High Plains Aquifer and a new method for estimating its hydraulic conductivity

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Outline

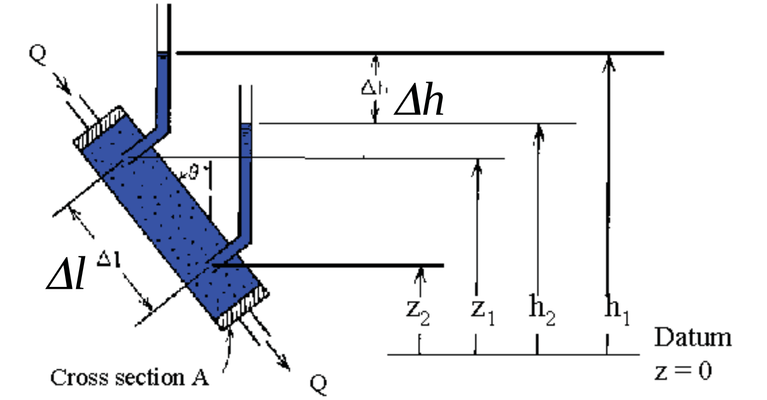
- Introduction
- High plains aquifer
- New methodology
- Parameter estimate
- Result
- Conclusion

Introduction

- Darcy's Law: Rate of flow is proportional to the hydraulic gradient:

$$q = \frac{Q}{A} = -K\frac{dh}{dl}$$

- q =flow rate (volume/time/area)
- dh/dl = hydraulic gradient
- K =hydraulic conductivity



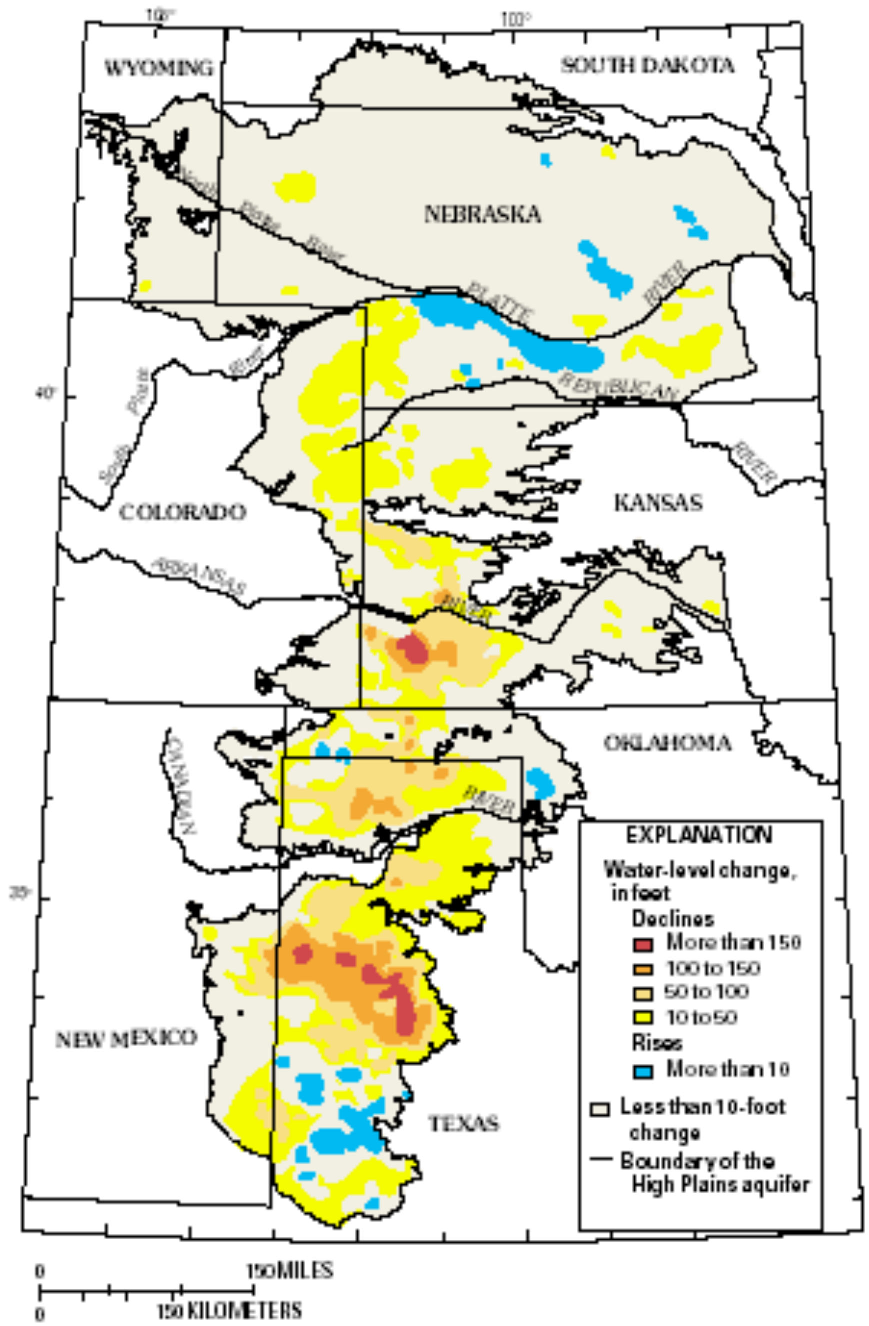
Experimental apparatus for the illustration of Darcy's law. After Freeze and Cherry, 1979

Hydraulic Conductivity (*K*)

- An important parameter in groundwater hydrology that describes the ease at which water moves through a porous medium.
- Function of porous media
- Function of fluid viscosity
- Large range of variability (up to several orders of magnitude).
- Measured by pumping test (expensive and time consuming)
- This study applies a new method for estimating *K* from drainage dissection patterns to High Plains Aquifer

The High Plains Aquifer

- One of the largest in the world, covering of parts of eight States from South Dakota to Texas.
- Unconsolidated alluvial deposits from Rocky Mountains
- Since early 1800s, irrigation water pumped from the aquifer has made the High Plains one of the Nation's most important agricultural areas.
- the intense use of ground water for irrigation has caused upto 100m decline in water-level in parts of Kansas, New Mexico, Oklahoma, and Texas.



Changes in ground-water levels in the High Plains aquifer from before ground-water development to 1997. (V.L. McGuire, U.S. Geological Survey, written commun., 1998.)

K is critical for water management and addressing water quality issues

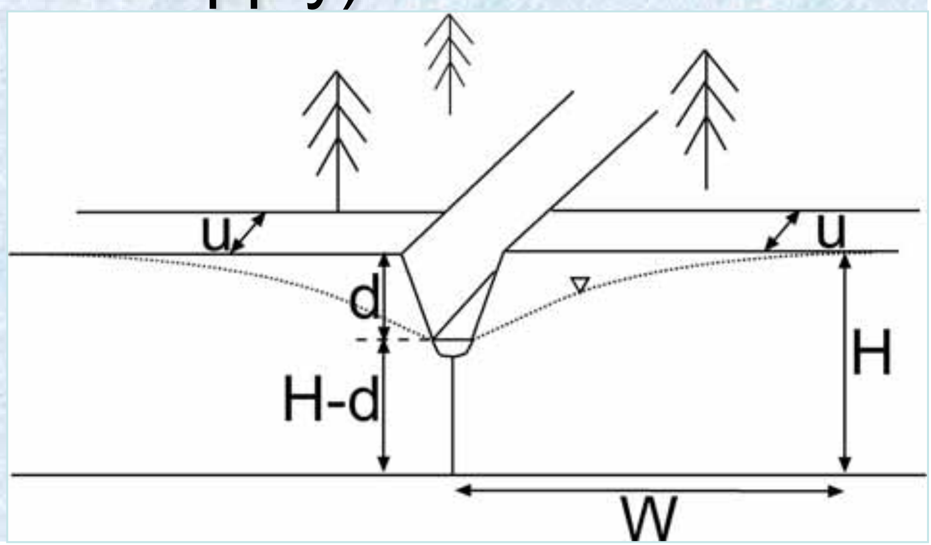
New Method to estimate *K*

- Groundwater and surface water are intimately related
- More permeable surface -> low drainage density
- Less permeable surface -> high drainage density
- Analogy: golf course irrigation system
- Equilibrium: drainage pattern -> *K*

Methodology

- Assumptions:
  - Aquifer is effectively drained (Steady state dynamic equilibrium developed over a long time).
  - Flow is primarily horizontal (Dupuit-Forchheimer assumptions apply).

H [L] = aquifer thickness
d [L] = valley depth
W [L] = effective drainage length
u = unit length (*u*=1)



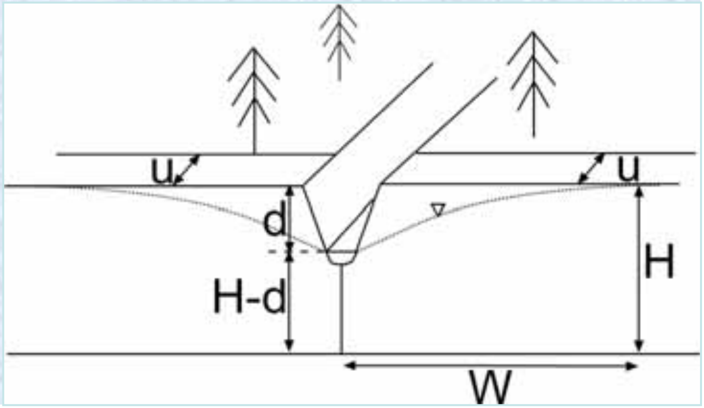
Methodology

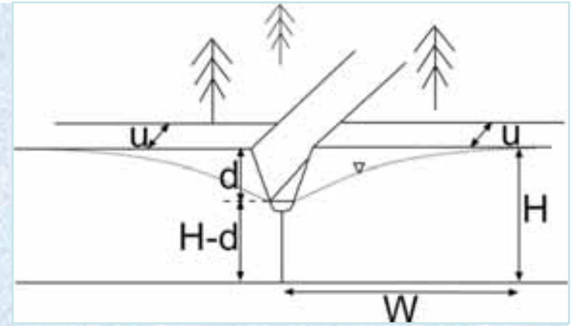
- The discharge per unit length (u=1) of the channel q' [L^2T^{-1}] is (Deming, 2002):

$$q' = \frac{1}{2} K \left(\frac{H^2 - (H-d)^2}{W} \right) \quad (1)$$

- Rearranging equation (1) to solve for hydraulic conductivity K [LT^{-1}] is:

$$K = \frac{2q'W}{H^2 - (H-d)^2} \quad (2)$$





$$K = \frac{2q'W}{H^2 - (H-d)^2} \qquad (2)$$

- *q'* can be estimated from precipitation (*p* [LT^{-1}]) and infiltration percentage (*i* [%, dimensionless]), assuming a steady state condition:

$$q' = \frac{p \times i \times (2Wu)}{u} = 2p \times i \times W \qquad (3)$$

$$K = \frac{4piW^2}{H^2 - (H-d)^2} \qquad (4)$$

H [L] = aquifer thickness
d [L] = valley depth
W [L] = effective drainage length
p [LT^{-1}] = preciptation
i = infiltration %

Parameter estimate

Table 1. Infiltration Percentage of Different Soil Type

Soil Type	Assigned Infiltration Percentage *i* (%)
Clay loam	2
Loam	5
Silt loam	8.5
Sandy loam	13
Sand	18
Caliche	1

- *H*: from existing data in GIS
- *p*: from 30-year annual mean precipitation
- *i*: determined by soil property
- *W*: estimated from DEM in GIS using downslope flowlength averaged by watershed
- *d*: estimated from DEM in GIS using Black Top Hat Transformation

$$K = \frac{4piW^2}{H^2 - (H-d)^2} \quad (4)$$

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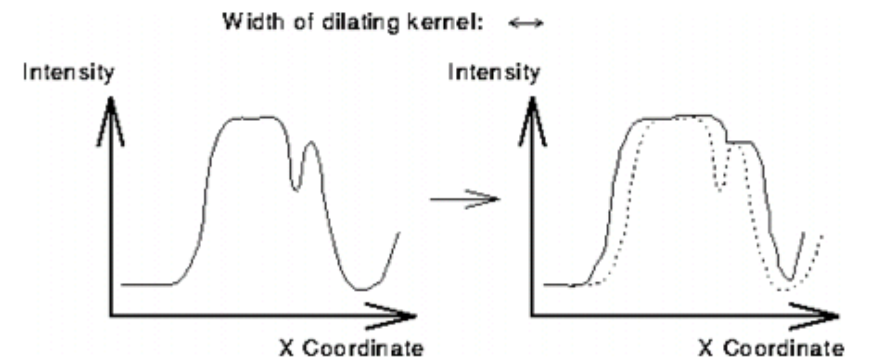
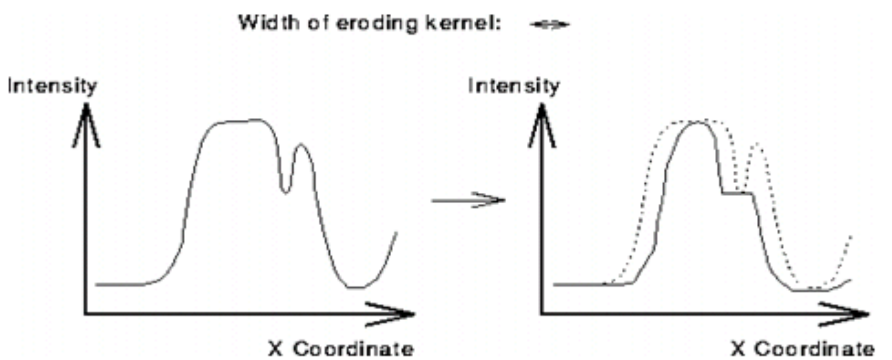
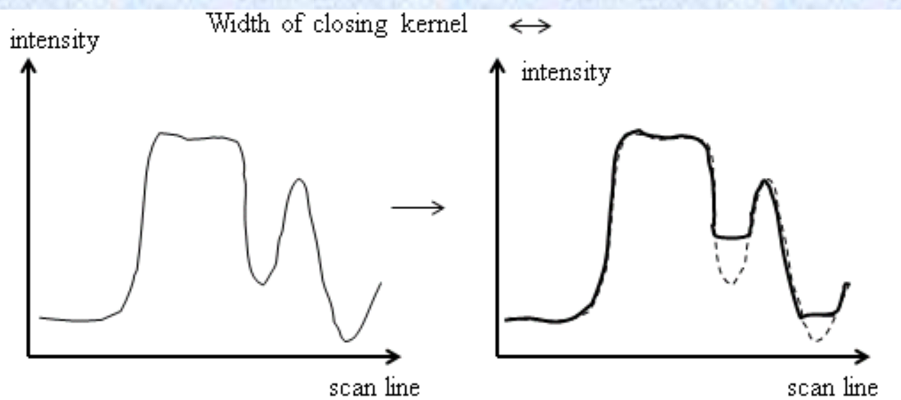


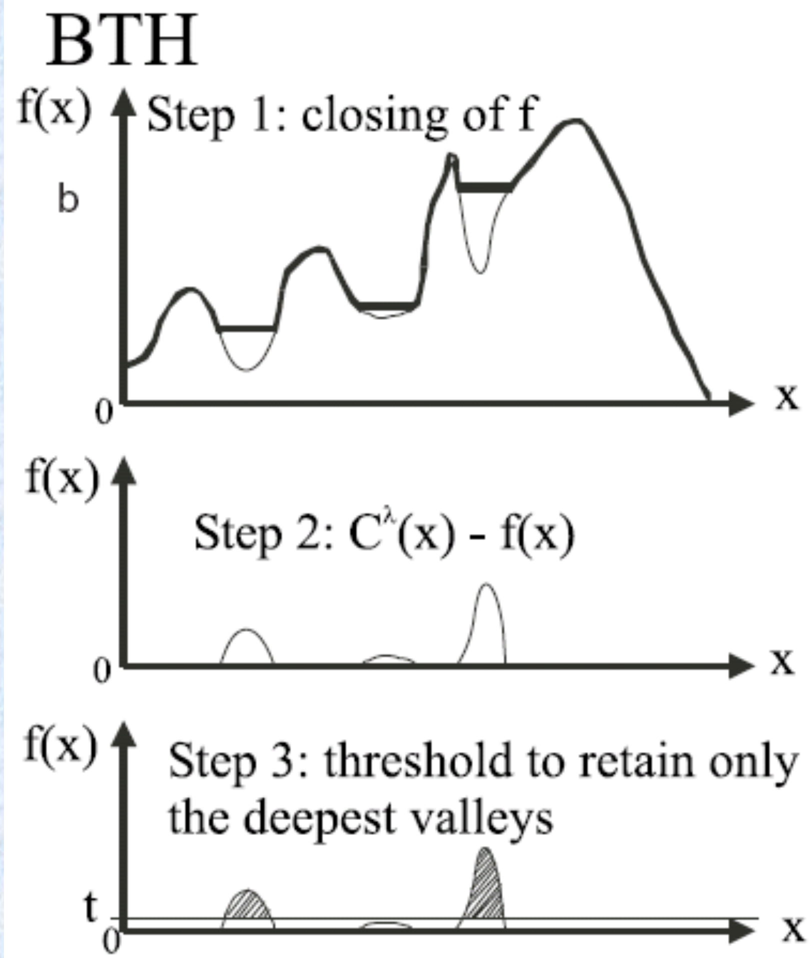
Dilation: find maximum within a moving window



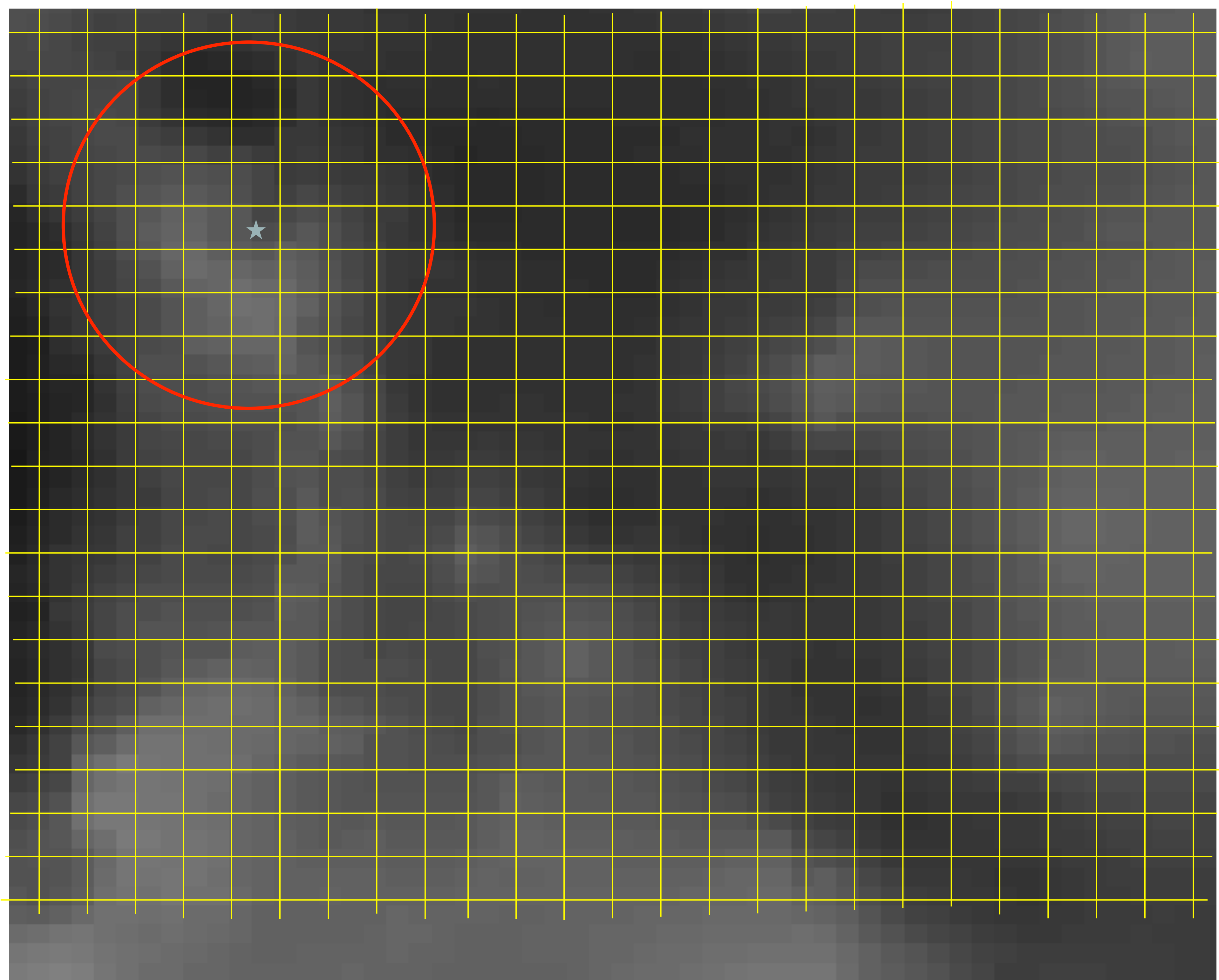
Erosion: find minimum within a moving window



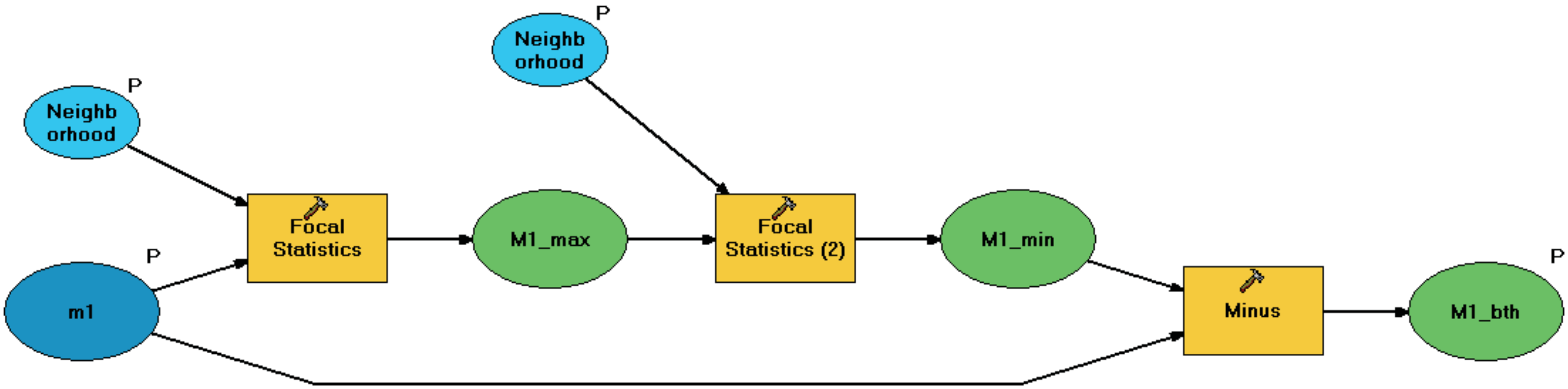
Closing: do dilation, then do erosion



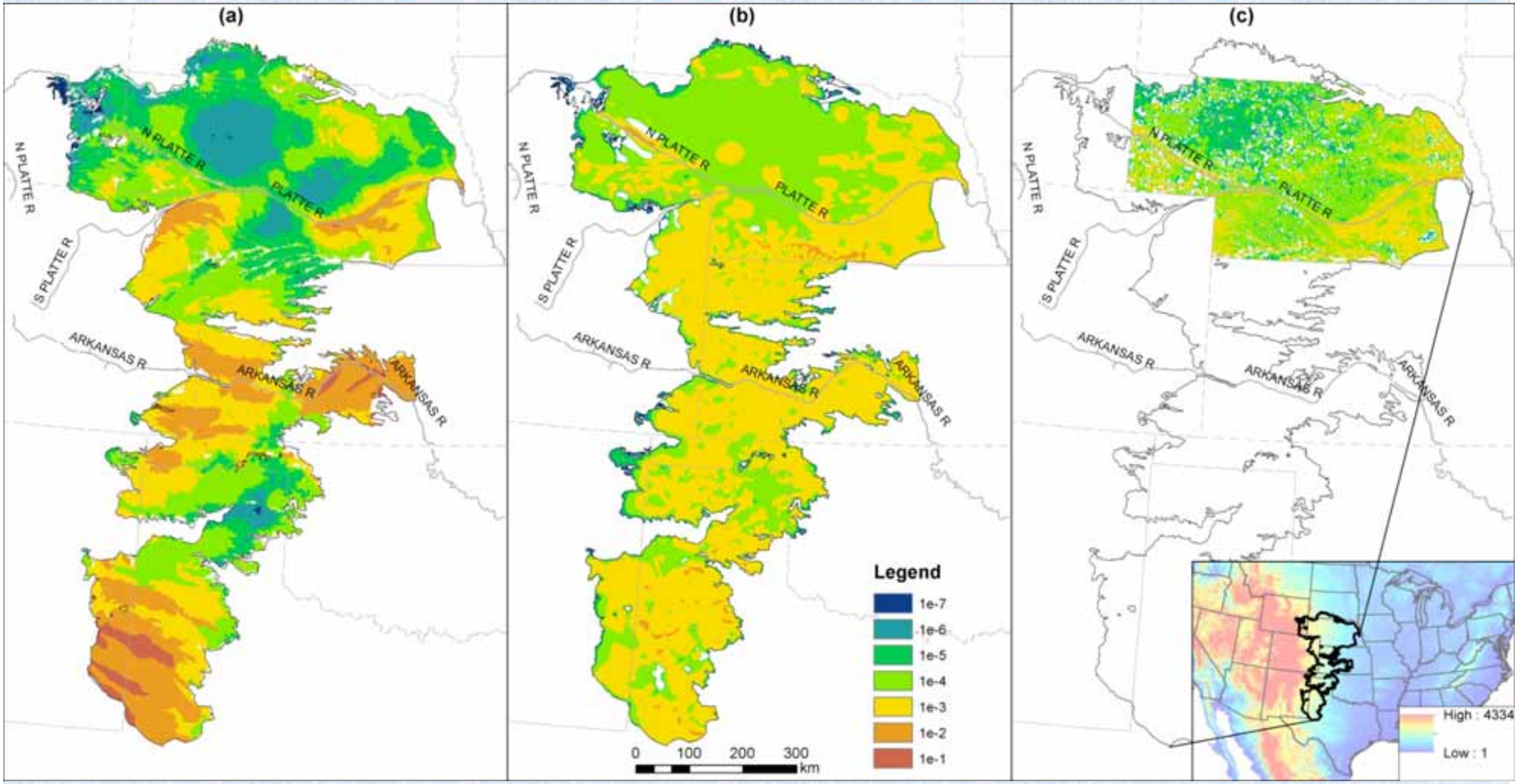
Black Top Hat transofrmation
= closing – original



BTH Function as a model



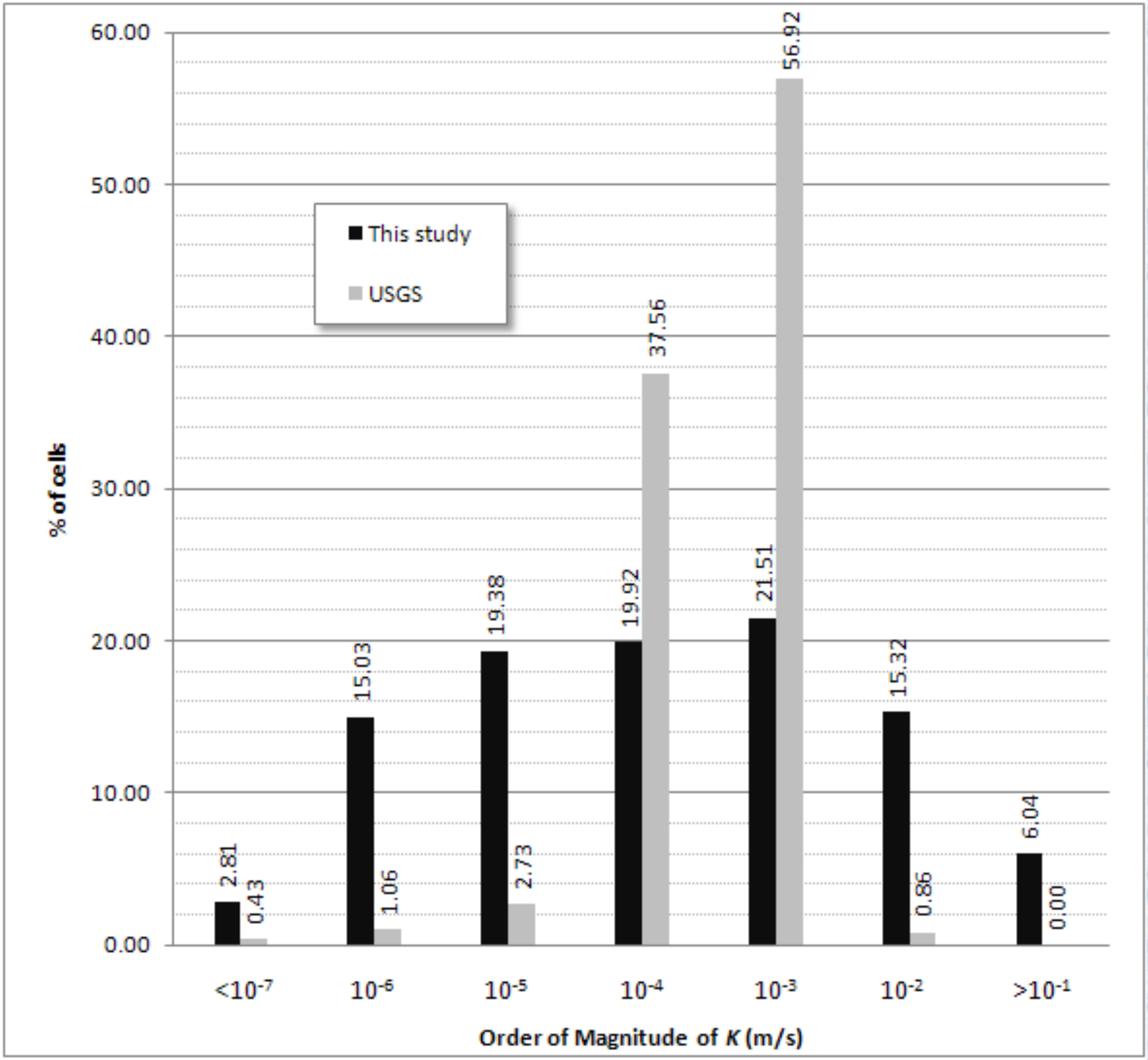
Neighborhood: circular, radius = 2.2 km



Our result

USGS data

Result from well pump data
In Nebraska



60.00
50.00
40.00
30.00
20.00
10.00
0.00
% of cells
This study
USGS
2.81
0.43
15.03
1.06
19.38
2.73
19.92
37.56
21.51
56.92
15.32
0.86
6.04
0.00
<10-7
10-6
10-5
10-4
10-3
10-2
>10-1
Order of Magnitude of K (m/s)

Conclusion

- Our method offers an effective and efficient alternative to existing methods for determining the detailed spatial variation of effective horizontal *K* in regional aquifer system (~100s km scale); good for remote or inaccessible area
- Result reveals a distinct relationship between surface drainage density and subsurface aquifer *K* on a regional scale.
- Result shows the pattern of sediment deposition by rivers draining the Rocky Mountains; can be used to study past sedimentation process

THANK YOU!
Questions?

- Luo, W., D.T. Pederson, 2012, Hydraulic conductivity of the High Plains Aquifer re-evaluated using surface drainage patterns, *Geophysical Research Letters*, v. 39, L02402, doi:10.1029/2011GL050200