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Using Digital Methods to Reconstruct Original Topography and Landscape Wetness in the Judicial Ditch 66 Watershed, Polk County, Minnesota

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Abstract:

The excavation of Judicial Ditch #66 has altered the topography of its hydrologic basin in Polk County, Minnesota. Records of how the pre-ditch landscape appeared do not exist. The original aim of this study was to develop and evaluate a method of manual data manipulation and combination to digitally restore the topography of a human-altered landscape.

Trial and error with the combination of spatial data from separate sources provided inadequate results. The study was subsequently divided into four parts. First, drainage area and its potential wetness were estimated using the 10 meter U.S. Geological Survey Digital Elevation Model (DEM). The $\ln(a/\tan \beta)$ potential wetness index is used, which is directly related to drainage area. Second, points representing ditches and berms were eliminated from National Resources Conservation Service (NRCS) spatial survey data. Third, we compared wetness indices of the restored and original landscapes. Finally, the wetness index for the restored landscape was compared to a soil map of the study area to determine if the areas of wetness correspond with hydric soils.

GIS software provides helpful tools, which can produce models that can simultaneously show multiple layers of information for an area. By estimating areas of wetness, this method allows the effects of restoration to be determined prior to any physical alteration of the landscape. The display of data and models on GIS maps will play a large part in helping to solve other restoration issues in the future.

1. Introduction:

Judicial Ditch # 66 is located in north central Polk County, Minnesota (Fig. 1). It diverts water from a gravel pit in the southern part of the watershed and flows north toward the Red Lake River. The ditch was created to drain wetlands for agriculture and convey excess water from the gravel pit, which breaches a shallow confined aquifer.

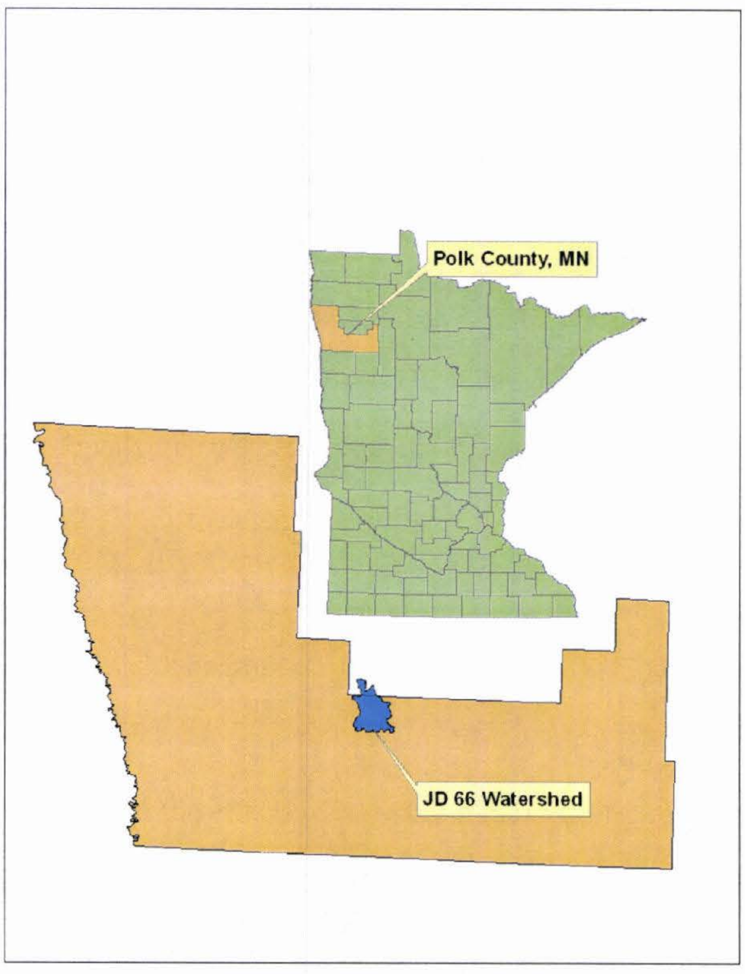

Figure 1: JD 66 Watershed location

The ditch lies within the Glacial Ridge Project, a large-scale conservation project, initiated by The Nature Conservancy, an international non-profit organization working to restore native prairie and wetland in Minnesota. The completed project will increase the connectivity of 12 present conservation areas to create a 35,000-acre refuge (The Nature Conservancy, 2004).

The project area has been extensively mapped, but an accurate representation of pre-ditch topography is not available. Topography has a large influence on hydrological conditions, such as groundwater flow and soil moisture. Linear structures such as ditches that are located near wetlands can have a large effect on the hydrology of the area (Skaggs et al., 2005). Manually eliminating the spatial data representing ditches and berms then gridding the remaining elevation points would generate a model that should be consistent with the past topography.

A wetness index may be used to describe the relative availability of water across the landscape (i.e., potential wet and dry areas) after restoration to a pre-ditch landscape. The terrain wetness index (TWI) is defined as $\ln(a/\tan \beta)$ where "a" is the local upslope area draining a certain point per unit contour length and "$\tan \beta$" is the tangent of the local slope angle in radians (β) (Beven and Kirby, 1979). For raster data, the variable "a" can be equated with the area of all cells that flow into a particular cell. Areas of high potential wetness should correspond with hydric soils when compared to a soil map of the area.

An accurate representation of pre-ditch topography in a digital form could provide invaluable information to restoration efforts for the area. It would be possible to make better estimates of wet and dry areas, and to use the results for decision-making tools in wetland restoration projects, especially for deciding on an appropriate native seed mix.

2. Goals:

The goals and objectives for the work described in this report follow:

- Define watershed for JD66 area using the 10m USGS DEM, and estimate potential wetness using TWI.
- Produce a DEM that represents the pre-ditch topography of the landscape, using NRCS spatial survey data, and estimate landscape wetness based on TWI
- Produce a DEM that represents present topography of landscape, using NRCS spatial survey data, and estimate relative wetness.
- Evaluate the results by comparison with map of hydric soils.

3. Data and Methodology:

The published 10 meter DEM was provided by the United States Geological Survey (USGS). In addition, more detailed topographic data for the ditch watershed were surveyed by the NRCS. The NRCS spatial data were irregularly spaced with point density ranging between eight and 80 meters. Farm Services Administration (FSA) aerial photos were obtained from the Minnesota Department of Natural Resources (2008). All data and layers are projected in Universal Transverse Mercator 1983 Zone 15N.

3.1 Delineation of watershed for study area and wetness index using 10m DEM

Using the Fill tool in ArcMap, the sinks within the USGS DEM were removed. Sinks are single cells or sets of adjacent cells with undefined drainage direction, due to all the surrounding cells having a higher elevation. This file is used as an input for the Flow Direction tool in ArcMap, which determines the direction of flow from each one of the raster cells. The new flow direction raster is used as an input for the Flow Accumulation tool in ArcMap. The values created by the Flow Direction raster are used to calculate the number of upslope cells flowing to a location. The cell near USGS stream gage 05078770 was used as the discharge point for delineation of the watershed. The original, unfilled DEM was then clipped around the shape of the watershed (Fig. 2). The Slope tool is used in ArcMap, which calculates the maximum local slope between each cell and its neighbors. The slope raster was converted from degrees to radians.

This produces a raster in which some of the slope values are equal to zero. This can create a problem when using the Raster Calculator for the equation, $TWI = \ln(a/\tan\beta)$ because of division by zero. When the slope for a cell equals zero, a minimum value of 0.000594 radians is assigned to prevent division by zero. This minimum slope was arbitrarily chosen as one-half of the minimum value within the entire slope layer.

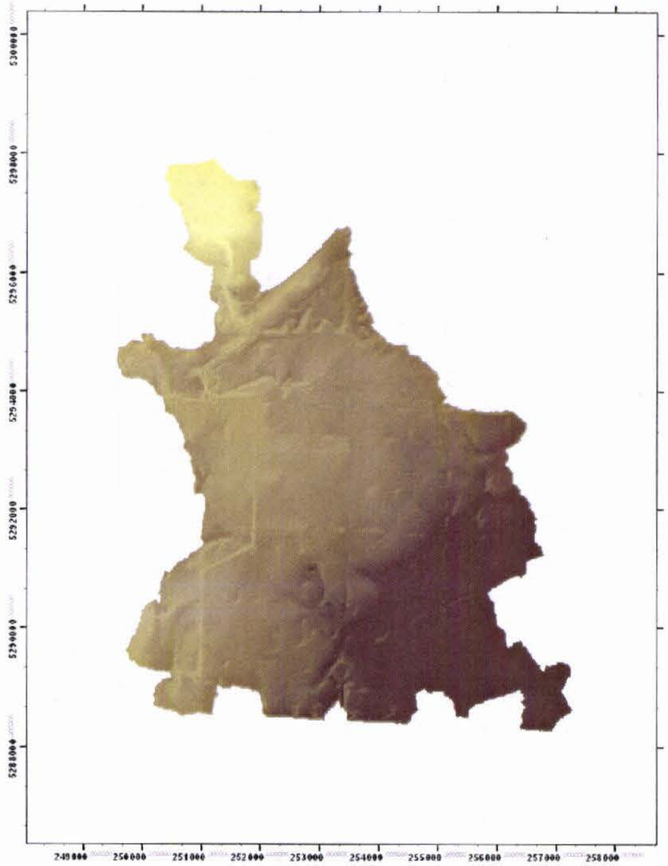

Figure 2: USGS 10 meter DEM clipped around the delineated JD 66 watershed

The Raster Calculator in ArcMap was then used to produce an estimation of wetness index for the study area. The resulting raster was filtered using the low pass filter tool, which smoothes the data by averaging the high and low values within each 3 x 3 neighborhood that surrounds the raster cell.

3.2 Combination of 10m USGS DEM with NRCS spatial survey data

Spatial survey data from the NRCS is clustered around the ditches at the site and provided enough resolution for anomalous points to be identified and eliminated. NRCS elevation data were plotted with 32 classes at equal intervals and given a contrasting color scheme. Most anomalous elevation points were then a different hue from their neighboring points. Color orthophotos provided by the FSA aided in locating anomalous points (Fig. 3). These points, which represent the ditches and berms, were manually deleted from the map. Approximately 2,400 data points were eliminated. Spatial survey data from the NRCS, however, covered only a small area of the watershed for the study area (Fig. 4).

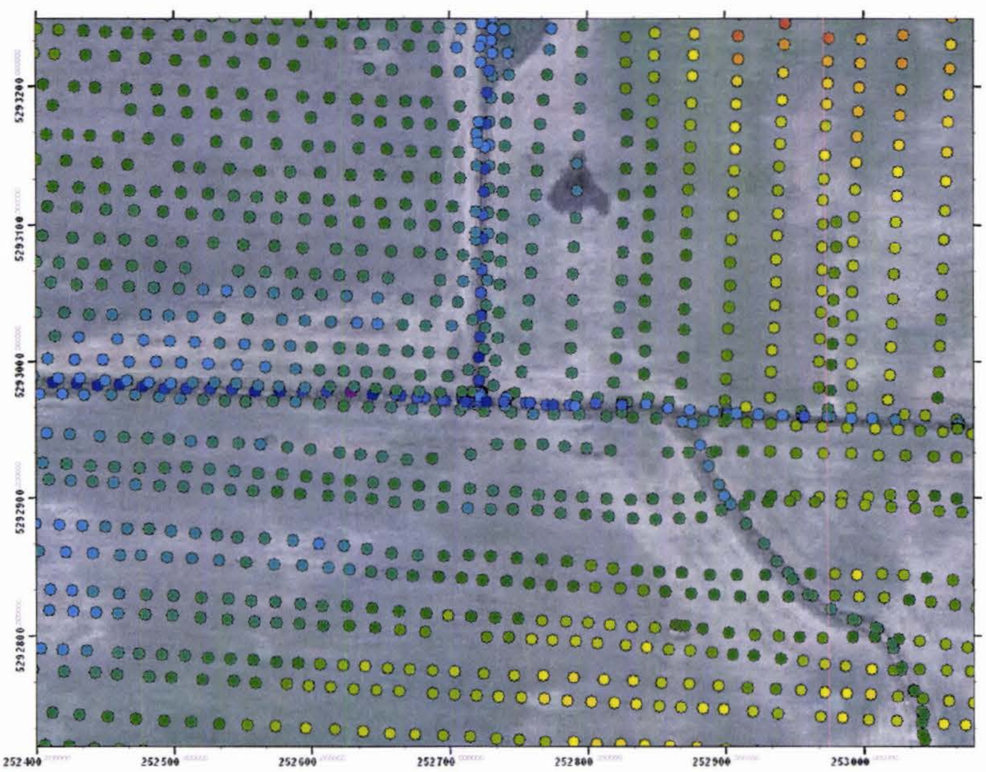

Figure 3: Identifying anomalous NRCS spatial survey points with contrasting color scheme

With the ditches the chief focus of the study, the NRCS data potentially could be combined with the DEM to create a grid of the entire watershed with higher resolution in the study area. The DEM was converted to a multipoint shape file from which all points within a 20-meter buffer of the NRCS data were selected and deleted.

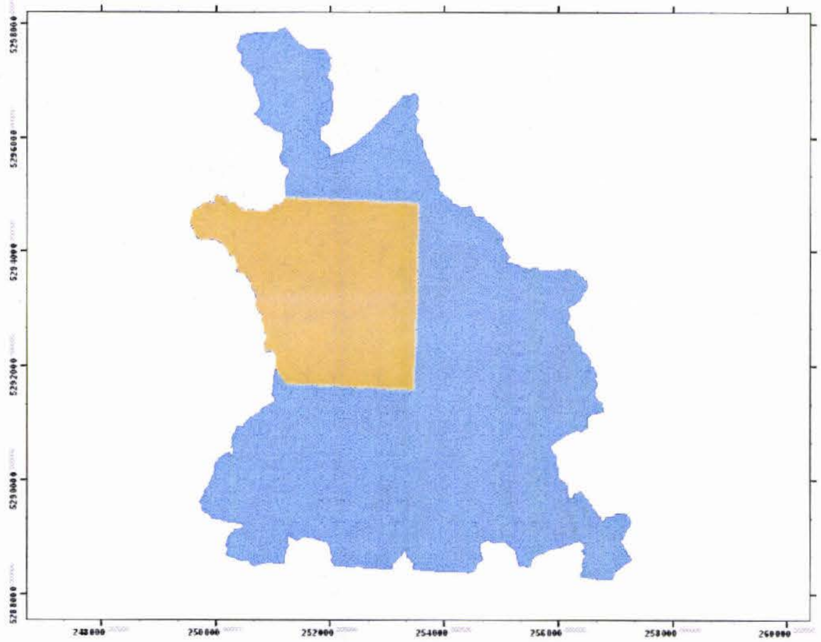

Figure 4: Judicial Ditch 66 watershed. Tan color represents the area covered by NRCS spatial survey

3.3 Creation of ditchless DEM and estimate of potential wetness using NRCS data

The study was then modified to a compare wetness index for the higher resolution NRCS data set to the USGS 10m DEM. The digital elevation model for the area was made by using the natural neighbor gridding algorithm within ArcMap. Natural neighbor was chosen for its simplicity when working with a large number of elevation points and anisotropic data. The method of interpolation is also shown to have very small effects on the effect of topographic index (Wu et al., 2007).

Natural neighbor interpolation creates grid values by applying weights to the nearest subset of input samples to a query point (Sibson, 1981). One reason natural neighbor interpolation was used is that the interpolated heights are within the range of samples used. It does not infer trends or produce peaks, pits, ridges, or valleys that are not already represented by the input samples. It uses only a subset of samples that surround a query point. The NRCS spatial survey points are also highly anisotropic, and natural neighbor works equally well with regularly and irregularly distributed data (Watson, 1992).

The raster DEM produced from natural neighbor interpolation of the edited NRCS spatial survey was used in conjunction with hydrological tools in ArcMap to estimate the potential wetness of the pre-ditch topography.

3.4 Creation of DEM and estimate of potential wetness using unedited NRCS data

The unedited NRCS spatial survey data were converted to a raster using natural neighbor interpolation. The DEM created was clipped around the overall watershed shape. The raster DEM produced was used in conjunction with hydrological tools in ArcMap to estimate the potential wetness of the present topography. This estimated wetness index for this file was used to compare the effectiveness of removing the ditch.

4. Results and Discussion:

USGS DEMs are produced by interpolation from the contours on a topographic map, and therefore provided insufficient resolution from which the ditch and berm points could be identified and removed. The wetness index produced from the DEM was not capable of showing the changes in wetness resulting from the removal of the ditches or berms (Fig. 5). Changes in wetness produced by removal from ditches within the NRCS data were compared alongside Fig. 5.

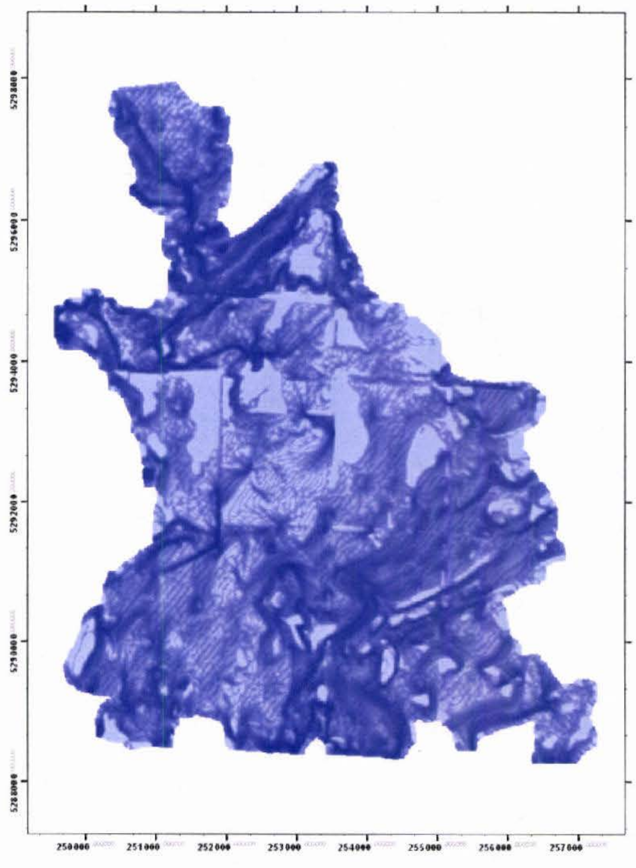

Figure 5: Estimated wetness index using USGS 10-meter DEM. The darker color indicates higher wetness index

The combination of NRCS spatial survey with the USGS 10-meter DEM produced a grid with strong linear artifacts around the buffer zone, thought to be produced solely from the buffer zone. The unedited data sets were then merged together in an attempt to seamlessly combine the two. Close inspection of the data points showed significant elevation differences in the two layers.

The results provide a map of the probable pre-ditch topography of the Judicial #66 basin by removing elevation points representing ditches and berms from the NRCS spatial survey data set (Fig. 6). The production of the pre-ditch map shows that it is possible to use GIS methods to show how landscapes may have been altered over time.

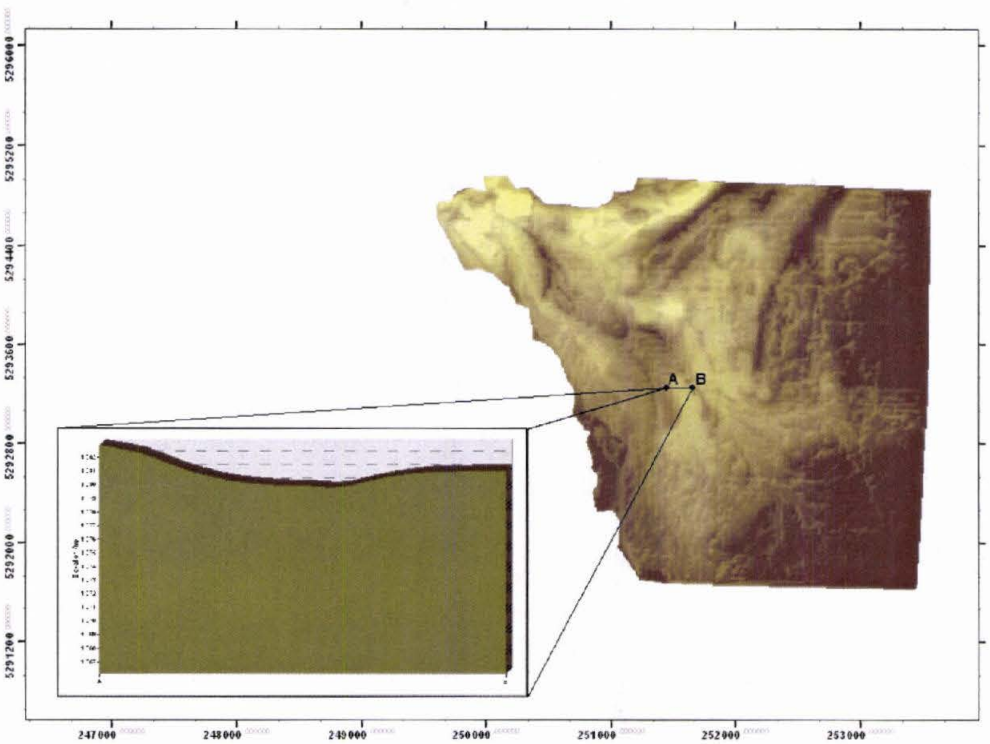

Figure 6: DEM with ditches and spoils removed.The cross-section shows pre-ditch topography

The enlargement in Fig. 6 is taken from an area in which the ditch intersects the cross-section perpendicularly in the north-south direction. The cross-section shows a gently sloping topography consistent with the estimate of undisturbed topography.

For evaluation of the restoration method, the same profile was to produce a cross-section from the DEM produced by natural neighbor interpolation of the unedited NRCS spatial survey data (Fig. 7). The cross-section displays the unnatural topography produced by the installation of the ditch.

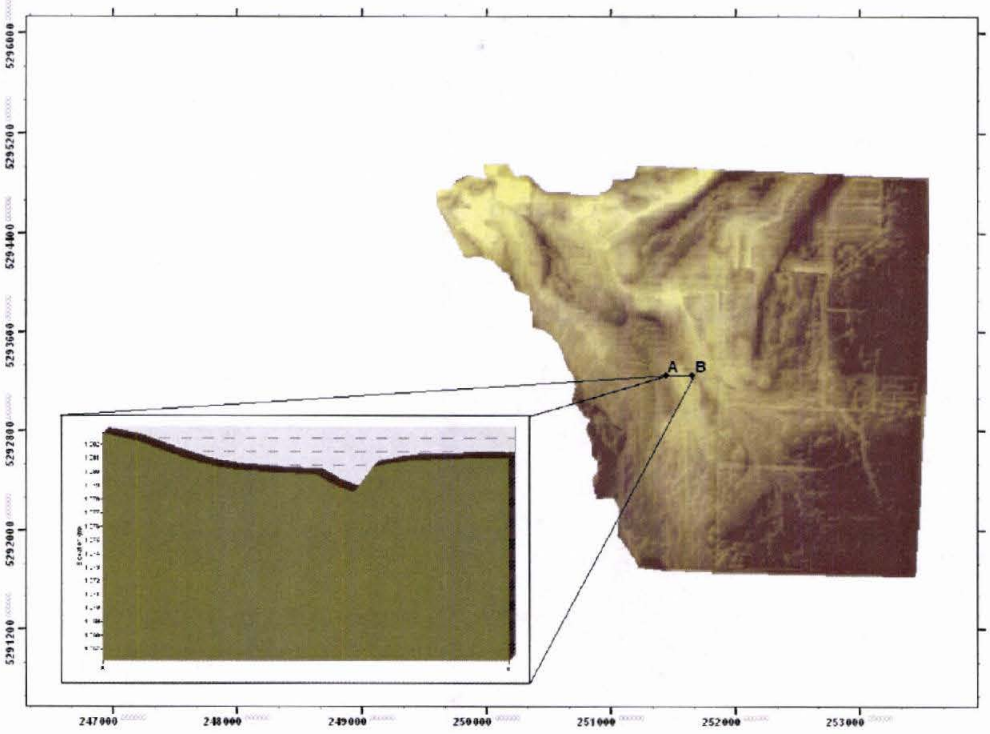

Figure 7: DEM produced from unedited NRCS spatial survey. The cross-section shows steep ditch banks

The wetness index created from the DEM of the unedited NRCS spatial survey shows that the low-lying ditches will be the most saturated (Fig. 8). The map shows strong linear wetness areas overlying the position of the ditches. The outside borders of the map also show some areas of high potential wetness. These areas remain ignored, as they are likely an edge effect produced from the gridding of elevation points. Comparison of this index with Fig. 5 suggests that the NRCS spatial survey more accurately reflects the effect of ditches in the area.

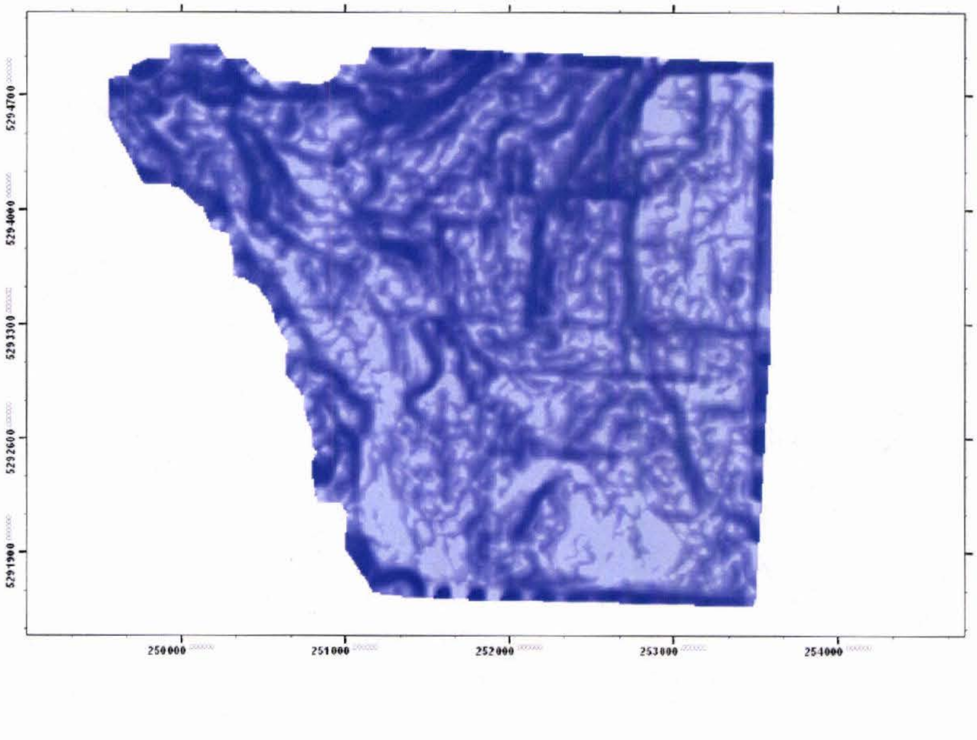

Figure 8: TWI from unedited NRCS spatial survey. The darker color indicates higher wetness index

Manually deleting over 2,400 elevation points from the NRCS spatial survey in order to remove any evidence of the ditches or associated berms produced a wetness-index dissimilar from the unedited spatial survey. Although the TWI from the ditchless DEM is also prone to the edge effect on the outside edges, it shows less linear trends in wetness (Fig. 9).

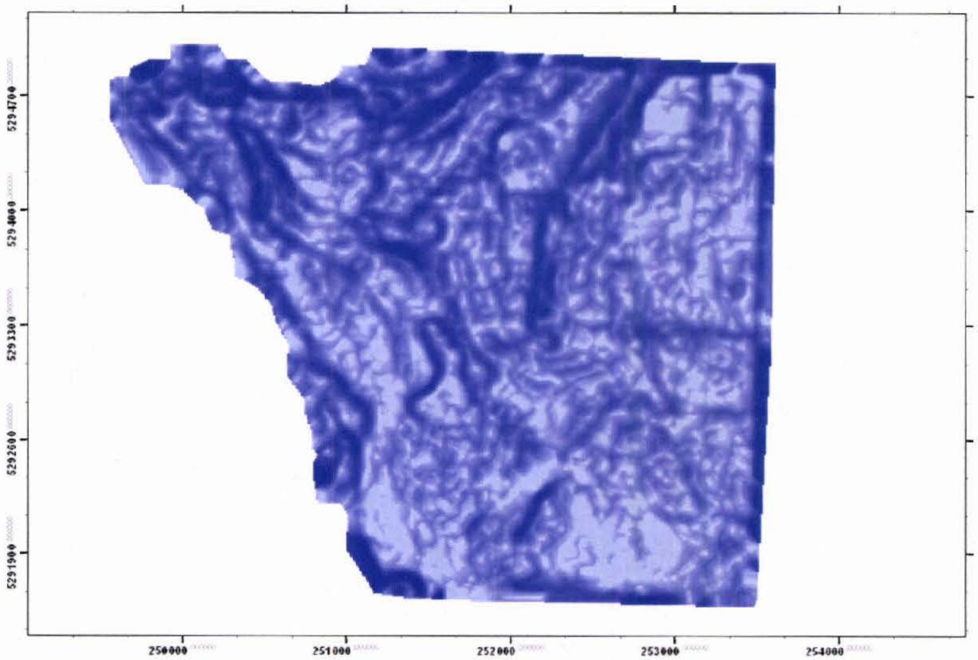

Figure 9: TWI from ditchless DEM. The darker color indicates higher wetness index

The DEM produced by gridding the entire NRCS spatial survey defines the areas in which the ditches and berms are present. By subtracting the grid produced by the NRCS spatial survey from the DEM, it is shown that the NRCS spatial survey provides the resolution needed to show the resulting changes from the data manipulation (Fig. 10). The subtraction of the DEMs also shows the edge effect produced by the creation of the elevation grids.

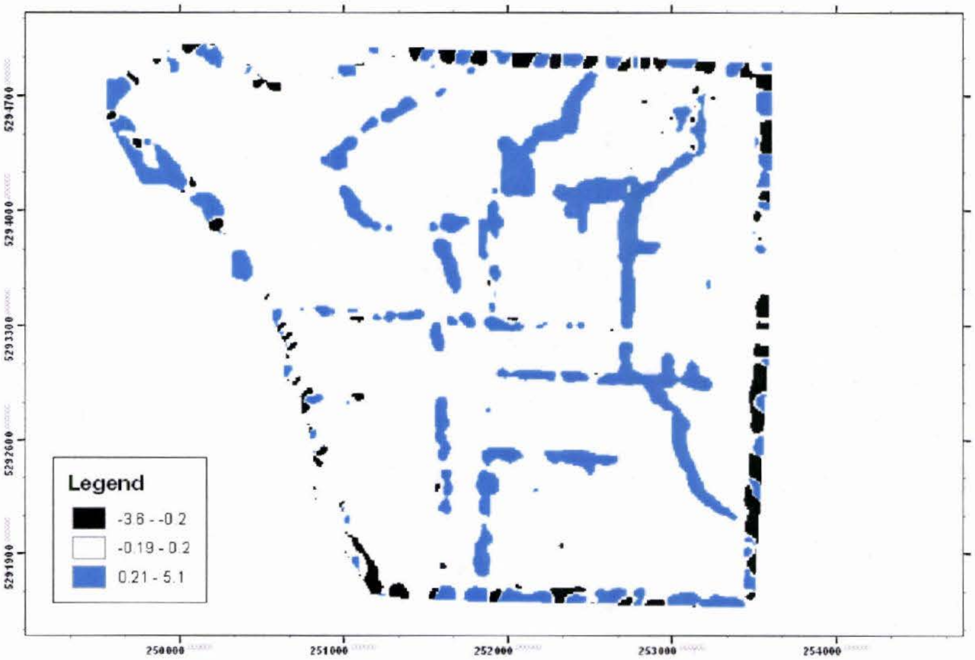

Figure 10: Subtraction of TWIs.

Overlaying a soils map with the wetness index estimated from the pre-ditch topography does not accurately evaluate restoration (Fig. 11). Most of the soils at the study site are hydric, making the correlation between wet areas and hydric soils uncertain. Overlying the same soil map with the wetness index produced from the present-day topography also shows a poor relationship between hydric soils and areas of saturation (Fig. 12).

The poor correlation between hydric soils and saturated areas is due to the heterogeneity of the soils in the area. The soils are mostly a mix of glacial till interspersed with dune and beach deposits. Therefore, areas that are predicted to be saturated may be underlain by more permeable soils and not display a high degree of correlation.

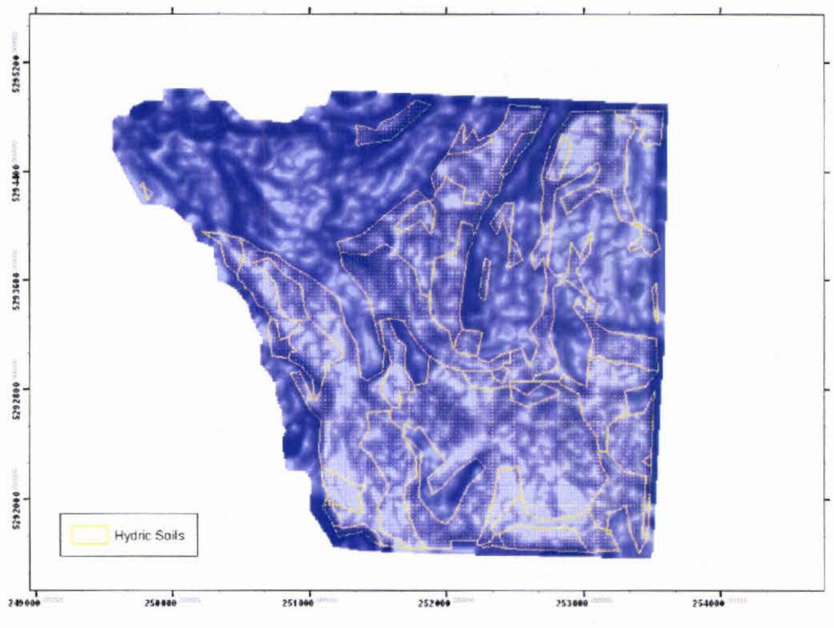

Figure 11: Hydric soil map overlying TWI for pre-ditch topography

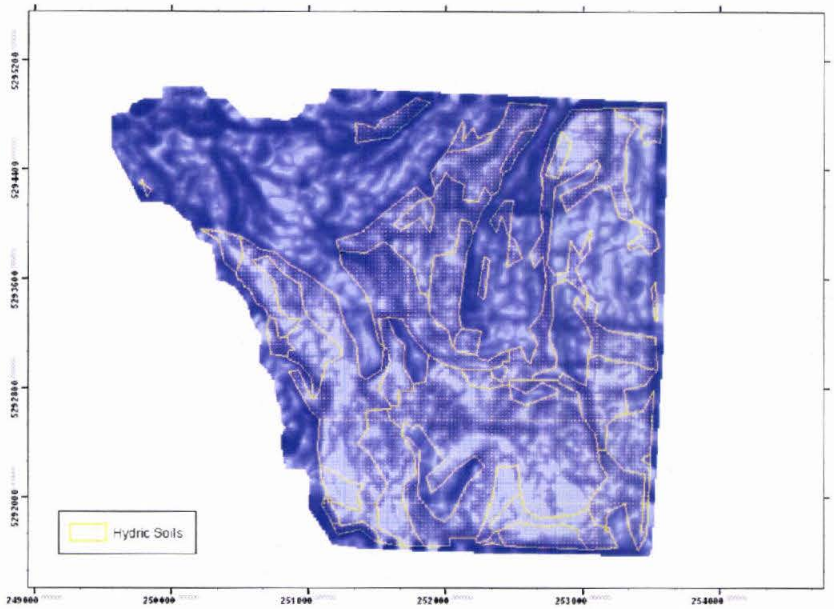

Figure 12: Hydric soil map overlying TWI for present topography

5. Conclusions:

In some cases, such as this one, it may be desirable to restore landscapes that have been altered over time by humans or natural processes. This method may prove useful for such situations in which researchers and conservationists wish to determine how the past topography of the site may have appeared and functioned.

The hydrology for the Judicial Ditch 66 site functioned differently before the area was drained and excavated by the addition of the ditches and gravel production sites. Restoration also has its own consequences; the removal of the ditch will alter the current landscape wetness of the site. The production of these maps provides a means to predict areas that will become either drier or wetter following restoration. Thus, the pre-ditch map can be used as a baseline for the restoration efforts.

These baseline maps of pre-ditch topography and wetness index are only estimates of the past circumstances. The performance of these estimates must be evaluated in the future in order to determine their accuracy. Comparison with sites that have undergone accurate mapping before and after alteration may show that by following the same methods, similar pre-alteration topographic maps can be produced using GIS interpretation.

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