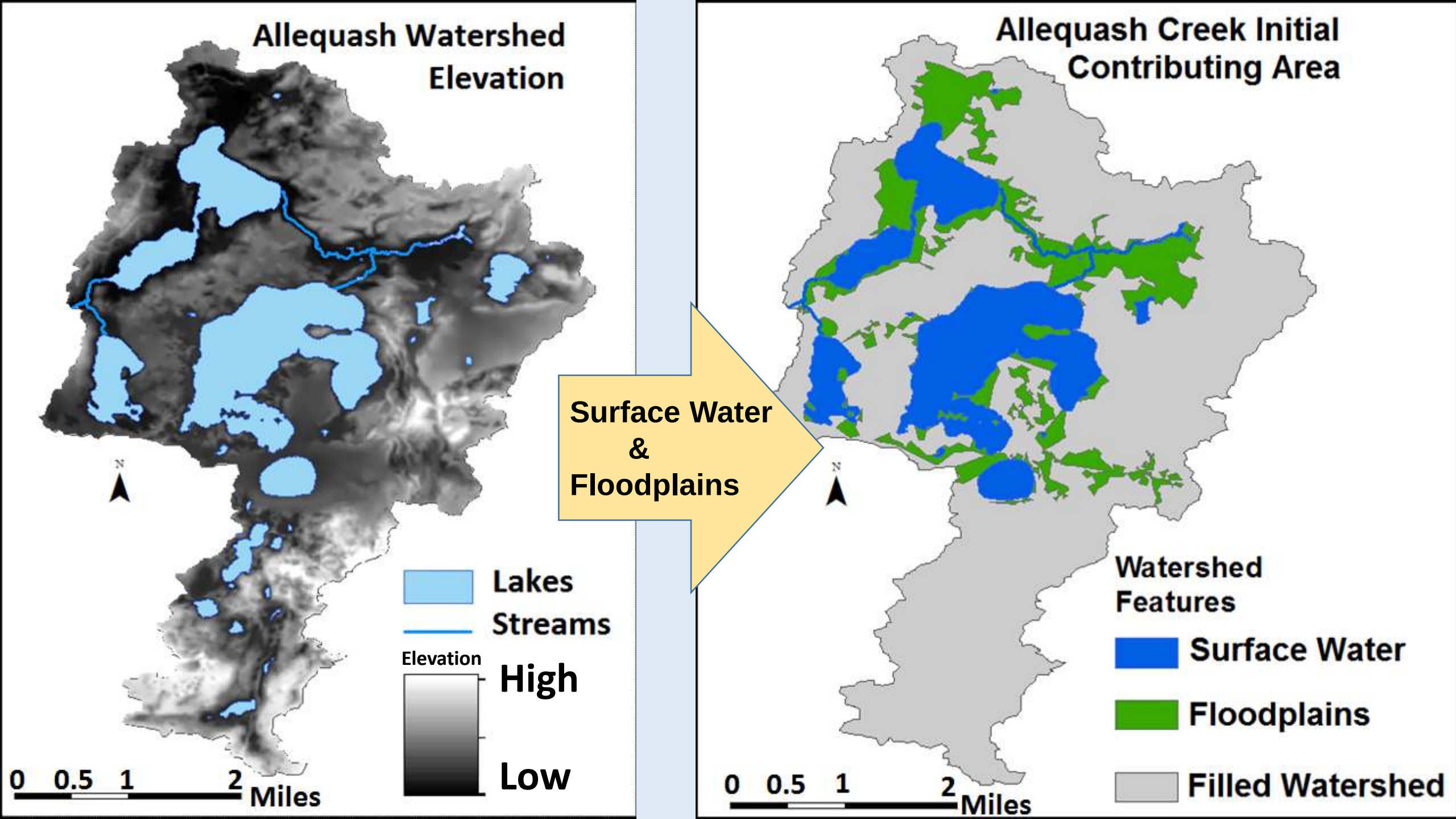




PCSA Delineation



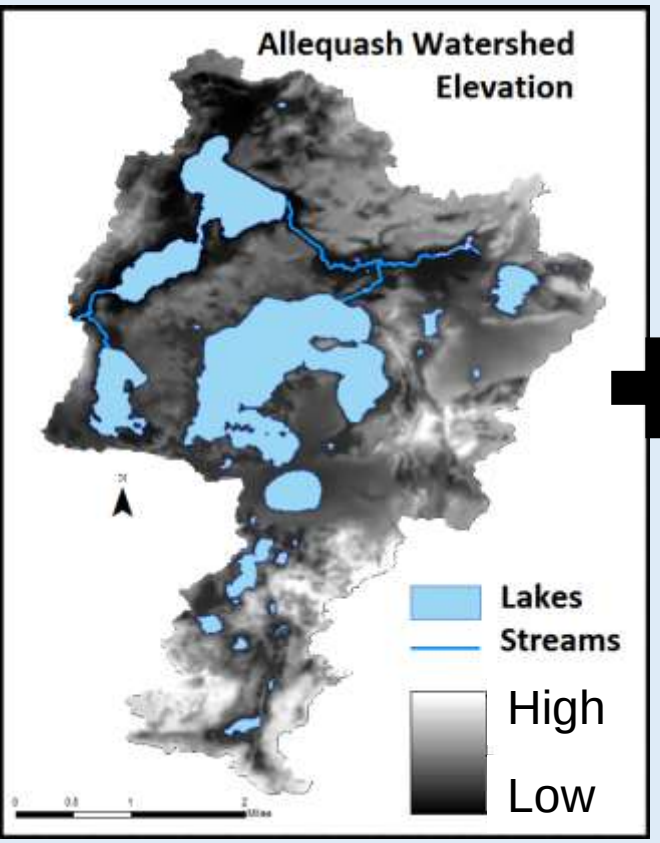

Internal Drainage
Stream
Floodplain
PCSA
Elevation:
High
Low


Allequash Watershed
Elevation
Lakes
Streams
Elevation
High
Low
0 0.5 1 2
Miles
Surface Water
&
Floodplains
Allequash Creek Initial
Contributing Area
Watershed
Features
Surface Water
Floodplains
Filled Watershed
0 0.5 1 2
Miles

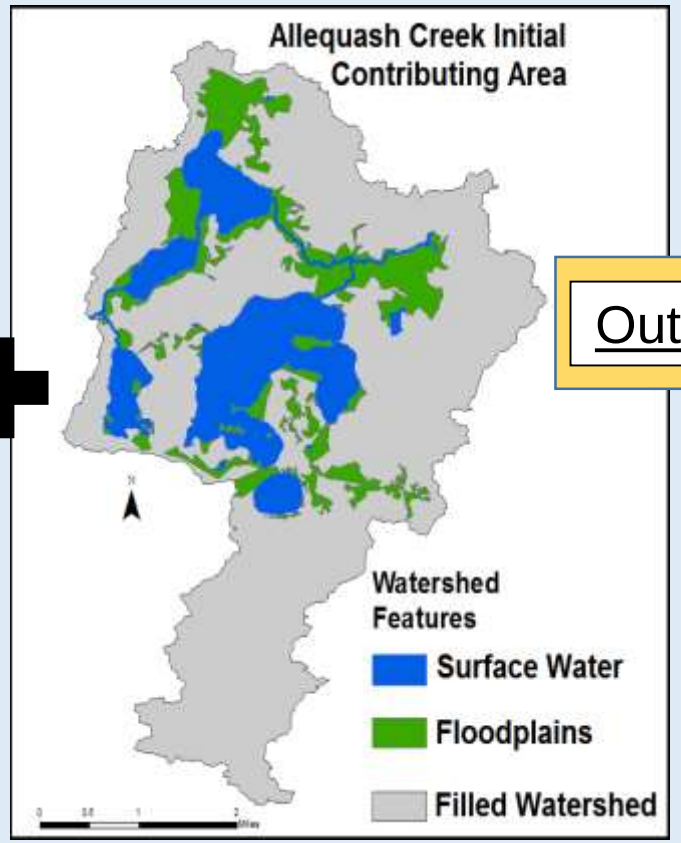
PCSA Delineation

Inputs

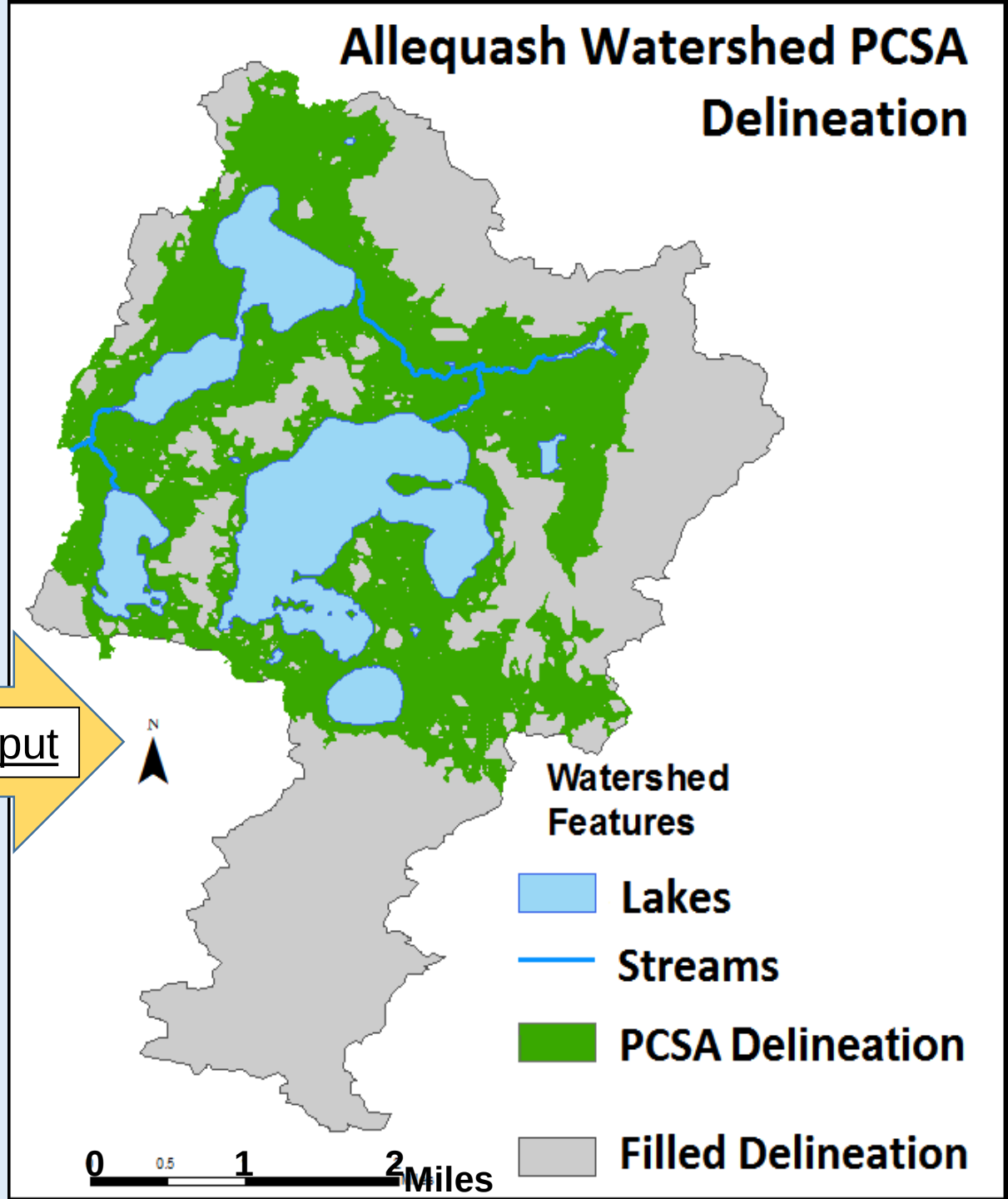
Unfilled DEM

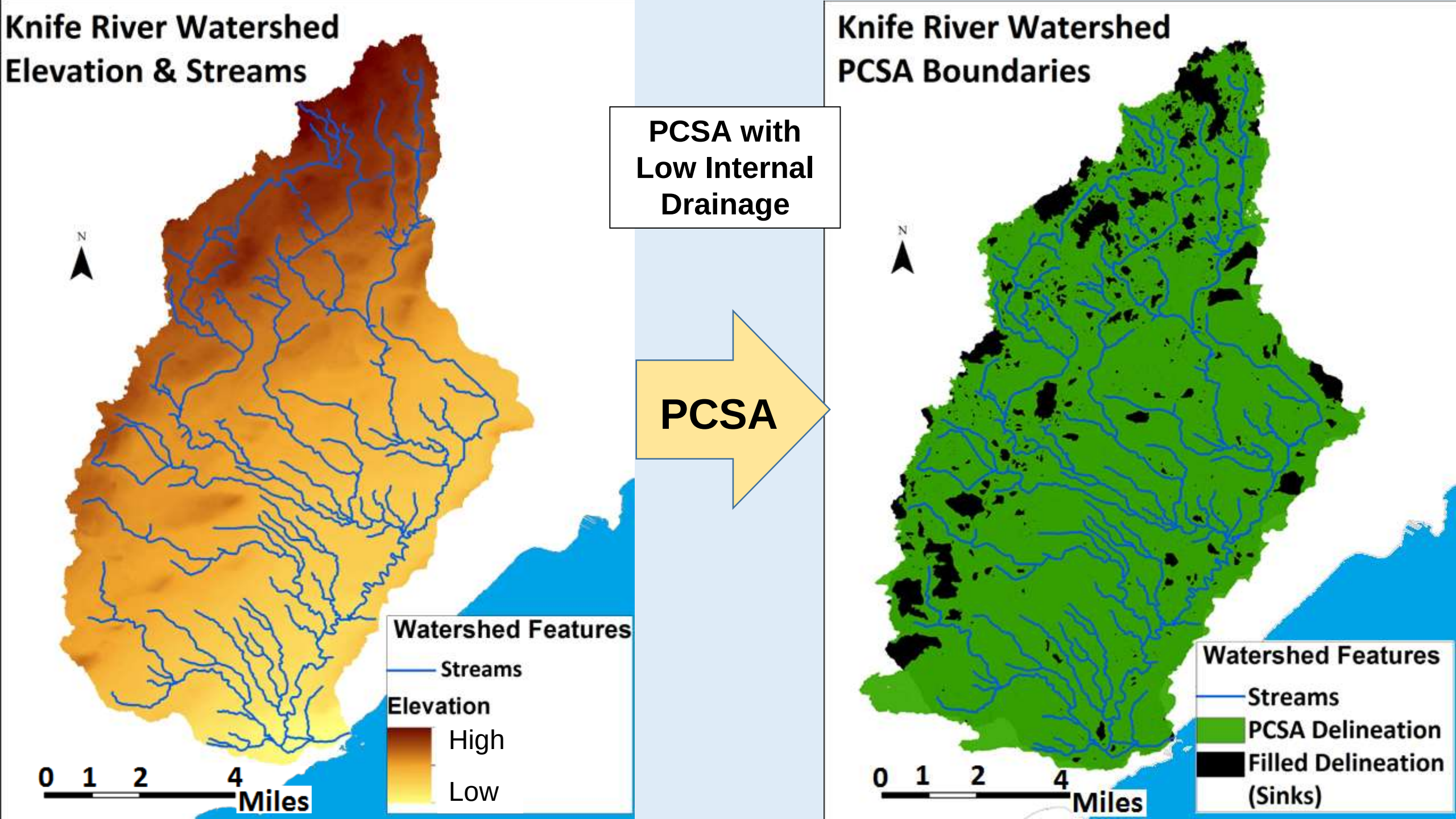


Initial Contributing Area



Output




Knife River Watershed
Elevation & Streams
N
Watershed Features
Streams
Elevation
High
Low
0 1 2 4
Miles
PCSA with Low Internal Drainage
PCSA
Knife River Watershed
PCSA Boundaries
N
Watershed Features
Streams
PCSA Delineation
Filled Delineation (Sinks)
0 1 2 4
Miles

Modeling Storm Runoff

- NRCS Curve Number Equation

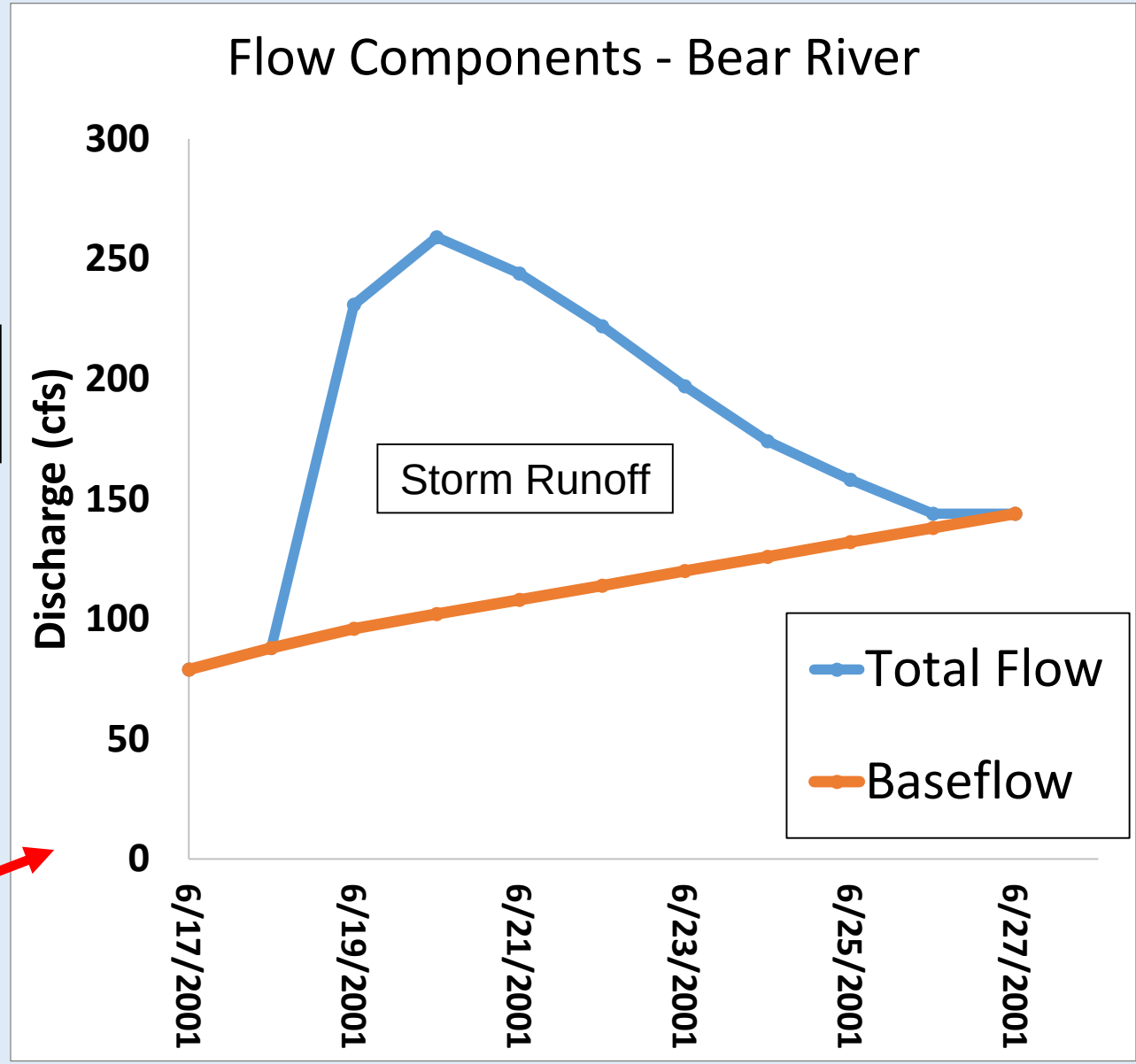
$$Q = \begin{cases} 0 & \text{for } P \le I_a \\ \frac{(P-I_a)^2}{P-I_a+S} & \text{for } P > I_a \end{cases}$$

$$S = \frac{1000}{CN} - 10$$

$$I_a = 0.2S$$

  - Hydric Soils
  - Land Use

- Results compared to Discharge

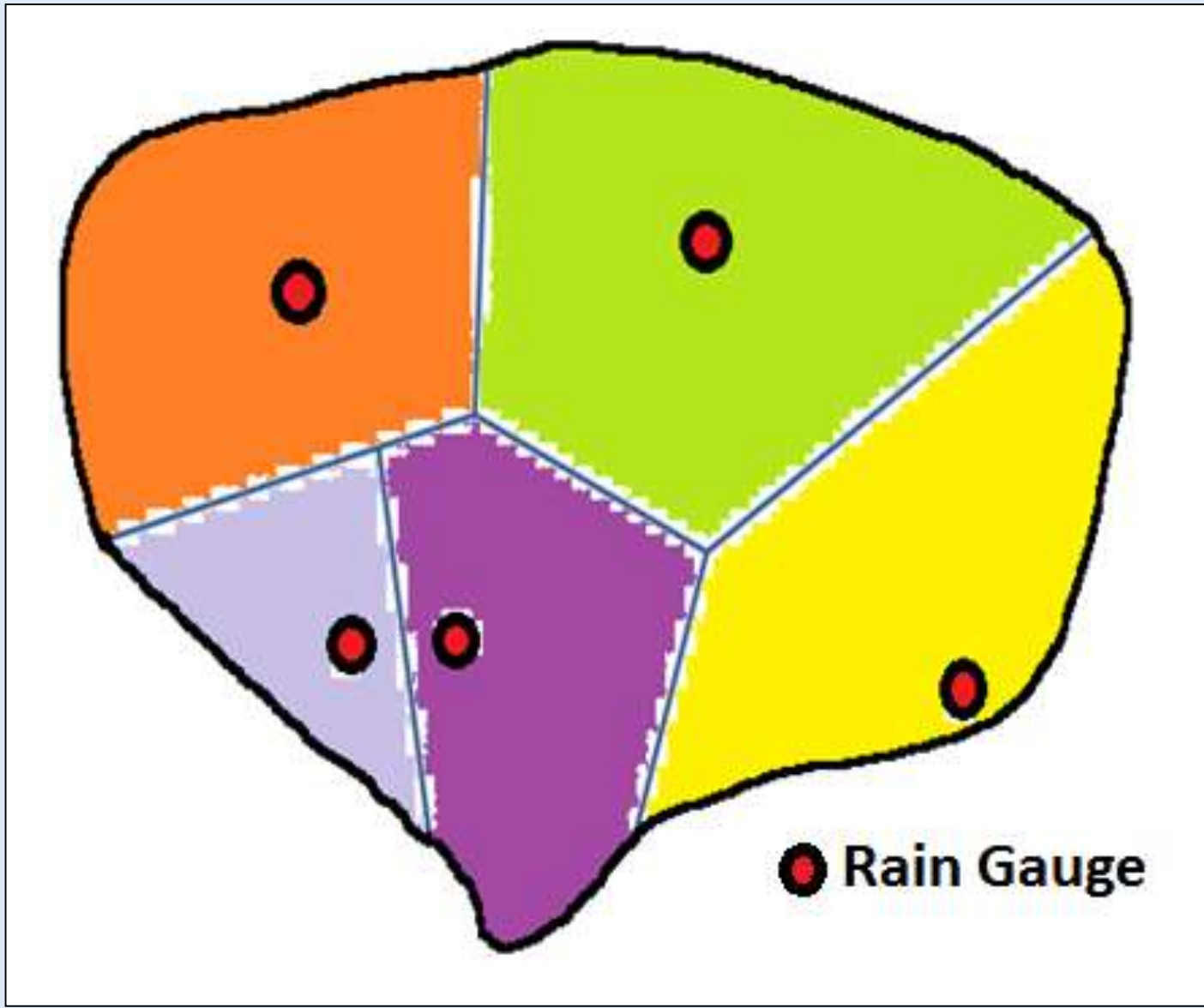


Selecting Storms

- Summer Precipitation
  - Summers within 1 Standard Deviation of watershed average
- Isolated storm events
- Largest responses in the gage records
  - Discharge & Precipitation

Precipitation Gauges : The Plan

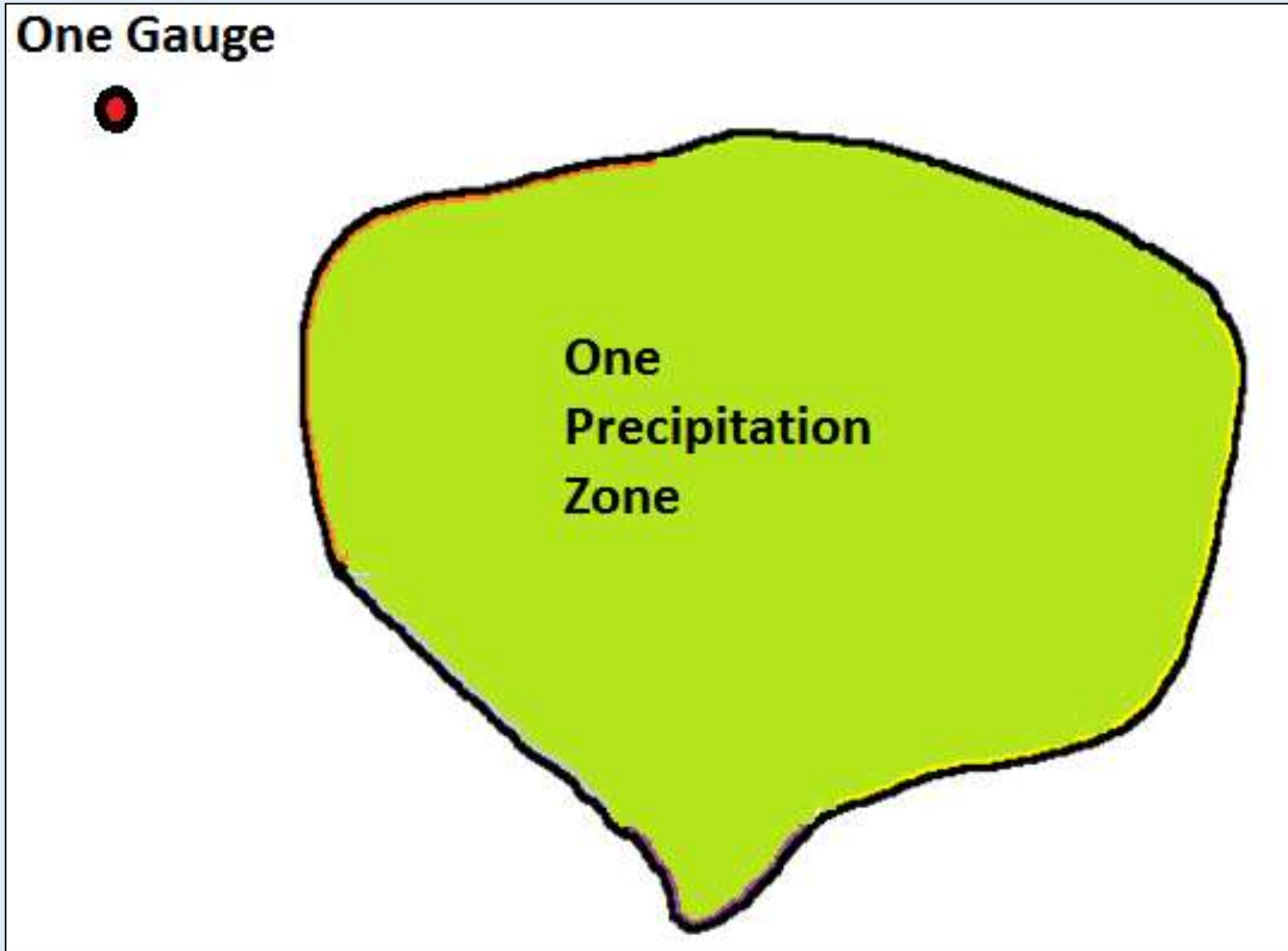
- The Plan:
  - Thyssen Polygons based on multiple gauges
- Most accurate representation of where rain fell



Precipitation Gauges : The Reality

- Normally only one gauge

- Best solution:
  - One rain zone for whole watershed
  - Limit watershed size



Analysis of Results

- **Model Error**:

(Model Runoff) – (Observed Runoff)

- **Normalized Error**:

$$\frac{\text{(Model Error)}}{\text{(Watershed Area)}} \qquad \frac{(ft^3)}{(ft^2)}$$

  - Useful with watersheds of varied sizes

Error compared to:

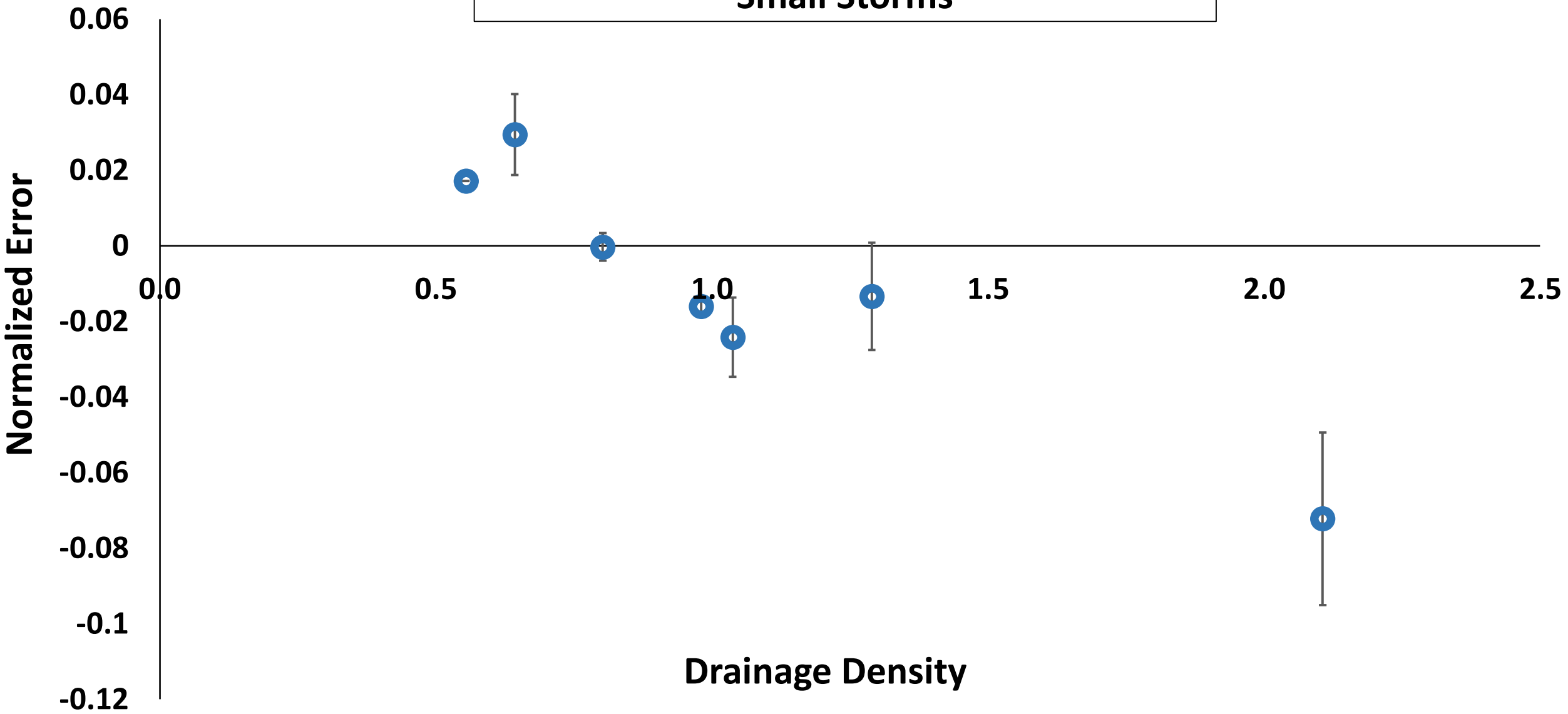
- Drainage Density
- Watershed Area
- % Internal Drainage
- Landcover types

Results : Differing Behavior by Storm Size

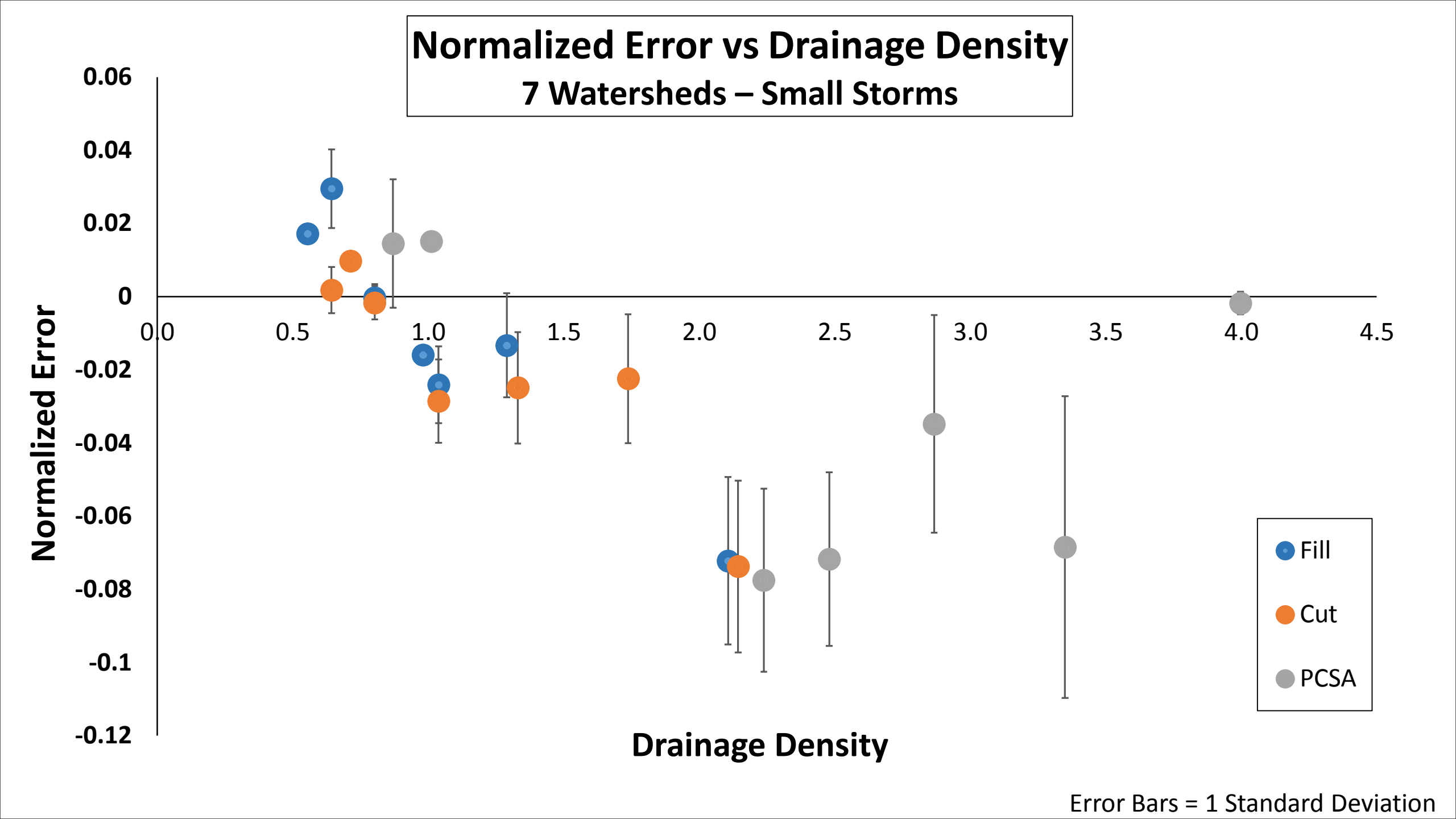
- **Small Storms:** (Under 0.2 feet)
  - Indications of possible trends
- **Large Storms:** (Over 0.2 feet)
  - Fewer indications trends than small storms

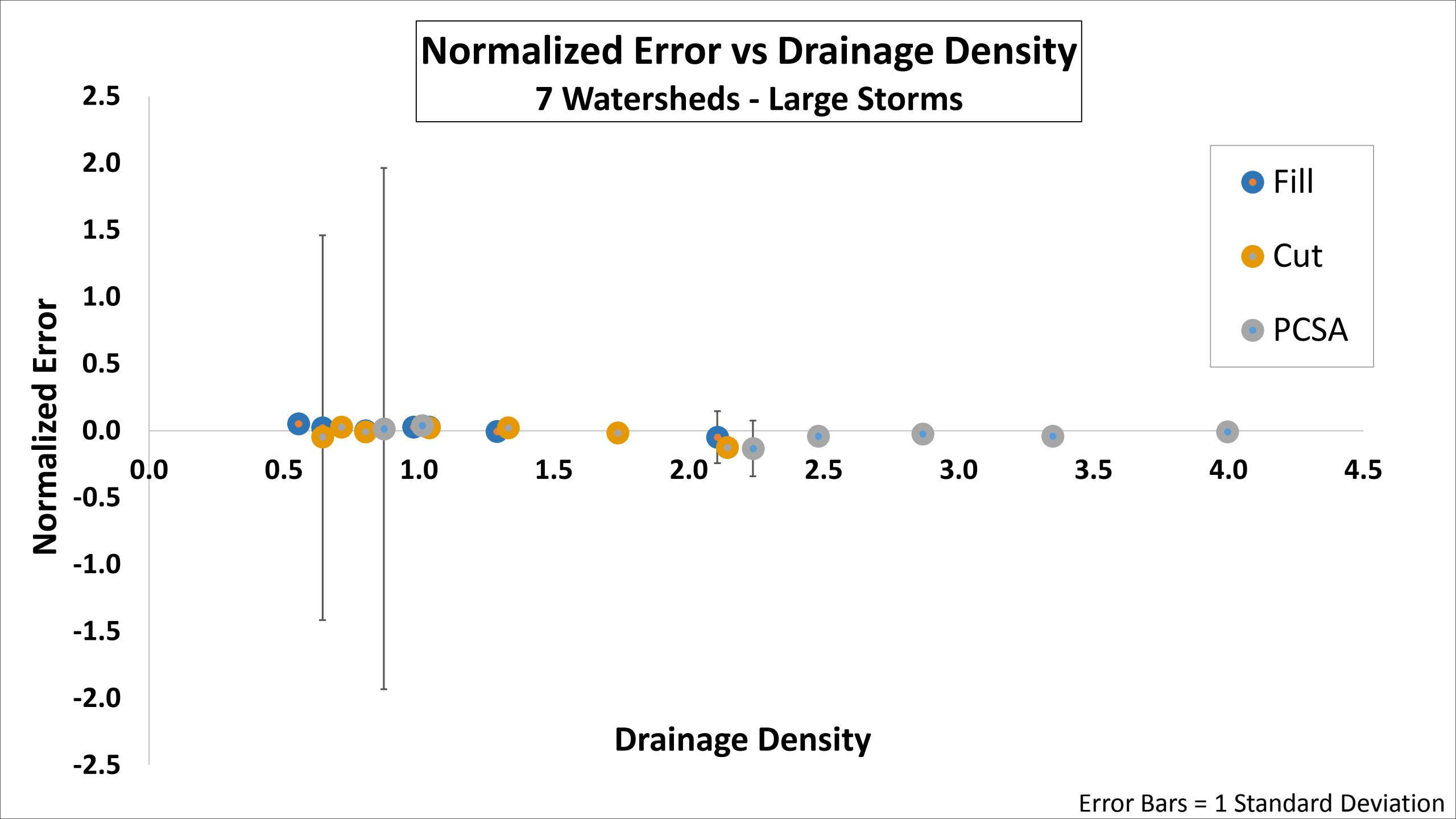
Filled Delineation vs Drainage Density

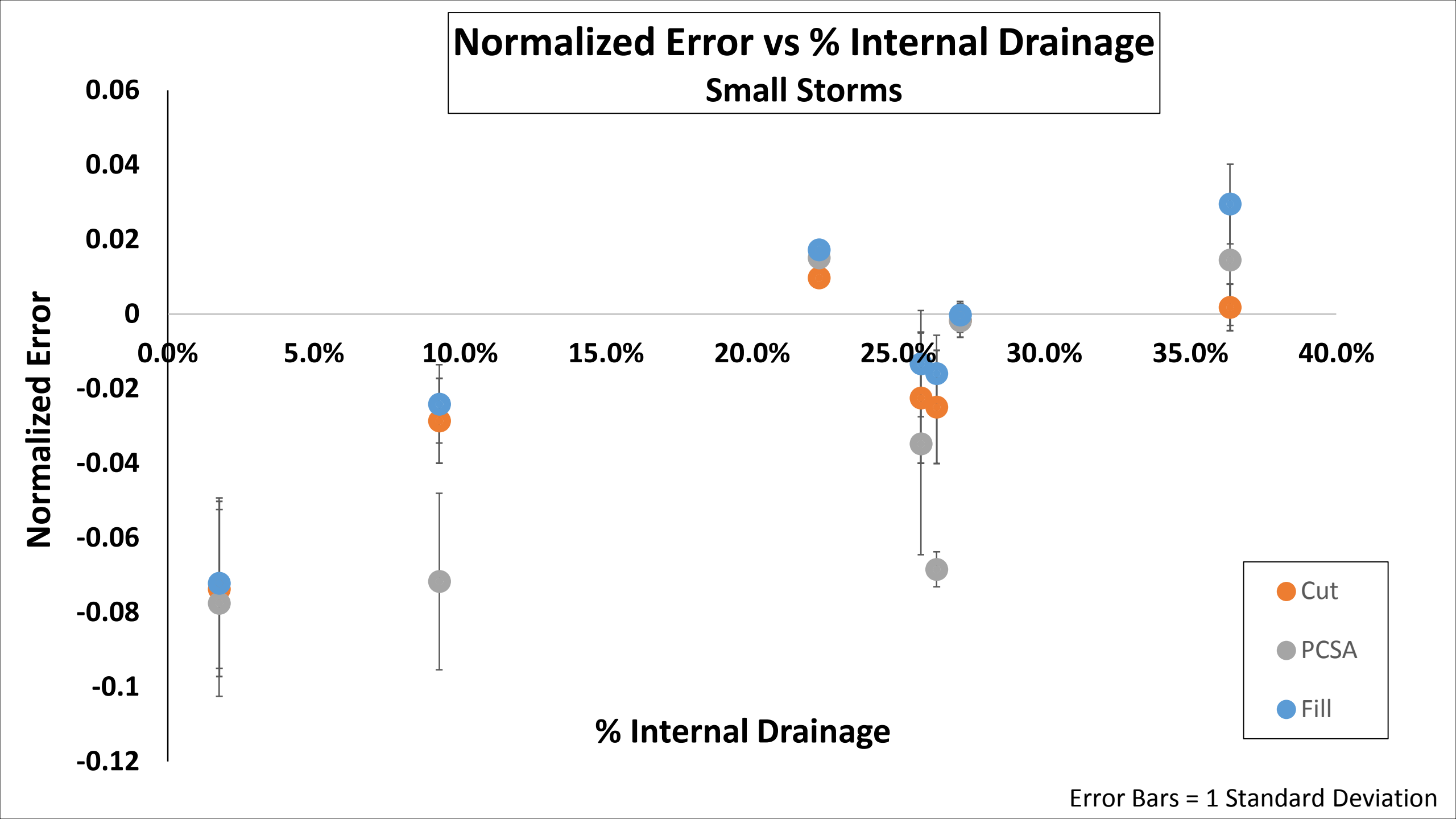
Small Storms



Error Bars = 1 Standard Deviation

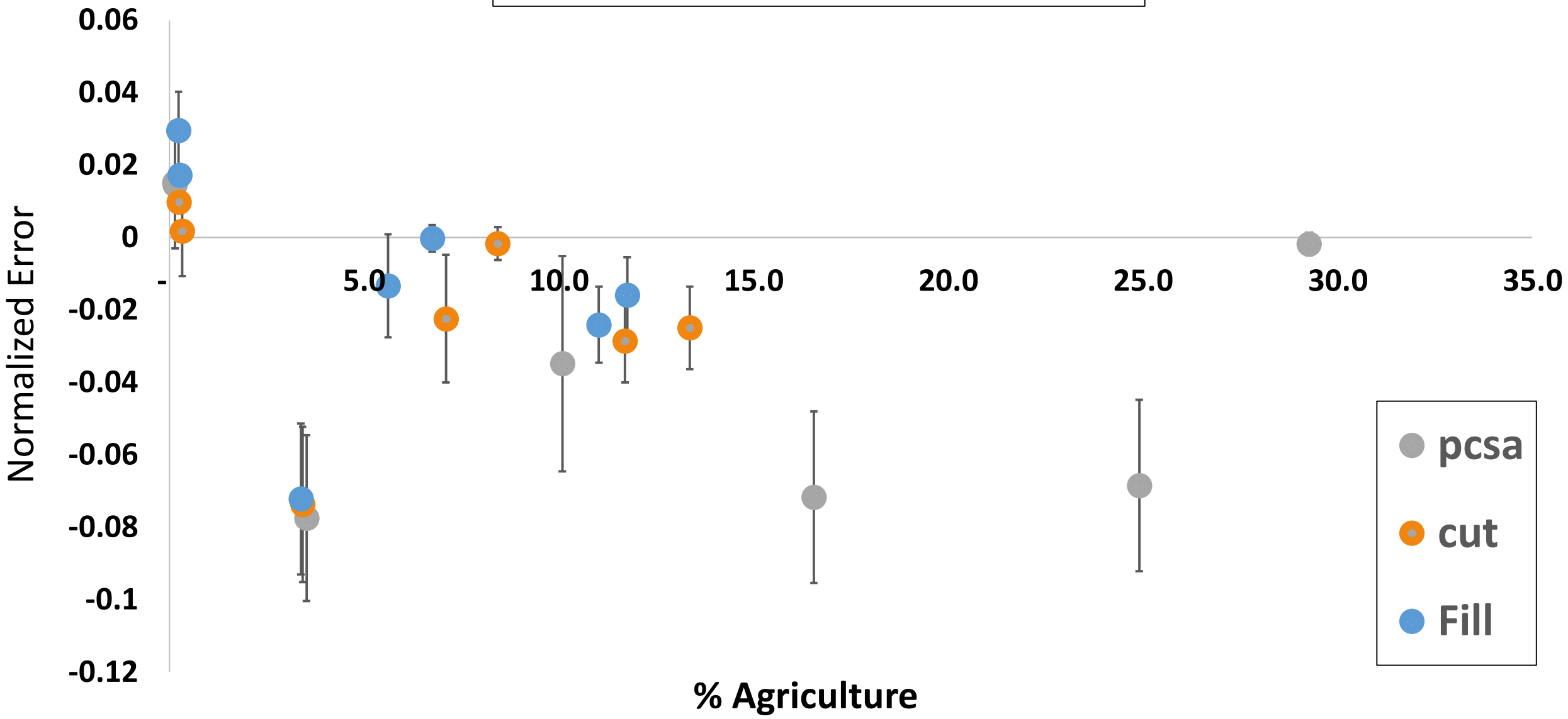

Normalized Error vs Drainage Density
7 Watersheds – Small Storms
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
Normalized Error
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Drainage Density
Fill
Cut
PCSA
Error Bars = 1 Standard Deviation


Normalized Error vs Drainage Density
7 Watersheds - Large Storms
Normalized Error
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Drainage Density
Fill
Cut
PCSA
Error Bars = 1 Standard Deviation

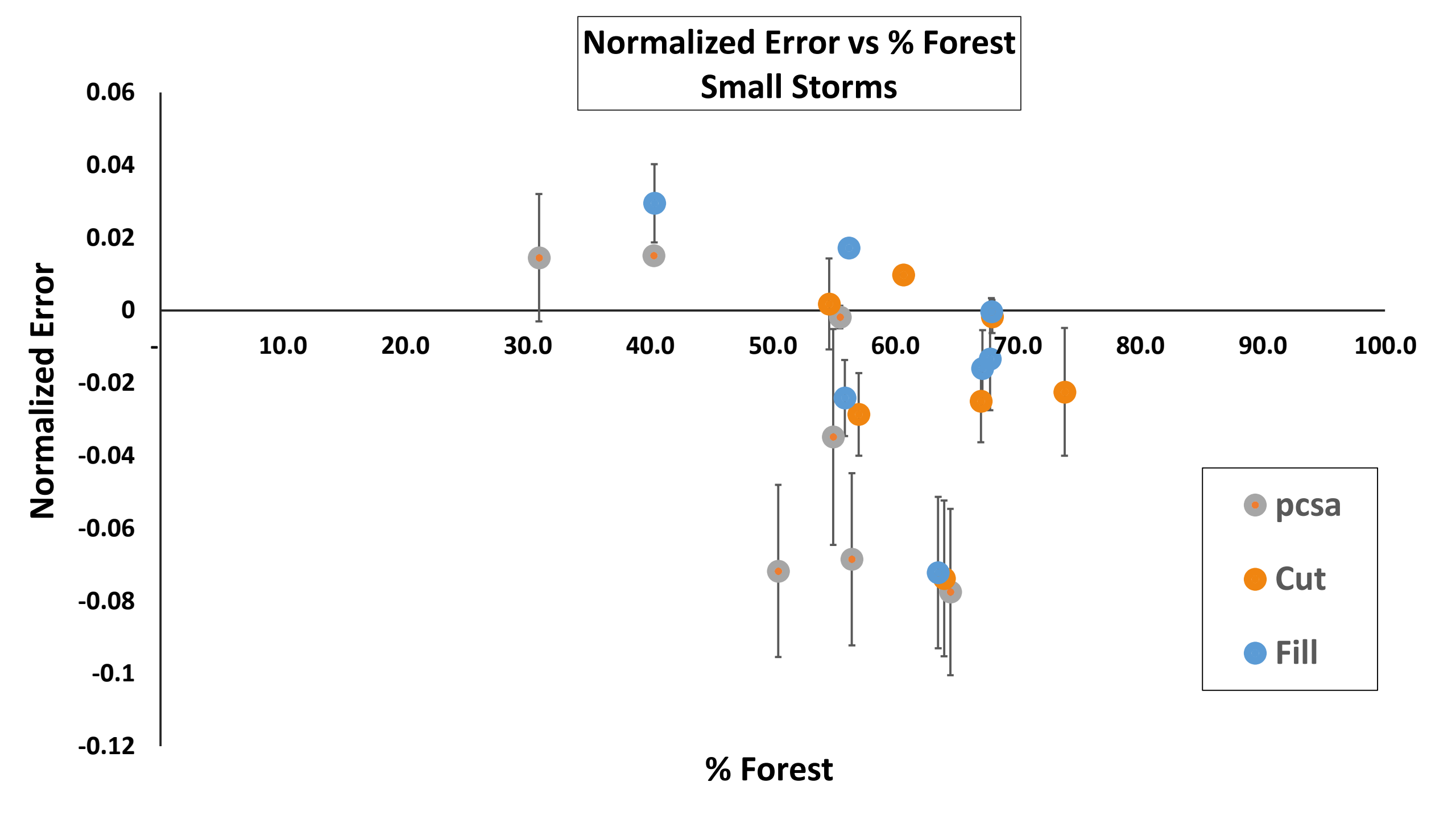

Normalized Error vs % Internal Drainage
Small Storms
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
Normalized Error
0.0%
5.0%
10.0%
15.0%
20.0%
25.0%
30.0%
35.0%
40.0%
% Internal Drainage
Cut
PCSA
Fill
Error Bars = 1 Standard Deviation

Normalized Error vs % Agriculture

Small Storms



Error Bars = 1 Standard Deviation


Normalized Error vs % Forest
Small Storms
Normalized Error
0.06
0.04
0.02
0
-
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
% Forest
pcsa
Cut
Fill

Conclusions

Based on Current Watersheds:

For Large Storms

- All models perform similarly
- Accounting for individual Watershed & Storm Characteristics is key

For Small Storms

- PCSA tends to underestimate
  - More suited for surface water pollutants than direct runoff volumes?
- Additional calibration required for PCSA?
  - Culverts, Overflowing wetland sinks

Additional Questions

- Why does model performance vary with storm size?
  - Are there other important variables?
    - Relief
    - Watershed Shape
  - Is antecedent moisture being accounted for?

- 3-5 additional watersheds being modeled
  - 10-12 watersheds total

Citations

- Jenson, S.K., Domingue, J.O. *Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis.* Photogrammetric Engineering and Remote Sensing, Vol. 54(11) 1593-1600. November, 1988.
- Macholl, Jacob. *Using a GIS Model to Idntify Internally Drained Areas and Runoff Contribution in a Glaciated Watershed.* Journal of the American Water Resources Assocation, vol. 47, no. 1. February 2011.
- Richards, Paul; Brenner, Andrew. *Delineating Source Areas for Runoff in Depressional Landscapes: Implications for Hydrologic Modeling.* Journal of Great Lakes Research 30(1):9-21. 2004.
- Taylor et al. *Scientific Investigations Report 2012–5071.* USGS, Reston, VA. 2012.
- Van Liew, Green C.H., Starks P.J. *Unit Source Area Data: Can it Make a Difference in Calibrating the Hydrologic Response for Watershed Scale Modeling?* Journal of Soil and Water Conservation. 62(3):162-170. 2007.