Modeling Regional Surface-flow in Glaciated Landscapes

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Abstract

GIS hydrologic modeling techniques are used to better understand regional surface-flow in the Prairie Pothole Region (PPR) of North America. The 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 with few organized drainage networks. High resolution digital elevation models are required to resolve subtle depressions of the low-lying landscape. This research uses an Interferometric Synthetic Aperture Radar (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. The research focuses on interpreting regional drainages, looking at patterns of wetland basin connectivity. Closed basins in wet years overflow forming surface connections, which eventually eliminate wetland features as the landscape ages.

Hydrologic modeling in GIS starts with good elevation data. The surfaces of low-lying, extremely flat areas, and/or containing numerous ponds and wetlands may not be adequately represented using DEMs created using hypsography data extracted from 1:24,000 scale USGS topographic maps (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 north-central Iowa, US to central Alberta, CA, and contains parts of Minnesota, South Dakota, North Dakota, Montana, Manitoba, and Saskatchewan. 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.

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 in Deuel County, SD, 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 (Deuel County, SD). 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 for resolving wetland features. Research revealed that a good number of depressional features identified in the IFSAR DTM were not actually wetlands (Gritzner and Millett, 2008) (Gritzner, 2009).

Hydrologic Modeling

Objectives of this study are to look at the distributional characteristics of depressional features – wetlands and non- wetland depressions – as they relate to linear drainage systems. The study areas are the glaciated landscapes of Clark, Codington, Hamlin, Grant, and Deuel Counties located in the PPR of eastern South Dakota.

Expanding the work from site specific research to a regional study requires processing some five counties of IFSAR Data. Using a 5-m IFSAR DTM as input, ArcHydro Beta Version 1.4 Tools are utilized in terrain preprocessing and drainage connectivity characterization. The first phase of the work is to prescreen sinks and evaluate depressions. All sinks less that 100 cells (2400 sq m) are eliminated. The depression evaluation tool in ArcHydro Beta generates fully attributed polygon feature classes for depressions and depression areas with data for fill depth, fill area, fill volume, bottom elevation, fill elevation, and drainage area. Depression areas are produced for each depression feature, regardless of size. Depression feature classes for the five counties are merged into a single feature class.

Conditioning phase of hydrologic modeling in GIS mandates 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. The three datasets: a filled DEM, flow direction raster and flow accumulation raster are created for each of the five counties.

The last phase of processing yields synthetic drainage lines. Drainage derived from a filled elevation model depict surface flow after depressions are removed and would unlikely appear as real drainages in the area except under exceptionally high precipitation. Stream networks are derived from flow accumulation data. Four threshold values are used in creating synthetic drainages. Setting the threshold flow accumulation value at greater and equal to 32000 (equivalent to a 25 * 32000 = 800000 sq m drainage area) creates a generalized drainage system. Threshold values of 5000 (125000 sq m drainage area), 3000 (75000 sq m area), 1000 (2500 sq m area) produce more detailed drainages. Raster drainages are converted to feature classes and subsequently merged into single feature classes, representing flow accumulation thresholds of 32000, 5000, 3000 and 1000.

Next phase of analyses uses the select by location function in ArcInfo to identify depressional features intersecting general and detailed synthetic drainage networks. Intersecting depressions are referred to as linked depressions and non intersecting depressions as isolated depressions.
Statistics for fill size in hectares, fill depth, and fill volume are generated for linked and isolated depressions as they relate to generalized and detailed synthetic drainages.

Regional Surface Drainage Analyses

Some 69277 depressions were resolved through depression evaluation of the IFSAR DTMs. Some 5383 or 7.7 percent of depressions intersected generalized drainages. The remaining 63894 or 92.2 percent are isolated depressional features. In contrast, some 54664 or 78.9 percent of the depressions intersected the most detailed drainages with14614 or 21 percent being isolated depressions. Clearly depressional wetlands as well as non wetland depressions are linked to lineage drainages when thresholds of flow accumulation values are set at relatively low values.

Figures show the linked depressions for both generalized and detailed drainages and isolated depressions for generalized drainages for Clark, Codington, Hamlin, Grant, and Deuel Counties, SD. Large depressional features are plainly visible on the map of linked depressions for generalized synthetic drainages (Figure 1)

Figure 1. Linked depressional features with generalized synthetic drainages.

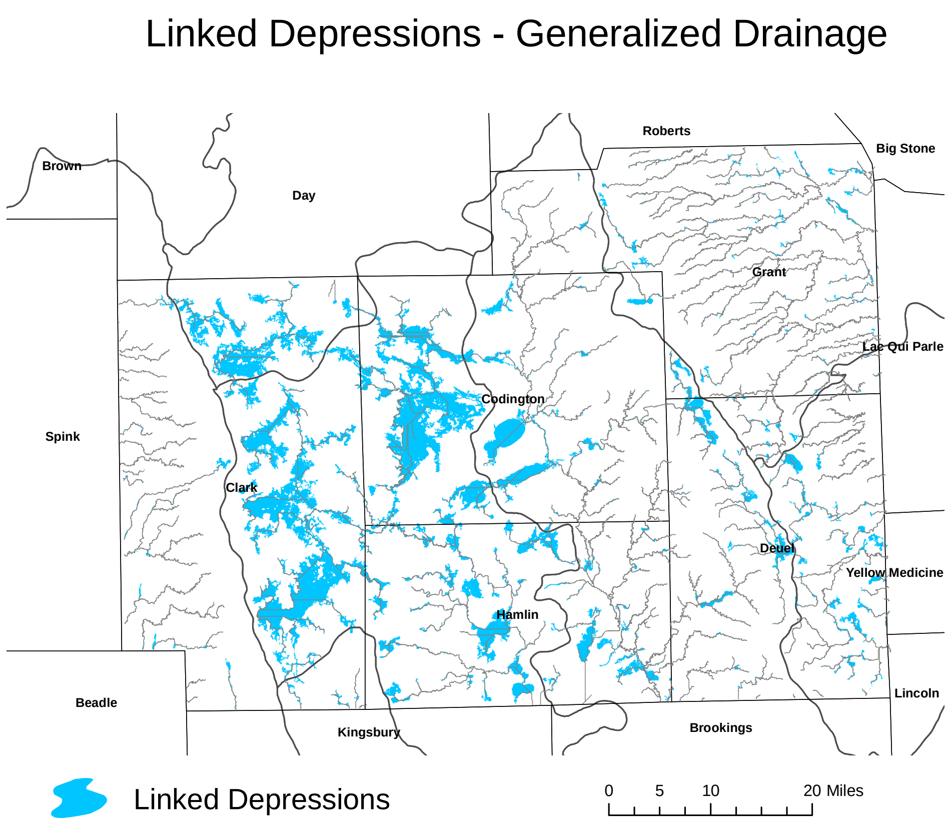


Figure 2. Isolated depressional features with generalized synthetic drainages.

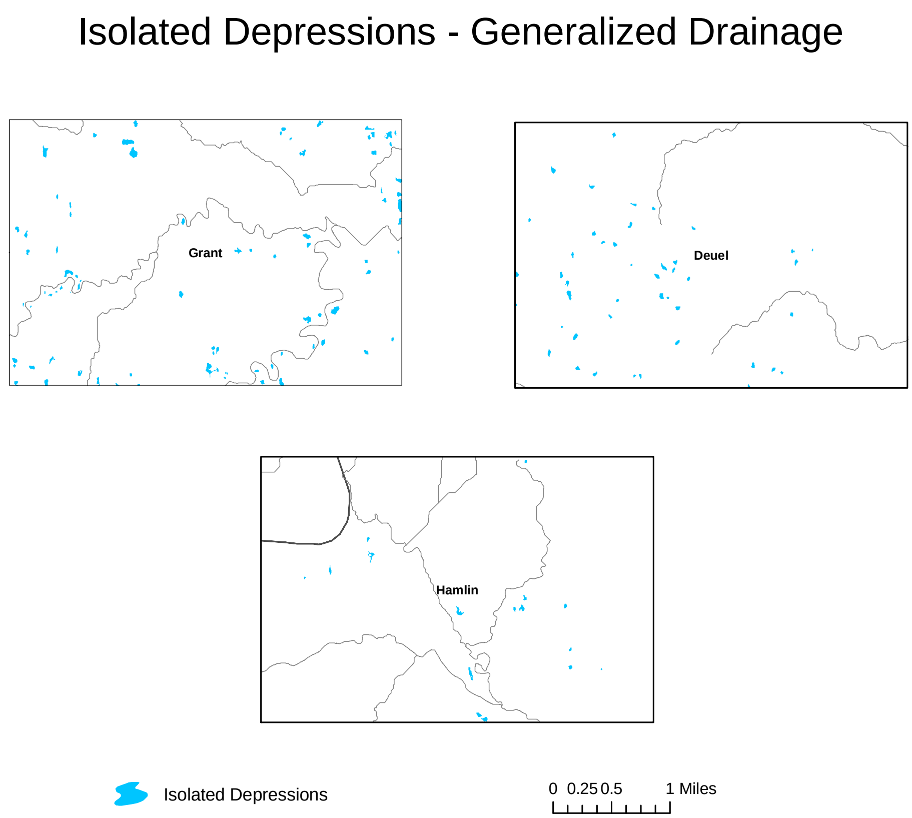
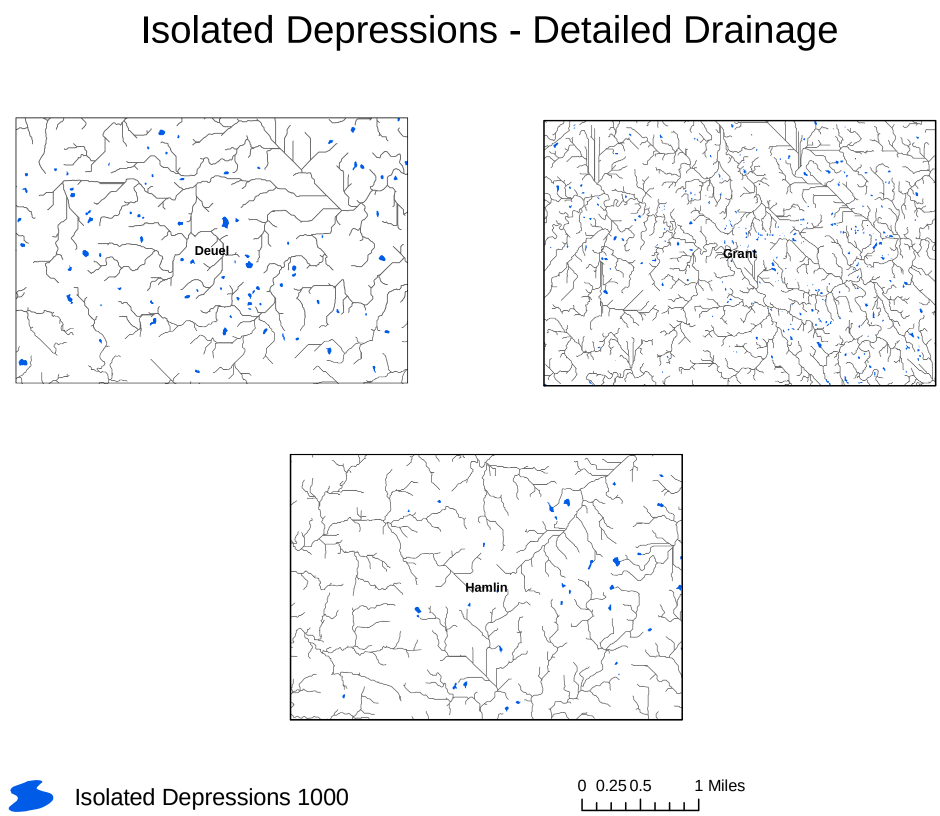


Figure 3. Linked depressional features and detailed drainage (1000 threshold value)



Statistics on linked and isolated depressions show that larger wetlands/depressions appeared linked to the generalized drainages and has drainages become more detailed the smaller features are included in the linkage (Table 1).

Table 1: Area and depth statistics for linked and isolated wetlands for generalized and detailed drainages. Type code: L-G = linked generalized, I-G = isolated generalized, L-D = linked detailed, I-D = isolated detailed. Area is in hectares.

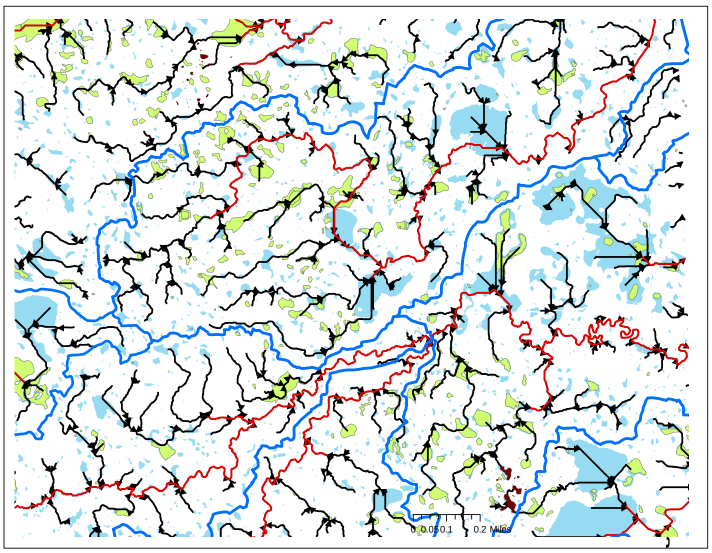
Type	Count	Area in h	Mean Area	Max Area	Mean Depth	Max Depth
L - G	5384	96954	17.9	11938	0.9	17
I - G	63894	88731	1.4	238	0.7	48

L - D	54664	181444	3.3	11938	0.7	48
I - D	14614	3741	.25	2	0.6	7

Figure 4 presents a more comprehensive look of the relationships between synthetic drainages and Crystal Springs and Orchid Meadows wetlands complexes in east-central Deuel County, SD.

Figure 4. 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

Initial sink selection for prefilling the IFSAR DTM determined the number of depressions/depression areas identified. Synthetic drainages show direction of flow of connected depressions. Some 5383 or 7.7 percent of depressions intersected generalized drainage, representing a minimal 800000 sq m drainage area. While some 54664 or 78.9 percent of the depressions intersected the most detailed drainages, which were defined by using flow accumulation threshold value of greater and equal 1000 equivalent to 10000 sq m drainage area. Modeled drainage connections between wetlands at Crystal Springs and Orchid Meadows, Deuel County, SD were verified by field inspection. Large shallow depressional features, many of them wetlands, having an average size of 17.9 hectares intersected the most generalized of the synthetic drainages (32000 flow accumulation threshold value). Lowering of the threshold value to 1000 decreased the average size of depressions to 3.3 hectares while significantly increasing the number of intersecting depressional features.

When modeled in a GIS, depressional wetlands and non wetland depressions on the Prairie Coteau of eastern South Dakota show connectivity through a system of synthetic drainages. Under high water conditions, these depressions including depressional wetlands will likely show drainage linkages and could in time disappear as the landscape matures. Through these analyses, normally isolated wetlands/wetland complexes can begin to be identified, conserved, and managed and drainage systems better understood. The role of groundwater in sustaining wetlands and surface flow in the PPR remains to be determined.

References

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