Modeling Surface-flow Characteristics in Glaciated Landscapes

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Abstract

The Prairie Pothole Region (PPR) of the US and Canada is characterized by thousands of shallow, water-filled depressions with sizes ranging from a fraction of a hectare to several square kilometers. The purpose of this work is to apply GIS hydrologic modeling techniques to further understanding of surface-flow characteristics of the PPR. High resolution digital elevation models are required to resolve subtle depressions of the low-lying landscape. This research uses an IFSAR-derived digital terrain model (DTM) and orthorectified radar imagery (ORI) as a base for developing a hydrologically-correct DEM and derivative products. This work builds on previous research piloted at two wetland complexes in Deuel County, SD. This phase of the research focuses on interpreting modeled drainages, looking at patterns of basin connectivity. Closed basins in wet years overflow forming surface connections, which eventually eliminate wetland features as the landscape ages. ArcHydro Tools are used extensively in the model development.

Background

Hydrologic modeling in GIS starts with good elevation data. DEMs created using hypsography data extracted from USGS 1:24,000 scale topographic maps have been shown to be inadequate for representing surfaces of low-lying, extremely flat areas and/or containing numerous ponds or wetlands (Blackwell and Wells, 1999). LiDAR (Light Detection and Ranging) and IFSAR-derived elevation models provide new, promising sources of data for modeling complex terrains. Previous research assessed bare-ground LiDAR data for their ability to resolve surface features in Devils Lake Basin, ND (Gritzner, 2006). While results were generally positive, the limited availability of LiDAR coverage was disappointing. Recent work is directed to looking at airborne Interferometric Synthetic Aperture Radar (IFSAR)-derived digital terrain models (DTM) as input into GIS hydrologic models.

Prairie Pothole Region

The Prairie Pothole Region (PPR), a 715,000 sq kilometer area, extends from Alberta, Saskatchewan, and Manitoba in Canada to Montana, North Dakota, South Dakota, Nebraska, Minnesota, and Iowa in the United States. Retreating glaciers left over 25 million depressional wetlands, which fill with snowmelt and rain in spring. The size of prairies potholes (sloughs) range from a fraction of a hectare to several square kilometers. Most depressional wetlands are small with an estimated median of .16 ha, only slightly larger than the 0.09 ha pixel size of Landsat TM data. Pothole wetlands are shallow, with depths generally less than a 1 meter and vary in permanency. Potholes can function as groundwater recharge sites, flow-through systems, or groundwater discharge sites. Surface flow characteristics are poorly understood. Pothole wetlands are often viewed as isolated (closed) basins, though in wet years they overflow and form surface connections with one another. Drainage in these incidences becomes more organized, a start of an integrated surface drainage system, that would eventually eliminate wetland features as the landscape ages. This research examines glaciated landscapes within Deuel County, SD in the Northern Prairie Coteau, focusing on two actively monitored wetland complexes – Orchid Meadows and Crystal Springs.

IFSAR Evaluation

IFSAR is an active imaging technique that has been developed for capturing digital elevation data. Relatively high resolution and low cost, IFSAR competes well with LiDAR in low relief, rural and non-forested landscapes. Sample spacing is 2.5 – 10 m, vertical accuracies are 30cm – 3 m RMSE with wide area acquisition capability.

In this study, IFSAR z values for a 5-m DTM were compared with ground survey data. For the Crystal Springs site, elevations for 80,027 upland survey points deviated less than .13 m on the average with a range of -2.09 to 2.08 m and standard deviation of .33 m. For some 1342 survey points in collected in wetland depressions, the average value was -.24 m with a range of -1.01 to .86 m and a standard deviation of .27 m (Gritzner and Millett, 2008).

IFSAR resolved all but two of the 18 wetlands at Crystal Springs and all 10 of the wetlands in the Orchid Meadows complex. The two unresolved depressions were small, shallow wetlands situated on undulating ground. Though not perfect, the IFSAR DTM was an improved product over the traditional map-derived DEM.

IFSAR data were further tested with construction of a hydrologically-correct DEM and DEM derivatives such as flow direction and flow accumulation matrices.

Hydrologic Modeling in ArcGIS

Conditioning phase of hydrologic modeling in ArcGIS requires the development of three general utility datasets. In the order that they are produced, they are a DEM with sinks filled, a grid indicating the flow direction for each cell, and a flow accumulation dataset in which each cell receives a value equal to the total number of cells that drain into it. Depressions or sinks in a DEM hinter flow routing and need to be handled prior to developing flow direction or flow accumulation grids. Many sinks are spurious, a result of DEM creation errors and should be eliminated (Jensen and Domingue, 1988). Other sinks represent real features such as depressional wetlands and should not be filled. For the study sites within the PPR, procedures are put into place to selectively fill sinks. This is a two-step process, first to separate real depressions from other sinks in data and second to construct a threshold mask to control the sink filling process.

Creating a realistic threshold mask requires an elevation model that properly resolves topographic depressions, a methodology for sink selection, and data for validation (Gritzner, 2006).

Modeling with ArcHydro Beta Tools

Using a 5-m IFSAR DTM as input, ArcHydro Beta Version 1.3 Tools were utilized in terrain preprocessing and drainage connectivity characterization.

Methodology for sink selection was as follows:

- Prescreen sinks. Eliminate all sinks with less than 100 cells (2500 sq m)
- Evaluate depressions. Products include fully attributed vector datasets that show depressions and their drainage areas and contain information on depth and area.
- Determine which depressions are wetlands. Results serve as a mask during the fill operation. GPS data collected for Crystal Springs and Orchid Meadow, National Wetland

Inventory data, orthorectified radar imagery (ORI), and NAIP DOQs were used to valid the selection process.

- Selectively fill the DTM.

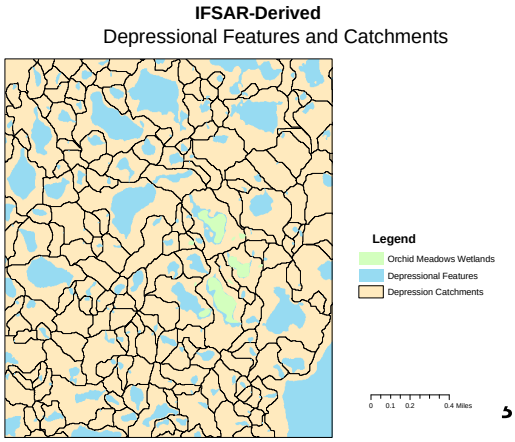
Terrain preprocessing tools in ArcHydro Beta Version 1.3 have several special options for DEMs that have sinks, for example, the flow direction with sinks tool. Beyond that normal procedures for preprocessing DEMs for hydrologic modeling were followed. Catchment polygon processing produced a dataset showing catchments for each of the depressions defined by the wetland mask. Terrain Morphology tools have additional special options. Drainage connectivity characterization produced a dataset showing the drainage to wetland depressions within catchments.

Surface Drainage Analysis of Study Sites

Three objectives of the analysis were to define drainage boundaries of depressional features, characterize drainage connectivity, and correlate with synthetic drainages.

Depression Evaluation tool in ArcHydro Beta Version 1.3 generates fully attributed polygon feature classes for depressions and depression areas. Features identified as depressions in IFSAR data represent depressional wetlands and non wetland depressions. Depression areas are produced for each depression feature, regardless of size (Figure 1). National Wetland Inventory (NWI) data are used to help identify real depressional wetlands. GIS data for Orchid Meadow wetlands, mapped by ground surveys, compare favorably to the IFSAR-derived depressions.

Figure 1. Depressional features and catchments derived from an IFSAR DTM.



Drainage characterization shows drainage into depressional features and linkages between various depressions (Figure 2). Close examination of Figure 2 reveals drainage from the higher positioned SP2 wetland to the lower positioned SP3 wetland. The NAIP DOQ with the drainage connectivity highlight the relief in the area (Figure 3).

Figure 2. Catchments and drainage connectivity within the Orchid Meadow wetland complex. For wetland labeling, SP = semi-permanent, S = seasonal, and T = temporary. Blue lines represent depression area boundaries. Black lines are flow into and through depressional features.

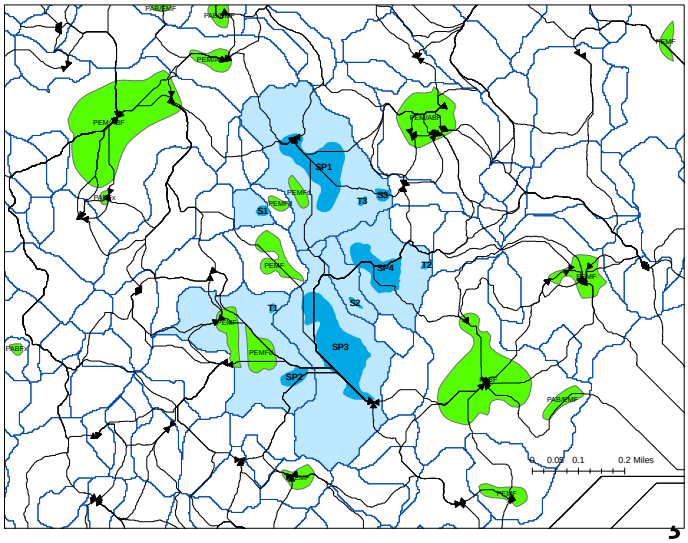
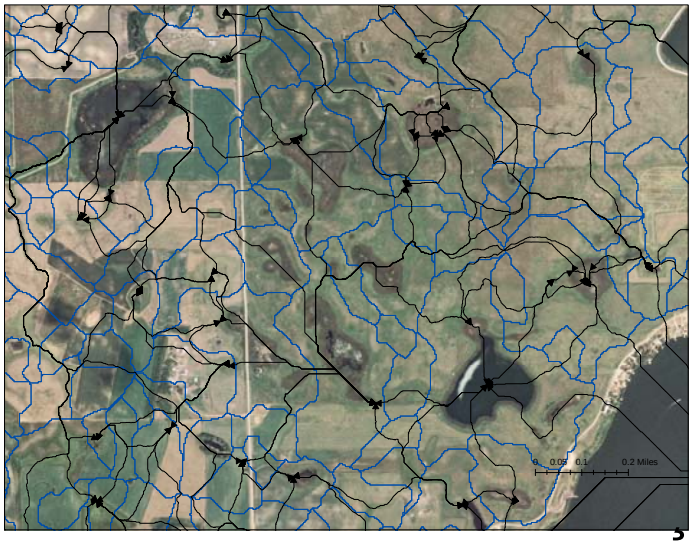


Figure 3. NAIP 2006 DOQ with drainage connectivity.



A second set of processing of the IFSAR DTM yielded synthetic drainage lines for Deuel County, SD. In this scenario, no mask was using during fill operation. Most depressions were filled.Using the Stream Definition tool, threshold values of 32000 and 5000 were used to produce major and minor drainage datasets. With absence of real wetland catchments, the drainages are both hypothetic and synthetic since they are derived from elevation model. Minor synthetic drainages were superimposed on the Orchid Meadow wetlands, flow line, and drainage area feature classes to examine the relationship between these data (Figure 4).

Figure 4. Orchid Meadow wetlands with synthetic drainage.

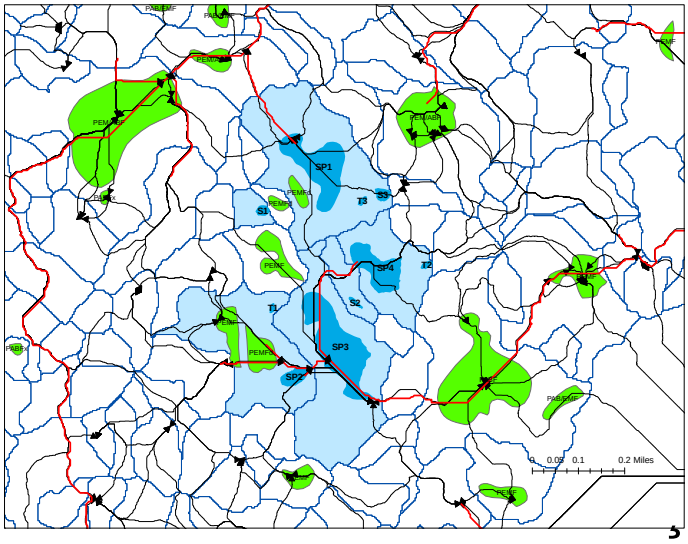
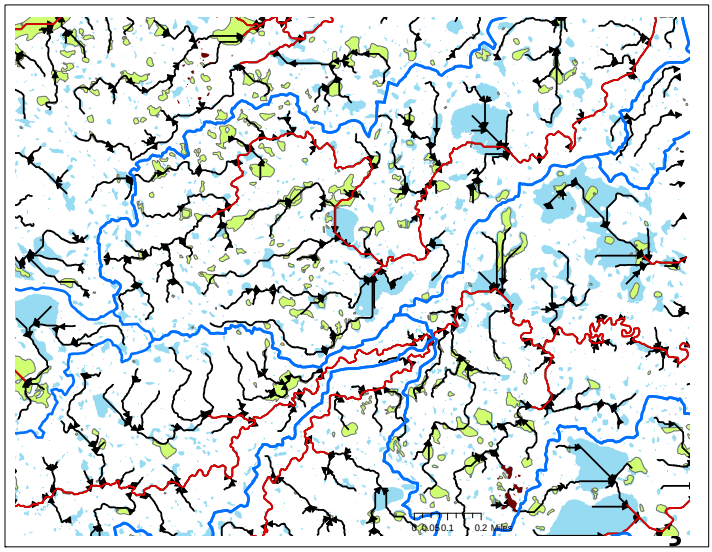


Figure 5 presents a more comprehensive look of the relationships between synthetic drainages and wetlands complexes in east-central Deuel County, SD.

Figure 5. Major and minor synthetic drainages from filled elevation model with Orchid Meadow and Crystal Springs wetland complexes, NWI wetlands, IFSAR depressions and 12 digit Hydrologic Unit Codes (HUC) boundaries.

Red lines are major drainages, black lines - minor drainages, green polygon features – NWI wetlands, blue polygons – IFSAR depressions, red polygons – study sites, and blue line boundaries – 12 digit HUCs.



Conclusions

This study used all depressions identified in the depression evaluation process to construct the threshold mask used to control filling of depressions. Initial sink selection for prefilling the IFSAR DTM determined number of depressions/depression areas identified. It is unknown what effect processing the original digital surface model (DSM) to create a digital terrain model (DTM) has resolving depression features.

Some 6% of depressions identified by processing the IFSAR DTM for Deuel County were coincident with NWI wetlands. Some 56% of the NWI wetlands were coincident with depressions in the IFSAR DTM.

Modeled drainage connections between wetlands at Crystal Springs and Orchid Meadows were verified by field inspection.

Synthetic drainages show direction of flow of connected depressions. Some 52% of depressions were along synthetic drainages. Under high water conditions, these depressions including depressional wetlands will likely show drainage linkages and could time disappear as the landscape matures. Through this analysis, truly isolated wetlands/wetland complexes can begin to be identified, conserved, and managed.

Role of groundwater in surface flow in the PPR is yet to be determined.

References

Blackwell, P. R. and G. Wells, 1999, “DEM Resolution and Improved Surface Representation,” ESRI Users Conference, *Proceedings*.

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