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
• 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?

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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

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Strong power function area-frequency relationships

1. Narrow range of slopes: $1.5 - 1.76$ (compare with Zhang et al. $1.6 - 1.8$)
2. Larger variation in intercepts – dependence on area?
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?
Let's zoom in further.....

**South Skunk Headwaters (11)**

\[ y = 1,398.06x^{-1.76} \]
\[ R^2 = 0.97 \]

**Upper South Skunk (11a)**

\[ y = 452.96x^{-1.43} \]
\[ R^2 = 0.97 \]

**Lower South Skunk (11b)**

\[ y = 269.34x^{-1.50} \]
\[ R^2 = 0.95 \]

**Drainage Ditch 64 (11c)**

\[ y = 149.87x^{-1.28} \]
\[ R^2 = 0.94 \]
Scaling Relationship Persists at Smaller Scales – Promise of Scale Invariance and Fractal Behaviors?

\[ y = 1.92x^{1.21} \]
\[ R^2 = 0.87 \]
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
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
- **Drying**: A constant evaporation rate of 13 mm/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 \((\lambda=0.23 \text{ per day, } \alpha=11 \text{ mm})\)
  - Case 2 \((\lambda=0.17 \text{ per day, } \alpha=15 \text{ mm})\)

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

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

Total Rainfall: 1075 mm  
Runoff Coefficient: 0.1

Total Rainfall: 837 mm  
Runoff Coefficient: 0.4
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

Drainage Ditch 71

Number of Depressions
Normalized Flow Length

Normalized Flow Length

Number of Depressions
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?