TERRAIN PREPROCESSING USING ARC HYDRO

NOVEMBER 29, 2013
TERRAIN PRE PROCESSING

Processing of DEM to delineate watershed

Several tools available online for this purpose

Arc Hydro tools to process DEM to delineate watershed, subwatersheds, stream networks
Different water programs that require accurate geospatial representations of the watershed under assessment:

- Accurate identification of:
  - Drainage area
  - Surface water quality monitoring stations
  - Flow gages
  - Points of wastewater discharge
  - Water intakes/outlets
ArcGIS-based system consists of two key components:

- Arc Hydro Data Model
- Arc Hydro Tools
  - The Arc Hydro tools operate in the ArcGIS environment
  - Some of the functions require the Spatial Analyst extension
SOFTWARE REQUIREMENTS

ArcGIS platform

Arc Hydro (for ArcGIS version in use)
  ◦ Arc Hydro Tools for ArcGIS 10.1 (beta available)
  ◦ http://blogs.esri.com/esri/arcgis/2012/07/16/arc-hydro-tools-for-10-1-beta-now-available/
DATA REQUIREMENT

DEM Grid

Hydrography Data
- *Stream network (vector data)*
ARC HYDRO TOOLBAR

6 menus
9 tools
Additional tools in the geoprocessing environment are available in the Arc Hydro Tools toolbox.
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<th>Name</th>
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<th>Toolbox</th>
<th>Description</th>
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<td>Terrain Preprocessing</td>
<td>x</td>
<td>x</td>
<td>Functions preprocessing a Digital Elevation Model (DEM). These functions are mostly used once in order to prepare spatial information for later use.</td>
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<tr>
<td>Terrain Morphology</td>
<td>x</td>
<td>x</td>
<td>Functions performing an analysis of a non-dendritic terrain (e.g. terrains with sinks).</td>
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<td>Watershed Processing</td>
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<td>x</td>
<td>Functions performing watershed and subwatershed delineation and basin characteristic determination. These functions operate on top of the spatial data prepared in the terrain preprocessing stage.</td>
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<tr>
<td>Attribute Tools</td>
<td>x</td>
<td>x</td>
<td>Functions computing and populating attributes such as identifiers and characteristics.</td>
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<tr>
<td>Network tools</td>
<td>x</td>
<td>x</td>
<td>Functions generating or manipulating properties of geometric (hydro) network.</td>
</tr>
<tr>
<td>ApUtilities</td>
<td>x</td>
<td></td>
<td>Functions managing the properties of the Arc Hydro project. These functions will be seldom used and are not detailed in this document.</td>
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</table>
| Buttons and Tools           | x       |         | - Flow Path Tracing  
- Interactive Flow Path Tracing  
- Point Delineation  
- Delinate using EPA Web Service  
- Batch Point Generation  
- Assign Related Identifier  
- Global Delineation  
- Trace By NextDownID Attribute  
- Main Flow Path Tracing |
| Arc Hydro Setup             |         |         | Functions setting up the Arc Hydro geoprocessing environment. |
| GIS Data Exchange           |         |         | Functions allowing exchanging GIS data between a geodatabase and an XML file. |
| H&H Modeling                |         |         | Functions performing Time Series and Green and Ampt calculations. |
| Terrain Preprocessing       | x       |         | Model performing basic terrain preprocessing workflow. |
| Workflows                   |         |         |                                                                        |
| Utility                     |         |         | Various utilities working in the Arc Hydro geoprocessing environment. |
ARC HYDRO TOOLS HAVE TWO KEY PURPOSES

1. to manipulate (assign) key attributes in the Arc Hydro data model
   ◦ These attributes form the basis for further analyses
   ◦ include the key identifiers (such as *HydroID*, *DrainID*, *NextDownID*, etc.) and the measure attributes (such as *LengthDown*)

2. to provide some core functionality often used in water resources applications
   ◦ includes DEM-based *watershed delineation, network generation*, and *attribute-based tracing*
Tools list – Toolbar
TERRAIN PROCESSING

- Flow Direction
- Adjust Flow Direction in Sinks
- Adjust Flow Direction in Streams
- Adjust Flow Direction in Lakes
- Flow Accumulation
- Stream Definition
- Stream Segmentation
- Combine Stream Link and Sink Link
- Catchment Grid Delineation
- Catchment Polygon Processing
- Drainage Line Processing
- Adjacent Catchment Processing
- Drainage Point Processing
- Longest Flow Path for Catchments
- Longest Flow Path for Adjacent Catchments
- Accumulate Shapes
- Slope

- Data Management DEM Manipulation
- Create Drainage Line Structures
- Create Sink Structures
- Level DEM
- DEM Reconditioning
- Assign Stream Slope
- Burn Stream Slope
- Build Walls
- Sink Prescreening
- Sink Evaluation
- Depression Evaluation
- Sink Selection
- Fill Sinks
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<th>Tool</th>
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<th>Available in Toolbox</th>
<th>Requires ArcInfo or ArcEditor</th>
<th>Requires Spatial Analyst</th>
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<tr>
<td>Level DEM</td>
<td>Fill the selected polygons (e.g. lakes) up to the FillElev value.</td>
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<tr>
<td>DEM Reconditioning</td>
<td>Enforce linear drainage pattern (vector) onto a DEM (grid). Implements AGREE methodology.</td>
<td></td>
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</tr>
<tr>
<td>Assign Stream Slope</td>
<td>Assign relative elevation to from nodes and to nodes of input streams. Elevations decrease with the digitized direction.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Burn Stream Slope</td>
<td>Burn linear stream slope into a DEM to force the direction of the flow in the stream.</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Build Walls</td>
<td>Build walls in a DEM (grid) at the boundary of selected input polygons.</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Sink Prescreening</td>
<td>Prescreen the input DEM by filling in the pits that do not match the criterion defining a potential sink.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Sink Evaluation</td>
<td>Generate and characterize the potential sinks for a DEM.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Depression Evaluation</td>
<td>Generate and characterize the potential depressions for a DEM.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Sink Selection</td>
<td>Select the potential sinks that should be considered as real sinks.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Fill Sinks</td>
<td>Fill sinks for an entire DEM (grid).</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Flow Direction</td>
<td>Create flow direction grid for a DEM grid.</td>
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<td></td>
<td>x</td>
</tr>
<tr>
<td>Flow Direction with Sinks</td>
<td>Create flow direction grid for a DEM with sinks that ensures that each cell within a sink flows toward a sink point. Also Sink Link grid defining the links for deranged areas.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Adjust Flow Direction in Lakes</td>
<td>Modify input flow direction grid within the input lakes with streams to ensure that each cell within a lake flows toward the closest stream within the lake.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Flow Accumulation</td>
<td>Create flow accumulation grid from a flow direction grid.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Stream Definition</td>
<td>Create stream grid with cells from a flow accumulation grid that exceed used-defined threshold.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Stream Segmentation</td>
<td>Create a stream link grid from the stream grid (every link between two stream junctions gets a unique identifier).</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Flow Direction with Streams</td>
<td>Update the input flow direction grid based on the input stream feature class to create an output flow direction grid, drainage line feature class and stream link grid that match as closely as possible the input streams, ensuring that the water flows downstream once it reaches a stream and respecting flow obstacles.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Combine Stream Link and Sink Link</td>
<td>Create a link grid combining the stream link grid representing dendritic areas and the sink link grid representing deranged areas (i.e. areas with sinks).</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Catchment Grid Delineation</td>
<td>Create a catchment grid for segments in the stream link grid or sinks in the sink link grid. It identifies areas draining into each link.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Catchment Polygon Processing</td>
<td>Create catchment polygon feature class out of the catchment grid.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Drainage Line Processing</td>
<td>Create streamline line feature class out of the stream link grid.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Adjacent Catchment Processing</td>
<td>Create adjacent catchment polygon for each catchment in the catchment polygon feature class. An adjacent catchment is the total upstream area (if any) draining into a single catchment.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Drainage Point Processing</td>
<td>Create a drainage point at the most downstream point in the catchment (center of a grid cell with the largest value in the flow accumulation grid for that catchment).</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Longest Flow Path for Catchments</td>
<td>Create longest flow path segments for each catchment and populates field LengthDown with the length to the most downstream point.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Longest Flow Path for Adjacent Catchments</td>
<td>Create longest flow path for each adjacent catchment.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Slope</td>
<td>Generates surface slope grid in percent or degree.</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Tool</td>
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</tr>
<tr>
<td>Batch Watershed Delineation</td>
<td>Create a watershed for every point in the batch point feature class. Results are stored in a watershed polygon feature class. Watersheds are overlapping if points are on the same stream.</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batch Subwatershed Delineation</td>
<td>Create a subwatershed for every point in the batch point feature class. Results are stored in a subwatershed polygon feature class. Subwatersheds are non-overlapping if points are on the same stream.</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batch Global Watershed Delineation</td>
<td>Create a global watershed and compute selected characteristics for each point in the batch point feature class.</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batch Watershed Delineation for Polygons</td>
<td>Create a watershed for every selected polygon feature in the batch polygon feature class. Results are stored in a watershed (polygon) feature class</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delineate from Multiple Inlets and Outlets</td>
<td>Create a watershed for input inlet and outlet points. Result is stored in a watershed (polygon) feature class and source points in a watershed point feature class.</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drainage Area Centroid</td>
<td>Create a point at the centroid of each polygon in a drainage area feature class and store it in a point feature class.</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longest Flow Path</td>
<td>Create a line following the longest flow path in a drainage area based on steepest descent as defined by the flow direction grid.</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longest Flow Path for Watersheds</td>
<td>Create a line following the longest flow path in a watershed based on steepest descent. More efficient implementation of Longest Flow Path based on preprocessed data.</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longest Flow Path for Subwatersheds</td>
<td>Create a line following the longest flow path in a subwatershed based on steepest descent. More efficient implementation of Longest Flow Path based on preprocessed data.</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main Flow Path</td>
<td>Create the main flow path line for a watershed by “walking” up the drainage lines with the biggest drainage area and extending to the boundary to minimize curvature-weighted flow length.</td>
<td>x</td>
<td></td>
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</tr>
<tr>
<td>Construct 3D Line</td>
<td>Build 3D lines from a selected set of 2D lines by extracting elevations from a DEM.</td>
<td>x</td>
<td></td>
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<tr>
<td>Smooth 3D Line</td>
<td>Smooth 3D lines linearly along the downstream direction of the line.</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow Path Parameters from 2D Line</td>
<td>Compute the length, slope and 10-85 slope of a longest flow path by extracting elevations from a DEM.</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow Path Parameters from 3D Line</td>
<td>Compute the length, slope and 10-85 slope of a 3D longest flow path by extracting elevations from the line.</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basin Length Points</td>
<td>Generate inlet and outlet points for a drainage area based on associated longest flow path. Used as input by Basin Length.</td>
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</tbody>
</table>
Getting Started with Arc Hydro

Basic Dendritic Terrain Processing
GETTING STARTED WITH ARC HYDRO

Open ArcMap
Save map
Load Arc Hydro Tools
Activate Spatial Analyst Extension
Load Data (DEM, Stream network)
**SET TARGET LOCATIONS**

Select ApUtilities > Set Target Locations

Select the HydroConfig node
Terrain Preprocessing uses DEM to identify the surface drainage pattern

- DEM Reconditioning
- Pit Removal (Fill Sinks)
- Flow Direction
- Flow Accumulation
- Stream Definition
- Stream Segmentation
- Catchment Grid Delineation
- Raster to Vector Conversion (Catchment Polygon, Drainage Line, Drainage Point Processing)
Basic dendritic terrain processing workflow
DEM RECONDITIONING

This function modifies a DEM by imposing linear features onto it.

Function: Terrain Preprocessing → Data Manipulation → DEM Reconditioning
AGREE: DEM SURFACE RECONDITIONING SYSTEM

DEM RECONDITIONING

DEM Reconditioning (AGREE)
- Add DEM Reconditioning (AGREE) module to the DEM manipulation menu.
- Export the reconditioned DEM.
- Export inputs and outputs.

Options:
- Raw DEM
- AGREE Stream
- AGREE DEM
- Stream buffer (number of cells)
- Smooth drop/raise (DEM Z-unit)
- Sharp drop/raise (DEM Z-unit)

Example:
- Smooth drop: Stream buffer = 5
- Sharp drop: Smooth drop/raise = 10
- Smooth drop/raise = 1000
AGREE (UT – Hellweger)

Before

Modified Terrain

After

Stream

Terrain

Removed

Buffer
When ‘Burn’ in is feasible?

When it should be use?
- sources of the data for the DEM and for known streams are the same (in scale and time)
- discrepancies in the patterns are due to the artifacts of the DEM construction and D8 flow direction determination

When it should **NOT** be used?
- Burning should not be used when the data sources are of different *scale* or *age*

**Important:** After the function is completed, make sure to fill the sinks to eliminate any potential depressions introduced by the burning process
DEM RECONDITIONING CONT...

Select the appropriate input DEM and linear feature (streams to burn in)
Fills the sinks in a grid

Higher elevation cells around a cell will trap water and not let water flow from that cell

Modification of elevation value is required to eliminate this problem
A pit is a set of one or more cells which has no downstream cells around it.

There are artificial pits in DEM which needed to be removed.

Otherwise these pits become sinks.

Pit Filling is increasing the elevation until the pit drains to a neighbor cell.
PIT FILLING

Original

Filled

Elevation (m)

Distance (km)
Function: Terrain Preprocessing → Data Manipulation → Fill Sinks
Computes the flow direction for a grid according to the 8-point pour flow direction model
In the direction of the steepest descent from a cell
EIGHT DIRECTION POUR POINT MODEL
STEEPEST SLOPE: D8 ALGORITHM

Topography defines drainage direction on the landscape

In a grid representation of topography, water flows from a cell to one and only one of its eight nearest orthogonal or diagonal neighbors in the direction of steepest descent

Through this concept a grid of flow accumulation from a DEM can be determined
Slope of steepest descent to define the pathway of water flowing downhill

\[ D8 \text{Slope} = \frac{\text{Drop}}{\text{Run}} \]

*drop* refers to the difference in elevation between the “from cell” and the “to cell”

Run is equal to the cell size for flow along the coordinate directions, and equal to \( \sqrt{2} \times \text{cell size} \) for flow in the diagonal directions.
Slope:

\[
\frac{44-22}{\sqrt{2}} = 15.56
\]

\[
\frac{44-37}{1} = 7
\]
FLOW DIRECTION GRID
Function: Terrain Preprocessing → Flow Direction
Flow Accumulation

Computes the flow accumulation grid for each cell in input grid that contains the accumulated number of cells upstream of a cell

Flow Accumulation Grid
Function: Terrain Preprocessing \(\rightarrow\) Flow Accumulation
The stream definition step identifies those cells that are “streams”.
The streams are defined as those cells that drain more area than a user specified threshold

**Function: Terrain Preprocessing → Stream Definition**
A default value is displayed for the river threshold representing 1% of the maximum flow accumulation.

Any other value of threshold can be selected. Smaller threshold will result in denser stream network and usually in a greater number of delineated catchments.
STREAM SEGMENTATION

The stream segmentation step uniquely numbers stream segments (links) between the confluences

Function: Terrain Preprocessing ~ Stream Segmentation
STRLNK GRID
This step identifies drainage areas (in grid format) that drain to each stream link.

Function: Terrain Preprocessing ~ Catchment Grid Delineation
This function converts a catchment grid into a catchment polygon feature (vector format)

Function: Terrain Preprocessing → Catchment Polygon Processing
The drainage line processing step defines stream segments in vector format.

Function: Terrain Preprocessing → Drainage Line Processing
The adjoint catchment processing step determines the cumulative area upstream from a catchment (in vector format).

Function: Terrain Preprocessing → Adjoint Catchment Processing
This function allows generating the drainage points associated to the catchments

Function: Terrain Preprocessing → Drainage Point Processing
Batch Watershed Delineation
Interactive Point Delineation
Batch Subwatershed Delineation
Flow Path Tracing
This function delineates the watershed upstream of each point in an input Batch Point feature class.

Make visible Fac, Catchment and DrainageLine datasets.

Click on the icon in the Arc Hydro Tools toolbar.

Click on the outlet grid cell at the watershed outlet.

A point will be created at the location of mouse click.
BATCH POINT GENERATION
Function: Watershed Processing → Batch Watershed Delineation
INTERACTIVE POINT DELINEATION

An alternative to delineate watersheds when you do not want to use the batch mode (process a group of points simultaneously) to generate the watershed for a single point of interest is the Point Delineation tool.
The new point will be added to the *WatershedPoint* feature class, and the new Watershed will be added to the *Watershed* feature class.
Batch Subwatershed Delineation

Arc Hydro creates the vector polygon sub-watersheds by processing the drainage points.

Sub-watersheds cover the drainage area upstream of the outlet points and downstream of all other points.

Function: Watershed Processing → Batch Subwatershed Delineation
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<th>ArcHydro Terrain Preprocessing Functions</th>
<th>Created With</th>
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<td>Original DEM Grid</td>
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<tr>
<td>Flow Direction Grid</td>
<td>Fill Sinks Grid</td>
</tr>
<tr>
<td>Flow Accumulation Grid</td>
<td>Flow Direction Grid</td>
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<tr>
<td>Stream Definition Grid</td>
<td>Flow Accumulation Grid and Arbitrary Stream Threshold Number</td>
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<tr>
<td>Stream Link Grid</td>
<td>Flow Direction Grid and Stream Definition Grid</td>
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<td>Catchment Grid</td>
<td>Flow Direction Grid and Stream Link Grids</td>
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<td>Catchment Polygons</td>
<td>Catchment Grid</td>
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<td>Drainage Line</td>
<td>Stream Link Grid and Flow Direction Grid</td>
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<td>Adjointment Processing Grid</td>
<td>Drainage Line and Catchment Polygon</td>
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<tr>
<td>Drainage Point</td>
<td>Flow Accumulation Grid and Catchment Grids</td>
</tr>
<tr>
<td>Batch Subwatershed Delineation Polygons</td>
<td>Flow Direction Grid and Drainage Points (Subwatershed Outlet)</td>
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</table>
REFERENCES

Arc Hydro: GIS for Water Resources by David Maidment (ESRI Press)

Arc Hydro Tools Overview:
http://downloads.esri.com/blogs/hydro/ah2/arc_hydro_tools_2_0_overview.pdf

Arc Hydro Tools:

Comprehensive Terrain Preprocessing Using Arc Hydro Tools: