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ArcMap Hydrology Toolset: WPES, How Do I...? Quick Guide

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WPES, How Do I...?



Quick Guide to

ARCMAP HYDROLOGY
TOOLSET

WPES, How Do I...?
Quick Guide to
ArcMap Hydrology Toolset

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The “WPES, How Do I...?” series of instruction manuals were originally developed for internal use by the Watershed Process and Estuary Sustainability Research Group (WPES) at the University of Maine. They have been updated and published through DigitalCommons@UMaine to provide open access for academic use.

This document is formatted for print in booklet form on letter size paper.

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Introduction

This document provides guidance for performing hydrological tasks using the Hydrology Toolset in ArcMap 10.x (ArcGIS Desktop) and assumes general familiarity with the program. For general ArcMap guidance, refer to “WPES, How Do I...?” Quick Guide to ArcMap Basics.

Hydrology Toolset

The Hydrology Toolset in ArcMap contains tools for performing hydrologic tasks and analyses related to the movement of surface water runoff across a digital elevation model (DEM). These tools are found in the Spatial Analyst toolbox and require an active Spatial Analyst license. In-depth documentation from Esri for the Hydrology Toolset is also available at <https://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/an-overview-of-the-hydrology-tools.htm>.

Basin

Uses flow direction raster to delineate all basins draining to the edge of a DEM. Does not allow for the specification of basin outlet locations (pour points). In most cases using the Watershed tool instead is preferable.

Fill

Eliminates all sinks (pits) from a DEM, producing a raster in which surface runoff from any cell can reach the edge of the DEM uninterrupted. This process is also known as hydro-conditioning. Max fill depth can be specified to avoid the elimination of actual closed (endorheic) basins. This is generally the first tool used in any hydrology workflow.

Flow Accumulation

Uses flow direction raster to calculate number of upstream cells contributing surface flow to each DEM cell (note that to calculate contributing area you must then multiply output values by DEM cell area). Method must match that used for the creation of the flow direction raster. Flow accumulation with DINF method takes considerably longer (factor of 10 or more) than with D8 method for substantially the same results.

Flow Direction

Calculates direction of surface runoff for each cell in a DEM based on slope to adjacent cells. Default type/method is D8 (all flow from a cell is routed in one of eight directions into single adjacent cell); this is the only method that will work when working with a DEM with “float” data type, which most LiDAR DEMs are.

Flow Distance

Uses DEM and stream channel rasters to calculate distance of overland flow from DEM cell into channel network. May be set to calculate either vertical drop or horizontal distance. Output raster cell values are lengths in map units.

Flow Length

Uses flow direction raster to calculate either downstream flow length from cell to edge of raster or longest upstream flow length from cell to watershed boundary. Output raster cell values are lengths in map units.

Sink

Uses flow direction raster to delineate raster layer of all sinks (pits) in DEM. Contiguous patches of pit cells are consolidated (e.g., a pond whose water surface in the DEM is below its outlet elevation would be considered a single sink). Sinks are numbered but no further information (such as depth) is calculated. In cases where depth/volume is important, using the [pit fill detection workflow](#) is preferable.

Snap Pour Point

Converts feature basin outlets (aka pour points) to raster to be used by Watershed tool. Each outlet should have a unique numeric identifier set in its attribute table before running this tool.

Stream Link

Converts stream network raster (where all stream cells are indicated with an integer value) to raster where each stream segment (reach) is assigned a unique identifier.

Stream Order

Uses stream network raster and flow direction raster to produce raster of stream order (Strahler or Shreve) for each stream segment.

Stream to Feature

Converts stream network raster to polylines with splits at each confluence (i.e., each reach is its own line segment). Ensure non-stream cells of raster are “Null” rather than “0” - the tool will otherwise create polyline features for all of these cells.

Watershed

Uses flow direction raster and snapped user-defined pour point(s) to produce raster of delineated watershed(s). Each pour point should have a unique numeric value, otherwise tool will combine resulting watersheds into single unit (this behavior may be desirable in uncommon cases where one basin does have two outlets, such as an estuary mouth that is split by an island).

Additional Tools in Workflows

For readers of print version of manual, tool documentation from Esri (blue links) can be found in the “Tool Reference” section at <https://desktop.arcgis.com/en/arcmap/latest/tools>.

Con (conditional)

Spatial Analyst Tools > Conditional

The [Con tool](#) evaluates a specified condition on a raster dataset. In the context of hydrology workflows, it is used to identify stream networks by evaluating whether flow accumulation is greater than a specified threshold, generally corresponding to an assumed area or length to stream initiation. This tool requires an active Spatial Analyst license.

Hillshade

Spatial Analyst Tools > Surface -or- 3D Analyst Tools > Raster Surface

The [Hillshade tool](#) creates a shaded relief raster from a DEM, giving the appearance of a 3D map and making it easier to interpret the terrain and visually locate features such as stream channels. It is often desirable to give some transparency (15-25%) to resulting hillshade layer in Table of Contents in order to see colormap from underlying DEM layer. This tool requires an active Spatial Analyst or 3D Analyst license.

Mosaic to New Raster

Data Management Tools > Raster > Raster Dataset

The [Mosaic to New Raster tool](#) is used to merge multiple rasters to create a single new raster. A common use case for this tool is combining DEM tiles into a single file that covers a full area of interest.

The [Mosaic tool](#) in the same toolset can be used to merge multiple rasters into an existing raster; this saves storage space, but does not preserve a copy of the target raster original data.

Raster Conversion toolsets

Conversion Tools > From Raster

Convert rasters to features, with option to create simplified features.

Rasters must be of integer data type.

[Raster to Polygon](#) – creates polygon for each raster zone (integer value).

Used to convert watershed raster to watershed polygons.

[Raster to Polyline](#) – creates polyline for each raster zone (integer value). Used to convert stream network rasters to stream polylines.

Conversion Tools > To Raster

[Polyline to Raster](#) – creates raster from polyline features. Resulting raster cell value may be from any attribute column of the input features. Cell size can be directly set as a numeric value, or user may browse to an existing raster layer to select that raster's cell size. Processing extent settings (under "Environments...") may be updated to snap (align) raster cells to those of an existing raster.

Raster Math toolset

Spatial Analyst Tools > Math -or- 3D Analyst Tools > Raster Math

Perform mathematical operations on raster datasets. These tools require an active Spatial Analyst or 3D Analyst license.

[Int](#) – converts raster data type to integer by truncating decimal (i.e., rounding down to nearest whole number).

[Minus](#) – subtract spatially coincident cell values of one raster from another; can also subtract specified numeric value from all cells.

[Times](#) – multiply raster cell values by those of another raster or a specified numeric value.

Zonal Statistics

Spatial Analyst Tools > Zonal

The [Zonal Statistics tool](#) is used to calculate a statistic (e.g. minimum elevation) from a raster within raster or feature zones. Output cells in the resulting raster dataset will reflect the statistic values for each overlaid feature, with null values for all other cells. Tool will fail if run while an editing session is active.

The [Zonal Statistics as Table tool](#) similarly calculates one or many statistics from a raster within zones, creating output in tabular form; the table may then be joined to a feature or raster attribute table.

Both of these tools require an active Spatial Analyst license.

An analogous tool in the 3D Analyst toolbox is [Add Surface Information](#) (*3D Analyst Tools > Functional Surface*), which adds a column in the feature's attribute table for each of multiple selected statistics; the features may then be converted to a raster separately. This tool requires an active 3D Analyst license.

Workflows

Tool names (referenced above) are indicated with **bold** text. Data layer names are indicated in *italics*.

Pit fill detection

1. Begin with bare earth DEM (*DEM*) and hillshade (*HS*) raster for area of interest.
2. **Fill** DEM.

Input surface raster: *DEM*

Output raster: *DEM_fill*

Note: Unless working with a known closed basin, “Z limit” field should be left blank.

3. **Minus** - subtract original DEM elevations from filled DEM.

Input raster 1: *DEM_fill*

Input raster 2: *DEM*

Output raster: *DEM_pits*

Note: Output raster will have positive fill depth in pit cells and zero values in all other cells.

4. Examine resulting fill depth raster (*DEM_pits*) for presence of artificial fills.

Note: Artificial fills occur where structures in the DEM (often roads) obscure real flow paths that pass below them (usually via culverts, as bridge structures spanning larger streams and rivers are generally removed during limited hydro-performed before public release of the bare earth DEM). The Fill tool then raises the surface level of the “sink” on the upslope side until it overtops the structure or finds another outlet (often along roadside drainage ditches).

- 4.1. Add *DEM_pits* to map above *HS* and set Layer Properties.
 - 4.1.1. Check “Display Background Value: 0” as null color (Symbology tab).
 - 4.1.2. (Optional) Change color ramp for increased visibility (Symbology tab).
 - 4.1.3. (Optional) Set layer transparency to 50% (Display tab).
- 4.2. Check for large or deep fill areas.

Note: These most noticeably occur where roads cut perpendicularly across valleys with relatively shallow bottom slopes, creating elongated fills reminiscent of reservoirs behind large river dams.

- 4.3. Scan along roads for intersections with channel or swale features visible in hillshade layer.

*Note: Artificial pit fill features here may be small but should nonetheless be cleared with appropriate culverts. This is particularly important when operating as part of a larger workflow related to surface flow routing. It can be helpful to create **flow accumulation** raster for filled DEM to help identify potential intersections.*

- 4.3.1. Where road is close to perpendicular to hillslope and channel feature continues on downslope side of road, this almost always indicates the presence of a road-crossing culvert.

- 4.3.2. Where road is close to parallel to hillslope and tail of fill points up road, this often indicates the presence of a driveway-crossing culvert along roadside.

- 4.4. Where possible, verify with Google Street View or similar.

Note: Even when stream or pipe/box are not directly visible (e.g., in thick roadside vegetation), common telltale signs of road-crossing culvert presence include raised line of cracks perpendicular to road surface where road base has settled on either side of culvert (alternately, dip where culvert pipe has partially collapsed), or paired drainage grates at nadir of dip in road.

5. Burn in culverts as necessary to remove artificial fills.

- 5.1. See hydro-enforcement workflow steps 4 – 6.

6. Repeat pit fill detection steps 2 – 5 as necessary until all artificial fills have been identified and cleared and only natural pit features remain.

*Note: **Fill** and **Minus** will be performed on each new iteration of hydro-enforced DEM (hydroDEM), but culvert burning should always be performed on original bare earth DEM (DEM).*

7. Final *DEM_pits* raster can be used to investigate statistics related to surface water detention storage:

- 7.1. Multiply raster value (fill depth) by cell area to calculate potential storage volume for each cell.

- 7.2. Overlay feature or raster layer (e.g., with **Zonal Statistics as Table** tool) to calculate storage statistics within zones of interest, such as by land cover or soil type.

Hydro-enforcement (“Burning in” culverts)

1. Begin with bare earth DEM (*DEM*) and hillshade (*HS*) raster for area of interest.
2. **If you already have line layer of delineated culverts with associated elevations:**
 - 2.1. Use **Polyline to Raster** to convert culverts to raster (*cv_raster*) with inlet elevation as the value field and the same cell size as *DEM*.
 - 2.2. Skip to step 6.

If you have line layer of delineated culverts without elevations:
Skip to step 5.

If you have point layer showing culvert locations: skip to step 4.

If you have none of these: continue to step 3.

3. Identify culvert locations.
 - 3.1. See [pit fill detection workflow](#) steps 2 – 4 for using presence of artificial fills to indicate likely culverts.
4. Create polyline feature for each identified culvert.
 - 4.1. Create new polyline shapefile or feature dataset (*Culverts*) in ArcCatalog.
 - 4.2. Make *Culverts* dataset editable.
 - 4.3. At each culvert location, draw polyline crossing artificial impediment.
 - 4.4. Save edits and stop editing session.
5. Use **Zonal Statistics** to create new raster with culvert cell elevations equal to minimum DEM elevations along culvert lines.
 - Input zone data: *Culverts*
 - Zone field: OBJECTID or other field with unique identifier for each culvert
 - Input value raster: *DEM*
 - Output raster: *cv_raster*
 - Statistics type: MINIMUM
6. Use **Mosaic to New Raster** to create hydro-enforced raster with culverts burned in.

Input Rasters: *DEM*; *cv_raster*

Note: Rasters should be in this order; if swapped, Mosaic Operator field must be correspondingly changed.

Raster Dataset Name: *hydroDEM*

Pixel Type: 32_BIT_FLOAT

Number of Bands: 1

Mosaic Operator: LAST

Watershed delineation

1. Begin with hydro-enforced bare earth DEM (*hydroDEM*) and hillshade (*HS*) raster for area of interest.
 - 1.1. See hydro-enforcement workflow.
2. **Fill** DEM.

Input surface raster: *hydroDEM*
Output raster: *DEM_fill*

Note: Unless working with a known closed basin, "Z limit" field should be left blank.
3. Run **Flow Direction** tool on DEM.

Input surface raster: *DEM_fill*
Output flow direction raster: *Flow_Dir*
Flow direction type: D8
4. Run **Flow Accumulation** tool on flow direction raster.

Input flow direction raster: *Flow_Dir*
Output accumulation raster: *Flow_Acc*
Flow direction type: D8

 - 4.1. Add *Flow_Acc* to map above *HS* and set Layer Properties.
 - 4.1.1. Set layer transparency to 75% (Display tab).
 - 4.1.2. (Optional) Increase flow line visibility by setting color ramp stretch type to "Minimum-Maximum" and lowering "High" value (Symbology tab).
5. Create watershed outlet feature(s).

Note: These are most commonly point features, as flow accumulation tends to collapse to single-pixel wide lines. However, wide channels (such as at mouths of larger rivers and estuaries) often feature multiple parallel flow accumulation

lines moving downstream. In these cases, it is helpful to instead create an outlet line feature across the mouth.

- 5.1. Create new shapefile or feature dataset (*Outlets*) in ArcCatalog.
- 5.2. Make *Outlets* dataset editable.
- 5.3. At each desired watershed outlet location, place point directly on flow accumulation line pixel.

Note: For outlet line features, outlet line should stretch from bank to bank and cross all flow accumulation lines.

- 5.4. Ensure each watershed outlet has a unique identifier in feature attribute table.

Note: In most cases, the OBJECTID field is sufficient. In rare cases where multiple outlet features correspond to a single watershed (e.g., two points or line segments at the mouth of a river split by an island in the middle), all features for that watershed must have the same identifier. Features may either be merged (available only for lines, not points), or a new attribute column may be added and populated accordingly.

- 5.5. Save edits and stop editing session.

6. **Snap Pour Point(s)** to outlet raster.

Input feature pour point data: *Outlets*

Pour point field: OBJECTID or other field with unique watershed identifier

Input accumulation raster: *Flow_Acc*

Output raster: *pp_raster*

7. Run **Watershed** tool.

Input flow direction raster: *Flow_Dir*

Input pour point data: *pp_raster*

Note: Using pour point features rather than snapped pour point raster often produces anomalous results and should be avoided.

Pour point field: Value

Output raster: *wshed_raster*

8. Run **Raster to Polygon** tool to convert watershed raster to features.

Input raster: *wshed_raster*

Field: Value

Output polygon features: *wshed_poly*

Note: Simplifying polygons (the default option) is generally recommended, with a caveat – any adjacent watershed polygons from the same watershed_raster layer will be simplified in such a way that their shared boundaries will match node-for-node, but if another adjacent watershed is subsequently delineated and simplified in a separate iteration of this workflow, the resulting polygon may have small boundary mismatches. If delineating adjacent watersheds in multiple iterations, polygons should not be simplified during raster conversion process.

Stream network delineation

1. Begin with hydro-enforced bare earth DEM (*hydroDEM*) raster for area of interest.

- 1.1. See [hydro-enforcement workflow](#).

2. **Fill DEM.**

Input surface raster: *hydroDEM*

Output raster: *DEM_fill*

Note: Unless working with a known closed basin, “Z limit” field should be left blank.

3. Run **Flow Direction** tool on DEM.

Input surface raster: *DEM_fill*

Output flow direction raster: *Flow_Dir*

Flow direction type: D8

4. **For channel initiation based on source area:**

- 4.1. Run **Flow Accumulation** tool on flow direction raster.

Input flow direction raster: *Flow_Dir*

Output accumulation raster: *Flow_Acc*

Flow direction type: D8

- 4.2. Skip to step 5.

For channel initiation based on overland flow length:

- 4.3. Run **Flow Length** tool on flow direction raster.

Input flow direction raster: *Flow_Dir*

Output raster: *Flow_Len*

Direction of measurement: UPSTREAM

- 4.4. Continue to step 5.

5. Run **Con** tool on flow raster.

Input conditional raster: [Flow raster created in step 4]

Expression: VALUE >= [Desired channel initiation condition]

Note: Replace “[Desired channel initiation condition]” with numeric value (no brackets). For Flow_Acc raster, this value will be the number of raster cells corresponding to the area to channel initiation – for example, if area to initiation were assumed to be 0.1 km² (100,000 m²) and you are working with a 2 m resolution DEM (cell area 4 m²), the initiation condition would be 25,000 cells and the Expression field would be entered as VALUE >= 25000. For Flow_Len raster, value will be the overland flow length in map units – for example, if length to channel initiation is assumed to be 1 km and your map units are meters, the initiation condition would be 1000 m and the Expression field would be entered as VALUE >= 1000.

Input true constant value: 1

Input false constant value: [Leave blank]

Output raster: *Stream_Net*

6. (Optional) Use **Stream to Feature** tool to create stream polyline features from stream network raster.

Overland flow distance calculation

1. Begin with delineated stream network raster (*Stream_Net*), hydro-enforced bare earth DEM (*hydroDEM*), and flow direction raster (*Flow_Dir*).

1.1. See [stream network delineation workflow](#).

2. Run **Flow Distance** tool.

Input stream raster: *Stream_Net*

Input surface raster: *hydroDEM*

Output raster: *Flow_Dist*

Input flow direction raster: *Flow_Dir*

Note: Use of flow direction raster is optional but does speed up processing time.

Distance type: HORIZONTAL

Statistics Type: MINIMUM

3. (Optional) Calculate average overland flow distance for catchment(s).

- 3.1. Begin with catchment raster (*wshed_raster*) or polygon features (*wshed_poly*).

- 3.1.1. See [watershed delineation workflow](#).

- 3.2. Run **Zonal Statistics** tool on flow distance raster.

Input zone data: *wshed_raster* or *wshed_poly*

Zone field: [Unique watershed ID column]

Input value raster: *Flow_Dist*

Statistics type: MEAN

*Note: To simultaneously calculate other statistics such as maximum and standard deviation, instead use **Zonal Statistics as Table** tool.*

DINF flow routing on floating point raster

*Note: **NOT RECOMMENDED** - Flow Accumulation tool on DINF raster can split flow and produce output values that do not monotonically increase when moving downstream, resulting in complications such as loops and gaps when delineating stream network from flow accumulation raster.*

D-Infinity flow routing methods require an integer data type raster, while most high-resolution DEMs are floating point. This workflow provides a workaround without sacrificing needed vertical resolution.

1. Begin with floating point type DEM raster.
2. **Times** – multiply DEM values by a power of ten to retain desired level of precision.

Note: Converting directly to integer type without multiplication results in elevations being truncated to the previous full meter, removing differentiation between cells and resulting in an unnatural step effect in the DEM.

Multiplying by 10^1 retains original DEM precision to the decimeter level, 10^2 to the centimeter level, and so on.

3. **Int** – convert resulting raster to integer data type.
4. Integer type raster can then be used for DINF routing methods in **Flow Direction** and **Flow Accumulation** tools.

*Note that if using **Flow Distance** tool to calculate vertical component of overland flow distance from integer DEM and DINF flow direction raster, results will be exaggerated by same multiplicative factor used in step 2.*