# Delineation of Nested Wetland Catchments and Modeling of Hydrologic Connectivity Using LiDAR Data and Aerial Imagery


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## Abstract

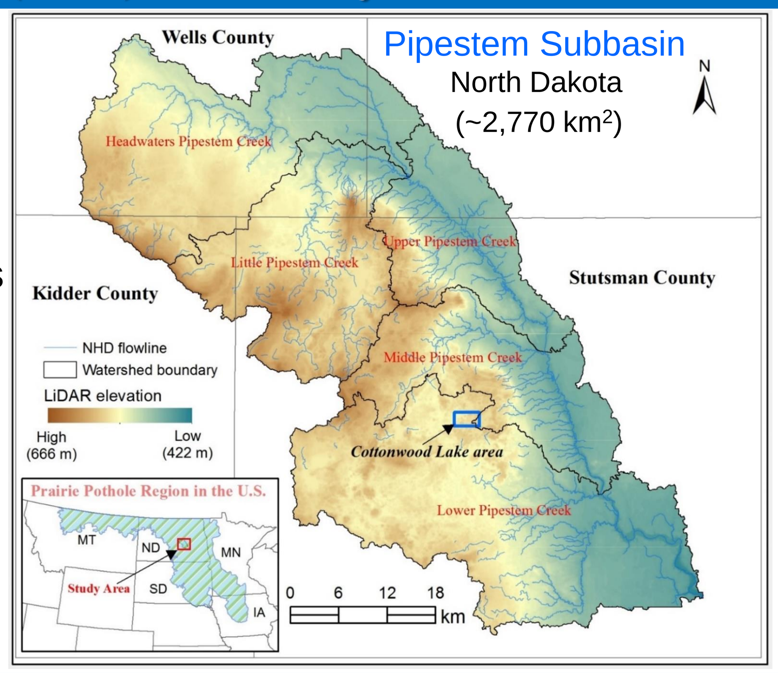

In traditional watershed delineation and topographic modeling, **surface depressions** are generally treated as spurious features and simply removed from a digital elevation model (**DEM**) to enforce flow continuity of water across the topographic surface to the watershed outlets. In reality, however, many depressions in the DEM are actual **wetland landscape features** that are seldom fully filled with water. The increasing availability of Light Detection And Ranging (**LiDAR**) data holds great potential for delineating wetland depressions. The research objectives are to:

- Delineate nested wetland depressions and corresponding catchments
  - Presents a concise and explicit representation of the nested hierarchical structure of wetland depressions and catchments
- Quantify potential water storage capacity of wetland depressions
  - Offers more realistic and crucial information of wetland water storage for hydrologic modeling
- Simulate surface hydrologic flow pathways
  - Contributes to improving overland flow modeling and hydrologic connectivity analysis


## Introduction

### Prairie Pothole Region (PPR) and Study Watershed

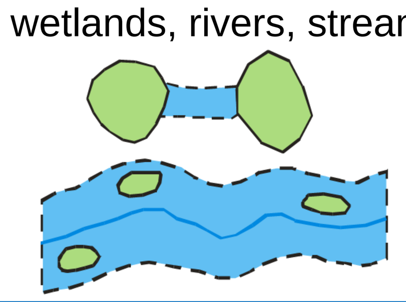
- PPR: ~ 715, 000 km² (*see inset*)
- characterized by millions of small and shallow wetland depressions
- provides critical habitat for many migrating and breeding waterbirds
- stores surface water and reduces peak runoff during flood events

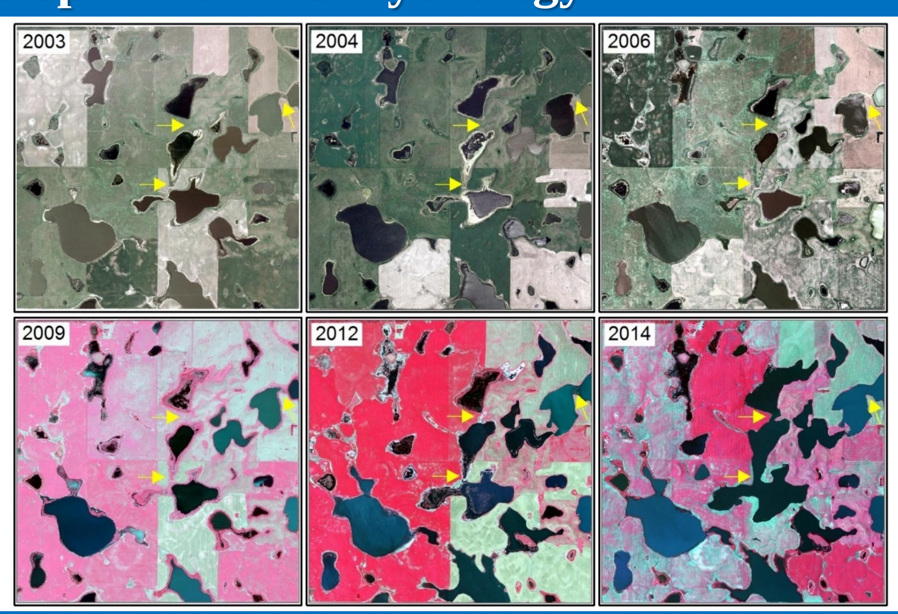



### Fill-Merge-Spill Wetland Hydrology

During wet periods:

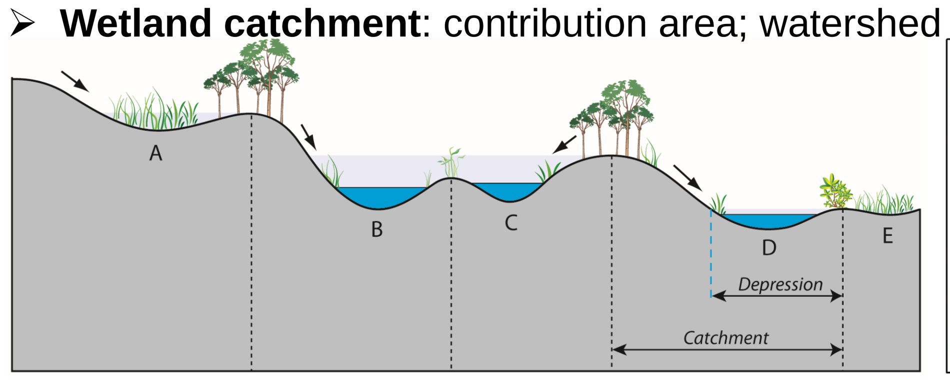
- Adjacent Wetlands can **fill and merge** to form larger wetland complexes
- Upstream wetlands can **spill** into downstream wetlands, rivers, streams



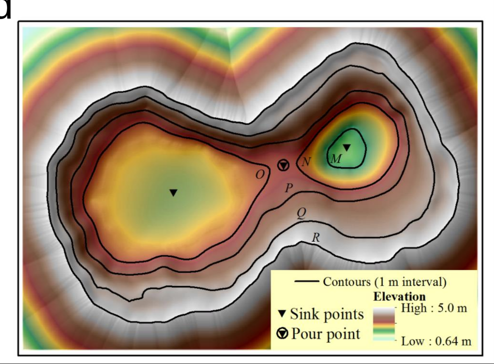



### Nested Hierarchy of Wetland Depressions and Catchments

- **Wetland inundation area**: existing surface water extent
- **Wetland depression**: maximum potential ponding extent
- **Wetland catchment**: contribution area; watershed




*Contour representation*




## Methods

**Wetland inundation areas**

- Data used: **LiDAR intensity image** (water bodies appear as dark features in the LiDAR intensity image due to water absorption of near-infrared spectrum)
- Method: thresholding technique

**Wetland depressions**

- Data used: **LiDAR DEM**
- Method: localized contour tree algorithm & volume calculation

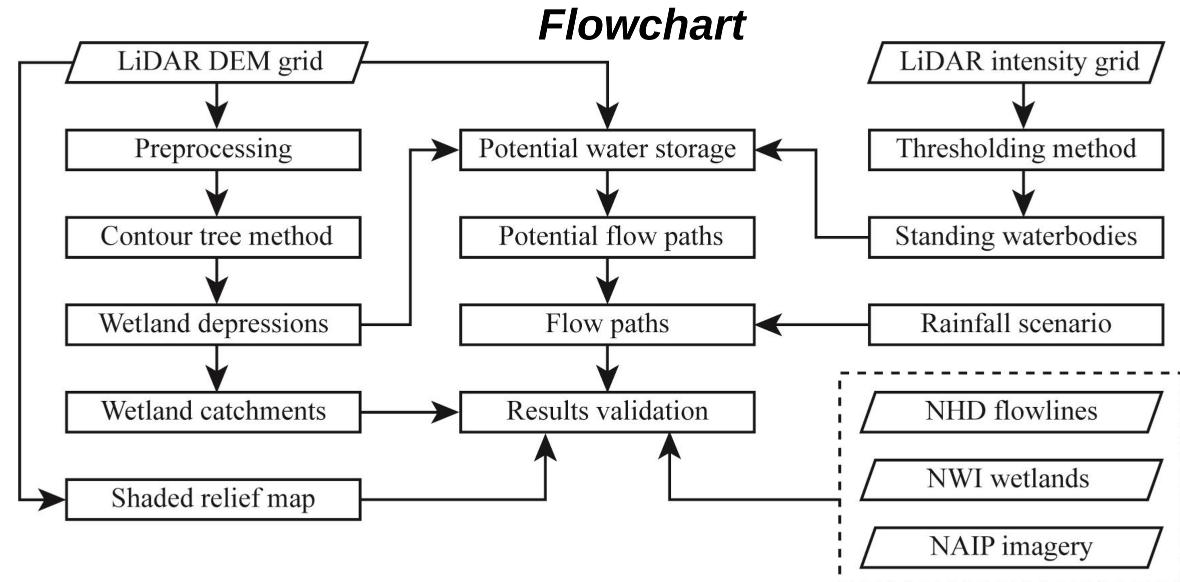
**Wetland catchments**

- Data used: LiDAR DEM and wetland depression polygons
- Method: watershed segmentation algorithm

**Surface hydrologic flow pathways**

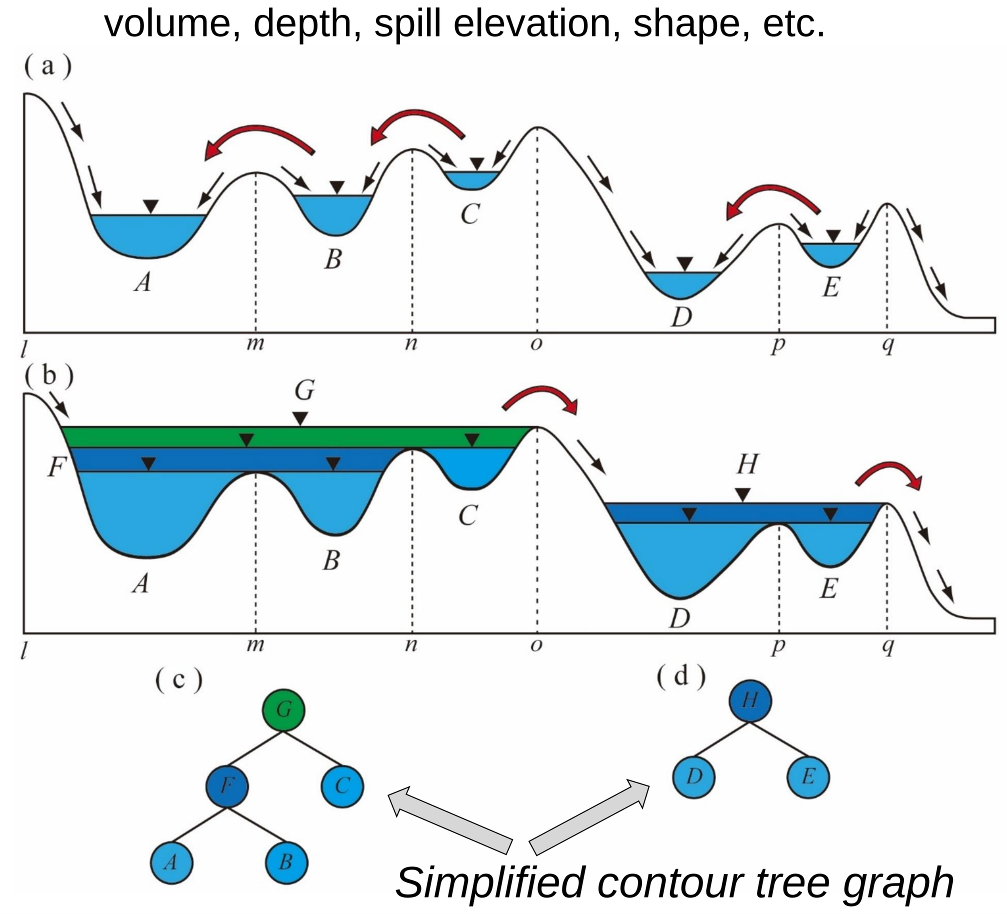
- Data used: LiDAR DEM
- Method: least-cost path search algorithm

***Flowchart***




**Graph theory-based localized contour tree method**

- Representation of nested hierarchical structure
- Contour tree graph consists of nodes and links
- **Node**: represents contour lines
- **Link**: represents adjacency
- **Topological properties**: hierarchical structure, adjacency, connectivity, containment, etc.
- **Geometric properties**: area, perimeter, storage volume, depth, spill elevation, shape, etc.

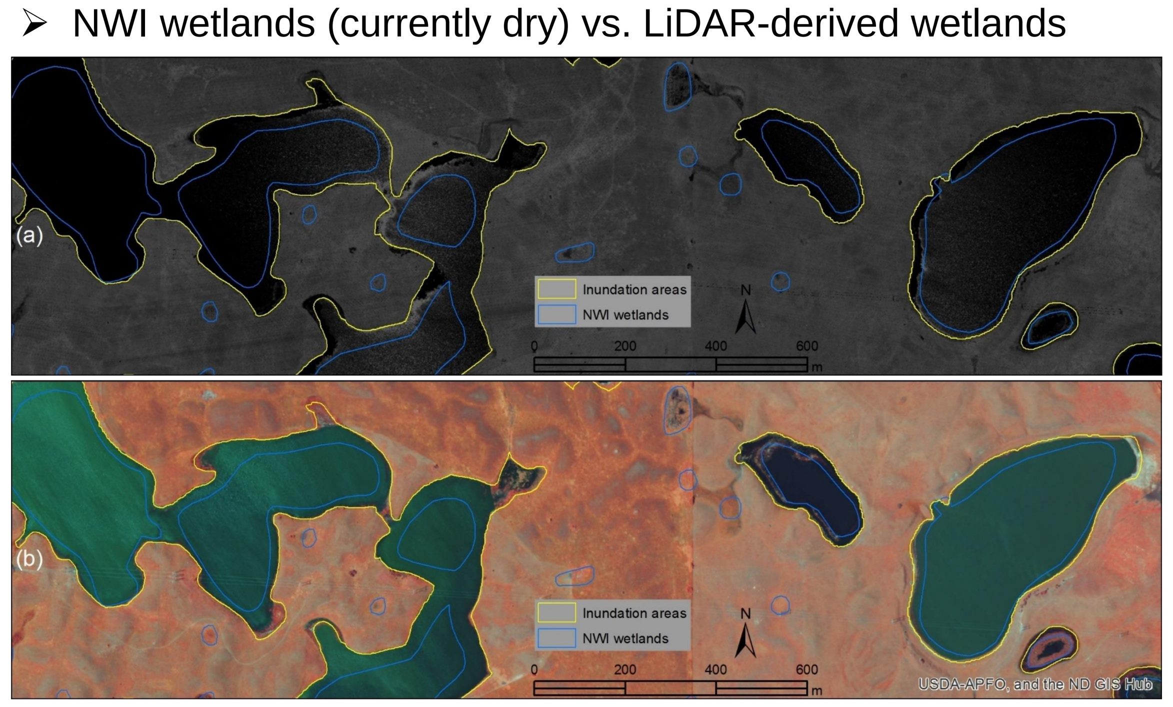



*Simplified contour tree graph*

## Results

**Wetland inundation areas**

- National Wetlands Inventory (NWI) derived in the 1980s could not reflect wetland water dynamics (***blue****-outline polygons*)
- LiDAR intensity data can delineate wetland inundation areas and provide up-to-date water extent (***yellow****-outline polygons*)
- NWI wetlands (currently dry) vs. LiDAR-derived wetlands




Summary statistics of NWI wetlands and LiDAR-derived inundation polygons

| Type | Count | Min (m²) | Max (m²) | Mean (m²) | Median (m²) | Sum (m²) |
|---|---|---|---|---|---|---|
| NWI polygons | 32,016 | 500 | 9,410,427 | 8,728 | **1,778** | 279,495,717 |
| Inundation polygons (overlap) | 15,784 | 500 | 7,348,000 | 17,650 | **1,825** | 278,523,863 |
| Dried NWI polygons (non-overlap) | 18,957 | 500 | 112,100 | 2,299 | **1,212** | 43,574,627 |

Summary statistics of LiDAR-derived wetland depressions and catchments

| Type | Min | Max | Mean | Median | Sum |
|---|---|---|---|---|---|
| Depression area (m²) | 1008 | 20,030,000 | 16,590 | **2592** | 554,506,299 |
| Catchment area (m²) | 1818 | 57,900,000 | 82,710 | **25,780** | 2,770,116,549 |
| Depression volume (m³) | 1 | 153,000,000 | 23,420 | **420** | 782,886,383 |
| Depression/catchment ratio (%) | 0.04 | 83.72 | 16.59 | **14.31** | 20.06 |

Summary statistics of wetland ponding depth and connectivity length

| Type | Count | Min (m) | Max (m) | Mean (m) | Median (m) | Sum (m) |
|---|---|---|---|---|---|---|
| Ponding depth | 33,241 | 0.00 | 7.64 | 0.23 | **0.16** | NA |
| NHD flowlines | 1840 | 3.89 | 15,530 | 762 | **317** | 1,402,226 |
| Connectivity length | 41,449 | 1.5 | 4,658 | 138 | **83** | 5,014,495 |
| Elevation difference | 41,449 | 0.01 | 70.89 | 2.14 | **0.89** | NA |

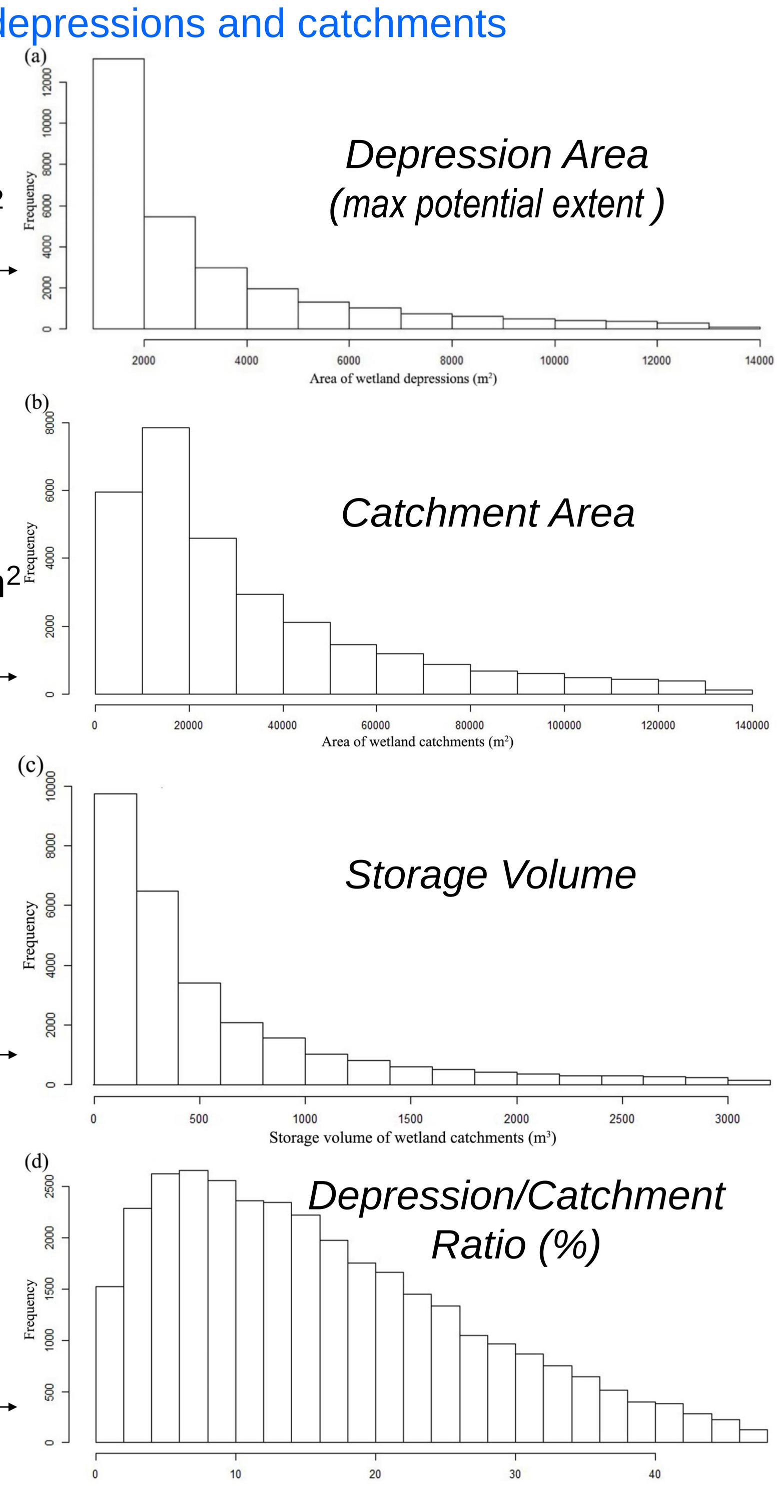
**Wetland depressions and catchments**

Median: 2592 m²

Median: 25,780 m²

Median: 420 m³

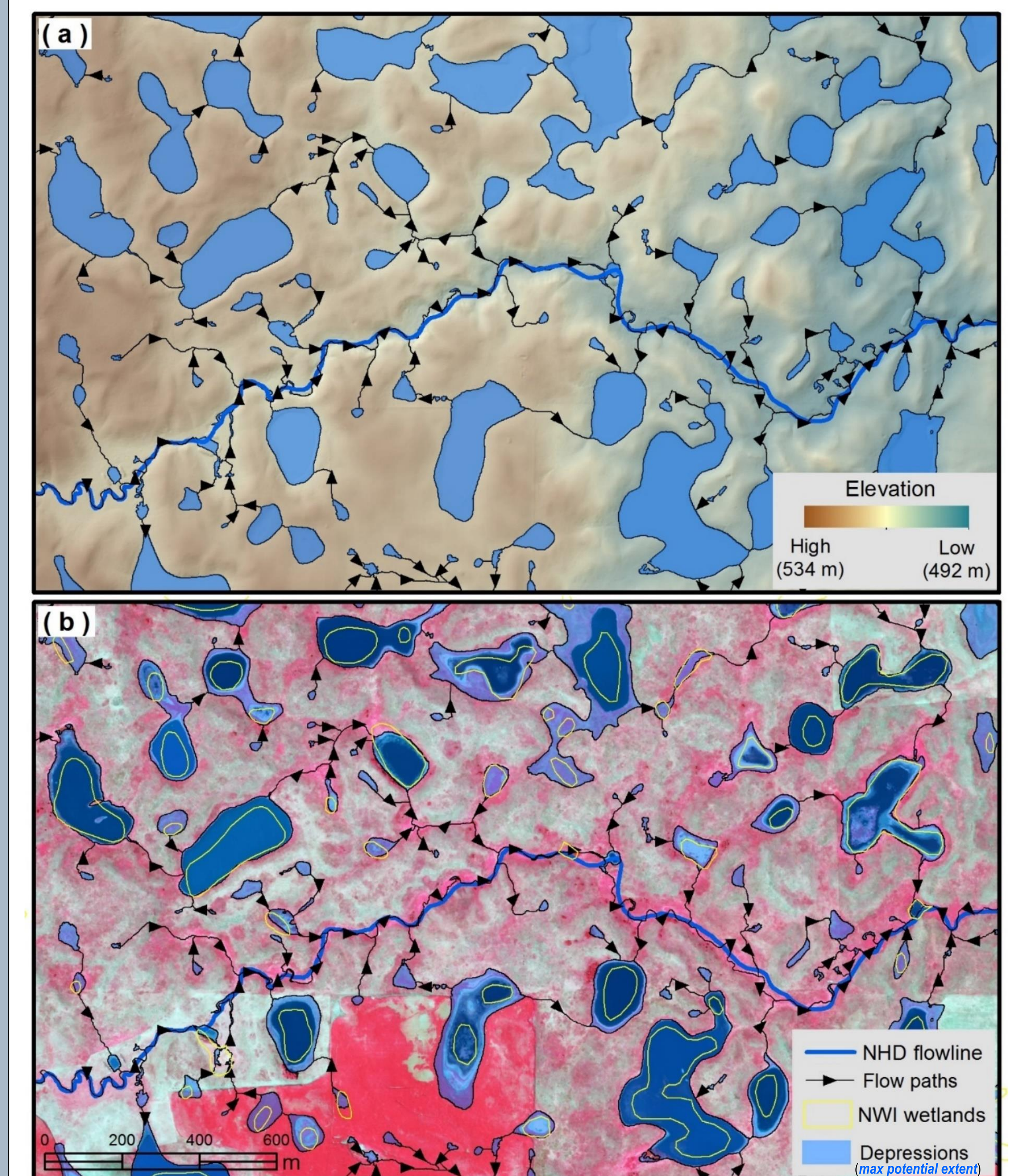
Median: 14.3%




## Results (*cont.*)

**Wetland depressions and surface hydrologic flow pathways**

- The derived flow network successfully captures **potential temporal or season flow paths** that were generally not available in the National Hydrography Dataset (NHD)
- Web map available at http://wetlands.io/maps/connectivity




## Conclusions

- LiDAR intensity and elevation data hold great potential for mapping prairie wetlands and studying wetland hydrology
- A semi-automated framework was developed for accurate delineation and characterization of wetland depressions, wetland catchments, and surface hydrologic flow pathways
- Analyzing hydrologic connectivity between wetlands and stream networks can better inform wetland regulation debates
- This work represents an initial step towards the development of a spatially distributed hydrologic model to fully describe the hydrologic processes in broad-scale prairie wetlands

## References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