W
A
T
E
R
S
H
E
D
S

Modeling
Watershed
Geomorphology

with
TNTmips®

Before Getting Started

The movement of water over land surfaces is an important environmental factor that is governed primarily by terrain shape. The Watershed process in TNTmips® analyzes an elevation model and defines drainage networks and the boundaries between different drainage areas (watersheds) along with related attributes. The exercises in this booklet lead you through the main procedures involved in watershed modeling with the Watershed process.

Prerequisite Skills This booklet assumes that you have completed the exercises in the tutorial booklets *Displaying Geospatial Data* and *TNT Product Concepts*. Those exercises introduce essential skills and basic techniques that are not covered again here. Please consult those booklets for any review you need.

Sample Data The exercises presented in this booklet use sample data that is distributed with the TNT products. If you do not have access to a TNT products DVD, you can download the data from MicroImages' Web site. In particular, this booklet uses the sample file WATRSHED in the TERRAIN data collection.

More Documentation This booklet is intended only as an introduction to watershed modeling. Details of the processes described here can be found in a variety of Technical Guides and QuickGuides, which are all available from MicroImage's web site.

TNTmips® Pro and TNTmips Free TNTmips (the Map and Image Processing System) comes in three versions: the professional version of TNTmips (TNTmips Pro), the low-cost TNTmips Basic version, and the TNTmips Free version. All versions run exactly the same code from the TNT products DVD and have nearly the same features. If you did not purchase the professional version (which requires a software license key) or TNTmips Basic, then TNTmips operates in TNTmips Free mode.

The Watershed process is not available in TNTview or TNTatlas. All the exercises can be completed in TNTmips Free using the sample geodata provided.

Randall B. Smith, Ph.D., 21 August 2013
©MicroImages, Inc., 2000-2013

You can print or read this booklet in color from MicroImages' Web site. The Web site is also your source for the newest tutorial booklets on other topics. You can download an installation guide, sample data, and the latest version of TNTmips.

http://www.microimages.com

Welcome to Modeling Watersheds

The Watershed process addresses the influence of terrain on surface water hydrology by modeling the movement of water over the land surface. The input data for the process is a DEM (Digital Elevation Model), a regular grid of elevation values stored as a raster object.

The Watershed process computes the local directions of flow and the gradual accumulation of water moving downslope across the landscape. From these intermediate results the process then computes the stream network and the boundaries between *watersheds*, the areas drained by particular stream systems. Watersheds can be further subdivided into *basins* associated with particular branches of the stream network. The flow path network, watershed boundaries, and basins are created as separate temporary vector objects. You can adjust several processing parameters to vary the level of detail in these objects before saving the final results. Varied attribute information is also created and saved with the flow paths and watersheds. The information created by these area-wide computations can be used as input for further analysis of water resource issues, flood and erosion hazard, and movement of pollutants.

An interactive tool is also provided to generate flow paths and basins for particular point locations in the elevation model. This tool is useful for analyzing the impacts of point-source pollutants within a watershed.

A sequential processing option is available for filling depressions in the elevation model prior to determining the flow routing. This procedure may be useful in assessing the influence of any natural depressions in the landscape.

Additional terrain analysis processes in TNTmips are introduced in a companion tutorial booklet *Analyzing Terrain and Surfaces*.

☑ choose Terrain / Watershed from the TNTmips menu
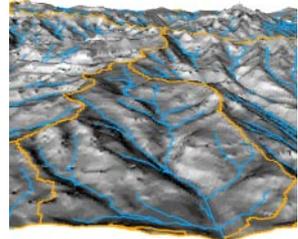
A 3D perspective view of a relief-shaded DEM with watershed boundaries (orange) and flow lines (blue) produced by the Watershed process.

An introduction to computing flow paths and watersheds is provided on pages 4-9, followed by a discussion of the database attributes computed for these features on pages 10-13. Other objects computed by the watershed process are described on pages 14-16. Pages 17-18 discuss methods for filling and draining depressions. The use of null cells and masks to control processing is covered on pages 19-20. Pages 21-22 describe methods for segmenting flow path lines. Sequential processing is covered on pages 23-27.

Begin Watershed Analysis

STEPS

☑ press the Open icon button in the Watershed Analysis window

☑ use the Select Object dialog to select DEM_W1 from the WATERSHD Project File in the TERRAIN data collection

☑ check that the Fill Depressions toggle button on the General panel is turned on

☑ press the Run icon button

Press the Save Results icon button to choose which of the temporary watershed layers you want to save to a Project File.

Starting the Watershed process opens the Watershed Analysis and Watershed Analysis View windows. The View window automatically displays the DEM you select for analysis and, after processing, selected results of the process.

The quickest way to fully delineate watersheds and flow paths in a DEM is to use the Fill Depressions option, which is turned on by default. (We will explore the impact of this choice on processing in later exercises.) The Watershed process creates a series of temporary vector and raster objects that present different aspects of the results. To save any or all of these objects, press the Save Results icon button on the Watershed Analysis window.
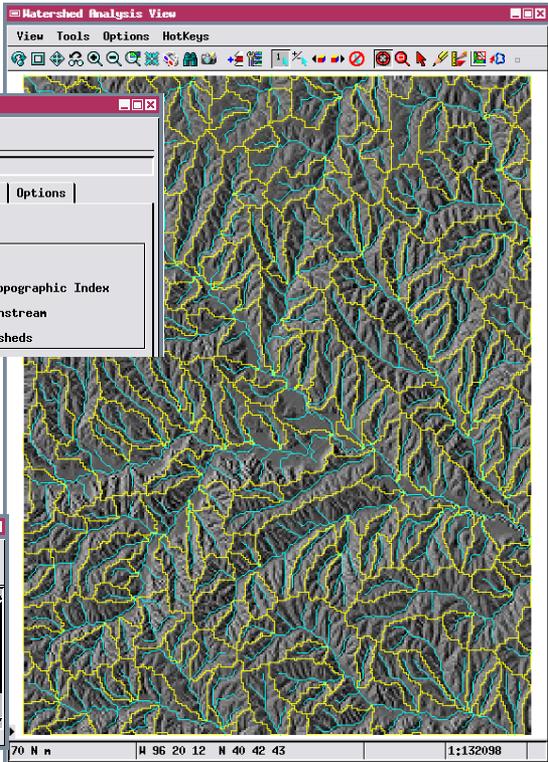
☑ press the Layer Manager icon button on the View window to open the Layer Manager
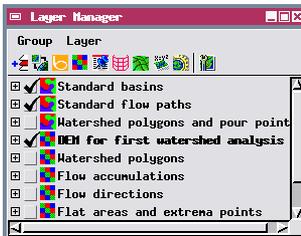
Flow Paths and Watersheds

After you run the Watershed process using the Fill Depressions option, two vector objects depicting standard basins (named STDBASIN) and standard flow paths (STDFLOWPATH) are displayed over the input DEM in the View window. Other output vector and raster objects are listed in the Layer Manager window but are initially hidden. We will return to the standard basins object later, but for the moment we will hide it and instead show the vector object representing watershed polygons (WATERSHED).

STEPS
☑ in the Layer Manager window, click on the

✔ Show / Hide checkbox for the STANDARD BASINS vector object to uncheck it and hide this layer
☑ turn on the checkbox for the WATERSHED POLYGONS vector layer

The lines in the flow paths vector (shown in cyan color) represent the computed network of actual and potential stream channels that drain each watershed. The boundaries of the watersheds are shown as blue polygons in the watershed vector object. The watershed boundaries follow topographic divides between different drainage systems.
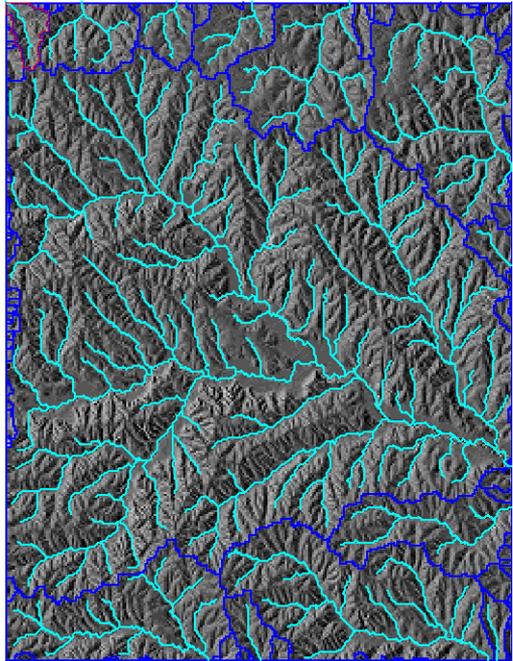
Use the Show / Hide checkboxes to control which of the available layers are currently displayed.

The type of layer names shown for the watershed objects in the Layer Manager depend on your Default Layer Name setting in the Display process. The illustrations here show object descriptions rather than object names as the layer names. Each temporary vector object created by the Watershed process is displayed with a pre-assigned color. You can change the color or line width by clicking the Vector icon button for a layer to open its Vector Layer Controls window.

Watershed Properties

- ☑ press the Watershed Attributes icon button on the toolbar on the Watershed Analysis window
- ☑ press the Select Watershed icon button at the top of the View window
- ☑ left-click with the mouse inside the large central watershed polygon

The selected polygon is highlighted in color in the View and in the Watershed Attributes window.

The Watershed Attributes window presents a list of the basic properties of the watersheds that were found by the process. When all depressions are filled, each watershed drains to the edge of the raster object (or to the boundary between valid and null raster values, which can be used to represent a coastline). Each watershed in this case has neither inflow from an upstream watershed nor outflow to a downstream watershed, as indicated by the lack of check marks in the Outflow and Inflow columns in the window. Watersheds that drain beyond the edge of the raster in the same direction may in fact join downstream and form parts of larger regional watersheds.

The watershed attributes include elevation values (minimum and maximum elevations within the watershed, plus minimum boundary elevation), and the area (in square meters) and perimeter (in meters).

The area and perimeter of each watershed are computed using the georeference information associated with the DEM or from the raster cell size if the DEM is not georeferenced. If no cell size has been specified, the line and column cell size are assumed to be 1 meter.

Flow Path Parameters

If you closely examine the watershed and flow path vector objects, you will see that flow paths do not extend all the way upstream to the watershed boundaries. Also, no flow paths are shown for some smaller watersheds around the edges of the DEM. The parameter values shown on the Flowpath and Basin panel are default thresholds that were used by the process to compute the current flow path and basin vectors. You can modify these parameter values and recompute new flow path and basin vector objects that show greater or lesser detail.

In order to generate flow paths, the Watershed process computes for each DEM cell the number of upstream cells that contribute flow to that cell. These flow accumulation values are used in part to trace flow paths upstream, beginning with the highest accumulation values where streams reach the boundaries of the area. The Outlet parameter sets the flow accumulation threshold for initiating a flow path at the edge of the raster. Only boundary cells with flow accumulation values greater than the Outlet threshold are used to initiate a flow path.

The Inlet parameter determines how far upstream each flow path is traced toward its headwaters. A flow path terminates when the flow accumulation value for the next upstream cell falls below the Inlet parameter value.

The Branch parameter controls the upstream splitting of flow paths at potential junctions between tributaries (branches). A branch flow path is created when the flow accumulation value at the mouth of the tributary exceeds the Branch parameter value.

STEPS
- ☑ close the Watershed Attributes window
- ☑ click on the Flowpath and Basin to expose its panel

Increase the value of the Outlet parameter if you don't want to create flow paths for smaller watersheds around the periphery of the DEM that currently show them.
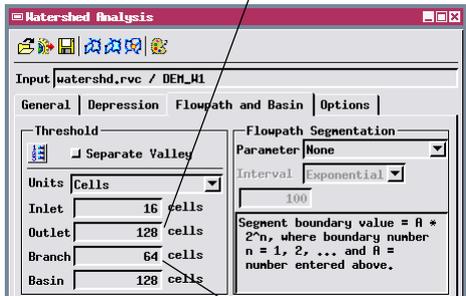
Decrease the values of the Inlet and Branch parameters if you want to extend flow paths closer to the upper watershed boundaries and increase the number of tributary flow paths shown.

To restore the default values for the Flow Path and Basin parameters, click the Set to Defaults icon button.

The Flowpath and Basin threshold values are computed internally with raster cells as the area units, but you can use the Units menu to choose from a standard set of area units (including square kilometers, hectares, and others) to use for the values of these parameters

Recompute Flow Paths and Basins

STEPS

☑ use the Show / Hide checkboxes in the Layer Manager window to hide the WATERSHED vector layer and show the BASINS layer

☑ on the Flowpath and Basin panel, change the value of the Inlet parameter to 32 cells

☑ change the value of the Branch parameter to 128

☑ change the value of the Basin parameter to 256

☑ press the Run icon button

☑ if you don't want to save the previous process results, click [No] in the Question window, otherwise click [Yes] and name the output objects

The polygons in the standard basins vector object (shown in yellow in the illustration on page 4) show subdivisions within larger watersheds. Each basin (subwatershed) is the area drained by a network of branches of the main stream. The lowest elevation in each basin is the junction between its stream network and a larger stream.

The Basin parameter sets an area threshold for generating basin polygons within each watershed. A basin polygon is created for each branch system that drains an area greater than or equal to the value set for the Basin parameter. Because flow accumulation is expressed as the number of cells contributing flow, the area of a basin is equivalent to the flow accumulation value of the cell at the mouth of its tributary system.

The changes you make to the flow path and basin parameters in this exercise create a less dense, less detailed flow path network with less numerous and shorter branches and less numerous and larger basins.
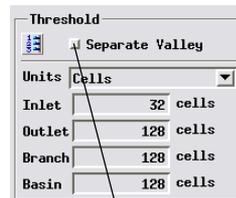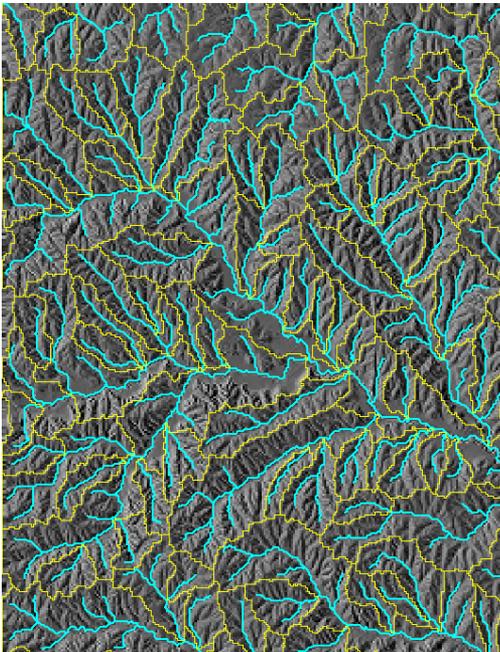
If you turn on the Separate Valley Polygons toggle before recomputing flow paths and basins, large elongate basins associated with master streams are partitioned into separate polygons at branch intersections. The minimum size of these polygons is also set by the Basin parameter value.

Basins and Flow Paths from Seed Points

In some instances you may want to know the extent of the watershed upstream from a designated point. For example, the point might represent a stream sample locality where a chemical anomaly was detected and the upstream watershed represents the region containing the potential source. On the other hand, if a point source of pollution has been identified, you would want to predict the downstream flowpath along which the pollutant would be dispersed.

The Seed Points tool allows you to place seed points that can be used to compute a downstream flow path, upstream basin, or both for each point. These options are controlled by the corresponding toggle buttons on the General panel in the Watershed Analysis window.

Seed points are listed on the Manual panel of the Graphic Tool Controls. You can delete a poorly-located point by pressing its Delete icon button.

Marked seed point

Cursor marking prospective seed point location

Computed basins and flow paths for two seed points.
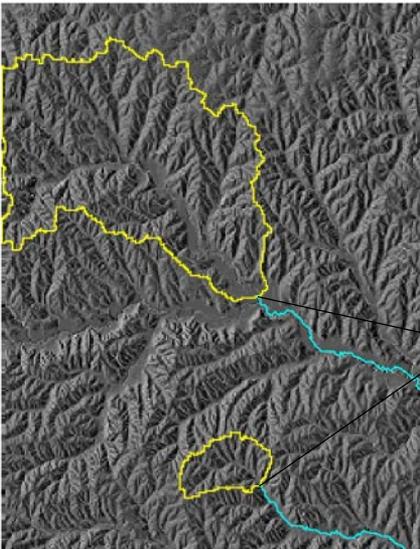
STEPS
☑ choose Manual from the Seed Points menu at the bottom of the Flowpath and Basin tabbed panel
☑ press the icon button for the Seed Points tool at the top of the View window
☑ left-click in the bottom of the major valley near the center of the area; a cross-in-circle cursor appears
☑ reposition the cursor if necessary to place it on the existing flow line, then right-click to add the point and compute the flowpath and basin (answer [No] in the Question window)
☑ left-click on a flow path in one of the smaller valleys
☑ right-click to add the point and compute an additional flowpath and basin for the new point

☑ when you are ready to return to computing flow paths and basins for the entire DEM, simply choose Automatic from the Seed Points Mode menu

Flow Path Attributes

STEPS
- ☑ turn on all of the toggle buttons in the Compute pane on the General panel
- ☑ press the Run icon button, then [No] in the Question window
- ☑ in the Layer Manager window, press the Expand / Collapse icon button ⊞ for the STANDARD FLOW PATHS layer
- ☑ repeat for the line element entry for this layer to show its tables
- ☑ turn on the Show Table checkbox for the STREAM_PROPERTIES table
- ☑ in the STDFLOWPATH table window, turn on the View All Records button
- ☑ repeat for the STREAM_DISTANCES table

All of the spatial layers created and displayed by the Watershed process have DataTips enabled by default. When you pause the cursor over the View, you get a DataTip listing a cell value or salient attribute value from each layer.

The Watershed process can compute many hydrologic and geomorphic attributes for the flow path lines and the watershed and basin polygons. A STREAM_PROPERTIES table is produced automatically whenever flowpath lines are computed. This table presents stream line attributes related to topography and hydrology: maximum and minimum elevations (elevations at upstream and downstream ends, respectively), elevation drop, average slope, line length as projected to the XY mapping plane, and the sinuosity ratio (line length divided by the straight-line distance between endpoints). All of these values are computed fields (as indicated by the blue field names) that read or compute their values from field values stored in various other tables.

STDFLOWPATH / LineDatabase / STREAM_PROPERTIES
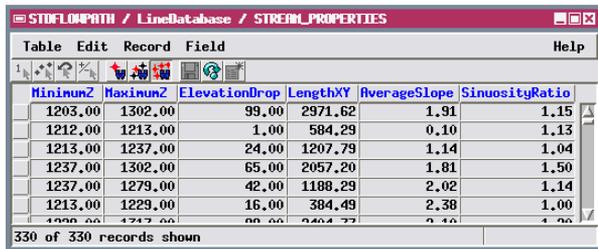
MinimumZ	MaximumZ	ElevationDrop	LengthXY	AverageSlope	SinuosityRatio
1203.00	1302.00	99.00	2971.62	1.91	1.15
1212.00	1213.00	1.00	584.29	0.10	1.13
1213.00	1237.00	24.00	1207.79	1.14	1.04
1237.00	1302.00	65.00	2057.20	1.81	1.50
1237.00	1279.00	42.00	1188.29	2.02	1.14
1213.00	1229.00	16.00	384.49	2.38	1.00
1220.00	1717.00	99.00	2404.77	2.10	1.20

330 of 330 records shown

A STREAM_DISTANCES table is computed whenever you have turned on either of the Flow Distance options on the General panel. Since each stream line has a finite length, separate distance values are computed for each end of a line (MinimumUp and Maximum Down for the upstream end, and MaximumUp and MinimumDown for the downstream end), along with average values for a line's midpoint.

STDFLOWPATH / LineDatabase / STREAM_DISTANCES
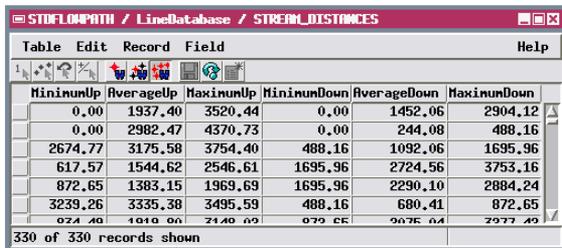
MinimumUp	AverageUp	MaximumUp	MinimumDown	AverageDown	MaximumDown
0.00	1937.40	3520.44	0.00	1452.06	2904.12
0.00	2982.47	4370.73	0.00	244.08	488.16
2674.77	3175.58	3754.40	488.16	1092.06	1695.96
617.57	1544.62	2546.61	1695.96	2724.56	3753.16
872.65	1383.15	1969.69	1695.96	2290.10	2884.24
3239.26	3335.38	3495.59	488.16	680.41	872.65
824.40	1918.90	2140.93	872.65	2075.04	3277.42

330 of 330 records shown

Stream Order

Since stream segments in each watershed join downstream to form larger streams, the relative importance of each segment can be expressed as a numerical rank or *order* within the stream network. The Watershed process computes stream order for each line element in the standard flow path vector object using four different ordering systems that are described and illustrated below. The resulting values are stored in the STREAM_ORDER table.

Strahler: The smallest headwater segments are assigned order 1. Order increases downstream by 1 whenever two streams of equal order join. For example, two streams of order 2 join to form a third-order stream. But the order number does not increase when a higher-order stream is joined by a lower-order stream.

Horton: This system begins with the same ordering scheme as the Strahler system, but the main stream maintains the same order number all the way upstream to a single headwater source. The order of major tributaries is treated in the same way. At each junction where two segments of equal Strahler order meet, the longest or most direct upstream segment is renumbered to the higher order of the main stream or branch.

Shreve: The order or "magnitude" of a stream segment formed at a junction is the sum of the magnitudes of the two tributaries. For example, the confluence of a magnitude 1 and magnitude 3 stream forms a magnitude 4 stream. The magnitude of any stream segment equals the number of its magnitude 1 sources, which means that the Shreve magnitude is more simply related to predicted flood flow than other ordering systems.

STEPS
- ☑ turn off the Show Table checkboxes for the STREAM_PROPERTIES and STREAM_DISTANCES tables
- ☑ turn on the Show Table checkbox for the table STREAM_ORDER
- ☑ in the STREAM_ORDER table window, select Switch to Single Record view from the Table menu
- ☑ press the Select icon button in the View window and select a segment of the stream that drains toward the lower right corner of the DEM as shown in the illustration

- ☑ close the STREAM_ORDER table

Scheidegger: This system defines for each segment an "associated integer" (shown in the STREAM_ORDER table) that is twice the Shreve magnitude. The Scheidegger stream order is the logarithm to the base 2 of the associated integer.

Strahler   Horton   Shreve   Scheidegger

Watershed and Basin Attributes

STEPS
- ☑ press the Expand / Collapse icon button ⊞ for the STANDARD BASINS layer
- ☑ repeat for the polygon element entry for this layer to show its tables
- ☑ turn on the Show Table checkbox for the ATTRIBUTES table
- ☑ in the ATTRIBUTES table window, select Switch to Single Record view from the Table menu
- ☑ repeat for the table ATTRIBUTES BY ORDERS
- ☑ use the select tool to select one of the basin polygons in the View

You can have the Watershed process compute a set of hydrologic attributes for basin and/or watershed polygons when you turn on the Geomorphic Attribute toggle for the respective polygon type on the General tabbed panel. The ATTRIBUTES table for each polygon type records attribute values for each entire polygon, while the ATTRIBUTES BY ORDER table partitions the attributes for each polygon by stream order, with one record for each stream order represented in a particular polygon.

These tables record several simple attributes such as the number of stream lines, total stream length in meters, and average stream length in meters. They also record a number of more complex attributes:

Drainage Density: total stream line length divided by the polygon area.

Constant of Channel Maintenance: polygon area divided by the total stream length (reciprocal of drainage density).

Length of Overland Flow: reciprocal of (2 * drainage density).

Stream Frequency: total number of streams divided by the polygon area.

Basin Length: maximum polygon dimension measured from the stream outlet.

Form Ratio: polygon area divided by the square of the basin length.

Elongation Ratio: ratio of the diameter of a circle with area equal to the basin area to the basin length.

Ruggedness Number: basin relief times drainage density.

Bifurcation Ratio: the mean (for all stream orders) of the number of streams of a given order divided by the the number of streams of the next higher order.

Length Ratio: the mean (for all stream orders) of the average stream length of a given stream order divided by the average length of the next higher order.

Hydrologic Connectivity Tables

Stream lines in the standard flow paths vector form a connected 3D line network in which tributary stream lines merge in the downstream direction. The subcatchments (standard basins) associated with these stream lines likewise are ordered by the direction of stream flow and the merging of tributaries.

The connectivity of these hydrologic elements is captured by the Watershed process in a series of tables that are automatically created for the standard flow paths and standard basins vectors. Each flow path line can flow into only one downstream line element; the ID number of that line element is recorded in the DOWNFLOW table for each stream line. A BASINS table is also created for the standard flow path vector if you have chosen to create the standard basins vector; this table records the ID number of the basin polygon in which each stream line lies.
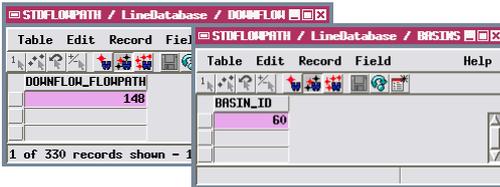
Two hydrologic connectivity tables are created for the standard basins polygons. Each basin polygon contributes flow to only one downstream basin; the ID number of that downstream polygon is provided in the BASINS table. The flowpaths table has a record for each flow path line showing the corresponding basin ID. Larger basins may contain a number of stream lines, so multiple records may be attached to a single basin polygon.

STEPS
- ☑ close the ATTRIBUTES and ATTRIBUTES BY ORDERS tables
- ☑ turn on the Show Table checkbox for the BASINS and FLOWPATHS tables in the STANDARD BASINS layer
- ☑ in the STANDARD FLOW PATHS layer, turn on the Show Table checkbox for the DOWNFLOW and BASINS tables

The hydrologic connectivity tables and their record attachments to flowpath and basin elements allow you to use the standard flow path and standard basins vector objects to perform higher-level spatial analysis and modeling that relate specific flowpath elements to corresponding areas of the landscape.

- ☑ press the Unmark All icon button in the View and close all of the open tables

Other Watershed Products

- ☑ use the Layer Manager to hide the STANDARD BASINS and STANDARD FLOW PATHS layers and show the STANDARD RIDGES layer
- ☑ hide the STANDARD RIDGES and DEM layers, then show the other raster layers discussed below

The Watershed process also produces one other optional vector object and several raster objects. Some of these products show particular aspects of the terrain and may be useful for specialized analysis, but others are primarily intermediate objects used to produce the objects discussed previously. The illustrations below show the northwest (upper left) quarter of some of these objects.
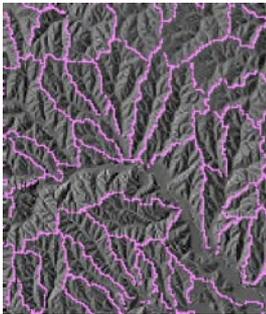
Lines in the Standard ridges vector object (shown in magenta) follow the topographic divides that separate different watersheds and basins. Portions of the basin boundaries that cross uniform slopes or flat areas are not included as ridge line segments.

Brighter tones in the Flow accumulation raster indicate higher flow accumulation values and trace out the branching pattern of potential flow paths. This intermediate object is used to generate the flow path vector object and the watershed and basin boundaries.
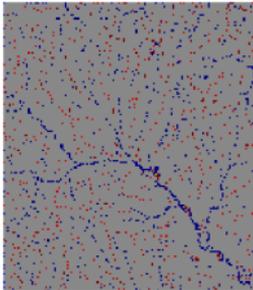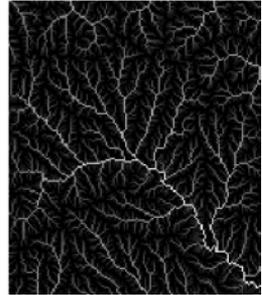
The Flat areas and extrema points raster indicates the location and type of locally-significant elevation values in the original DEM. To assess its signficance, each elevation is compared to that of its 8 nearest neighbors. The majority of cells are not significant and are shown in gray. Cells that have isolated (single) local maximum or minimum values are shown in bright red and bright blue, respectively. Cells that are part of contiguous groups forming local maxima or minima are shown in dark red and dark blue. Flat areas are in yellow.

Two other intermediate raster objects are created in the Watershed process. Values in the Flow directions raster (shown to the right) encode the local direction of flow relative to the surrounding 8 cells. The direction value increases clockwise from top right to top. This raster is used along with the Flow accumulation raster to produce the final flow path and basin vector objects. The Watershed raster (not shown) contains a unique cell value for each watershed.
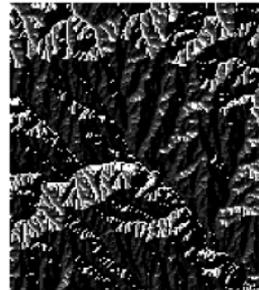
Hydrologic Properties of the Terrain

Toggle buttons on the Compute pane of the Watershed Analysis window's General tabbed panel allow you to choose to produce a number of additional raster objects that are not required to compute watersheds and flowpaths but nevertheless record significant hydrologic properties of the terrain. These four raster objects are described and illustrated below.
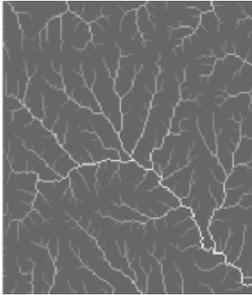
Specific Catchment Area depicts for each cell the upslope contributing area per unit flow width perpendicular to the flow direction. This value is computed from the local flow accumulation and flow direction values and the cell dimensions. This property is used as a parameter in modeling hillslope runoff and resulting soil erosion.

Compound Topographic Index (CTI), also referred to as a wetness index, predicts zones of increased soil moisture where the landscape area contributing runoff is large and the local slopes are low, such as at the base of hillsides and in valley bottoms. The index value for each cell is computed as:
CTI = natural log (Flow Accumulation / tan (slope)).
This property is used in soil landscape modeling and in analysis of vegetation patterns.
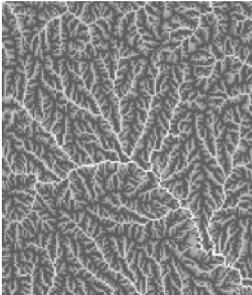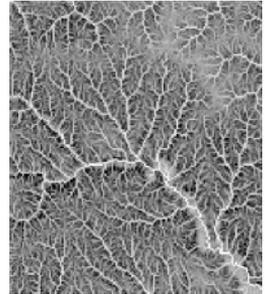
Maximum Upstream Flow Distance maps the longest flow distance from any part of the upstream watershed boundary to the current cell. This property can be used in modeling erosion rates and sediment yield.

Downstream Flow Distance maps the flow distance downstream from each cell to the outlet of its watershed. This distance has applications in the analysis of downstream dispersal of pollutants and sediment.
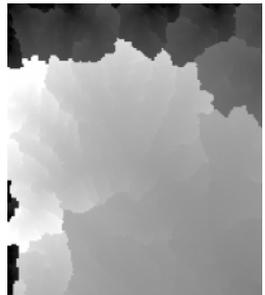
Adjusted Elevation

- ☑ use the Layer Manger controls to hide the raster objects examined on the previous page and show the ADJUSTED ELEVATION raster (which displays without relief shading)

DEM_W1 includes no large natural depressions like the one illustrated below. It does have many small spurious depressions, but you would need to look very closely to see any noticeable differences between it and the depressionless DEM.

Depressions are areas in a DEM that are completely surrounded by higher elevation values. Some natural processes can form sizeable natural depressions, and human activities such as mining and quarrying create smaller depressions. But natural depressions are rare in common landscapes that are shaped primarily by stream flow, and consequently most depressions in a DEM do not represent real landscape features. They are data errors, or result from the averaging involved in assigning elevation values to cells of finite area. These spurious depressions interfere with the correct routing of flow paths during the watershed analysis, especially in areas of low relief.

The Watershed process solves this problem by first locating and "filling" the depressions. It increases the values of cells inside each depression to the elevation of the lowest bounding cell (the pour point or outlet), simulating the natural filling of depressions with water to form ponds and lakes. When you run the Watershed process with the Fill Depressions option turned on, a depressionless version of the DEM (ELEVATION, with object description "Adjusted elevation") is created. This depressionless DEM is used to compute the flow paths, basins, and watersheds.
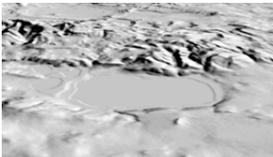
Perspective view of a relief-shaded DEM with a large natural depression partially filled by water to form a pond (uniform gray surface in center). The water level is lower than the lowest natural outlet (pour point).
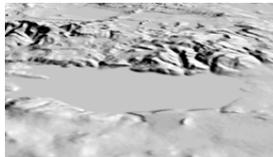
Perspective view of the corresponding area of the depressionless DEM. Elevations in the depression have been raised to the level of the lowest pour point, simulating complete filling with water.
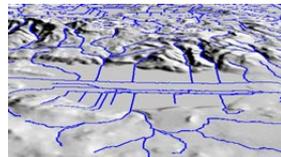
Computed flow paths overlaid on the depressionless DEM. Flow paths are routed across the flat areas created by filling depressions, linking inlet streams and outlet streams.

Filling Depressions

The filling of depressions is controlled by area and depth thresholds that you set on the Depressions tabbed panel. The Area and Null Area fields allow you to set the maximum number of cells and the maximum number of null cells, respectively, for a depression to be filled. The Depth field sets the maximum depth allowed for a depression to be filled. An additional depth parameter sets the threshold depression size above which the depth limit is applied; smaller depressions of any depth are filled.

The DEM in this exercise includes a shallow depression in the upland area between the major drainages. This depression is larger than the Area value we intially set (5000 cells) and so is not filled in the first Run. With the *Put null cell at bottom of unfilled depressions toggle* turned off, the result is that no flowpaths are computed and only watershed polygons are displayed. The watershed polygon with the yellow point symbol on its northern boundary includes the unfilled depression. You can examine the Depression attributes (see page 25) to investigate depression size. In this case increasing the Area threshold in the second run fills the depression and allows flowpaths to be computed.

STEPS
- ☑ press the Open icon button, then [No] in the Question window
- ☑ in the Select Object window, choose object DEM_WFD and press [OK]
- ☑ on the General panel, turn off all of the toggle buttons except Fill Depressions and Flowpaths
- ☑ on the Depression panel turn off the *Put null cell at bottom of unfilled depressions* toggle
- ☑ in the Fill Maxima Per Depression control group set the Area value to 5000
- ☑ press the Run icon button
- ☑ note the watershed with yellow pour point in left center of the area
- ☑ increase the Area value to 10000
- ☑ press the Run icon button, then [No] in the Question window

Watershed with unfilled depresssion

Routing flow across the flat areas formed by large filled depressions can produce artificially straight flow paths across those areas.
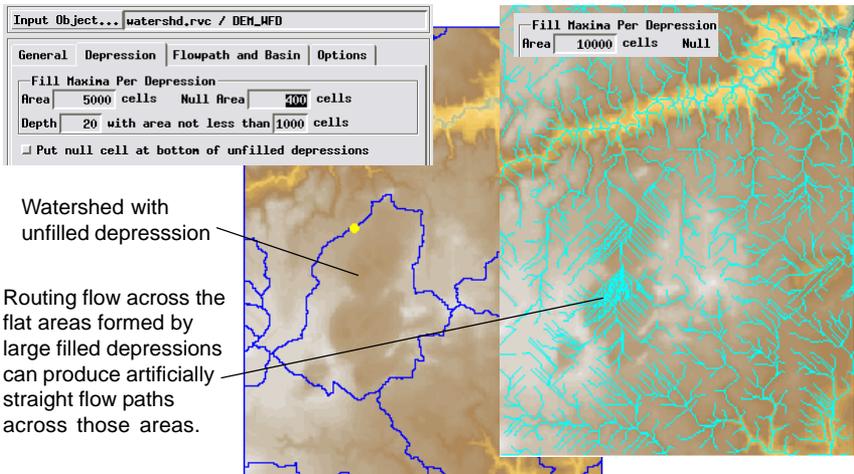
Draining Depressions

STEPS

- ☑ press the Open icon button, then [No] in the Question window
- ☑ in the Select Object window, choose object DEM_WDD and press [OK]
- ☑ on the Depression panel, turn on the *Put null cell at bottom of unfilled depressions* toggle
- ☑ in the Fill Maxima Per Depression control group set the Area value to 500
- ☑ set the cell number threshold for the Depth setting to 100
- ☑ press the Run icon button
- ☑ turn on the Watershed polygons vector layer

The DEM in this exercise includes several natural depressions caused by chemical weathering of the limestone that underlies the area and which is exposed at lower elevations. Within these depressions, surface water drains inward and some streams disappear into sinkholes that connect to cave systems.

In order to replicate the internal drainage of these depressions in the Watershed process, we have adjusted the depression-filling settings to prevent these small depressions from being automatically filled (reduced the maximum depression area and the threshold for triggering the depth limit). We've also toggled on the option to put a null cell at the bottom of unfilled depressions. When flowpaths are found, each of these null cells acts as an outlet or drain to nucleate a drainage network within the depression (see the following page).
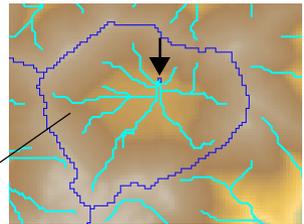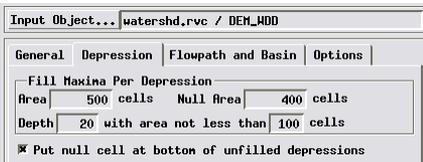
Magnified views of several closed depressions. Arrows indicate null cells placed in bottom of each.
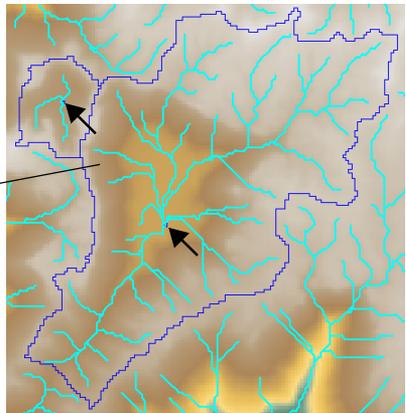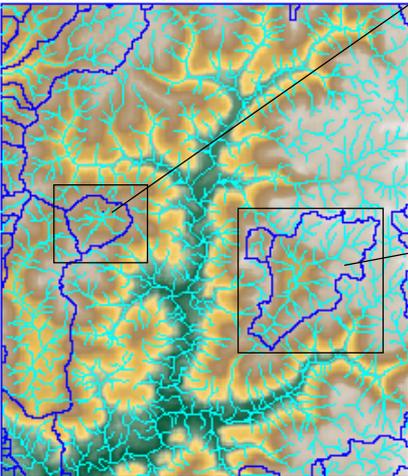
Use Null Cells to Limit Processing

The Watershed process traces watersheds, flow paths, and basins to the edge of the DEM raster or to the boundary between valid elevation values and *null cells*. A null cell is a "blank" or "no data" cell in a raster object. For example, a DEM that has been resampled to a map projection may be rotated so that valid elevation values do not fill the full rectangular extents of the raster object, leaving "blank" areas at the edges and corners that are set as null cells. (Null cells may be designated by a reserved numerical value in the raster or by a null mask.) These null areas are automatically excluded from processing in the Watershed and other TNT processes, and they are displayed transparently in the View window.

In a DEM of a coastal area the ocean is normally represented by cells with a value of 0, which of course is the elevation value that represents mean sea level. But since real drainage systems terminate at the coastline, there is no reason to include the ocean areas in the analysis. As shown by the DEM in this exercise, by designating the cells in the ocean area as null you can automatically exclude them from processing.

You can use the Mask Editor to edit the null mask to designate null areas for a DEM or any other raster object. You can access the Mask Editor from the TNTmips menu (Image / Utilities / Edit Mask) or from the Layer Manager in the Display Process (by right-clicking on the DEM's layer entry and selecting Mask Editor from the dropdown menu).

Standard Flow Paths for DEM_W2

ocean area displayed transparent

---

page 19
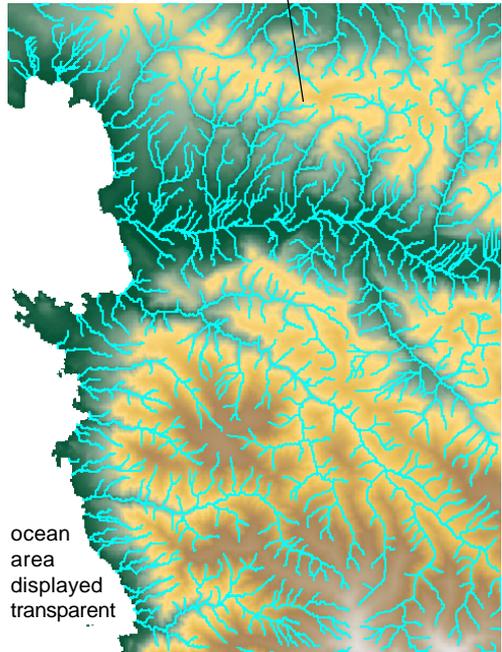
Mask Parts of the DEM

STEPS

- ☑ press the Open icon button, then [No] in the Question window
- ☑ use the Select Object dialog to select DEM_W3 from the WATERSHD Project File
- ☑ on the General panel, turn Off the Basins toggle
- ☑ on the Flowpath and Basin panel, set the Branch value to 128
- ☑ on the Options tabbed panel, press [Mask...]
- ☑ in the Select Object window, select the MASK_W3 object from the WATERSHD Project File
- ☑ turn on the toggle next to the Mask button
- ☑ note the Crater Lake area is masked out and is transparent in the View
- ☑ press the Run icon button

Another way to limit processing to particular parts of a DEM is to use the masking capability of the Watershed process. A mask is a binary raster object that contains a value of 1 for each cell that will be processed and a value of 0 for cells that will be excluded. You can use a mask to exclude a particular area that spans a range of elevation values. In the Crater Lake (Oregon, USA) example used in this exercise, we might be interested in drainage patterns in the area surrounding the crater and want to exclude the lake surface and inner crater walls. The lake occupies a crater at the summit of an extinct volcano.

You can load a mask raster that you have prepared outside the Watershed process by pressing the Mask button on the Options panel and turning on the adjacent toggle button to apply the mask in the View and for processing. This panel also includes a menu for setting compression options for the raster objects created by the Watershed process.
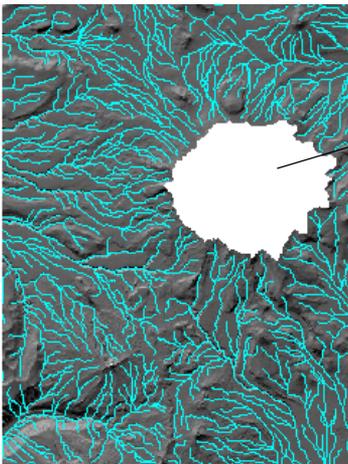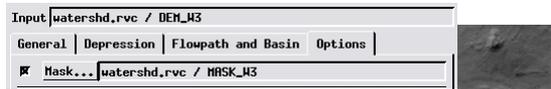
DEM without mask

The mask used here was produced using a region object created with the Basin region generation method.
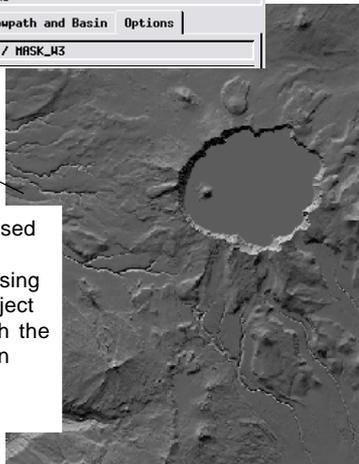
Flowpaths computed for the terrain outside the rim of Crater Lake; the crater walls and lake surface were excluded from the analysis using the mask.

Segment Flow Paths by Elevation

The Watershed process provides the option to create a segmented flowpath vector object in addition to the standard flowpath vector. A segmented flowpath vector has additional nodes inserted to divide line elements based on values of either elevation or flow accumulation. All attributes of the flowpath lines are recomputed for lines that have been split by the segmentation procedure.
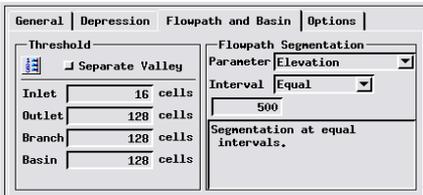
In this exercise we segment flowpaths based on elevation, using an equal elevation interval of 500 meters. The flowpath lines extend from an elevation of 1068 meters to maximum of 2406 meters. Our segmentation results in line elements in three elevation ranges: 1068 to 1500 m, 1500 to 2000 m, and 2000 to 2406 m. The segmentation procedure produces a Range table with a record for each range, and each record is attached to all corresponding flowpath lines. The steps in this exercise show how you can use the range values as the basis for styling the segmented lines By Attribute.
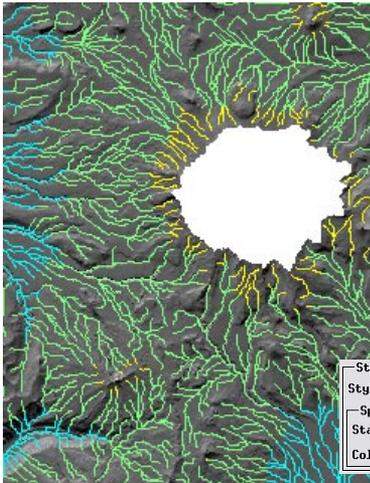
☑ on the Flowpath and Basin tabbed panel, set the Parameter menu under Flowpath Segmentation to Elevation

☑ set the Interval menu for segmentation to Equal and enter 500 in the field below the menu

☑ press the Run icon button

☑ in the Layer Manager, turn on the Show/Hide toggle for the SEGMENTED FLOW PATHS layer and left-click on its Layer Controls icon button

☑ on the Lines tabbed panel of the Vector Layer Controls window, choose New - By Attribute from the Style menu and press the adjacent Specify button

☑ in the Select Table/Field window that appears, choose RANGE from the Table list and Minimum from the Field list, then press [OK]

☑ on the Automatic tabbed panel of the Assign Styles window, under Style Options choose RGB from the Color Path menu

☑ use the Start Color and End Color buttons to choose cyan and yellow colors, respectively as shown

☑ press [OK] on the Assign Styles, New Table, and Layer Controls windows

Segment by Flow Accumulation

☑ press the Open icon button, then [No] in the Question window

☑ select DEM_W1 from the WATERSHD Project File

☑ on the Flowpath and Basin tabbed panel, set the Parameter menu under Flowpath Segmentation to Flow Accumulation

☑ set the Interval menu for segmentation to Exponential and enter 2000 in the field below the menu

☑ press the Run icon button

☑ in the Layer Manager turn on the SEGMENTED FLOW PATHS layer and open its Layer Controls

☑ on the Lines tabbed panel of the Vector Layer Controls window, choose New - By Attribute from the Style menu and press the adjacent Specify button

☑ in the Select Table/Field window that appears, choose RANGE from the Table list and Minimum from the Field list, then press [OK]

☑ on the Automatic tabbed panel of the Assign Styles window, choose All Same from the Style By menu

☑ under Size, set the second Width value to 1.50

☑ press [OK] on the Assign Styles, New Table, and Layer Controls windows

Segmenting flow paths by flow accumulation values relates the segments to the upstream area that contributes flow to each segment. Since flow accumulation values increase rapidly downstream along flow lines, it is appropriate to use the Exponential interval selection for this type of segmentation. With this option the interval value you enter is used to define the size of the first flowpath interval; in this example an interval value of 2000 results in an initial value range of 0 to 1999. But each successive flow accumulation interval is twice as large as the previous one, as shown by the illustration below of the Range table created for this exercise. The later steps in this exercise show how you can set up styling By Attribute based on the Range table with differing widths (rather than colors) set for the different flow accumulation ranges.
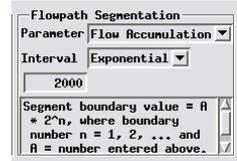
Range table created in this exercise.
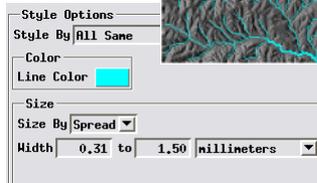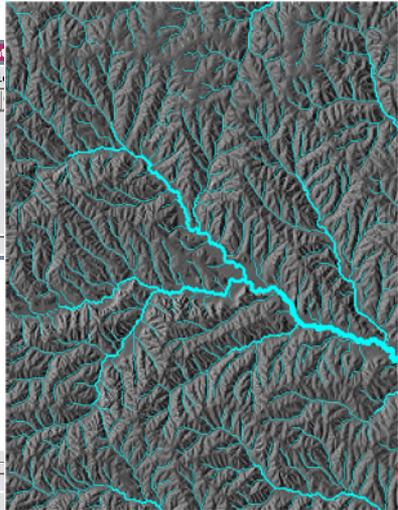
Segmented flow paths styled with differing line widths based on flow accumulation range.

Process Depressions Sequentially

When you run the Watershed process with the Fill Depressions option turned off, the process takes a sequential approach to filling depressions and finding watersheds. In the initial run the process finds depressions in the original DEM and creates watershed polygons. If you press the Run button again, the process attempts to fill all remaining depressions. In many cases, however, small depressions may be nested inside larger ones. As these small depressions are filled they merge into a residual larger depression. These complex relationships may not be resolved in a single processing pass, so it may take several runs to fill all depressions. Only when all depressions are filled does the process compute and display flow paths and basins.

If all depressions are not filled at the end of a run, a set of watershed polygons are displayed automatically in the View window. Some of these watersheds drain to the edges of the raster (or to a null boundary), while others drain into a remaining depression in the adjusted DEM. Yellow point symbols in the watershed vector object indicate the locations of *pour points* along the boundaries of watersheds containing a depression. A pour point is the point through which water would spill over into the downstream watershed if the depression were completely filled.

By running the Watershed process sequentially, you can investigate the characteristics of watersheds and depressions at each stage and identify depressions that are natural features of the landscape rather than DEM artifacts.

STEPS
- ☑ press the Open icon button, then [No] in the Question window
- ☑ select DEM_W4 from the WATERSHD Project File
- ☑ turn off the Fill Depressions toggle button on the General panel

General	Depression
⊿ Fill Depressions	
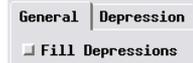
- ☑ press the Run icon button

The DEM used in this series of exercises has a cell size of 30 meters and shows a mountainous terrain that has been modified greatly by glacial erosion. Natural depressions and lakes are common in glacially-eroded valleys such as these.

pour points
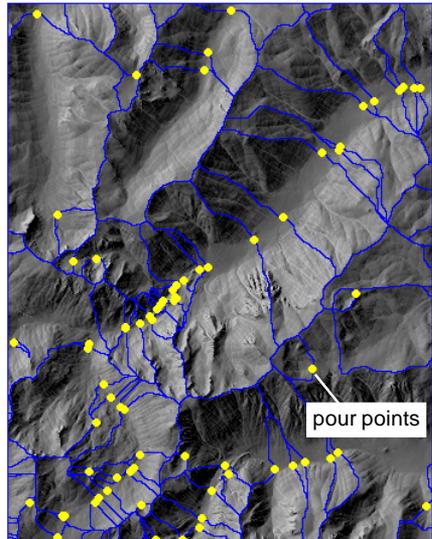
Watershed Relationships

STEPS
- ☑ press the Select Watershed icon button at the top of the View window
- ☑ left-click with the mouse inside the large watershed polygon at the center of the DEM
- ☑ press the Watershed Attributes icon button on the Watershed Analysis window

When depressions remain in the adjusted elevation raster, a single large watershed may be divided into a number of individual watershed polygons. A particular watershed polygon may have one or more upstream watersheds that would drain into it if their depressions were filled. The same watershed may also drain into a downstream watershed (or less commonly more than one) if its depression is filled. These relationships are displayed graphically when you use the Select Watershed tool to select a watershed polygon. The *active watershed* and its upper and lower neighbors are shown in different highlight colors.
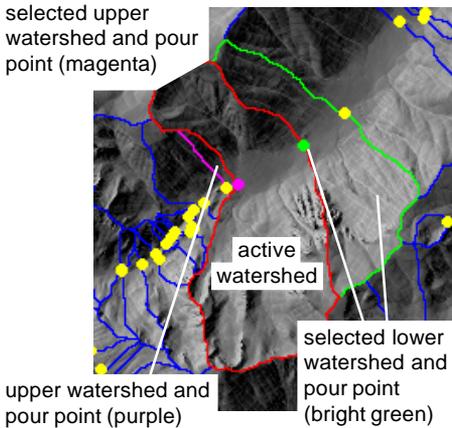
One neighboring upper watershed (if any) is automatically designated the *selected upper watershed* and shown in a different highlight color than the remaining *upper watersheds*; the same system is used for multiple lower watersheds.

You can use the icon buttons on the Watershed Attributes window (illustrated below) to use these hydrologic relationships to change the active watershed selection.

selected upper watershed and pour point (magenta)

active watershed

selected lower watershed and pour point (bright green)

upper watershed and pour point (purple)

Previous Lower Pour

Move Through Lower Pour

Next Lower Pour

Previous Upper Pour

Move Through Upper Pour

Next Upper Pour

Depression and Pour Point Attributes

The Depression Attributes window lists the ID numbers of all of the watersheds containing depressions, along with each depression's area and volume. If a watershed containing a depression is selected in the View, its record is highlighted in the list in red. For example, the watershed selected in the previous exercise is number 19, and its included depression covers 10,800 square meters (a fraction of the watershed area). The input DEM has a cell size of 30 meters, so the area of a single cell is 900 square meters. Dividing the depression area by the cell area shows that this depression covers 12 raster cells.

Depression Attributes

Watershed	Area	Volume
16	900	2700
17	134100	475200
18	5400	5400
19	10800	15300
20	900	900
21	900	900
22	900	2700
23	900	900
25	31500	64800
26	1800	2700

Depression
Total 76
Active 19

Identification numbers of the upper and lower pour points for the active watershed are highlighted in the Pour Attributes window in the appropriate colors. The columns Left and Right list the numbers of the watersheds that lie on the respective sides of the vector line separating them (relative to the arbitrary direction of that line in the vector topology). The arrows indicate the direction of potential flow through the pour point. In this example, pour point 10 is the selected lower pour point for watershed 19, which drains to watershed 18. The upper pour for watershed 19 is number 13, which drains into watershed 19 from watershed 23.

Pour Attributes

Pour	Left	Flow	Right	Z
6	10	<=	14	2277.00
7	4	<=	15	3362.00
8	16	<=	17	2301.00
9	17	<=	18	2338.00
10	18	<=	19	2348.00
11	20	=>	11	3034.00
12	22	<=	21	2461.00
13	19	<=	23	2388.00
14	23	<=	22	2398.00
15	21	<=	26	3267.00
16	21	<=	27	3088.00
17	29	<=	30	2483.00
18	21	<=	29	2472.00

Pour
Total 73
Double 9
Active 0
Lower 10
Upper 13

Fill Depressions Selectively

☑ close the Pour Attributes, Depression Attributes, and Watershed Attributes windows by pressing their respective Close buttons

☑ in the Manual Filling section of the Depression panel in the Watershed Analysis window, turn on the Lower toggle button

☑ press the Run icon button, then [No] in the Question window

When you have selected a watershed polygon with the Select Watershed tool, you can run the watershed process again to fill only the depression in that watershed or those in watersheds hydrologically related to it as well. These options are controlled by the Manual Filling toggle buttons on the Depression panel.
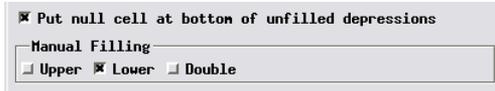
With the Upper manual filling option on, the process attempts to fill depressions in the selected watershed polygon and in all watersheds upstream from it. The Lower manual filling option fills depressions in the selected watershed polygon and in all watersheds downstream from it. If neither of these toggle buttons is turned on, then only the depression in the selected polygon is filled. (If no watershed polygons are selected, all watershed polygons are processed). In any of these cases, depression-filling stops if the process encounters a double depression (see next page).
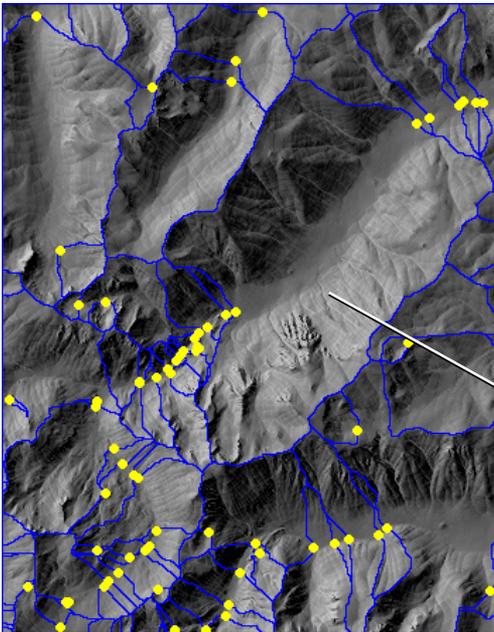
New watershed polygon created by filling depressions in the selected watershed polygon and in those downstream from it (until a double depression was encountered). Other watersheds were unaffected.

Double Depressions and Pour Points

If two adjacent depressions share a pour point, and neither has another pour point that is lower in elevation than the shared one, then the two depressions form a *double depression*. The pour point that they share is termed a *double pour point*. If either of these depressions is filled, it will spill over through the double pour into the other member of the double depression. Only when both members are filled will flow continue to downstream watersheds.

The watershed and depression selected in this exercise form part of a double depression. Pour point 53 is the double pour point linking the two members. Double pour points are indicated in the Pour Attributes window by a double-headed arrow in the Flow column.

Pour	Left	Flow	Right	Z
52	80	=>	76	2535.00
53	75	<=>	81	2515.00
54	84	<=	71	2862.00
55	79	<=	84	2861.00
56	73	<=	79	2827.00
57	81	<=	85	2529.00
58	87	<=	86	3194.00
59	89	=>	79	3123.00

You can choose to fill only double depressions by turning on the Double manual filling toggle button and then running the process. This options fills all double depression pairs within the DEM without regard to any set of watershed polygons you may have selected (unlike the other manual filling toggle buttons).
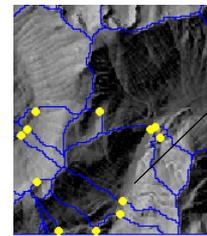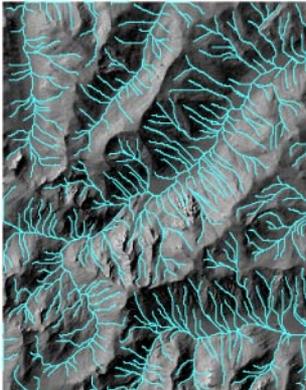
Final flow paths for the DEM

STEPS
☑ select the watershed polygon with ID 81 near the center bottom of the DEM, as shown in the illustration below
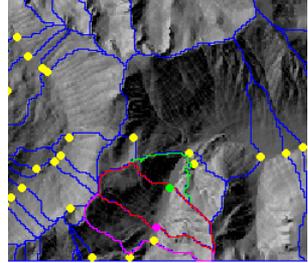
☑ press the Pour Attributes icon button
☑ in the Pour Attributes window, scroll down to show pour point 53
☑ on the Depressions tabbed panel of the Watershed Analysis window, turn off the Lower manual filling toggle and turn on the Double toggle button
☑ press the Run icon button, then [No] in the Question window

Filling merges the double depressions. For this example the merged watershed drains northeast through a pour point to the major valley.

☑ turn off the Double manual filling toggle
☑ press the Run icon button, then [No] in the Question window; this run should produce flow paths

Advanced Software for Geospatial Analysis

MicroImages, Inc. publishes a complete line of professional software for advanced geospatial data visualization, analysis, and publishing. Contact us or visit our web site for detailed product information.

TNTmips Pro   TNTmips Pro is a professional system for fully integrated GIS, image analysis, CAD, TIN, desktop cartography, and geospatial database management.

TNTmips Basic   TNTmips Basic is a low-cost version of TNTmips for small projects.

TNTmips Free   TNTmips Free is a free version of TNTmips for students and professionals with small projects. You can download TNTmips Free from MicroImages' web site.

TNTedit   TNTedit provides interactive tools to create, georeference, and edit vector, image, CAD, TIN, and relational database project materials in a wide variety of formats.

TNTview   TNTview has the same powerful display features as TNTmips and is perfect for those who do not need the technical processing and preparation features of TNTmips.

TNTatlas   TNTatlas lets you publish and distribute your spatial project materials on CD or DVD at low cost. TNTatlas CDs/DVDs can be used on any popular computing platform.

Index

MicroImages, Inc.

www.microimages.com