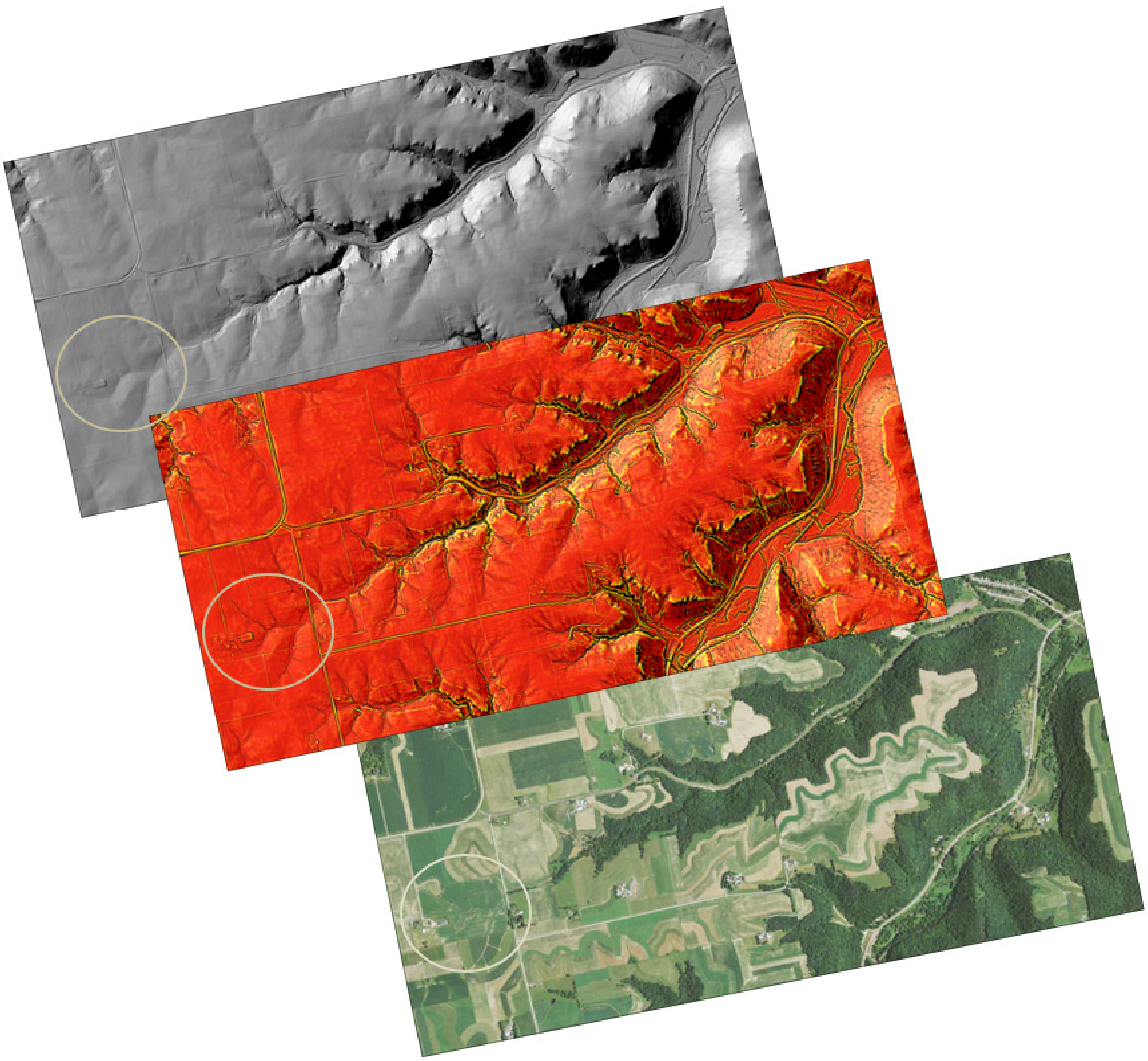
MINNESOTA IT SERVICES
@ DEPARTMENT OF NATURAL RESOURCES

Hydrographic Position Index (HPI): Description and Symbolization

Combining LiDAR-derived Digital Elevation Model (DEM) Analysis, Raster Classification, and Color Symbology for Pseudo-3D Terrain Visualization to Enhance Hydrography Interpretation on the DEM Landscape.



Technical Report

MN Information Technology Services @ MN Department of Natural Resources

Hydrographic Position Index (HPI)

SEARCH TAGS

Digital Elevation Surface | Digital Elevation Model | DEM | Digital Dam | Break Line | Breach Line | DEM Hydro-modification | Depression | DEM Enforcement | DEM Conditioning | Terrain Analysis | Hydro-Terrain Analysis | Hydrographic Position Analysis | HPI | Flow Accumulation | Filled DEM

SUGGESTED CITATION

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COVER DESIGN

White circles indicate a focus area for comparison between 1) Hillshaded DEM, 2) Hydrographic Position Index, 3) 2013-DOQ. The HPI exploits the ability of the DEM to illustrate the water conveyance features and landscape hydrologic connectivity. By Sean Vaughn, GIS Hydrologist, MNIT@DNR

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Chapter 1

1. INTRODUCTION

In recent years, DEMs have become a commonly applied and valuable data product for land managers and decision makers throughout Minnesota. As a result, modern approaches to landscape and natural resource management have seen an increased use of complex hydrology related models, tools and geographic information system (GIS)[1][2] technology to describe landscape dynamics of watershed systems. This is especially true in the water quality and quantity sciences where accurate representations of Earth's surface improve model results. Correspondingly, emerging conservation targeting tools dependent on accurate digital terrain representation (e.g., ACPF[3]) are bridging Digital Elevation Models (DEM)[4] analysis with targeting of best management practice (BMP) implementation and conservation practices. Capitalizing on lessons learned from users of Minnesota's LiDAR data and derived products, this paper introduces GIS technicians, and technical decisions makers to a product and map symbology developed by Information Technology Services (MNiT) at Minnesota Department of Natural Resources (DNR) called ***hydrographic position index*** (HPI) that accentuates the location of water conveyance landforms on Earth's surface in DEMs.

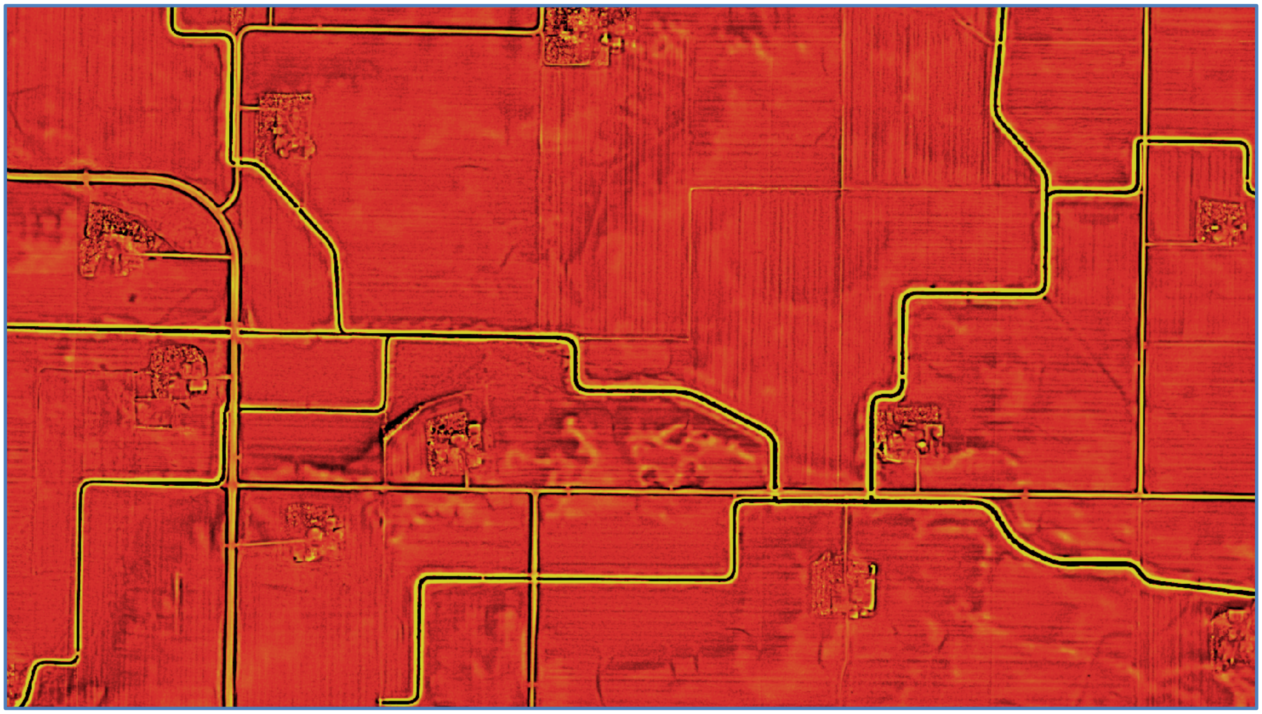


Image 1 – HPI symbolized with the Fire Color Scheme without Topographic Treatments (i.e., hill-shaded DEM). Dark signatures define localized low areas that may contain and or route water. Yellow signatures illustrate local elevations higher than those cells trending towards black.

2. LESSONS LEARNED

2.1 VIEWING LIDAR DATA

One of the most powerful functions of a GIS is the ability to display data for visual interpretation of resources. This is especially true for high accuracy Light Detection and Ranging (LiDAR)[5]-derived data. In fact, from what we have learned from our surveys and LiDAR training throughout Minnesota, the most common application for LiDAR-derived DEMs and hill-shaded rasters[6] derived from these DEMs, is their utilization as a backdrop or base data product for landscape visualization, hydrography[7] interpretation and heads-up digitization of Earth's landforms.

3. BACKGROUND

3.1 USER DEMONSTRATED NEED

Through our questions and discussions with customers and audiences, it became apparent that GIS technicians are hesitant or lack the training needed to manipulate display and symbology properties of DEMs and other LiDAR-derived raster products for feature enhancement to meet different user needs. As a result, we incorporated unique DEM display techniques into our LiDAR training framework. It also became apparent that users of LiDAR data for hydrologic applications would benefit from a readily available, published, authoritative product that illustrated hydrologic connectivity of the landscape. The HPI has proven successful for meeting this need.

3.2 MINNESOTA'S LIDAR PROCUREMENTS DID NOT MAP WATER

The LiDAR instrumentation used in Minnesota's LiDAR collections were topographic *Airborne LiDAR Mapping* (ALM)[8][9] systems operating in the infrared spectrum[10]. The LiDAR pulses of these systems are quickly absorbed or refracted in the water column and not returned to the ALM. As a result, detection of surface water on the landscape was not consistent. However, LiDAR data and derived products provide an accurate representation of the topographic landform features that contain and route excess surface water of the hydrologic cycle. Unique products derived (e.g., DEMs, hill-shaded DEM) from these data products serve many different user needs associated with topography visualization and hydrologic modeling.

3.2 ILLUSTRATING LANDSCAPE HYDROGRAPHY WITH HPI

Minnesota's HPI helps in the visualization and interpretation of landforms associated with water features on earth's surface Built from the concepts of terrain roughness,[11], topographic/terrain ruggedness index (TRI)[12] and topographic position index (TPI),[13][14] the HPI is a special terrain raster dataset and color scheme developed by the author.

The HPI evolved from a research and development (R&D) project that set out to create a product that could provide a sense of visual depth perception without the influences of cast shadows from hill shading of LiDAR-derived DEMs in the viewing environment (see Image-7). The HPI for Minnesota is produced from a LiDAR-derived, 3-meter resolution DEM that has *(1)* specific geoprocessing settings and *(2)* special symbology applied to the raster to exploit hydrographic signatures on the DEM landscape. These products and techniques allow for accurate hydrographic feature identification, digitization, and extraction (see Figure-1).

4. HPI TECHNICAL DESCRIPTION

4.I. WORKUNITS | Spatial Extent

The HPI for Minnesota represents a mosaic of eighty-seven (87) individual county raster work units. These individual work units are a mosaic themselves comprised of 3-meter DEMs built on the individual tiles of Minnesota's published LAS[15] LiDAR data holdings.

4.II. SOFTWARE AND PRINCIPLE TOOLS | Definition

The HPI for Minnesota was created using the Esri Spatial Analyst extension in ArcGIS 10.2. The neighborhood statistical analysis tool -- *Focal Statistics* was the principle HPI development tool; DEM filtering and data normalization *were* additional spatial analysis treatments deployed in some areas of analysis. Regional LiDAR data acquisition accuracy and resulting source DEM quality played an important role in defining when such data massaging was going to improve the visual esthetics of the HPI product. As a result, the HPI for Minnesota was not created under one workflow or set of parameter inputs to the Focal Statistic tool.

4.3 NEIGHBORHOOD ANALYSIS | Factors for Consideration

Four factors considered for HPI creation that influence the *Focal Statistics* tool settings were *(1)* quality of the LiDAR collection, *(2)* the LiDAR bare-earth DEM quality, *(3)* landscape topography (i.e., vast flat agricultural landscapes vs. step terrain with sharp breaks) and *(4)* DEM resolution. Therefore, the process for developing Minnesota's HPI rasters required experimentation with different neighborhood analysis shapes (e.g., annulus, circle, and rectangle) and other parameters (e.g., radius, distance, height and width) passed to the *Focal Statistic* tool. This research and development resulted in the the creation of region specific HPI rasters most suited for topography and hydrography identification from the publicly available LiDAR tile-mosaicked county DEM datasets.

4.4 DEM RESOLUTION | A Simple Parameter

DEM resolution can be the easiest identifiable parameter for consideration and the most influential to in HPI R&D. For example, neighborhood parameters used on a 3-meter resolution DEM will produce different results than a 1-meter DEM because there are nine 1-meter grid cells for every one 3-meter grid cell. Therefore, the 1-meter resolution DEM has the potential for a greater amount of elevation variability in localized areas of analysis using *Focal Statistics*. For example, LiDAR pulse returns hitting individual large rocks with high profiles in dry ephemeral watercourse channels may obscure the ability of the *Focal Statistics* process to define the channel banks because the surface elevations of the rocks may negatively influence the mean value of the neighborhood analysis.

4.5 NARROW NEIGHBORHOOD PARAMETERS | Tool Settings

By keeping the neighborhood analysis narrow, contrasting HPI values can occur on sharp planes defining topographic breaks representing banks and edges of landforms that contain and convey water on Earth's surface (e.g., channels and lake edges). *Focal Statistics* neighborhood shapes of circles and rectangles with small areas of analysis such as 3-cells by 3-cells proved to produce the most consistent and reliable HPI results for much of Minnesota's landscape.

4.6 HPI DEVELOPMENT | Description and Loose Work Flow

4.6.a Filter

Some regions of analysis across Minnesota benefited from a low-pass filter. Although *Low-pass filters* are recognized as a "smoothing" technique and *High-pass* filters are recognized as "edge-enhancing" filters, both operate on a 3-by-3 cell window over the DEM. As a result, a Low-pass filter traversing the detailed elevation values of the LiDAR-derived DEM successfully removed extreme neighborhood elevations (e.g., erratic rocks on the landscape or in a dry channel with high vertical profile and noise remaining from LiDAR point classification algorithms). Filtering techniques were used with caution and at a minimum because some fidelity of the topographic breaks beneficial to HPI development can be lost.

filter_dem = **FILTER**(sourceDEM,LOW, DATA)

sourceDEM = dem_3m_m, Minnesota's published LiDAR-derived DEM

LOW = Low Pass Filer

DATA = DATA — Specifies that if a NoData value exists within a neighborhood, the NoData value will be ignored. Only cells within the neighborhood that have data values will be used in determining the output value. This is the default.

Equation 1 - FILTER Syntax Example (regional work unit specific application).

4.6.b Mean

Elevation values of individual grid cells in the source DEM (dem_3m_m) are passed into a unique overlapping neighborhood kernel-calculation for each individual cell (processing cell) using the *Focal Statistics tool* with a *Mean* statistics operator.[16] This statistics operation computes an output raster with new values representing the arithmetic mean elevation value of all cells in the neighborhood analysis including the processing cell.

nbrhd_mean = **FOCALSTATISTICS**(sourceDEM, {neighborhood}, "MEAN","DATA")

sourceDEM = dem_3m_m, Minnesota's published LiDAR-derived DEM

{neighborhood} = user defined parameters.

MEAN = Calculates the mean (average value) of the cells in the neighborhood.

DATA = DATA — Specifies that if a NoData value exists within a neighborhood, the NoData value will be ignored. Only cells within the neighborhood that have data values will be used in determining the output value. This is the default.

Equation 2 - MEAN Neighborhood FOCAL STATISTICS Syntax Example.

4.6.3 DEM Variance

The sample *mean* and source DEM variance is calculated by subtracting the *Focal Statistics* resultant raster (nbrhd_mean) from the source DEM (dem_3m_m) using the *MINUS* tool.

dem_variance = **MINUS**(sourceDEM, nbrhd_mean)

sourceDEM = dem_3m_m, Minnesota's published LiDAR-derived DEM

{neighborhood} = Calculated in equation #2.

nbrhd_mean = Calculates the mean (average value) of the cells in the neighborhood.

Equation 3 MINUS Syntax Example.

4.6.4 Standard Deviation | Quantifying Elevation Variation

Computing the *standard deviation* (STD) of the analysis neighborhood is calculated with the same *Focal Statistics* neighborhood settings (i.e., {*neighborhood*}) used in calculating the MEAN (*nbrhd_mean)*.

nbrhd_stdd = **FOCALSTATISTICS**(dem_3m_m, {neighborhood}, "STD","DATA")

sourceDEM = dem_3m_m, Minnesota's published LiDAR-derived DEM

{neighborhood} = user defined parameters.

STD = Calculates the mean (average value) of the cells in the neighborhood.

DATA = DATA — Specifies that if a NoData value exists within a neighborhood, the NoData value will be ignored. Only cells within the neighborhood that have data values will be used in determining the output value. This is the default.

Equation 4 - STANDARD DEVIATAION Neighborhood FOCAL STATISTICS Syntax Example.

4.6.5 HPI Normalization | Data Massaging

The standard deviation values of "*nbrhd_stdd*" can be used to perform a *normalization* on the source DEM raster (*dem_3m_m)*. This statistically teases out the influence of outlier elevation values; essentially dividing by the standard deviation is intended to scale the mean towards "0" while maintaining the shape of the original distribution of the values.

hpi_nrmlz = ("SourceDEM" – "meanDEM") **/** ("nbrhd_stdd")

or

hpi_nrmlz = ("dem_variance") **/** ("nbrhd_stdd")

sourceDEM = dem_3m_m, Minnesota's published LiDAR-derived DEM

nbrhd_mean = Calculated in equation #2.

dem_variance = Calculated in equation #3.

nbrhd_stdd = Calculated in equation #4.

Equation 5 - HPI Normalization Syntax Example for Map Calculator

4.6.6 Complete HPI Formulas | Calculations Simplified

The preceding equations can be synthesized into simplified equations in Map Calculator.

hpi = " sourceDEM " **– FOCALSTATISTICS**(sourceDEM, {neighborhood}, "MEAN","DATA")

sourceDEM = dem_3m_m, Minnesota's published LiDAR-derived DEM

{neighborhood} = user defined parameters.

MEAN = Calculates the mean (average value) of the cells in the neighborhood.

DATA = DATA — Specifies that if a NoData value exists within a neighborhood, the NoData value will be ignored. Only cells within the neighborhood that have data values will be used in determining the output value. This is the default.

Equation 6 - HPI Combined Syntax Example for Map Calculator.

hpi_nrmlz = ("sourceDEM" **– FOCALSTATISTICS**(sourceDEM, {neighborhood}, "MEAN","DATA"))/ **FOCALSTATISTICS**(sourceDEM, {neighborhood}, "STD","DATA")

sourceDEM = dem_3m_m, Minnesota's published LiDAR-derived DEM

{neighborhood} = user defined parameters.

MEAN = Calculates the mean (average value) of the cells in the neighborhood.

STD = Calculates the mean (average value) of the cells in the neighborhood.

DATA = DATA — Specifies that if a NoData value exists within a neighborhood, the NoData value will be ignored. Only cells within the neighborhood that have data values will be used in determining the output value. This is the default.

Equation 7 - HPI Combined Syntax Example for Map Calculator.

4.7 HPI DISSEMINATION PRODUCTS | Efficiency Techniques

4.7.1 Floating Point to Integer

Publication, dissemination and display efficiencies of statewide-mosaicked data products can benefit from data massaging techniques. One method is to scale the values from floating point to 8bit-integer values (0 to 255) to make HPI rasters faster and more responsive for application.

rescaled_hpi = (source_hpi **–** min value from source_hpi) ***** max scale value **/** (max value from source_hpi **–** min value from source_hpi) **+** min scale value

sourceDEM	= HPI rasters calculated from equation's #6 and #7.
min value from *source_hpi*)	= Calculated raster statistic (e.g., ⁻3.7061)
max value from *source_hpi*	= Calculated raster statistic (e.g., 5.8558)
min scale value	= 0
max scale value	= 255

Equation 8 - Syntax Example for rescaling from floating point to 8bit-integer values (0 – 255).

4.7.2 Removing Outliers

Another method of scaling the HPI rasters is to truncate or clip extraneous values from the range of values. HPI values calculated with a localized *Focal Statistic* neighborhood typically fit within a narrow range spanning only several digits +/– of zero. However, large HPI assemblages of mosaicked LiDAR-derived DEMs contain their own unique outlier minimum and maximum values from actual elevation extremes and/or computation noise in the data. These values can make rendering the products difficult for distribution bundling and display applications. Since realistic HPI values for Minnesota rarely exceed values less than negative ten (⁻10) and greater than positive ten (⁺10), extreme values can be safely reclassified without sacrificing HPI signature detail. This technique first multiplies the floating-point data by 100 before scaling, which tends to retain a majority of the detail of the original data. Next, a Spatial Analyst conditional *if/else*, evaluation statement (CON statement) is used on each of the input raster cells.

```
Con("input_hpi" > 10, 10, Con("input_hpi " < ¯10, ¯10, " input_hpi "))

    input_hpi = HPI rasters calculated from equation's #6 and #7.
```

Equation 9 - Syntax Example for rescaling/reclassifying data values $< {}^{-}10$ and $> {}^{+}10$ using a CON statement.

5. HPI COLOR SCHEME

5.1 FIRE COLOR SCHEME | Background

The HPI color schematic is built on the widely distributed "Fire" symbology suite of parameters developed by the author (<u>see</u> section 11, Fire Color Scheme Used to Create the HPI Signatures). Although an abstraction to colors typically associated with the cartography of terrain, this unique symbology relies on the warm yellow and red hues that trend to black as a means to bring visual order to the high and low elevations of localized landscapes. Additionally, yellow and red hues are used in the cartographic arena as colors that favor the mind's eye ability to interpret depth. As a result, colored features of the HPI can appear as though they rise off the image. The perception of depth is enhanced more by draping a transparent HPI over the DEM-derived hillshade.

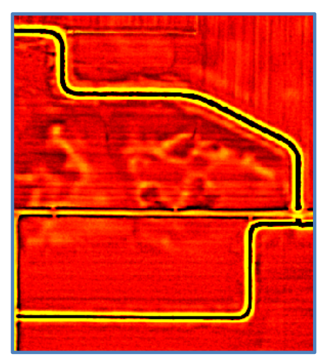


Image 2 – Fire Color Scheme

In the HPI, individual raster cells are colored through map symbology based on their positive and negative differences to the surrounding neighboring cells. *Dark cells* of the HPI indicate localized negative differences defining local neighborhood topographic low elevations, while the *yellow cells* indicate localized positive differences illustrating high points in the terrain (e.g. local hills and road crowns).

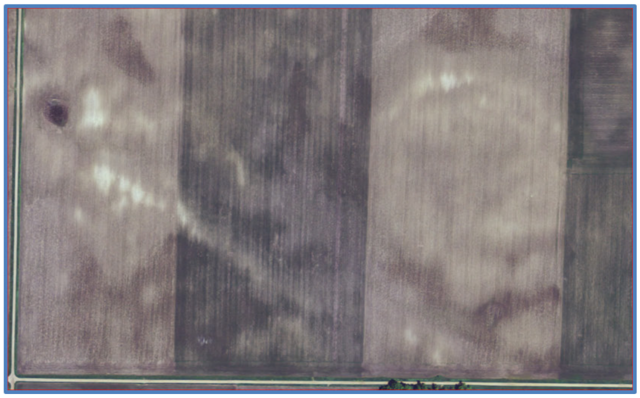
5.2 BLENDED HUES | Red to Yellow and Red To Dark-red Blends

These blends of the color spectrum within the *Yellow to Dark Red* color ramp indicate areas of localized-consistent relief forming ***Local Zones of Elevation Similarity*** (LzEs). Using the HPI as an illustration tool for exploiting hydrography features, the sharper contrasting colors of yellow and black tend to be more valuable than the colors of the LzEs. Dark red to black linear signatures in the HPI are chains of adjacent localized low cells; visually, these darker areas meld to form visible local drainage paths (LDP). Collectively, LDP form watershed-wide ***local drainage networks*** (LDN).

5.3 YELLOW SIGNATURES | Localized High Points

Cells trending towards yellow in an HPI raster are zones of higher neighbor relief than cells or zones trending towards red, dark red and black, which indicate lower elevations. For example, roads and localized terrain peaks exhibit brighter yellow areas. However, that does not mean a hill with exceptional height exists at every zone of cells trending towards yellow hues. In *image-3- right* for example, yellow areas of the HPI in an agricultural field match the lightly shaded areas on a digital orthophoto quadrangle (DOQ). Even at the localized field scale, each product is representing slight differences in elevation values that are influencing visual signatures from remote sensing technologies.

Soil types with less moisture retention in localized relief tend to have lighter color signatures. Therefore, the beige signatures in the DOQ (see *image-3, left*) represent areas of higher localized peaks of dryer soils. From the illustrations of image-3, we can see the correlation between the DOQ and HPI, validating the effectiveness of the HPI signatures identifying localized topographic differences.



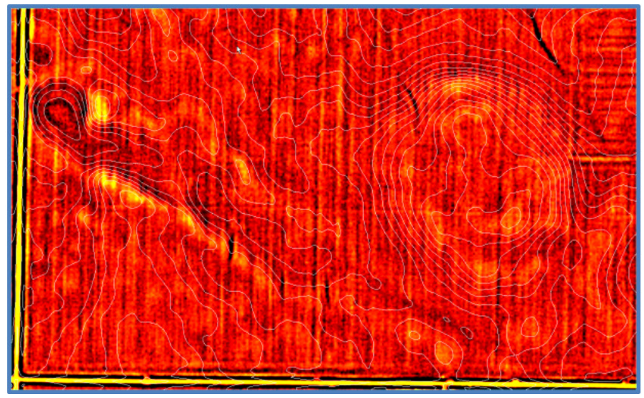


Image 3 – Localized topographic high elevations with drier soils represented in the DOQ image (left) as white signatures (colors) in the agriculture fields. The HPI represents the same features as yellow signatures (right).

5.4 BLACK SIGNATURES | Localized Low Points

As the color blend signatures trend toward black in the HPI, the more an individual cell's elevation values are less than their neighborhood mean cell elevation values. Therefore, the blackest signatures indicate cells with values sharply less than their neighborhood cells, which define localized elevation depressions.

Concentrations of cells with black symbology forming organized linear striations indicate ***localized linear depressions*** (LLD). These LLD features form strong signatures within the HPI raster representing incised topographic landforms on Earth's surface that convey concentrated flow. From these signatures, we have greater success identifying the head or start of concentrated flow on the landscape (i.e. formation of channels, erosion headcut/knickpoints,). This visual pattern based on statistical neighborhood raster analysis enhances the ability to define LDN.

5.4.1 Key Topics for Consideration Related to HPI Black Signatures

LiDAR data captures the detail of Earth's surface, how a technician represents that detail in a derived DEM is influenced by the resolution of the DEM and symbology settings utilized for displaying the data. For example, the black HPI signatures are independent of map scale and watershed scale; however, these signatures are DEM resolution dependent (i.e., 1-meter and 3-meter horizontal dimensions).

Black signatures are helpful for identifying water conveyance landforms that could be lost in techniques such as flow accumulation threshold development and stream order classification.

The black signatures give equal hydrologic significance to all topographic landforms that convey water; there is no intention to categorize watercourse features into perennial, intermittent, seasonal or ephemeral classifications from the HPI.

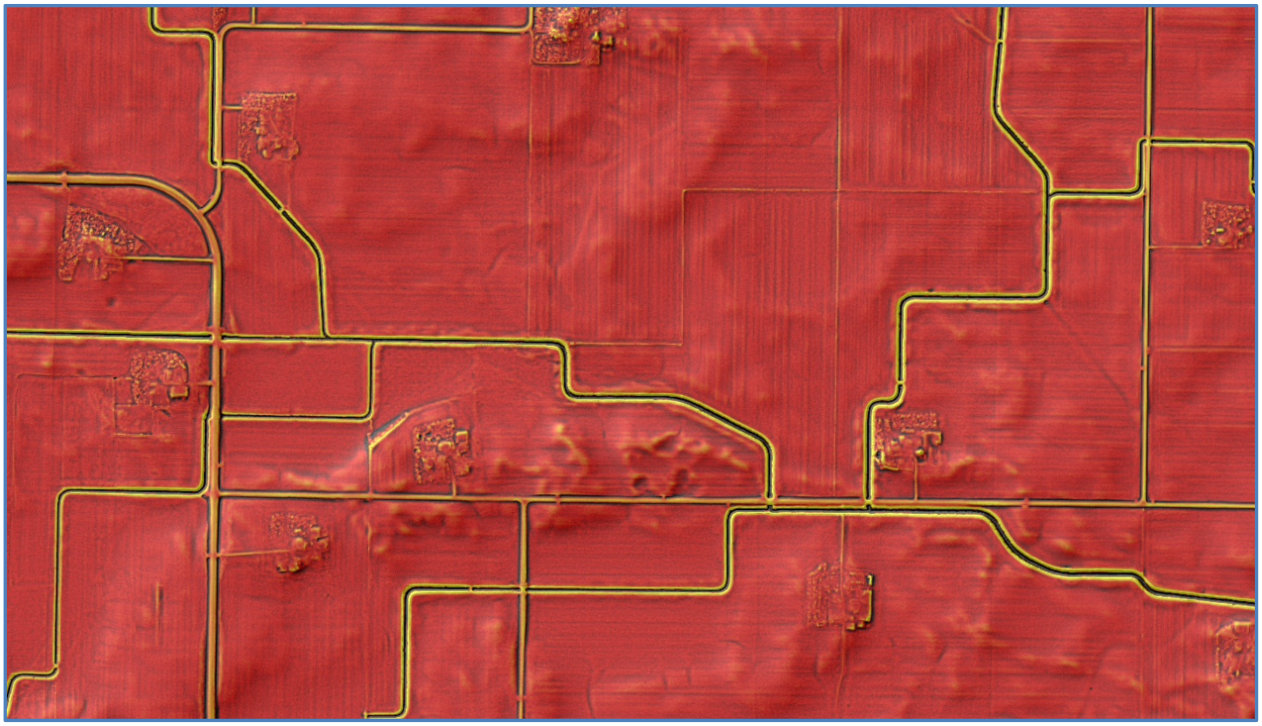


Image 4 - HPI Draped on a hillshaded DEM

6. LOCALIZED WATERSHED INTERPRETATION

The HPI allows the user to visualize the hydrology, and geomorphology relationships of Earth's surface as a system of sub-watersheds and water conveyance features, without having to conduct detailed hydrological analysis. For example, the localized highpoints on the HPI surface represented by colors trending towards yellow allow the interpreters' eye to visualize local drainage watershed (LDW) boundaries by visually connecting the high points of the HPI surface (see Image-5). The HPI can also serve as visual backdrop for validation of hydro-terrain analysis derived watersheds.

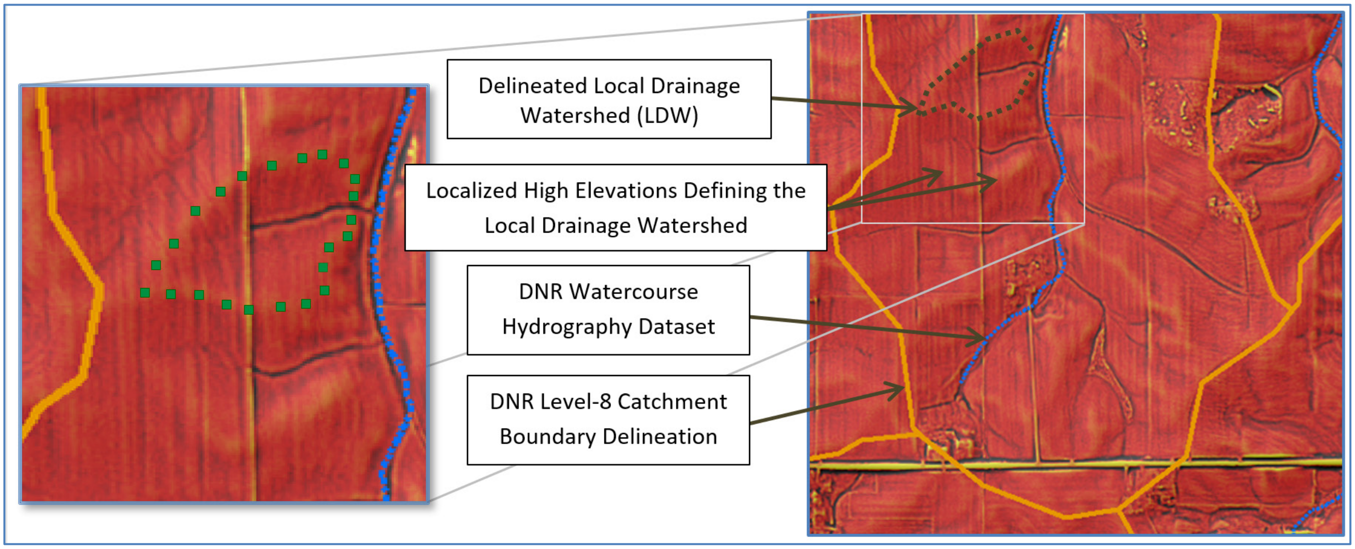


Image 5 - Localized Watershed Interpretation

7. CAST SHADOWS

7.1 Hill-SHADED DEM | DESCRIPTION

The hill-shaded DEM [1] is the standard derived product used to bring a simulated 3-D visual perspective to the viewing environment. The hill-shaded DEM is a synthetic illumination of a surface based on the elevation value, slope and aspect for each cell in a raster. This surface illumination is obtained by setting a position for a hypothetical light source (modeled position of the sun) and calculating the illumination values of each cell in relation to its neighboring cells. The hypothetical light source is dependent on an azimuth and altitude to project the simulated light source across the DEM landscape (see *Image-6*).

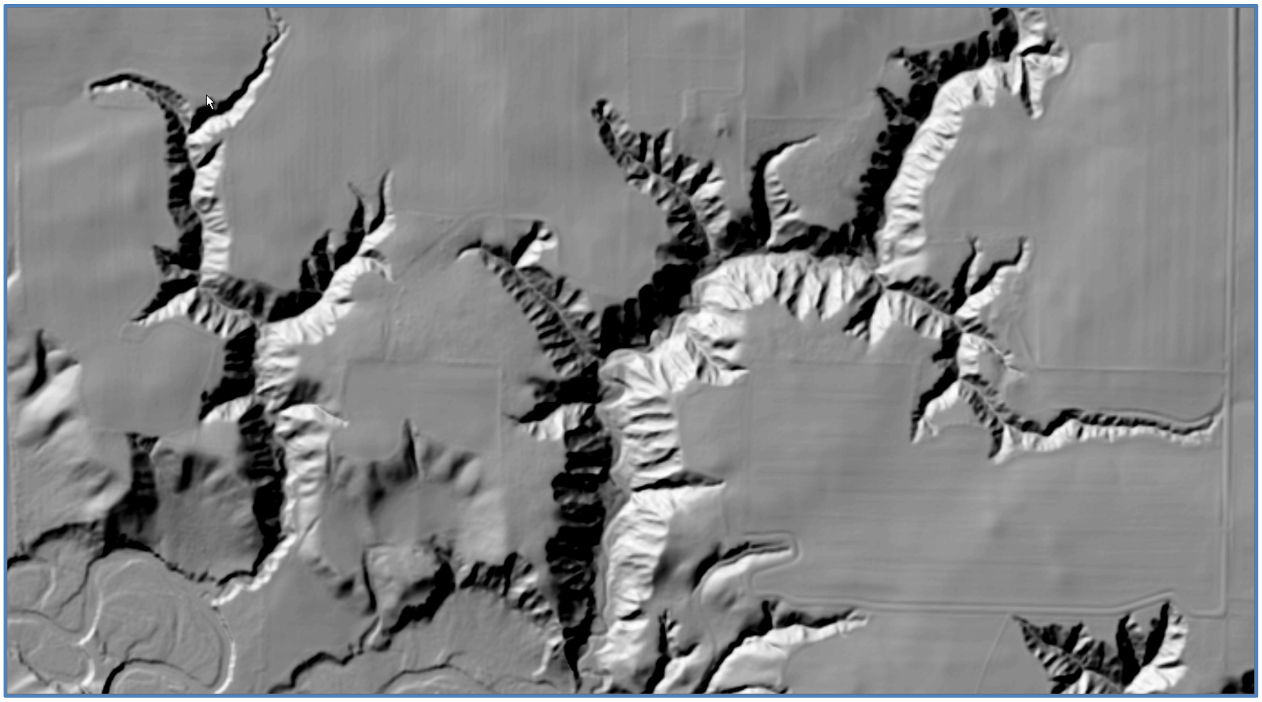


Image 6 - Example of a 3-meter LiDAR-derived Hill-shaded DEM.

This derived hillshade DEM becomes the foundation for creating visually appealing relief maps that are beneficial for interpreting locations of surface water movement on the landscape. Unfortunately, projecting an illumination across the landscape produces form and cast shadows. A *form shadow* is the shadowed regions on a form itself (e.g., a shadow on a portion of a hill not in direct light) whereas, a *cast shadow* is that shadowed region beyond the form creating the shadow. Collectively, these shadows become zones of rendered darkness (i.e., non-illuminated) in the DEM hillshade, which can hide obscure topographic signatures in DEMs and other derived products. This is especially true with the accuracy and detail captured in LiDAR-derived DEMs. For example, when a technician reviews a DEM in standard heads-up planar view, cast shadows can conceal the actual ditch width as well as the center of a ditch (see *Image-7*) because:

- Landscape features that have narrow facets parallel to and facing the direction of the DEM synthetic illumination source with localized high elevation values are washed out with light gray to white colors of the symbology color ramp.
- Topographic landforms that have facets perpendicular to the synthetic illumination (i.e., facing away)and localized low elevation values are blackened

out by the modeled shadows represented by the darkest colors of the color ramp symbology (see *Image-6*).

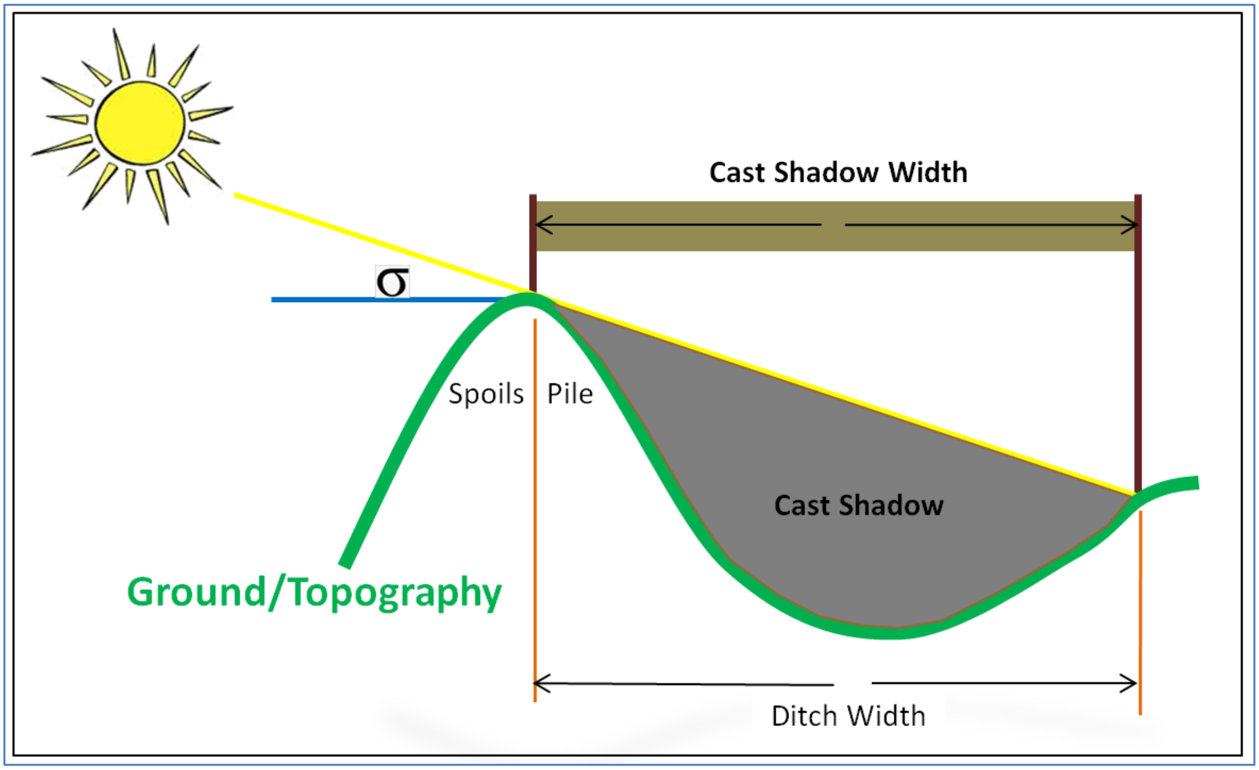


Image 7 – Illustration of shadows cast from elevated ditch excavation spoil pile across adjacent ditch.

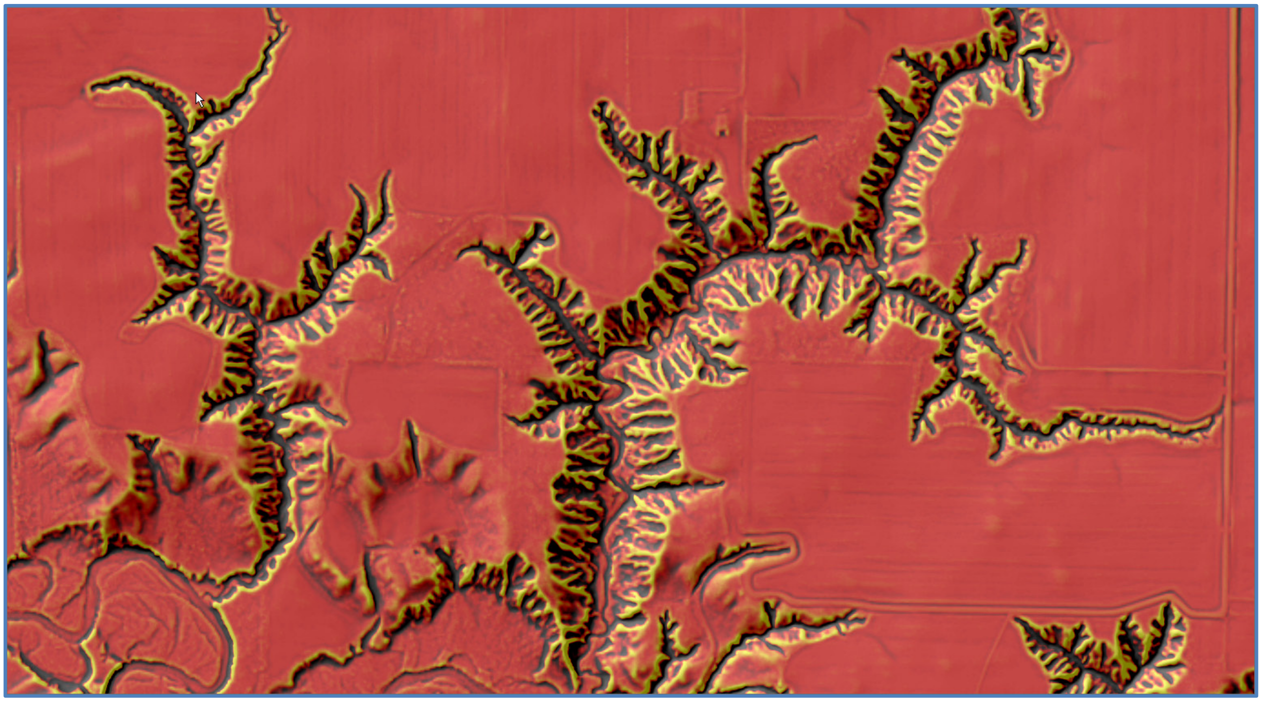


Image 8 – Example of a HPI created from 3-meter LiDAR-derived DEM draped on the Hill-shaded DEM raster of Image 1 above.

8. hDEM AND DERIVED HYDROGRAPHY VALIDATION

This Section is under heavy construction 08/2017

Although it can serve many needs related to landscape interpretation, the intended design of the HPI is to assist in the identification of water conveyance landforms on the landscape. The unique characteristics of the HPI have proven to be superior to aerial photography, contours and hillshaded DEMs used alone for identifying landscape hydrologic connectivity for much of Minnesota. When used together in a GIS viewing environment, these base datasets (i.e., aerial photography, LiDAR DEM derived-contours, hill-shaded DEM and the HPI) form a valuable asset for identifying and understanding Earth's surface hydrologic connectivity. As a result, the HPI will support the validation of *(1)* hydro-modified DEMs (hDEM)[17] derived from Minnesota's published LiDAR-derived DEMs and *(2)* automated hydrography generated from these products (e.g., watercourses and watersheds).

8.1 DEM HYDRO-MODIFICATION | TECHNICAL DESCRIPTION

DEM hydro-modification is a technical process that uses digital terrain analysis in a geographic information system (GIS) to modify grid-cell elevation values through breaching, trenching and filling processes for the replication of water movement on Earth's landscape.

8.1.1 Breaching

Digital Dam Breaching is a specialized DEM treatment that removes the impediments of modeled, concentrated-water flow, by lowering grid cell elevation values associated with digital dams, to a value in harmony with downgradient elevation values at locations defined by special breaklines called digital dam breach lines.

8.1.2 Trenching

Burning or *Long Line Burning* is a specialized DEM treatment that ***lowers*** *grid-cell elevation values* for grid cells that have boundaries coincident with unique long vector polylines, creating a synthetic open water conveyance channel on the DEM surface outside of mapped DEM water conveyance channels.

- These long vector polylines represent long distance forms of subsurface concentrated water conveyance (e.g., drain tiles, storm sewers, etc.) that exceed typical road culvert lengths.
- Long vector polylines are typically sourced and or digitized from storm sewer and drain tile inventories.

8.1.3 Filling

Filling is a specialized DEM treatment that removes depressions on the DEM landscape by ***raising*** *grid cell elevation values* to a height equal to the lowest elevation of the depression wall and or un-breached digital dam.

8.2 HDEM HYDROLOGIC INTEGRITY

The DEM hydro-modification process should strive to maintain the integrity of the LiDAR-derived elevation values to ensure Earth's landscape hydrology, hydrologic connectivity and topography is properly represented in the hDEM for visual and computational analysis. This is accomplished by modifying the minimum number of grid cell elevation values necessary in a way that allows the hDEM to still serve as a surrogate for Earth's landscape.

8.3 VALIDATION OF hDEMS

As described earlier, the color scheme of sharp color contrasts in the HPI differentiate local elevation zones of similarity (ELZS) and local drainage paths (LDP) for the interpretation of LDN in the DEM. Therefore, the HPI can serve as a backdrop for interpretation and verification of other DEM and hydro-terrain analysis derived products intended to model landscape hydrology.

8.3.1 VALIDATION | Background

- For an hDEM to be properly hydro-modified, it must be capable of creating a flow accumulation grid (raster) that is coincident with the topographic water conveyance features represented in the HPI.
- Additional validation support for determining flow network placement can be aided by the used of aerial photography, source LiDAR-derived DEM, LiDAR-derived DEM hillshade and LiDAR-derived contours.
- Recognizing that Minnesota's published source DEMs are a first-generation LiDAR-derived product, a technician-created hydro-

modified DEM (hDEM) is a second generation LiDAR-derived product that has undergone special treatments to influence water movement on the digital surface.

- The most common treatment is the breaching of digital dams by lowering elevation values to allow water passage. Project specific hDEMs are typically created to meet a particular business need. If the data products of the project are intended for use by others to meet a multitude of current and future business needs, the hDEM should go through a quality control and assurance verification process to assess the level of accuracy of derived water conveyance hydrography.
- Submitting an hDEM to a technician self-led validation process will help the developer test their hDEMs' ability to accurately represent water movement in Earth's water conveyance landforms.
- Examples of these landforms that route concentrated flow include erosion nick points, head cuts and channels representing grass waterways and watercourses. The best method for testing the hydrologic and hydrographic quality of an hDEM is to develop a flow network from the hDEM flow accumulation raster and compare that flow path product to the source/first generation hDEM.

Channels defining erosion nick points, head cuts, grass waterways and watercourses (e.g., ditches, streams and rivers).

8.3.2 VALIDATION CRITERIA

1. Spatial Extent.

   The spatial extent (length of feature) of the flow accumulation and flow network shall extend up gradient on the digital landscape until it approximates the location where concentrated flow forms.

   a. Evidence of concentrated flow is discernible by the formation of water conveyance features (i.e., channels) – those formations of Earth's surface that capture, contain and route excess water of the hydrologic cycle down gradient.
   b. The landscape features associated with concentrated flow have been captured by Minnesota's LiDAR data and represented as black linear signature in the HPI (see *5.3 Black Signatures*, *Image-5* left)
   c. The formation of concentrated flow defines the headwaters of watercourse tributaries.
   d. Using the elevation values of the DEM, the starting point of these black signatures will be defined by the highest elevation values of the coincident grid cells with the flow accumulation and or vector flow network.
   e.
2. The spatial extent (feature length) of the flow accumulation grid and or derived vector flow network shall be contained in a drainage area representing the business need the hDEM serves. In other words,
3.

8.3.3 hDEM Validation Workflow

1.) Create hDEM-derived Flow network. The flow network is a compilation of local drainage paths (LDP) for the entire DEM/watershed single line-width vector representation compilation of flow paths of the landscapes dendritic pattern for the entire DEM/watershed.

DEM → hDEM → Flow Direction → Filled DEM → Flow Accumulation → Flow Path/Network

Data Product	Format	Description	Generation from Source LiDAR Data
DEM	Grid / Raster	MN Published Source DEM	First Generation
hDEM	Grid / Raster	Hydro-modified DEM: Technician created DEM using special treatments to raise and/or lower source DEM elevation values to influence hydrologic properties of the DEM for hydrography specific business needs.	Second Generation
Flow Direction	Grid / Raster	A flow direction grid created from the hDEM.	Third Generation
Flow Accumulation	Grid / Raster	A flow accumulation grid created from the flow direction grid.	Third Generation
Flow Network	Vector Lines		Third Generation

2.) Drape the Flow Network on the HPI.

- The technician derived LDP, must exist within (i.e., be coincident with) water conveyance landforms captured by the parent/source LiDAR-derived DEM and illustrated in the HPI.
- If the hDEM-derived flow network deviates from the illustrated HPI water conveyance landforms (e.g., black linear signatures) then a digital dam likely still exists within the hDEM and should be removed.
- The point where HPI water conveyance features originate (e.g., erosion headcut) can be a surrogate for the location on Earth's surface where concentrated flow forms from overland flow. Flow accumulation threshold settings in the hDEM process should be modified to approximate these origins of HPI water conveyance features.
- When the derived watercourse features extend upstream from the watershed outlet entirely within the HPI water conveyance features to the point where they originate, the hDEM work can be considered complete.
- Accurate flow networks can be processed with special treatments to represent linear water features for disseminated hydrography datasets.
- Used in a quality control workflow, the HPI is the base dataset serving as the principle backdrop for validation of DEM hydro-modification work, and flow accumulation/ flow network authentication.

9. HPI Limitations

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9.1. WATERCOURSES IN DENSELY VEGETATED WETLAND COMPLEXES.

W

9.2. DOES NOT RECORD ABSOLUTE DITCH DEPTH.

10. Procurement: Viewing and Loading the HPI Service

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The HPI is available as a statewide publically available cache data service from MNiT@DNR. The HPI can be (1) viewed in a web browser or (2) ingested into ArcGIS as a map service.

URL:

http://arcgis.dnr.state.mn.us/public/rest/services/environment/mndnr_hydrographic_position_index/MapServer?

9.2 INGESTING THE HPI INTO ARCMAP FOR GIS APPLICATIONS

Add the HPI Service using ***Add data – GIS Servers*** in ArcCatalog or ArcMap

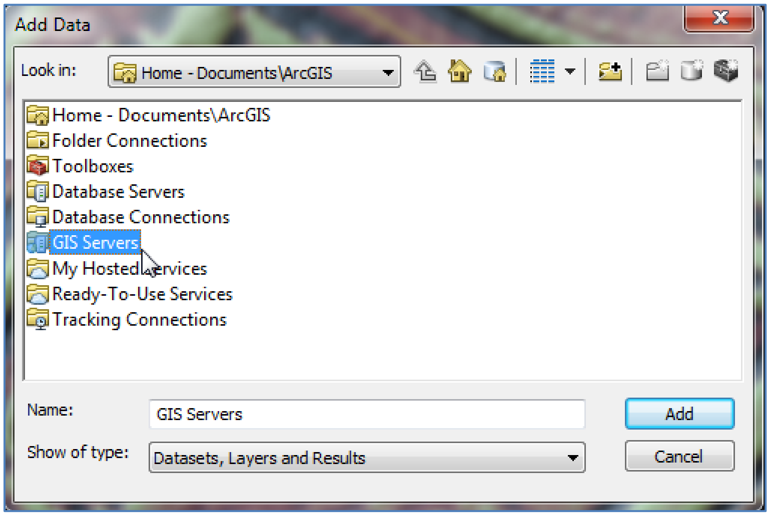
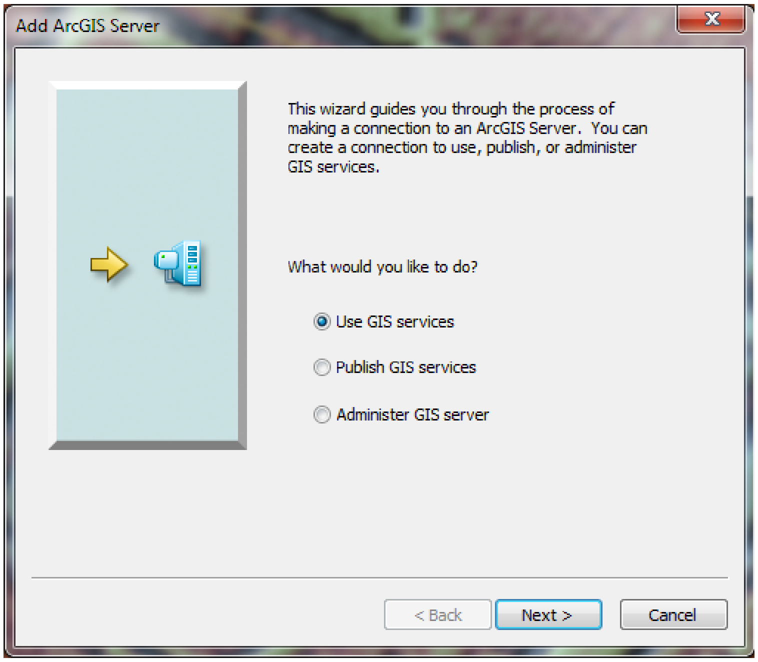


Image 9 - The Arc Map, Add Data dialog for GIS Server.

Add ArcGIS Server

Select Use GIS Services

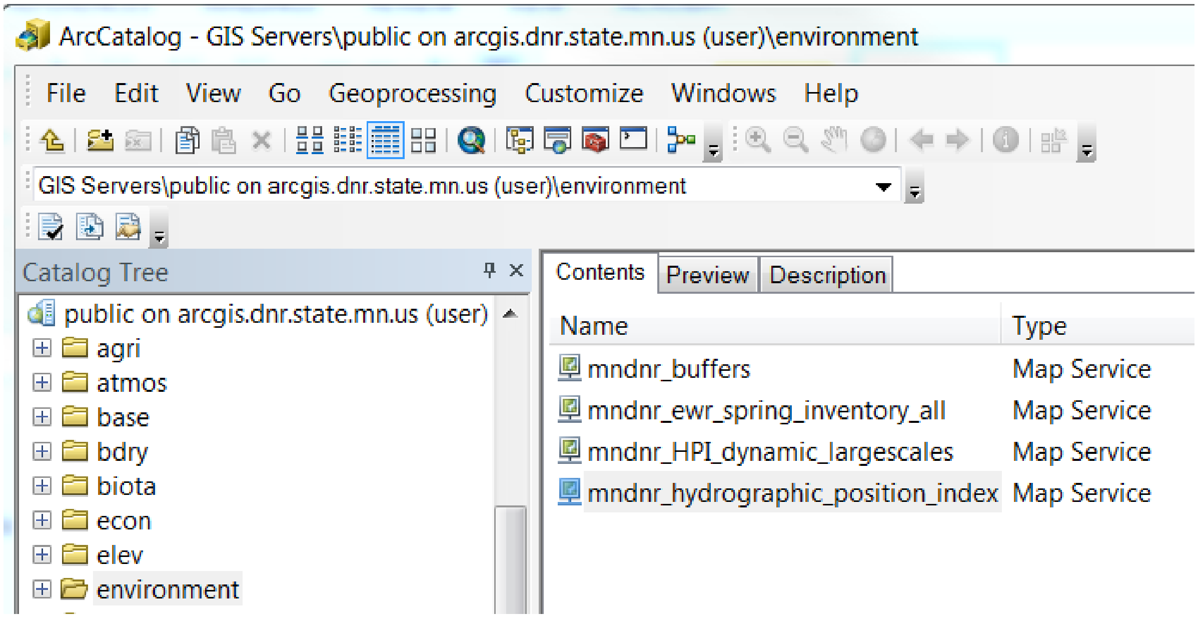


Copy and paste the HPI URL in the ***Server URL*** window.

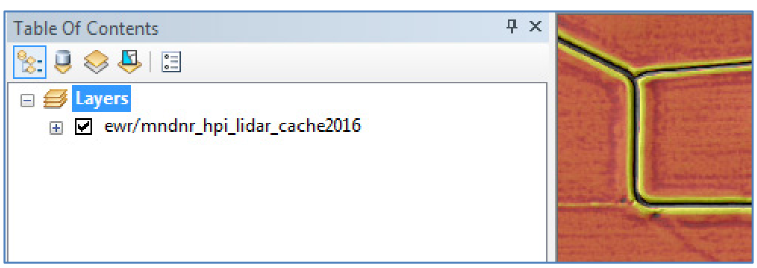
http://arcgis.dnr.state.mn.us/public/rest/services/environment/mndnr_hydrographic_position_index/MapServer?

Note: No user name or password is required.

Navigate into the ***environment*** folder, select ***mndnr_hydrographic_position_index and drag it to your*** ArcMap *Table of Contents*



The HPI will load into ArcMap Table of Contents as *environment/mndnr_hydrographic_position_index*.



11. Fire Color Scheme Used to Create the HPI Signatures

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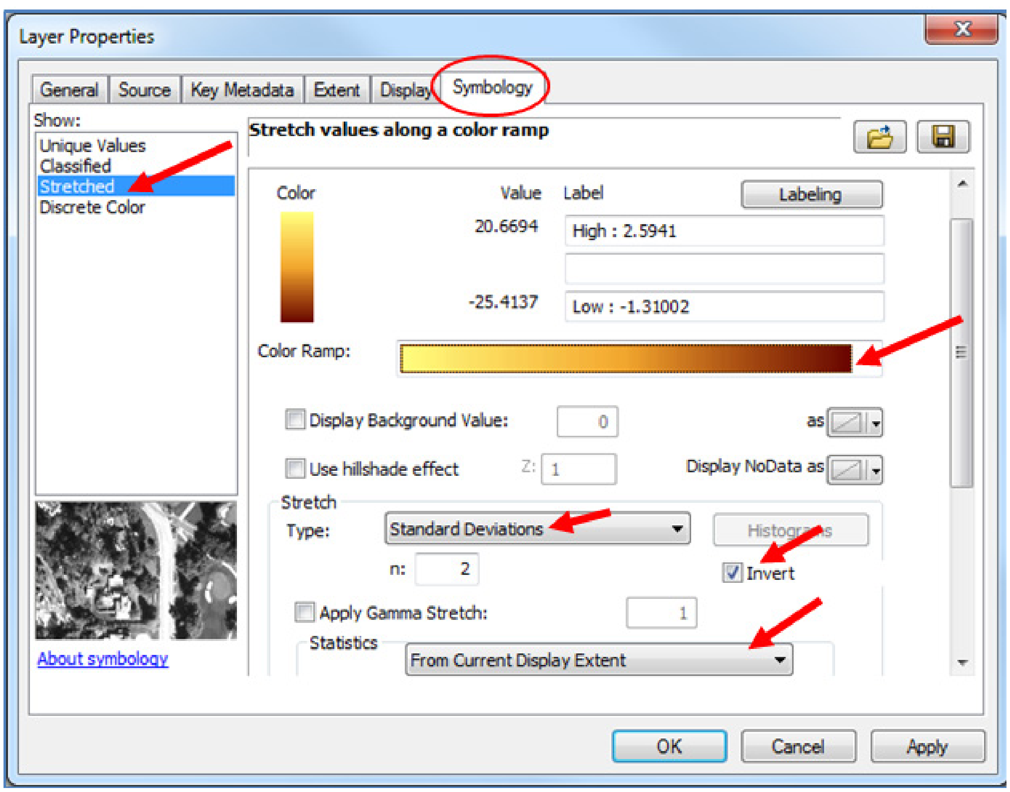
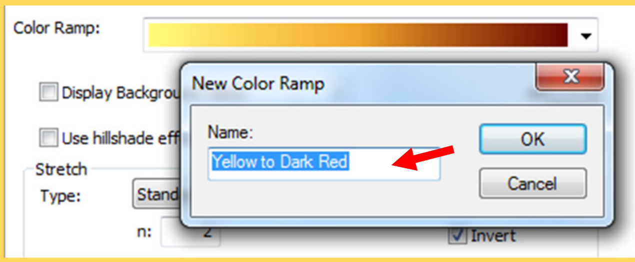
The HPI is a flat raster enhanced with a color scheme named "Fire" which adds a subtle visual perception of depth and exploits water conveyance features of the DEM landscape. The unique visual qualities of the HPI are complimented by the shaded relief of the source DEM (see *Image-1*).

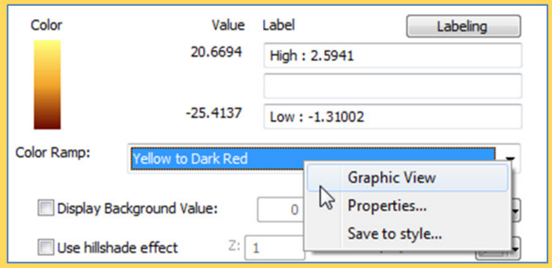
11.1. LAYER PROPERTIES | Symbology Tab

- **Set:** *Show:* **Stretched**
- **Set:** *Color Ramp:* **Yellow to Dard Red*** (should be 5th ramp up from bottom of drop-down in the default list)
- **Set:** *Stretch:* Change to **Standard Deviations**
- **Set:** *Invert* box: **Checked**
- **Set:** *Statistics:* From **Current Display Extent**



Note:** You can ensure you are using the correct Color Ramp by right-mouse-clicking on the color ramp and selecting ***Save to style to identify the color ramp *(*you are not saving a new style, this is for guidance only). Another option would be to right-mouse-click on the color ramps and uncheck ***Graphic View***, this results in a text description of each color ramp from which you can identify the ***Yellow to Dark Red*** ramp.



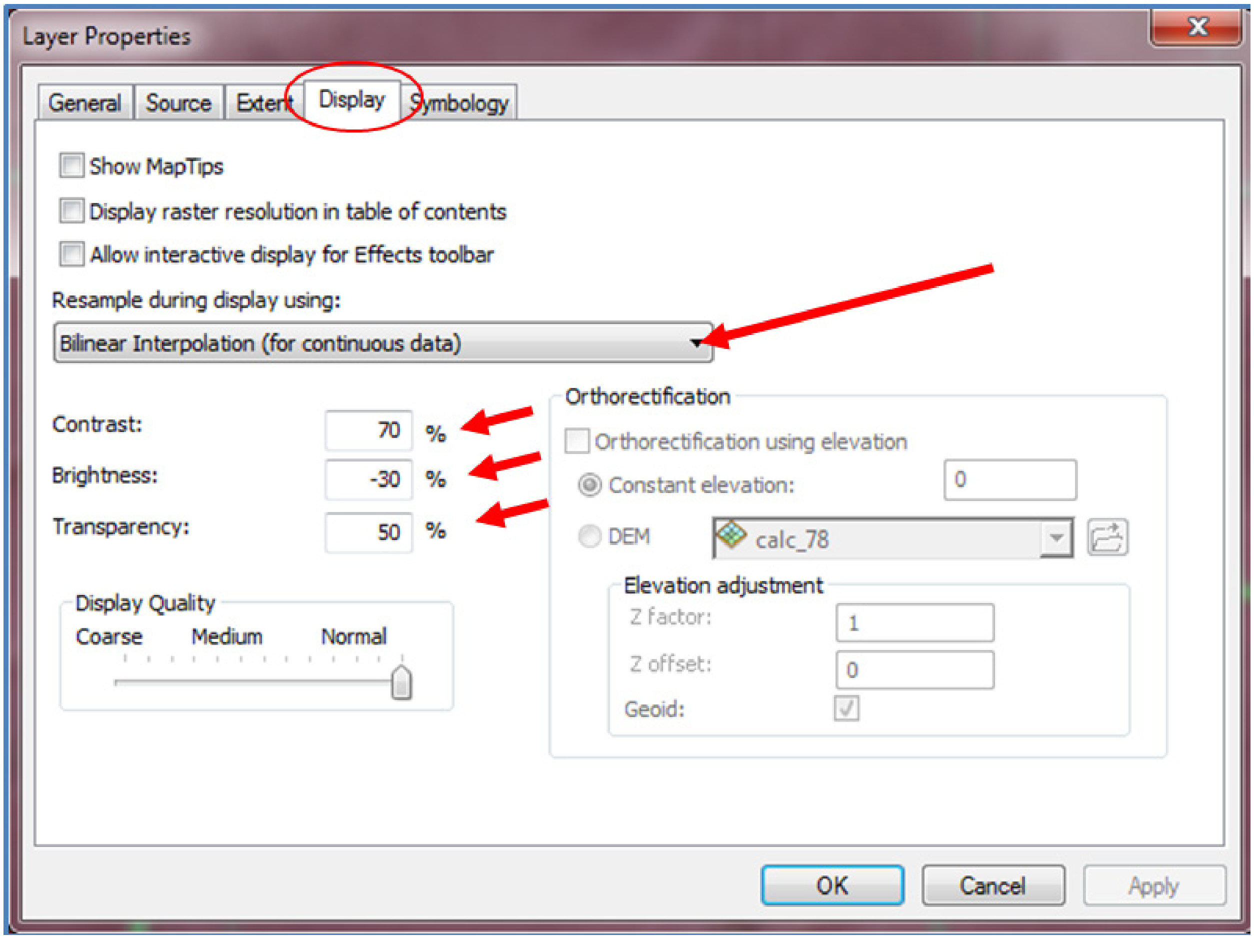


11.2. LAYER PROPERTIES | Display Tab

- **Set:** *Resample during display using:* **Bilinear Interpolation** (for continuous data)
- **Set:** *Contrast* [**70%**]

  Brightness [**-30%**] (negative thirty)

  Transparency [**50%**]



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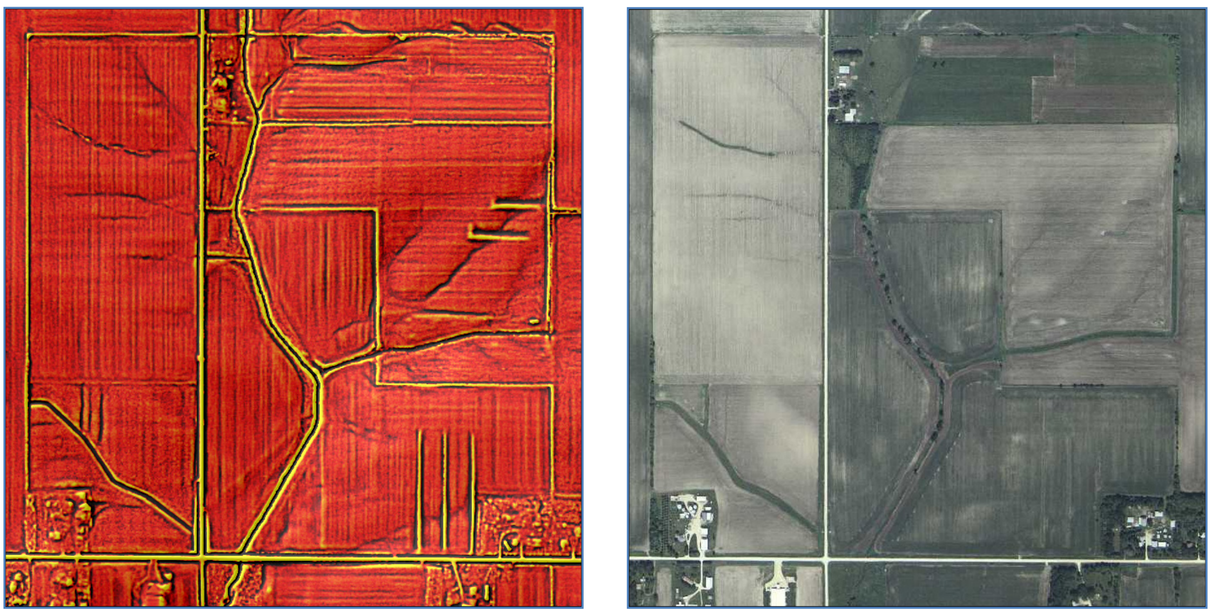
13. Appendix

13.1. HPI SHORT DESCRIPTION

This section contains a box with illustrations and text intended to serve as a sort description for the HPI for educational purposes. This box can be copied with permission from the author and inserted into educational material and presentations.

Hydrographic Position Index (HPI)

Illustrating Surface Water Conveyance and Connectivity for Hydrography Interpretation and Development



[**left**] *Hydrographic Position Index* (HPI) raster with the Fire color scheme draped on a hill-shaded Digital Elevation Model (DEM). [**right**] 2013 Digital orthophoto quadrangle of the same area covered by the HPI.

During the creation of the HPI, elevation values of individual grid cells in the source DEM are analyzed in a simple neighborhood grid calculation using the Esri ArcMap Focal Statistic tool. This operation computes an output raster with new values representing the difference between the source (input) cell's elevation value and the mean elevation value of the cells in the neighborhood.

Features colored yellow in the HPI above (left) represent localized high points on the landscape. In contrast, black features are localized low elevation topographies. Water conveyance landforms such as ditches, gullies, and grass-waterways appear as linear black striations in the raster. These signatures indicate an occurrence of concentrated water from perennial, intermittent, seasonal and ephemeral flow. The greater the positive mean-difference between the local elevation values and a cell, the more yellow signatures present. The opposite is true for black, which provides a coarse surrogate for topographic depth. Although the high-resolution aerial image on the right illustrates the general hydrology of the landscape, a much greater level of detail is depicted in the LiDAR-derived HPI product on the left.

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14. Reference

[1] GIS – What is GIS?. Esri. Archived from the original on 2015-12-28 . Retrieved 2015-12-28.

[2] GIS – Geographic Information Systems. Wikipedia. Archived from the original on 2015-12-28 . Retrieved 2015-12-28.

[3] ACPF – Agricultural Conservation Planning Framework – *"a watershed planning toolbox is intended to leverage modern data sources and help local farming*

communities better address soil and water conservation needs". Archived from the original on 2015-12-15 . Retrieved 2015-12-15

[4] DEM – Digital Elevation Model. Wikipedia. Archived from the original on 2015-12-15 . Retrieved 2015-12-15.

[5] LIDAR – Light Detection and Ranging— *"is a remote sensing method used to examine the sGrface of the Earth"*. NOAA. Archived from the original on 2015-12-15 . Retrieved 2015-12-15.

[6] HILLSHADE – *How Hillshade Works*. Esri. Archived from the original on 2015-12-28 . Retrieved 2015-12-28.

[7] HYDROGRAPHY – *International Hydrographic Organization - Definition of Hydrography*. Retrieved 2015-12-15.

[8] AIRBORNE LIDAR MAPPING. *The National Center for Airborne Laser Mapping (NCALM).* Archived from the original on 2015-12-15 . Retrieved 2015-12-15.

[9] AIRBORNE LIDAR MAPPING – *LiDAR 101: An Introduction to Lidar Technology, Data, and Applications.* National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center. 2012. Revised. Charleston, SC: NOAA Coastal Services Center. Archived from the original on 2015-12-28 . Retrieved 2015-12-28.

[10] INFRARED – Infrared (IR). Wikipedia. Archived from the original on 2015-12-28 . Retrieved 2015-12-28.

[11] TERRAIN ROUGHNESS – Cooley, S. (2014). *Terrain Roughness – 13 Ways*. GIS 4 Geomorphology. Archived from the original on 2015-12-15 . Retrieved 2015-12-15.

[12] TRI – Riley, S. J., S. D. DeGloria and R. Elliot (1999). A terrain ruggedness index that quantifies topographic heterogeneity, Intermountain Journal of Sciences, vol. 5, No. 1-4, 1999. Archived from the original on 2015-12-15 . Retrieved 2015-12-15.

[13] TPI – Weiss, A. 2001. Topographic Position and Landforms Analysis. Poster presentation, ESRI User Conference, San Diego, CA. Available, by permission from Jenness Enterprises, at http://www.jennessent.com/arcview/TPI_jen_poster.htm. Archived from the original on 2015-12-15 . Retrieved 2015-12-15.

[14] TPI – Klimanek, M. (unk), *Geoinformation support of derived mapping based on digital terrain model*. Faculty of Forestry and Wood Technology, Department of Geoinformation Technologies. Mendel University of Agriculture and Forestry Brno, Czech Republic. Archived from the original on 2015-12-15 . Retrieved 2015-12-15.

[15] LAS File Format – LAS (LASer) File Format, Version 1.4. Archived from the original on 2016-08-19. Retrieved 2016-08-19.

16 Focal Statistics – How Focal Statistics Works. Esri. Archived from the original on 2015-12-28 . Retrieved 2015-12-28.

17 **^** Vaughn, S.R., (2016). *hDEM: Definitions and Classifications of Hydrologic DEM Modification for Minnesota*. Technical manuscript. MNiT@Minnesota Department of Natural Resources – Ecological and Water Resources.