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Hydrologic Connectivity of Drained Wetlands in Iowa's Prairie Pothole Landscapes

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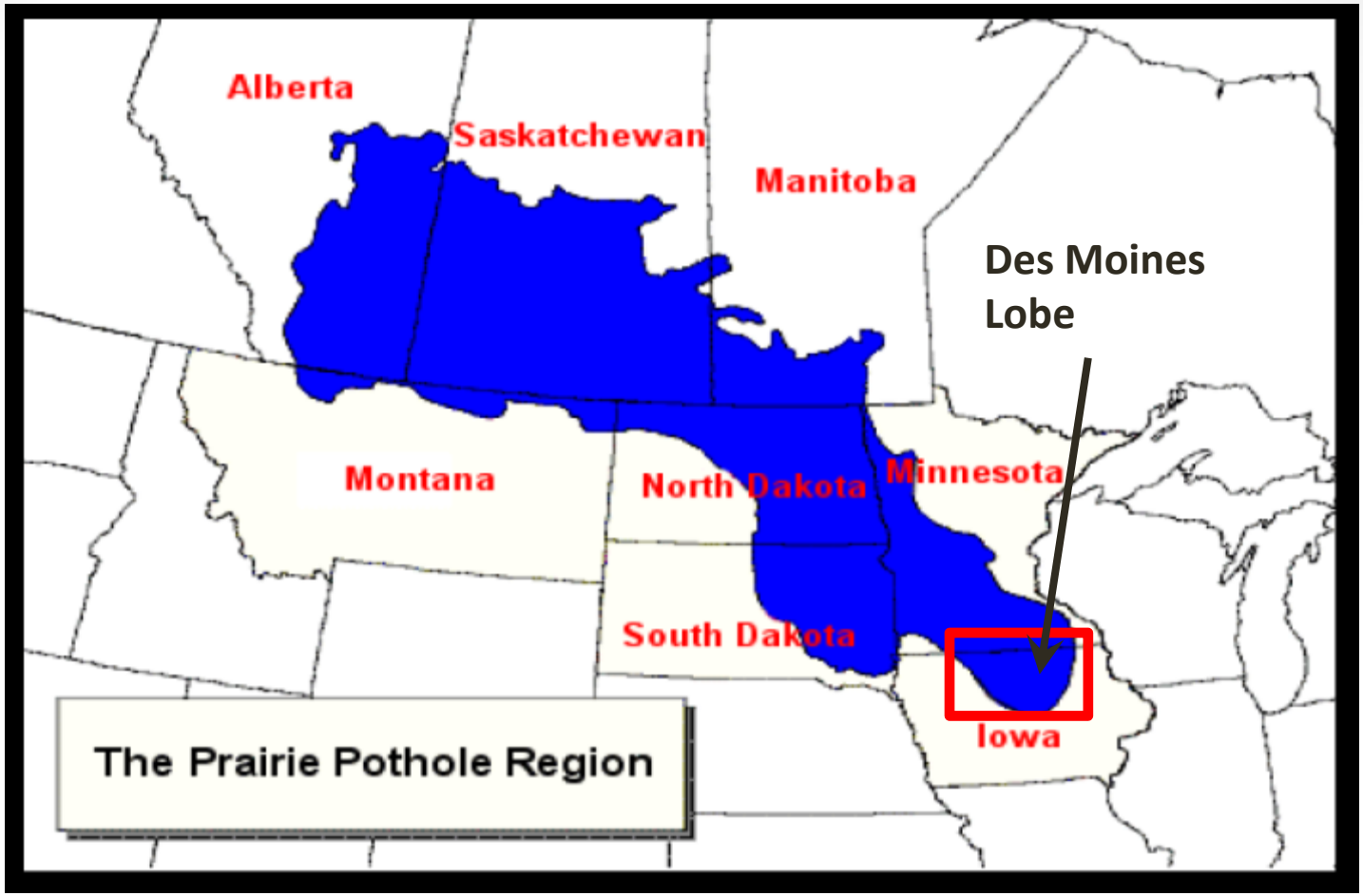
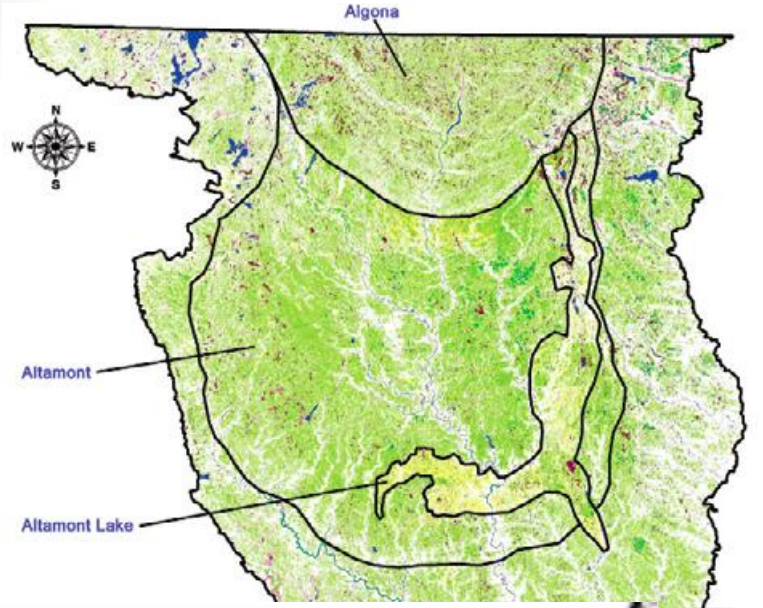
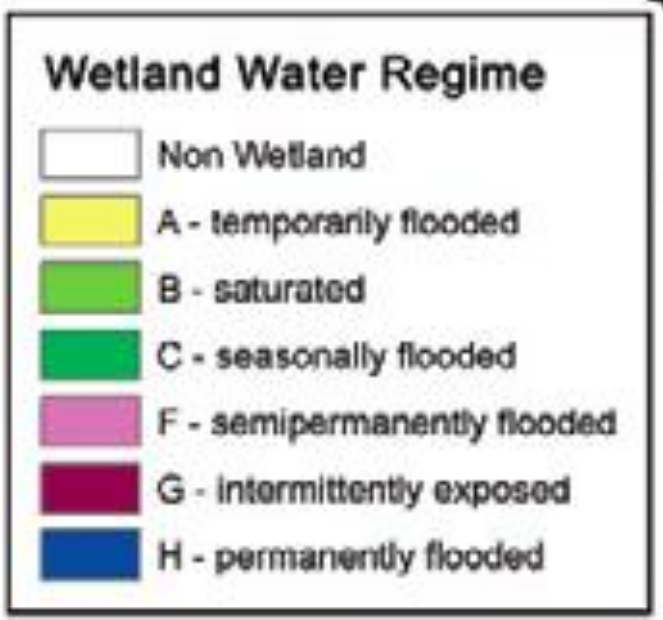


- Area greater than 700,000 km^2 characterized by depressional or palustrine wetlands locally called prairie potholes
- Created by the retreat of the Wisconsin-age Glaciers
- In Iowa, organized drainage in the late nineteenth and early twentieth century resulted in most potholes being drained and converted into agriculture
- Estimated wetland losses in the Des Moines Lobe: 95 – 99%
- Research to date has focused more on the north-westerly prairie pothole regions..

Spatial Distribution of Historical Wetland Classes on the Des Moines Lobe, Iowa



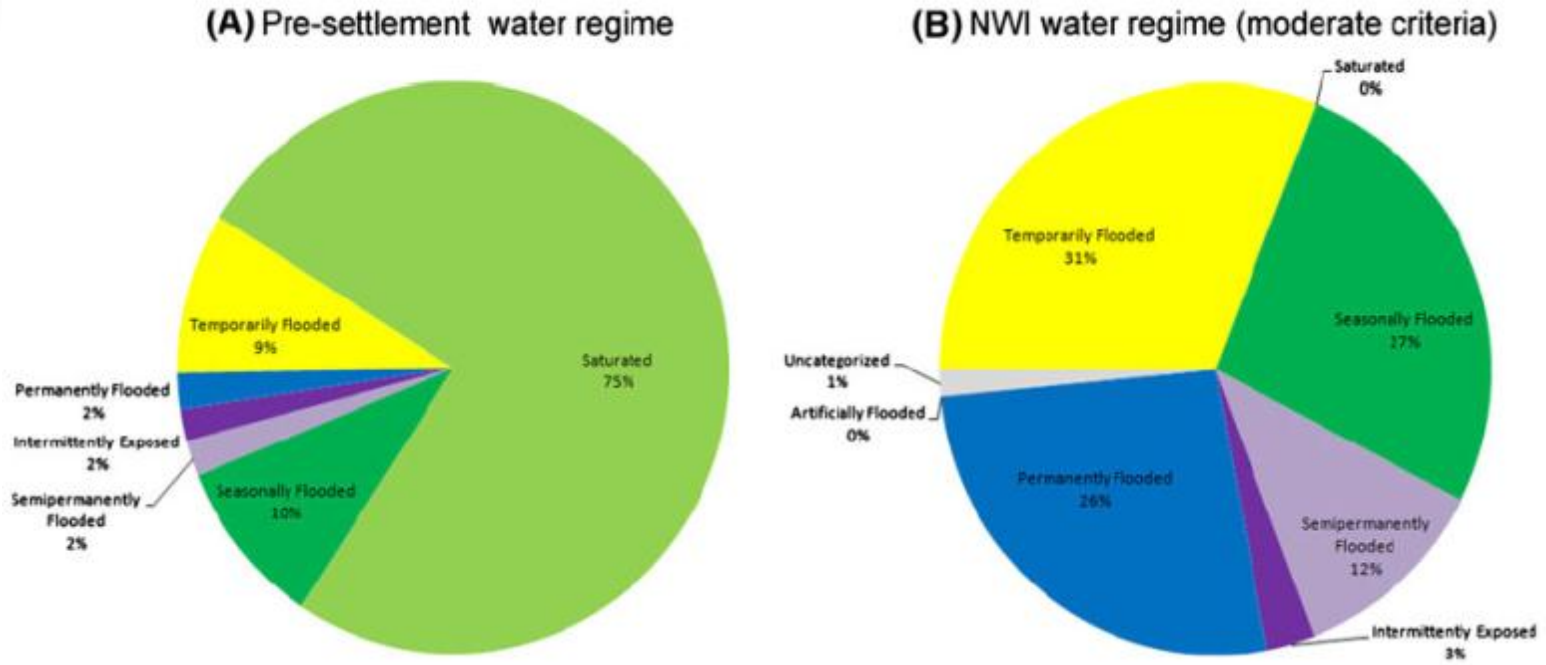


- Small and shallow potholes were easier to convert to farmlands than large deep ones
- Pre-drainage wetlands mostly in the saturated regime, while now mostly in semi-permanently or permanently flooded regime

Increase in Hydroperiod

Miller et al. (2009)

Wetland hydrologic class change from prior to European settlement to present on the Des Moines Lobe, Iowa … Miller et al. (2012)



- Restoration today is focused on larger wetlands with longer hydro-periods
- But loss of the smaller wetlands had a significant affect on the diversity of plants and animals
- Shouldn't we focus on restoring the wetland size distribution, instead of simply wetland area?
- Which wetlands to restore, and where in the landscape?

Iowa Wetland Assessment and Restoration Plan

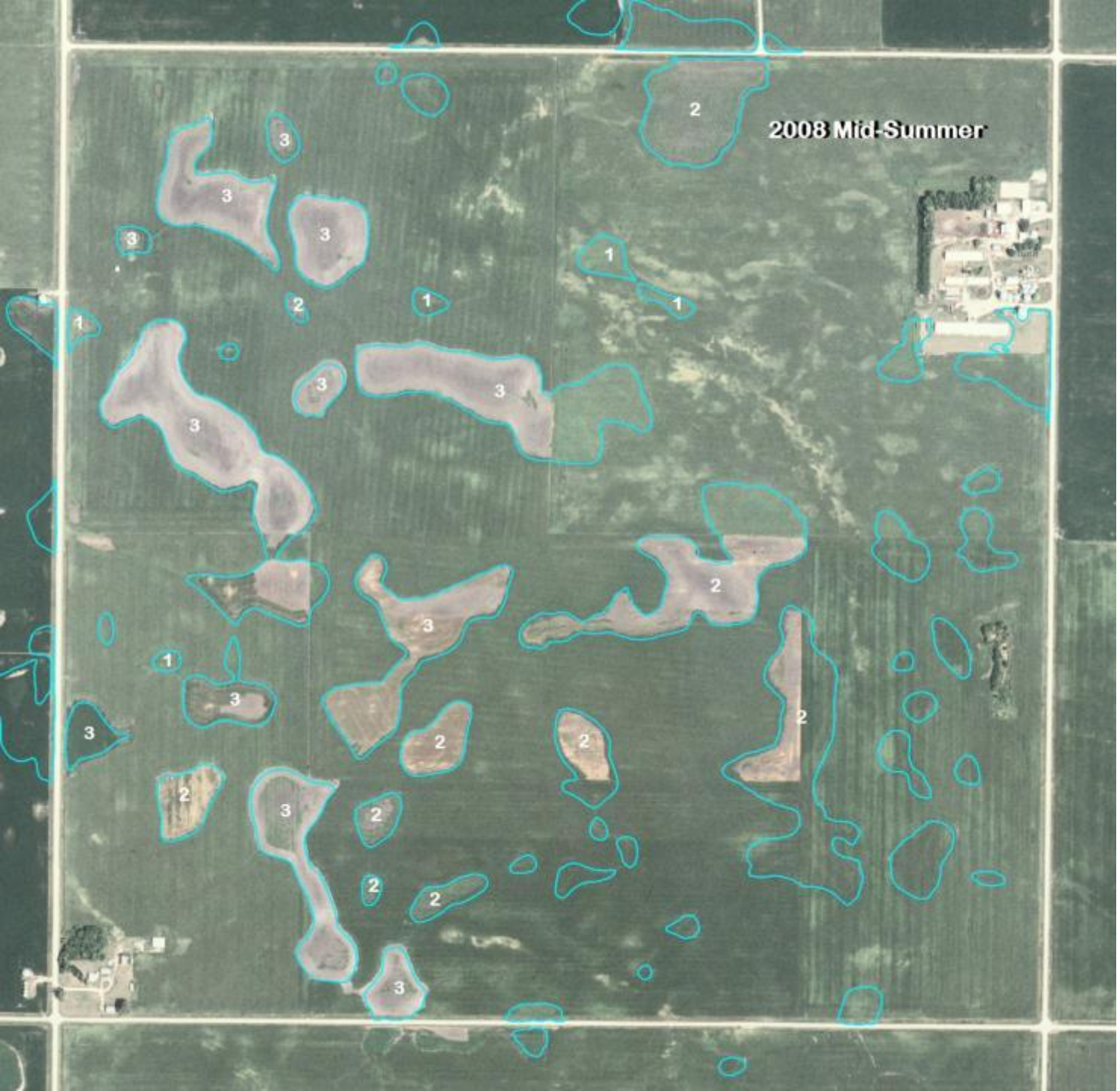
Objective: Develop a defensible understanding of the breadth of wetland restorations required to have a significant impact on water quality, flooding, and habitat concerns

Opportunity:

- Billions need to be spent on Iowa's drainage infrastructure for farmlands to be productive
- LiDAR – provides a new ability to map and model our landscape

- Consistent yield losses in depressional areas for multiple years an argument for additional tile drainage -- The Iowa Plan
- Or…restore some of these to wetlands?

Slide courtesy of Chris Ensminger at Iowa DNR



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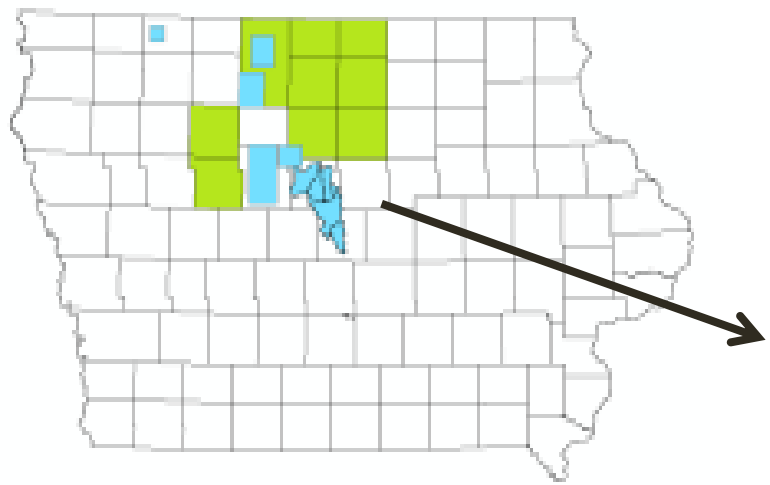
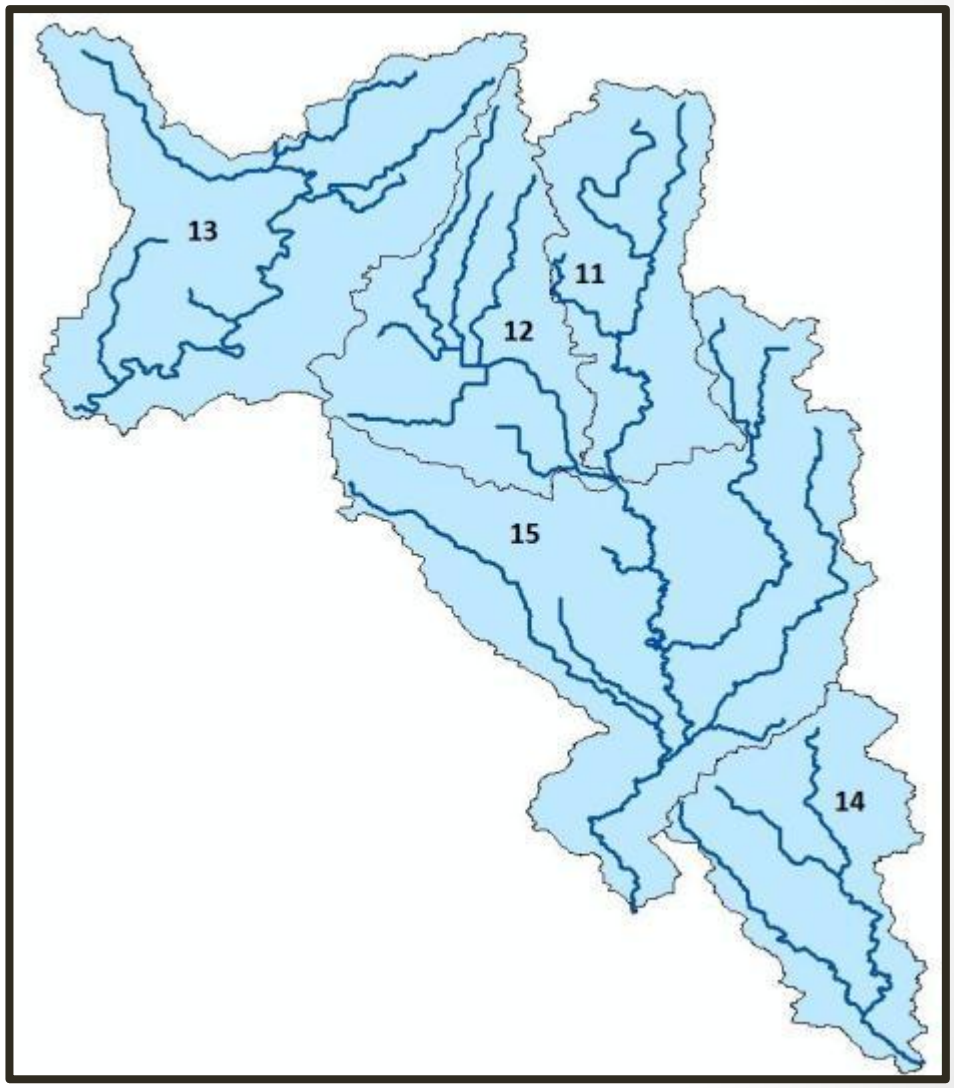
Questions

- What are the attributes (size classes, volumes) of these depressional areas over the landscape? Is there a method to the madness?
- Legacies and Trajectories: How have these areas been modified as a function of past climate and land-use shifts? How do we expect these regions to change as a function of climate and land-use changes?
- How are the depressional areas connected – in space and in time?

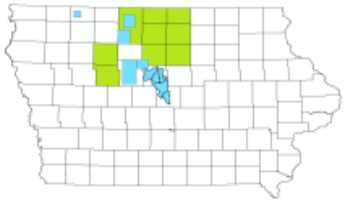
LIDAR





ID	Area (km²)
11	172
12	207
13	319
14	182
15	470

LIDAR



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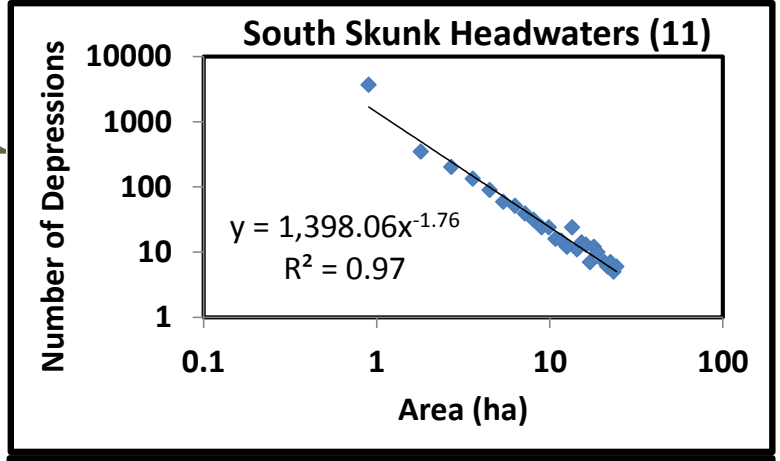
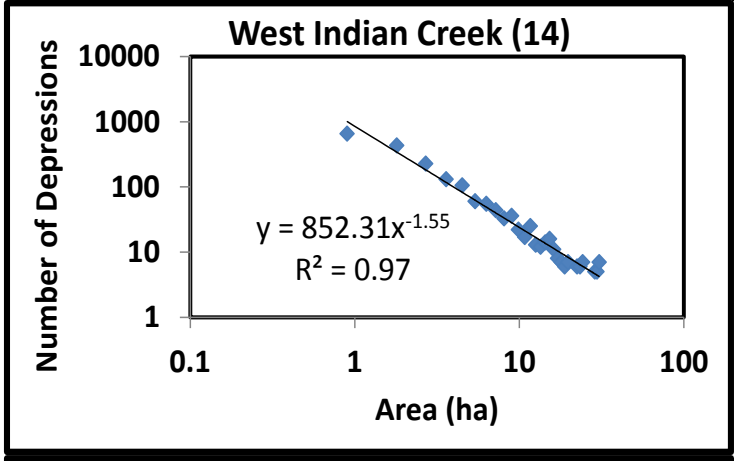
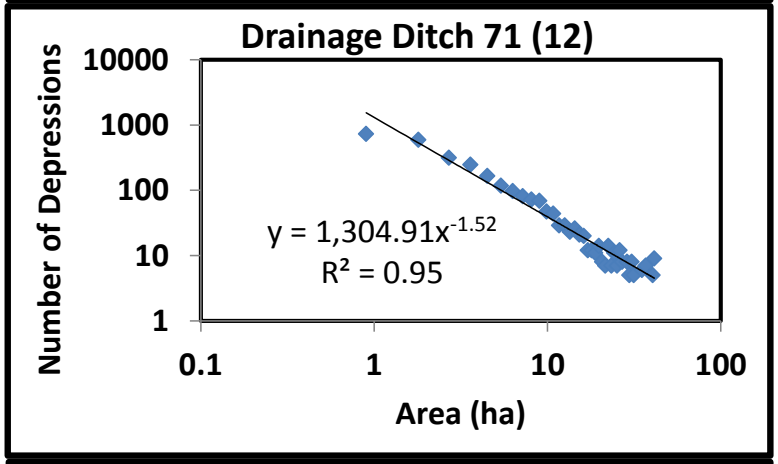
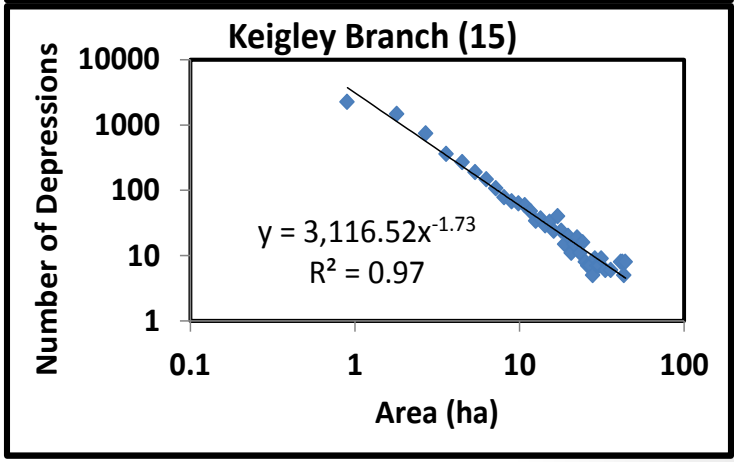
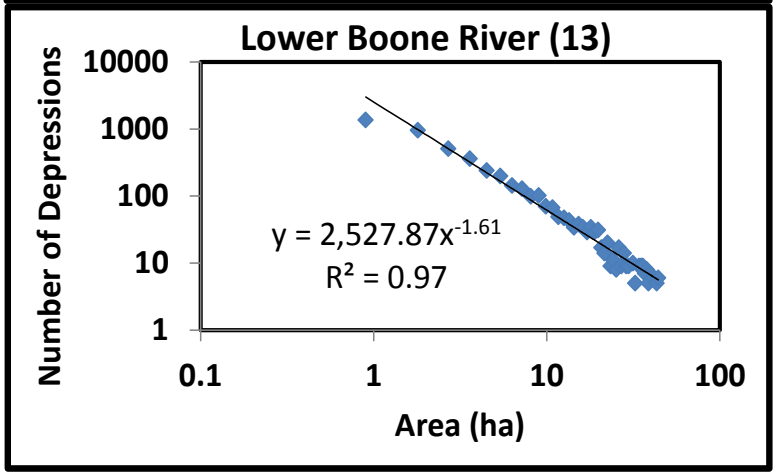




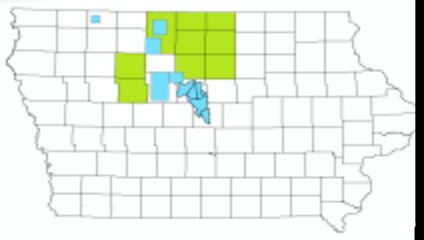


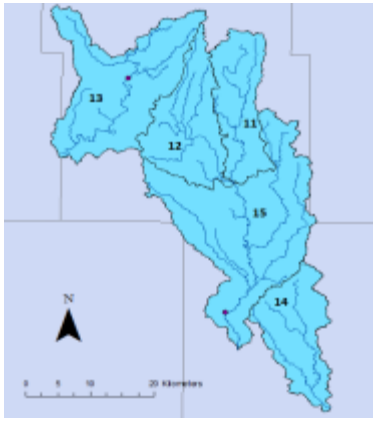




1. Strong power function area-frequency relationships
2. Narrow range of slopes: – 1.5 – 1.76 (compare with Zhang et al. -- - 1.6 to – 1.8)
3. Larger variation in intercepts – dependence on area?

LIDAR





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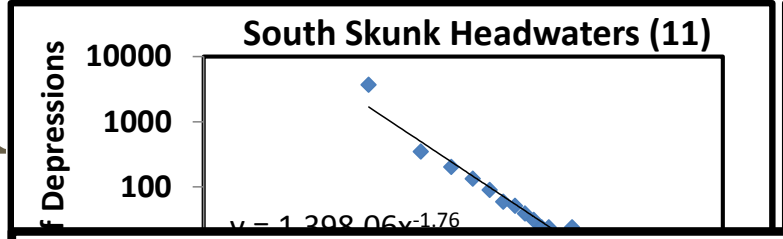
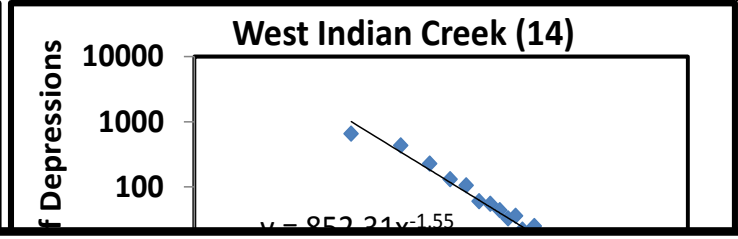
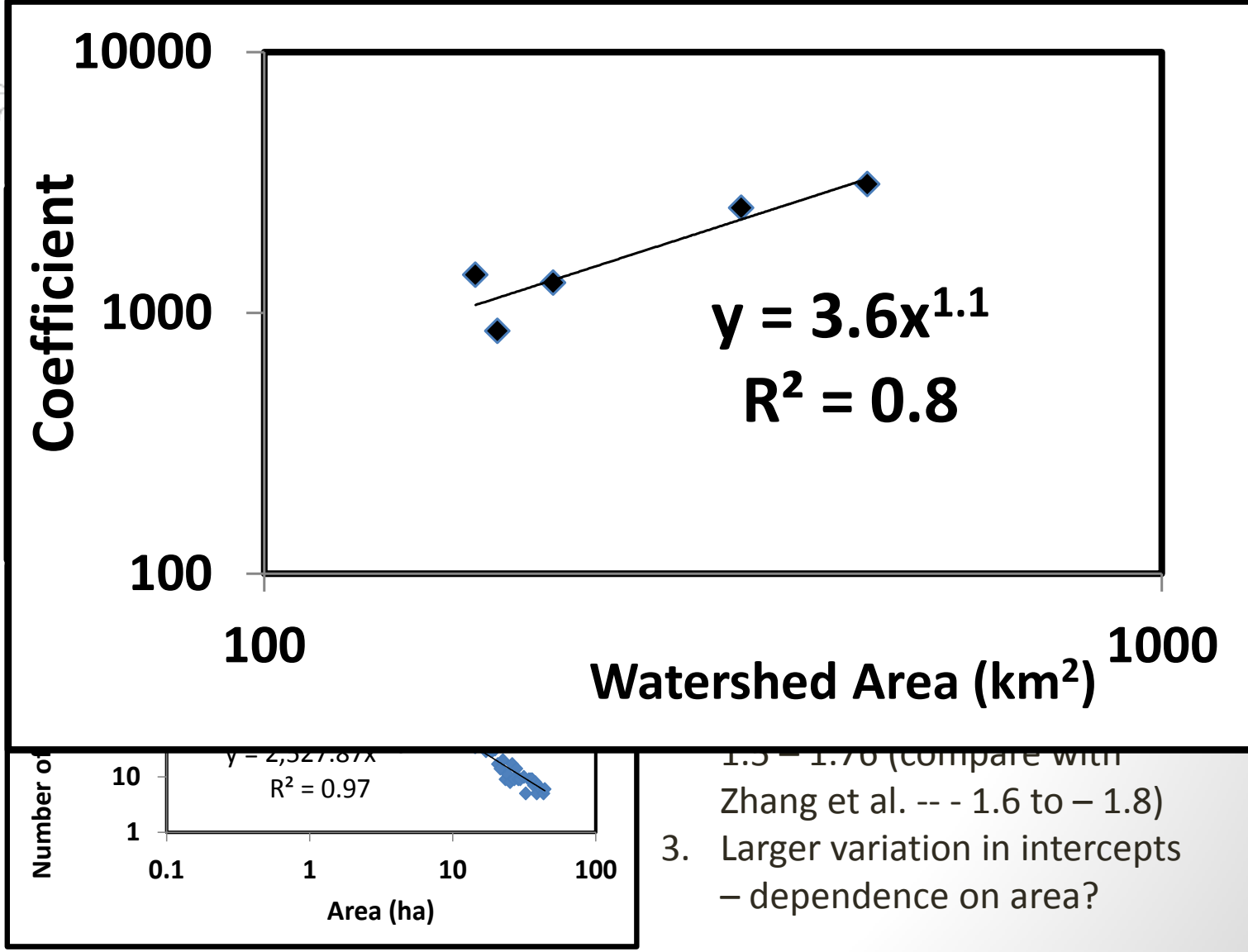


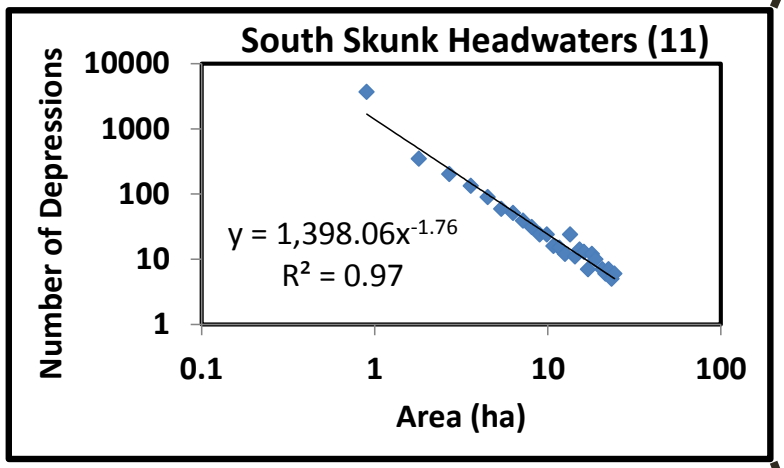


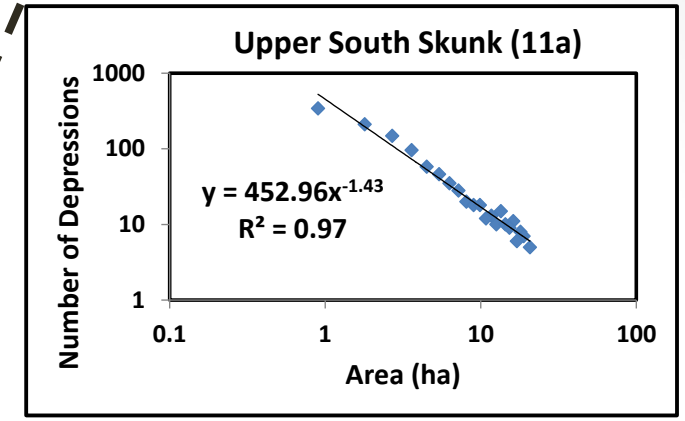


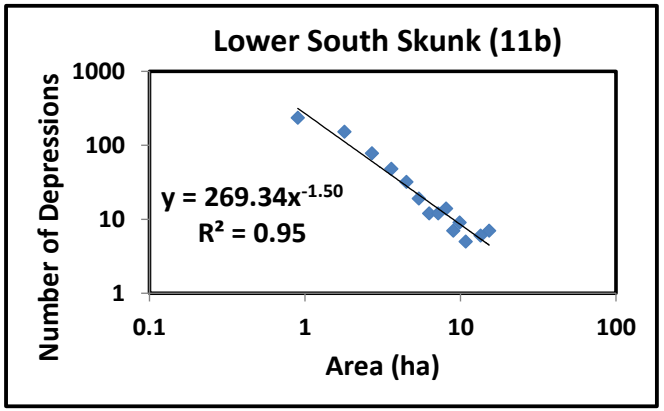
1.5 – 1.76 (compare with Zhang et al. -- - 1.6 to – 1.8)

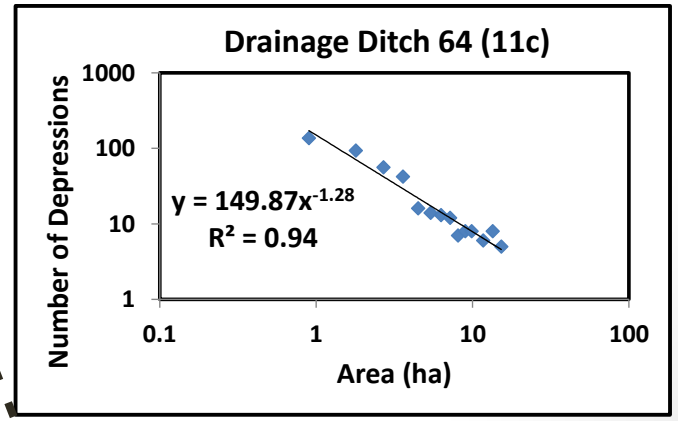
3. Larger variation in intercepts – dependence on area?

Lets zoom in further…..

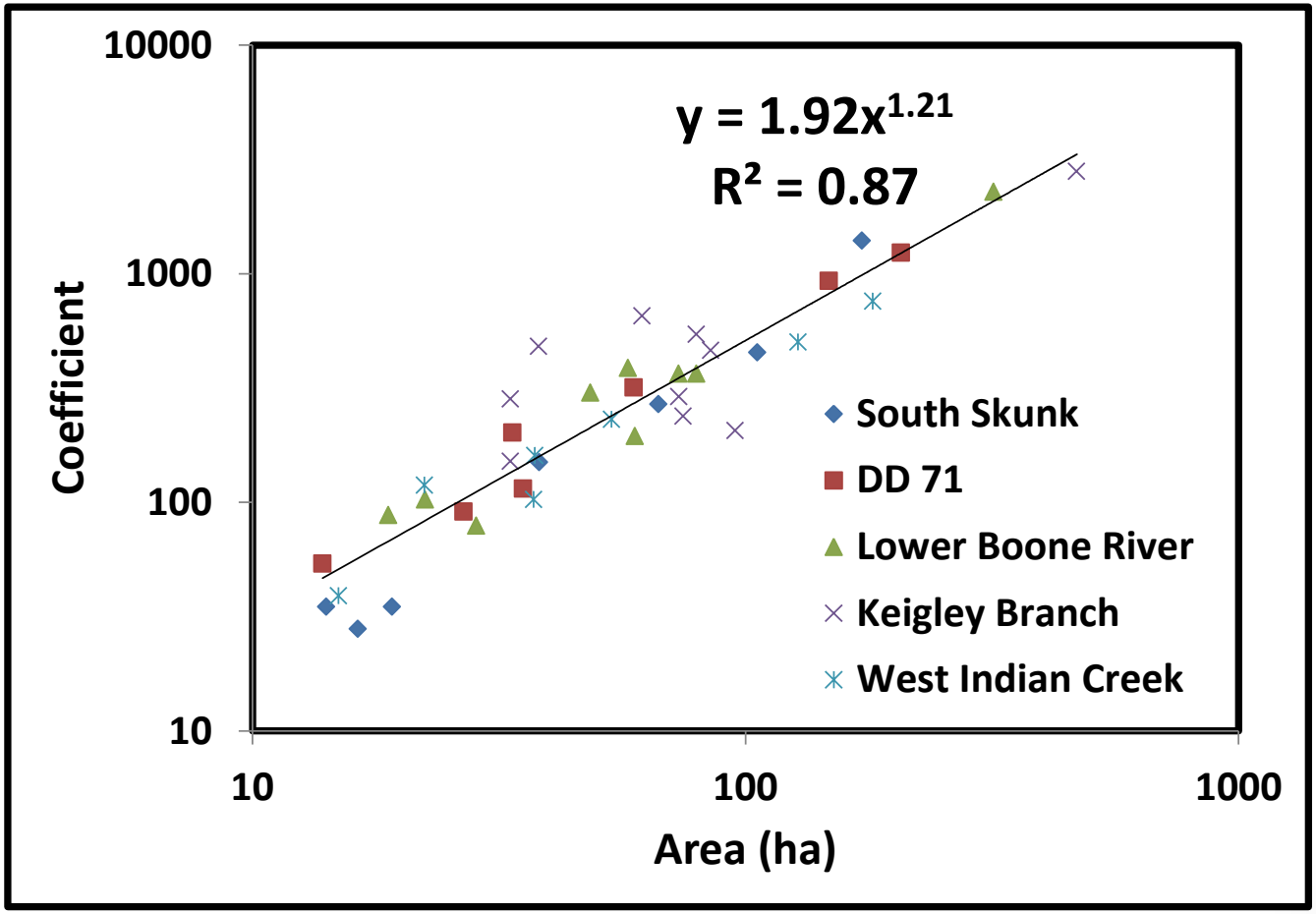




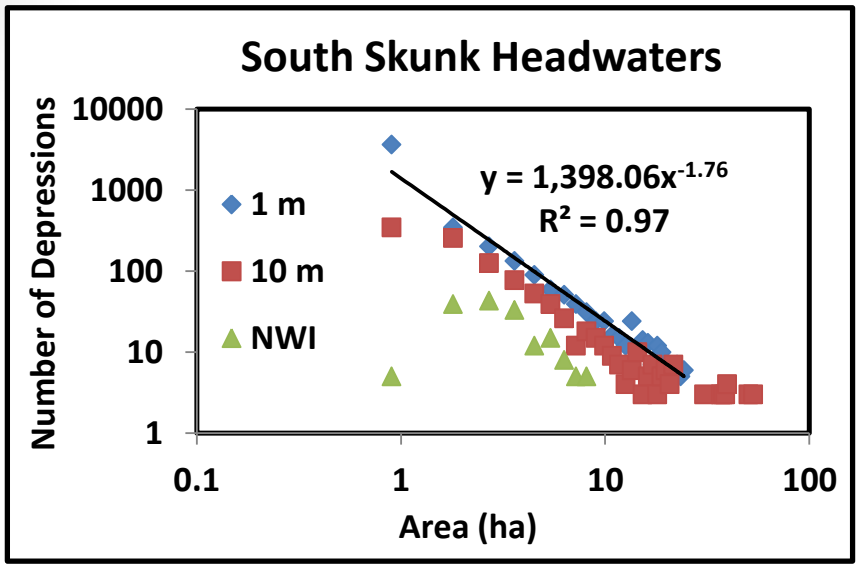


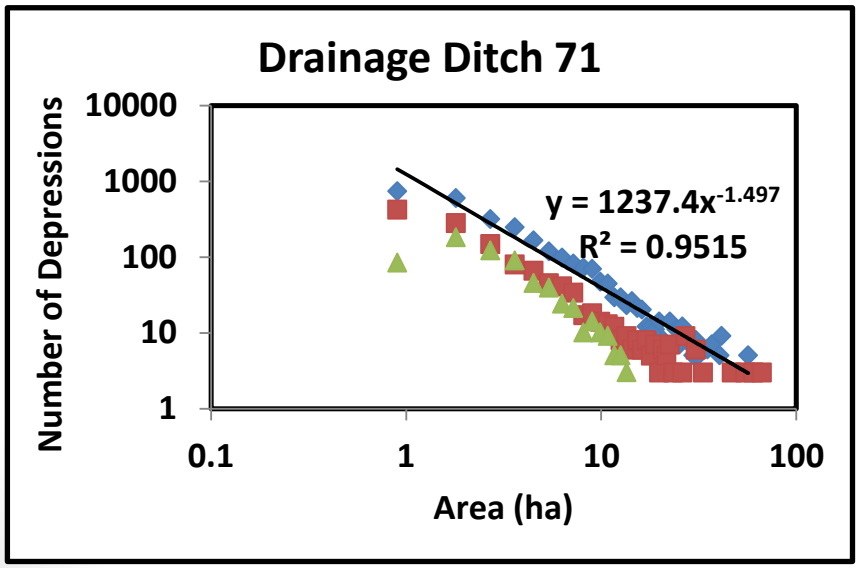


Scaling Relationship Persists at Smaller Scales – Promise of Scale Invariance and Fractal Behaviors?



LIDAR vs. 10 m DEM vs. NWI





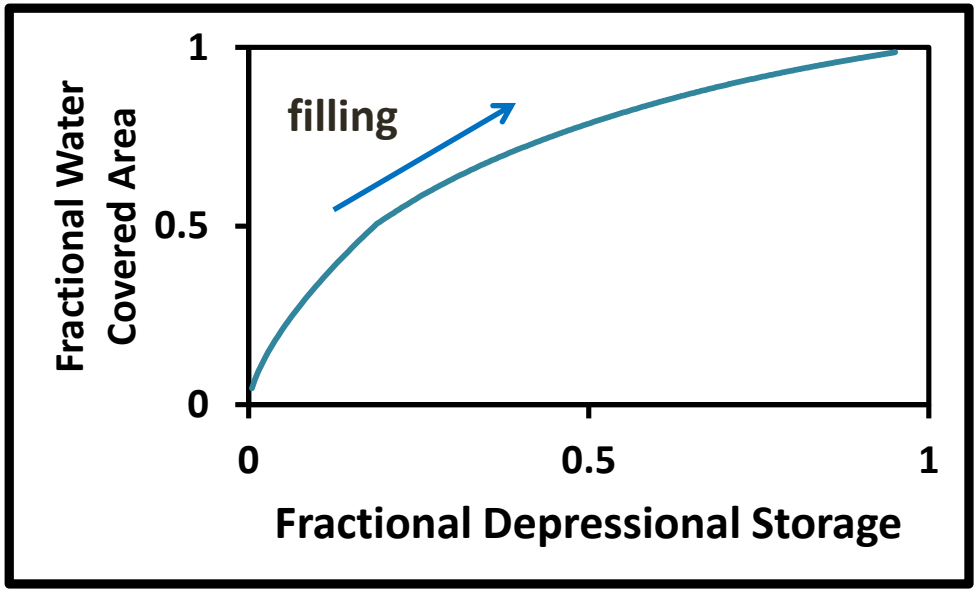
- 1 m DEM detects more depressions than 10 m DEM
- National Wetlands Inventory (NWI) database – least
- Scaling relationship vanishes for NWI data…human impact?
- Miller et al. (2009) – preferential loss of smaller potholes

Questions

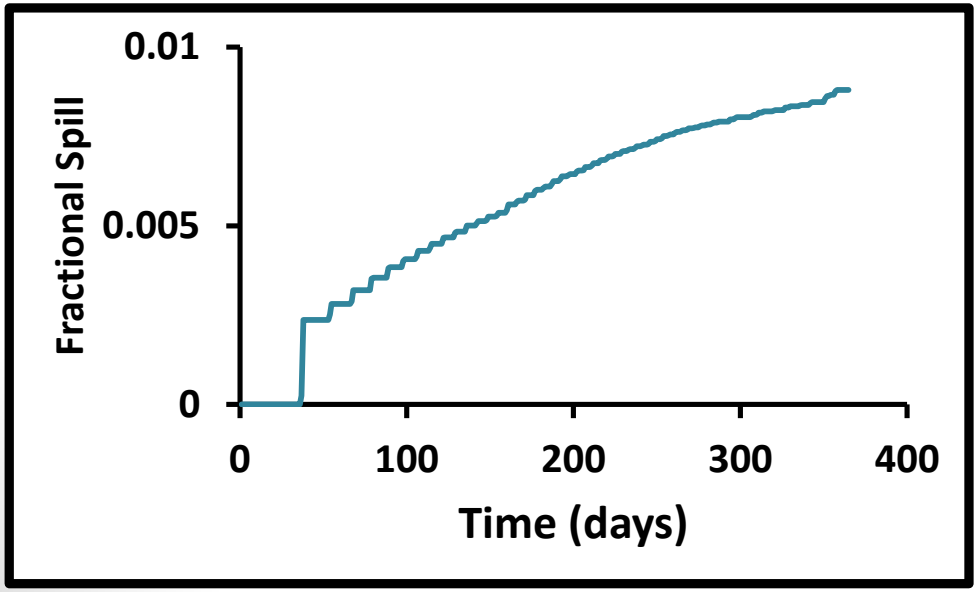
- **What are the attributes (size classes, volumes) of these depressional areas over the landscape? Is there a method to the madness?**
- Legacies and Trajectories: How have these regions been modified as a function of climate and land-use shifts? How do we expect these regions to change as a function of climate and land-use changes?
- How are the depressional areas connected – in space and in time?

How do depressions fill and drain?

Most hydrologic models accumulate to create one reservoir per watershed. But a distribution of reservoirs behaves differently..



- Frequency-area Distribution of the pothole system: $N = 809A^{1.6}$
- Filling: A constant rainfall rate of 2.5 mm/day applied to initially empty potholes



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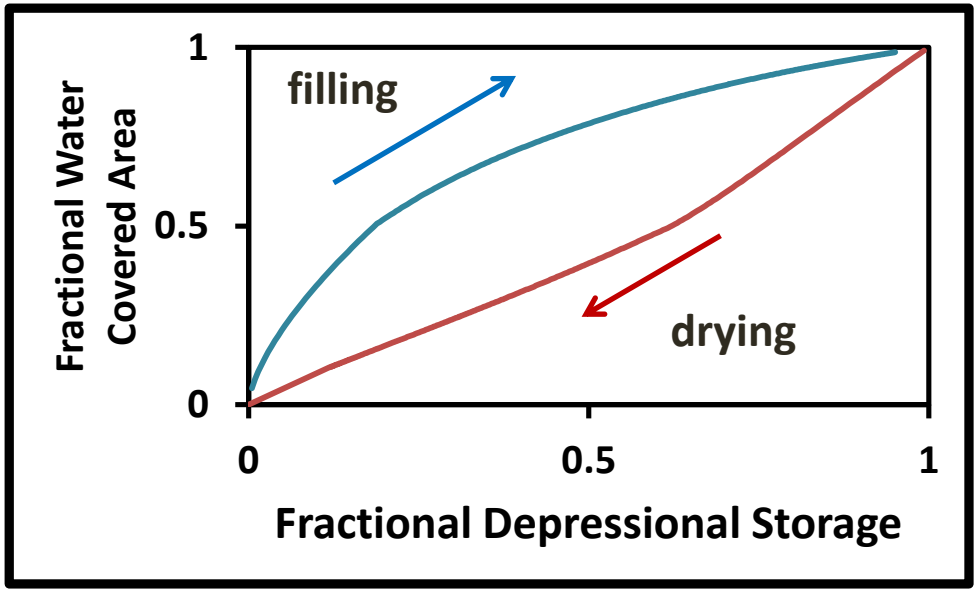
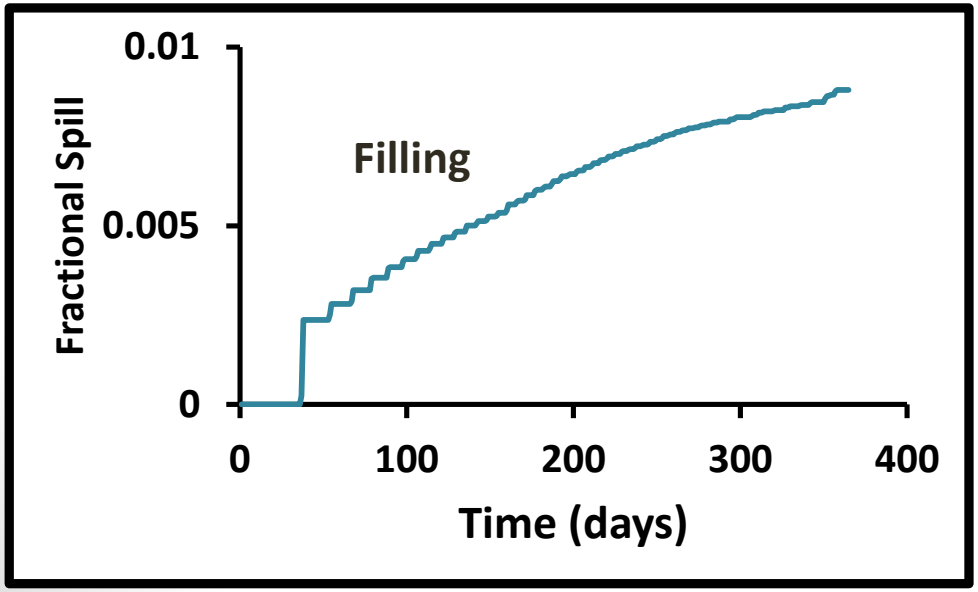
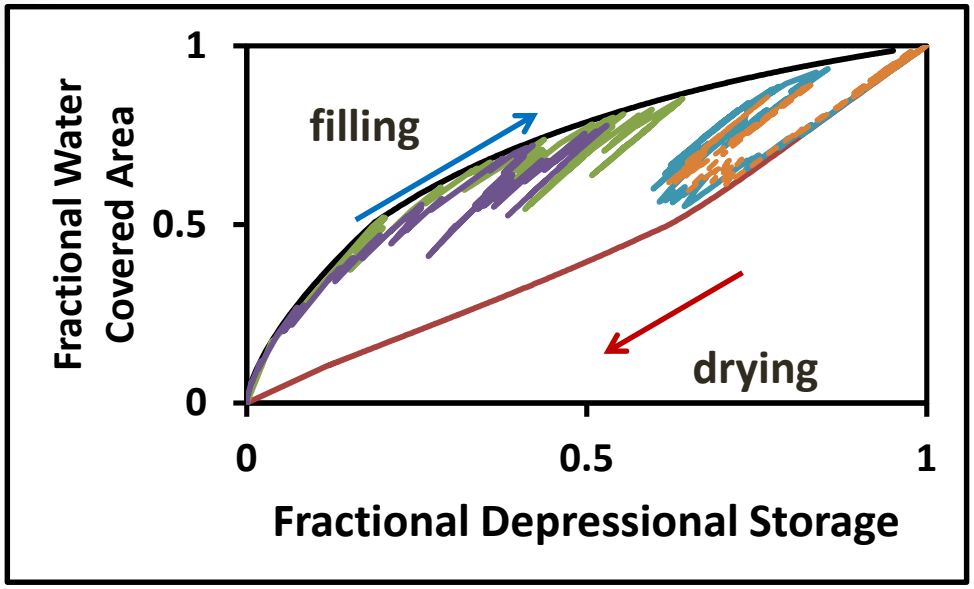




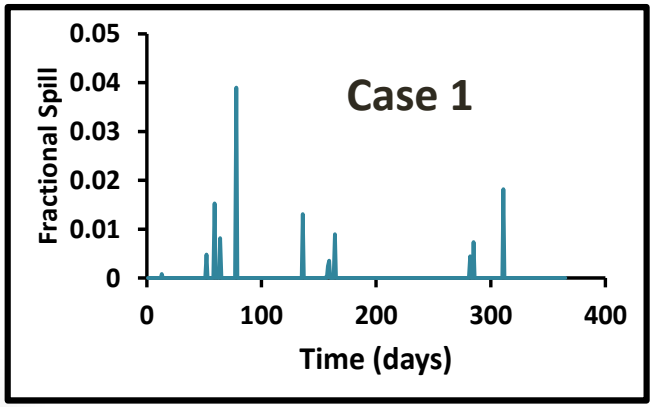
- Frequency-area Distribution of the pothole system: $N = 809A^{1.6}$
- Filling: A constant rainfall rate of 2.5 mm/day applied to initially empty potholes
- Drying: A constant evaporation rate of 13mm/day applied to initially full potholes
- **Hysteresis** arising from pothole size distribution
- Area under the hysteresis loop defined by size-frequency distribution

How do depressions fill and drain?

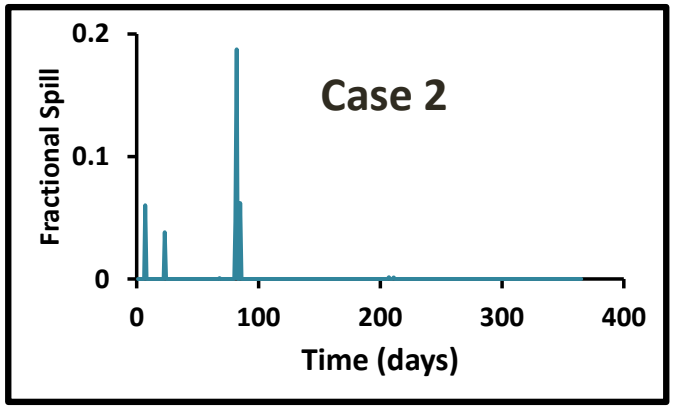


- Poisson Rainfall Distribution
  - Case 1 (λ=0.23 per day, α=11 mm)
  - Case 2 (λ=0.17 per day, α=15 mm)

- Provides a framework for understanding the role of climate and anthropogenic impacts on these landscapes



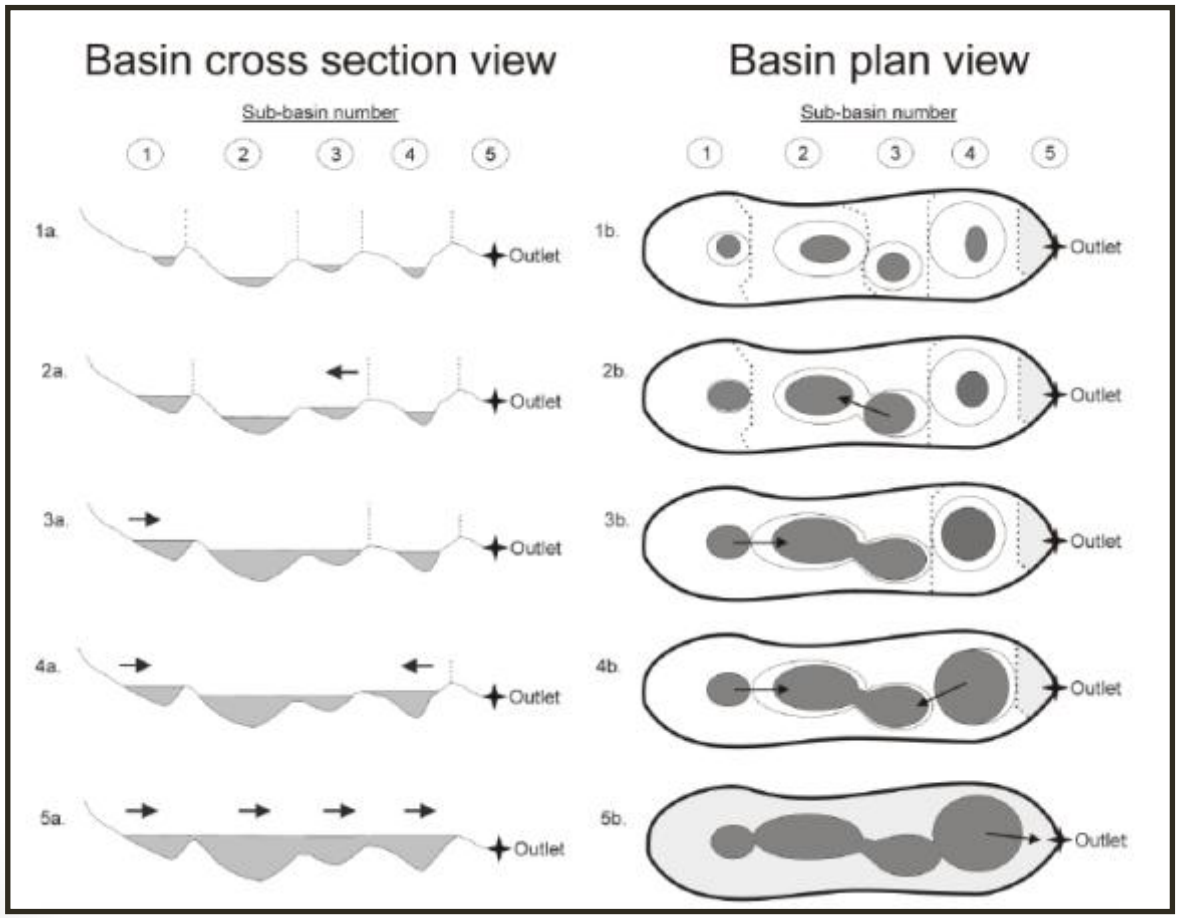
Total Rainfall: 1075 mm
Runoff Coefficient: 0.1

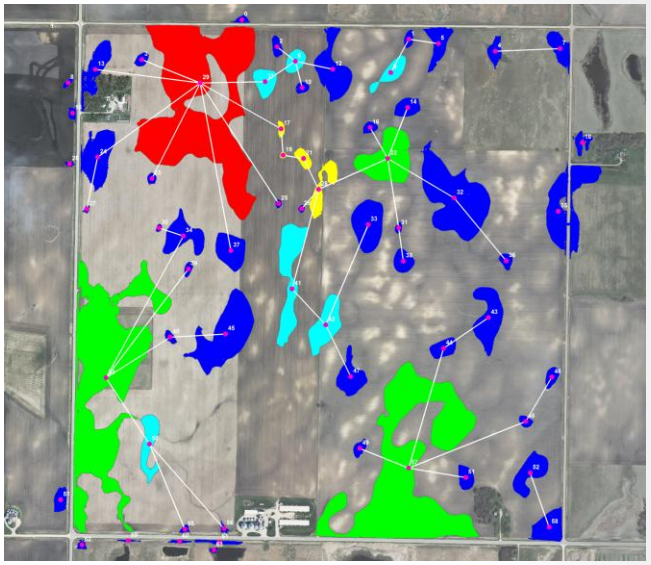


Total Rainfall: 837 mm
Runoff Coefficient: 0.4

- Climate change alters the rainfall distribution – more intense events
- Land-use shifts (drainage of potholes, restoration) can alter the frequency-area distributions

But potholes are not isolated:
Hydrologic Connectivity in Space and Time





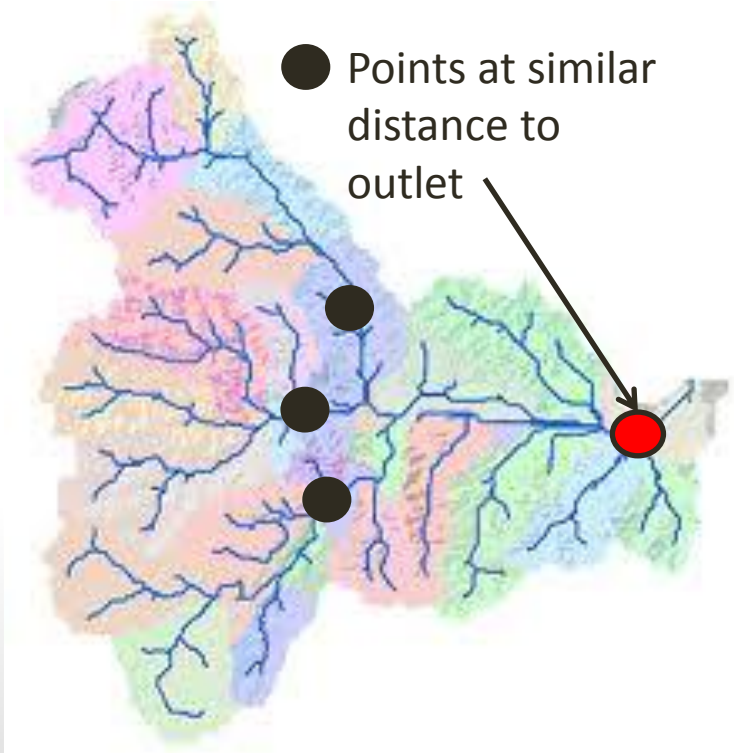
- Numerically possible to create such fill-spill models
- But, computationally intensive

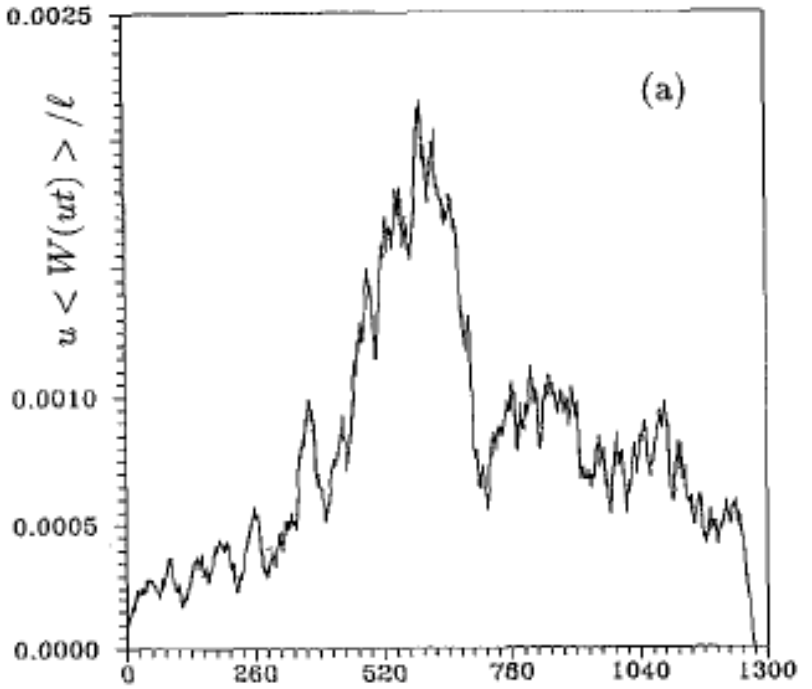
Simpler Scaling Behavior:
Is there a method to the madness?

Shaw (2010)

Connectivity in Space: Width Function Concept

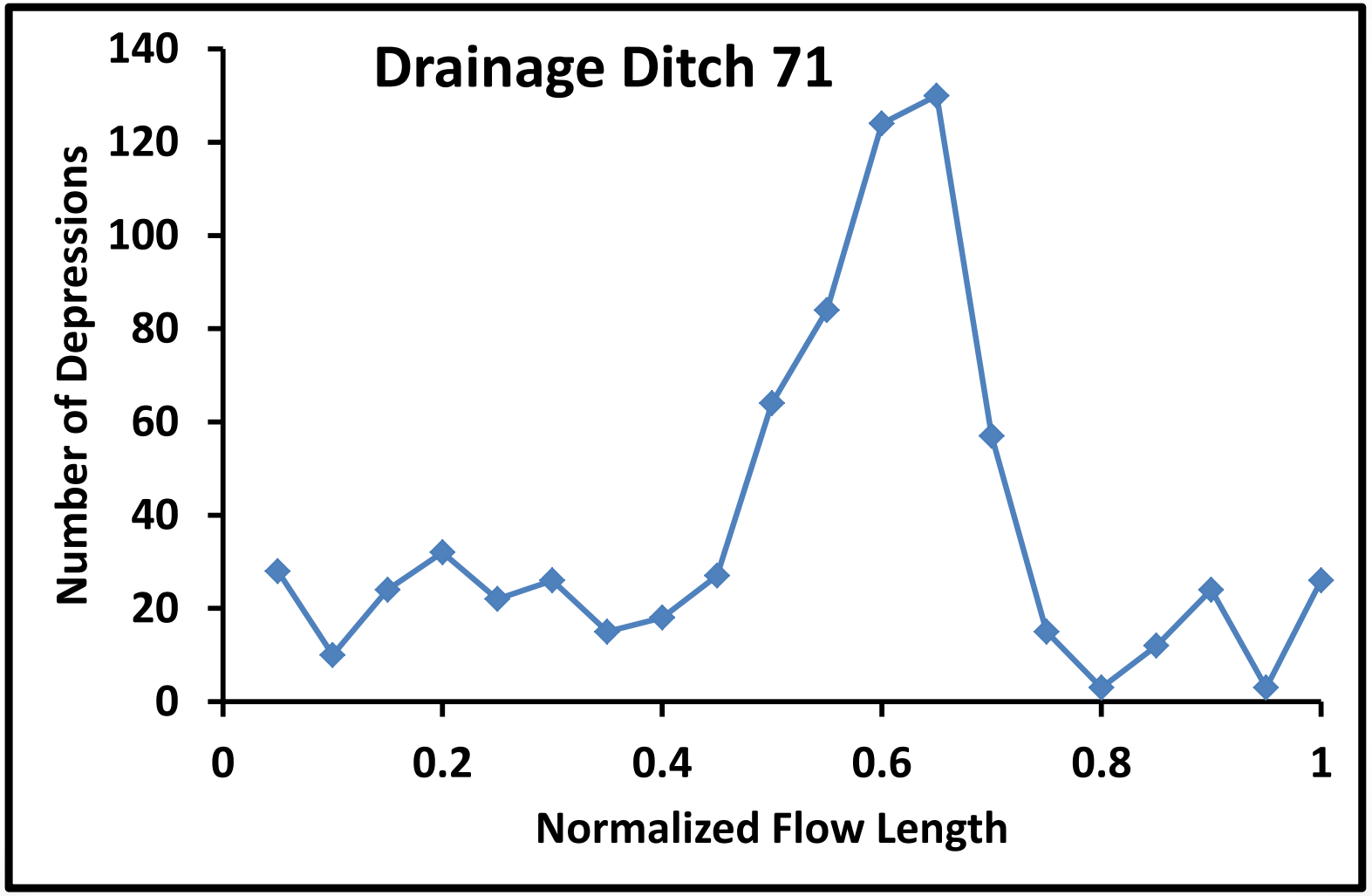
- Width function W(x) in River Networks (Shreve, 1969)
  - W(x) is the number of links in a flow network at a distance ‘x’ from the outlet – distance along network
  - Peak Streamflow scaling along river network controlled by W(x)





Width Function in Depressional Landscapes:

Number of depressions at a distance ‘x’ from the outlet



Summary and Significance

What are the attributes (size classes, volumes) of these depressional areas over the landscape? Is there a method to the madness?

- Consistent power function relationship between size and frequency of depressions
- Narrow range of exponent of power function
- Unique fractal scaling of the coefficient of power function with basin area
- Comparing LIDAR with NWI data indicates preferential draining of smaller wetlands

What is the relevance of such scaling behavior?

- If prairie wetlands in a given region can be treated as members of a frequency distribution, a conceptual model of an areal fraction of a prairie basin can be considered to be statistically representative of the entire basin…

Legacies and Trajectories: How have these areas been modified as a function of past climate and land-use shifts? How do we expect these regions to change as a function of climate and land-use changes?

- Simple model developed indicative of memory in these landscapes

How are the depressional areas connected – in space and in time?

- Width function as a viable approach to describe wetland connectivity

Path forward: Interesting questions…

- How does a distributed network of wetlands buffer hydrologic and biogeochemical responses?
  - Can distributed storage reduce flooding, nutrient loads?
- How does hydrologic connectivity get modified as a function of climate (more intense rainfall) and anthropogenic controls (increase in tile drainage)?
- Can wetland restoration be aimed at restoring a distribution of wetlands, rather than just the more permanent ones? Can it be made economically feasible?


Thank You
Questions?