Lesson 2: Introduction to surface hydrology

Topic: Basic surface hydrology

Goals

In this lesson, you will learn:

- the fundamental elements of hydrologic modeling and analysis
- how to determine the direction of water flow from cells in a study area
- the importance of eliminating sinks from the drainage area
- the importance of including the entire drainage area in the study area
- how to determine flow accumulation in the cells of a grid
- how to find the distance, both upstream and downstream, from a given cell
- the methods used to delineate and order stream segments
- how to generate watersheds for streams and points

TOPIC 1: Basic surface hydrology

This lesson begins with a caveat: Hydrologic analysis is a complex subject. The concepts and tools presented to you here are, in themselves, not sufficient to undertake hydrologic analysis or modeling. Real-world situations frequently do not conform to the assumptions and conditions that underlie the examples presented in this lesson. However, the concepts discussed here will help you understand the basic principles of surface hydrologic analysis.

Surface hydrologic analysis (as opposed to underground hydrologic or groundwater analysis), seeks to describe the behavior of water as it moves over the surface of the Earth. Most simply, this type of analysis includes:

- obtaining a mathematically correct representation of the surface of the area to be analyzed, considering the elevation of the surface at a given point to be the value of a grid cell at that point

- determining the direction water would flow from each cell on the surface
- determining to which adjacent cell water would flow when each cell is doused with a given amount of water
- finding those cells which get considerable flow accumulation and delineating them as creeks, streams, and rivers, either persistently or when flooding occurs
- developing a network of these creeks, streams, and rivers; determining a hierarchy of them; and classifying them as to volume, relative to their upstream tributaries
- determining the areas (watersheds) that feed into given creeks, streams, and rivers and determining the outlets (pour points) of these watersheds
- determining into which watershed and water entities a given quantity of liquid (such as a polluting spill) might flow.

This lesson covers the basic hydrologic tools available in ArcView Spatial Analyst and does not utilize the Hydrologic Modeling sample extension. For a more precise and extensive approach to hydrologic modeling, try the *Spatial Hydrology Using ArcView GIS* ESRI Virtual Campus course.

Concept

Avenue requests used in hydrologic analysis

In ArcView, most hydrologic analysis is accomplished in one of two ways:

1. Generating new grids. This operation is usually accomplished by entering Avenue requests in the Map Calculator. Of course, you could use these same requests in Avenue scripts to semi-automate the process--but, as you will see, the decisions that need to be made along the way as to "what's next" in the analysis make this a less obvious approach
2. Using the sophisticated ArcView Hydrologic Modeling extension. This extension is beyond the scope of this module, but this module makes a good introduction to it.

Described below are some of the Avenue requests commonly used in hydrologic analysis.

- The FlowDirection request determines the direction of flow from each cell of a surface grid. The grid generated by FlowDirection must be well-behaved. The sort of analysis we are describing specifically excludes land areas that contain lakes or ponds. The assumption is that all the water placed on the grid will ultimately exit the grid at one or more low points on its edge.
- Assuming that the study area involved does not contain lakes or ponds, one of the ways the grid can be ill-behaved is to contain a cell that is lower than its surrounding neighbors; such a cell is called a sink. Sinks distort the analysis; to find them, use the Sink request. (Editing grids with sinks is beyond the scope of this lesson. See the ESRI Virtual Campus course on hydrologic analysis.)
- Another requirement of the grid is that the cells of primary interest--for example, the mouth of a river near a town that might flood--must include all the "uphill" cells. That is, all the cells that constitute the drainage basin for the cells of interest must be considered. The FlowAccumulation request may be configured to compute the amount of water that flows into each cell from all of its uphill cells.
- Stream networks are characterized by small creeks flowing into larger ones, these flowing into small streams, and so on. It is useful to speak of the "order," or relative size, of such water entities. The smallest creeks are labeled order 1. Larger entities have larger integer numbers. The StreamOrder request handles the process of assigning order numbers to streams. Both of the two principle methods for numbering streams (Strahler and Shreve) are available.

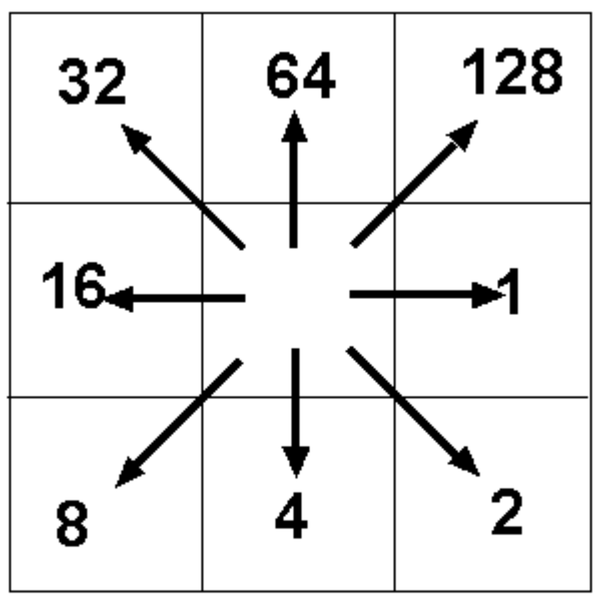
- The Mississippi River has a watershed consisting of all the land that supplies water to it. The smallest creek also has a watershed that consists of all the land that supplies water to it. The creek's watershed may be contained in the Mississippi's watershed, so the delineation of watersheds (or drainage basins, catchment areas, and contributing areas, as they are also called) is not trivial, either in concept or calculation. The WaterShed request assigns cells to such areas.

In addition to the Avenue requests discussed above, an important operation which precedes surface hydrology analysis is the generation of a surface grid that gives the elevation at every cell. There are several ways to do this. One way is to use the Interpolate Grid option on the Surface menu.

Concept

The FlowDirection request

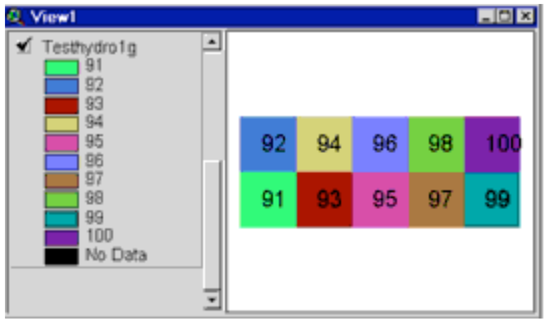
The primary data source for hydrologic operations in ArcView GIS is a grid of flow direction. This grid is formed by the FlowDirection request to a grid of surface elevation; we will call the resulting grid "DirectionOfFlow." Each cell in the DirectionOfFlow grid contains an integer number; these numbers are powers of 2: 1, 2, 4, 8, 16, 32, 64, and 128. (Just why these numbers were chosen, rather than 1, 2, 3, etc. has a historical and computer component, which will be discussed below.) Each number indicates a direction, as shown by the diagram below:



Each number indicates a direction.

The idea is, simply, that the precipitation that falls or otherwise appears on a given cell flows to an adjacent cell. To which of the eight adjacent cells? The one indicated by the number and the arrow in the diagram above, which points in the direction of the steepest descending slope.

For example, consider the simple grid shown below. The numbers in the cells indicate elevation.

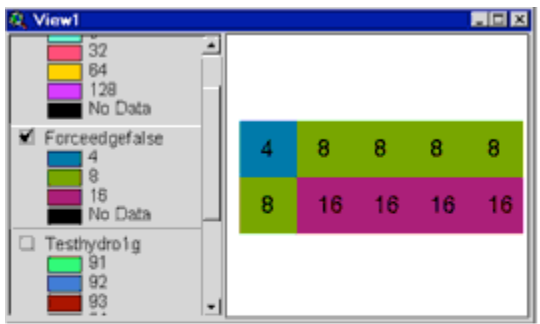


The numbers in the cells indicate elevation. [Click to enlarge]

The range in altitude is from 100 to 91, sloping gradually from east to west and a bit from north to south. When the FlowDirection request:

```
[Testhydro1g].FlowDirection(false)
```

is applied to this grid, the resulting grid looks like this:



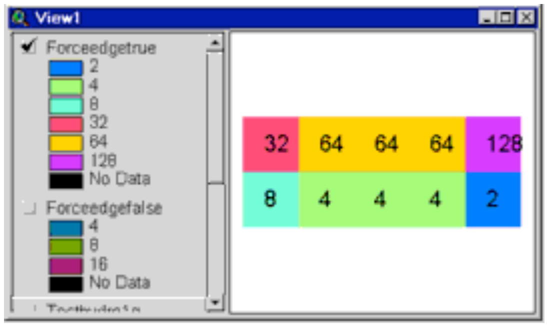
The results grid from Map Calculator expression[Testhydro1g].FlowDirection(false) [Click to enlarge]

Note, by referring to the first graphic above, that water flows from each cell to the nearest neighbor cell so that the water flows down the steepest slope, except from the cell with lowest elevation in the southwest, where it flows off the grid.

FlowDirection's only argument is the binary switch called ForceEdge. When ForceEdge is false, cells along the edge of the grid are treated as any other cells in the grid, except that if none of the five adjacent edge cells have lower elevation than the edge cell under consideration, the flow will be directly off the side of the grid. If ForceEdge is true, the flow from edge cells is off the edge of the grid, regardless of the presence of adjacent lower cells. Thus:

```
[Testhydro1g].FlowDirection(true)
```

generates the following grid:



The result grid from the Map Calculator expression [Testhydro1g].FlowDirection(true) [Click to enlarge]

The lowest point on the grid must be on an edge. This requirement is not as stringent as it sounds. If you think of any rectangular piece of real estate, it will have depressions in it, which will fill with water under the right circumstances. Exhibit a network of valleys that will hold linear bodies of water, at least one of which will flow off the edge of the grid or be a combination of depressions and networks of valleys. As already indicated, the ArcView hydrologic tools presented here do not work with lakes. They are strictly for stream networks. Lakes, which would constitute sinks, are not allowed.

It is worth remarking on the rather strange choice of numbers used to indicate flow direction. You've learned that water flows from any given cell to one of the eight adjacent cells. In the previous lesson on proximity, the directions were indicated simply by the integers one through eight. Why then, are we dealing with numbers such as 32 and 64?

In the early days of hydrologic analysis, which correspond to the early days of computers, central processing unit speeds were slow and storage space in memory was at a premium. It was efficient to use a single bit (a 1 or 0) in each position in a computer byte. Those positions correspond to columns in the base two number system. Those columns are designated 1, 2, 4, 8, and so on. The precedent set at that time endures in the hydrologic modeling field today.

Concept

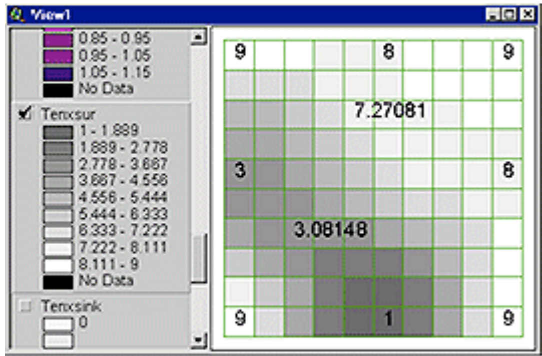
Flow accumulation: Drainage delineation and rainfall volume

Once you have a grid that indicates flow direction, a number of other interesting and useful calculations are possible. In particular, you can determine the locations of all the linear bodies of water and you can determine from slope and elevation those areas where water may accumulate during times of intense precipitation. This is accomplished with an Avenue request having the following syntax:

```
[DirectionOfFlow].FlowAccumulation([WeightGrid])
```

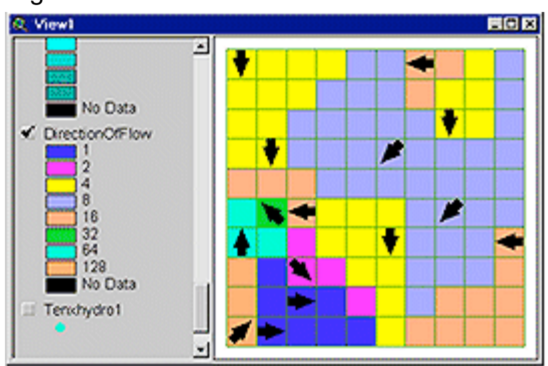
Basically, the value in each cell in the resulting grid contains the sum of the amount of water that has fallen on all the grid cells upstream from it. The intent is to simulate the flow, or potential flow, of water to form creeks, streams, and rivers. If the WeightGrid parameter is Nil, each cell is presumed to have one unit of water (say an inch) to contribute. Under this condition of "uniform rainfall," you can think of the number in a given cell as the number of cells upstream from that cell.

To illustrate, examine the following elevation surface. Note that the low points are in the middle of the south edge (elevation 1) and the west edge (elevation 3). All around the rest of the grid the elevations are 9 or somewhat less.



Low points are in the middle of the south edge (elevation 1.0) and the west edge (elevation 3.0). [Click to enlarge]

From this, you can produce a DirectionOfFlow grid using the FlowDirection request. Some arrows have been scattered on the grid to show flow direction.

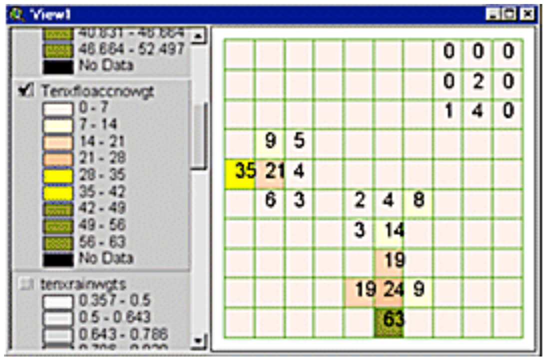


The grid resulting from the FlowDirection request. The CellTool extension was used to display arrows showing flow direction. [Click to enlarge]

Now, applying the FlowAccumulation request to the DirectionOfFlow grid produces a grid that shows, for each cell, the water that accumulates due to adding up the accumulations from the cells "above" it. The grid below depicts some of these accumulation values.

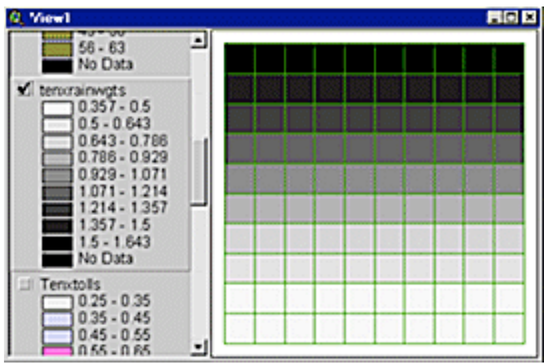
The largest accumulation is in the south, which had the lowest elevation. Another point of considerable accumulation is in the middle of the western side. If you look at the flow grid and the accumulation grid, you can get an idea of where and why the stream channels developed.

Note that some cells have the value 0, indicating that no cells are uphill of them. Note also that most of the cells accumulate very little water, whereas some accumulate a great deal of it--just as you might expect, since most of the land around us is uncovered by water but there are numerous creeks and streams. Finally, if you add up the values of the southern and western pour points (63 and 35) you get 98. Because there are 100 cells total, 98 of them are above the two pour points.



Because there are 100 cells in total, 98 of them are above the two pour points. [Click to enlarge]

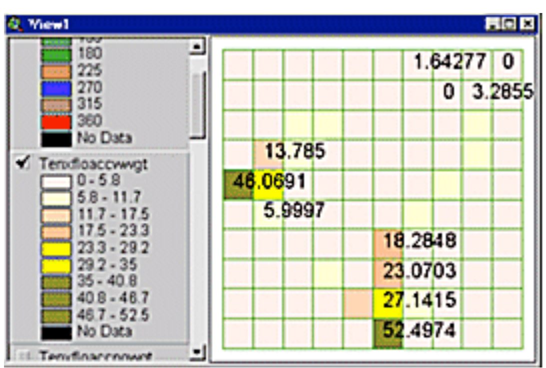
The above grid was developed with a WeightGrid value of Nil. Each cell, therefore, received the same amount of rain and was presumed to absorb the same amount of water. You can change that by specifying a number for each cell in the study area. Consider a WeightGrid that looks like this:



This weight grid represents a gradation in rainfall, which was heaviest in the north. [Click to enlarge]

If you consider that this was a rainfall event, and that the values in the grid cells constitute inches of rainfall, you can see that much more rain fell in the north than in the south across the study area. The total amount of rainfall is approximately the same as in the previous example, but there the rainfall was distributed uniformly.

Now you can apply the FlowAccumulation request with this weight grid. The results, shown below, indicate that considerably more water volume showed up at the western pour point than before, because the rain was lighter in the south. In fact, with the weight grid, about as much water flows west as south. With no weight grid, almost twice as much flowed south as west.



This grid is the result of applying the FlowAccumulation request using the previous weight grid. [Click to enlarge]

You can see from this example that hydrologic modeling can be a complex operation with many variables and parameters.

Concept

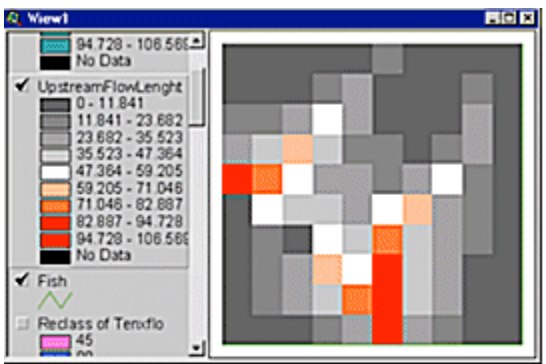
Calculating the length of a potential linear water body

The length of a potential creek or stream is a useful thing to know when modeling. You can apply the FlowLength request to the DirectionOfFlow grid to show either the length of the flowing water from each cell upstream or downstream. Upstream flow length for a given cell is the distance, totaled from cell to cell, from the given cell to the origin of the longest path of water (the top of its basin) coming into that cell. Downstream flow length from a given cell is the distance from that cell to the pour point for the water passing through the given cell. The general syntax for the FlowLength request is:

```
[DirectionOfFlow].FlowLength([weightGrid],upStream)
```

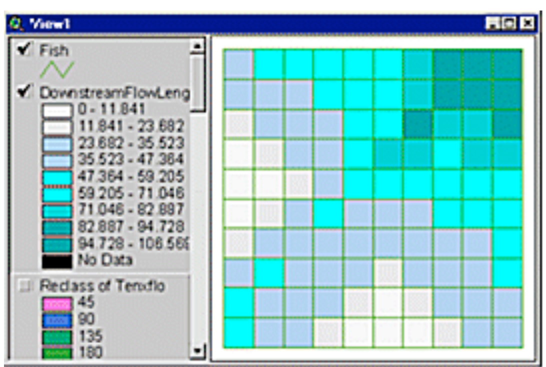
Below are the grids for both the upstream and downstream flow lengths of our 10 x 10 grid. The particular request used to produce the upstream flow length grid was:

```
[DirectionOfFlow].FlowLength(Nil,true)
```



The resulting grid of upstream flow length. [Click to enlarge]

To produce the downstream flow length, you substitute "false" for "true" in the upStream parameter of the request.



By substituting "false" for "true" in the upStream parameter of the request, you get a downstream flow length grid. [Click to enlarge]

The weightGrid argument in FlowLength operates in precisely the same way as does the weight grid (impedance, cost surface) in Lesson 1: It multiplies the length through each given cell by the value in the geographically equivalent cell in the weight grid. The weight grid provides the cost or impedance for water to flow through each cell. Thus, you could simulate the fact that water flowing through forested land takes longer to cover a given distance than water flowing over rock.

You can use the output of FlowLength to find the length of the longest flow path in a given basin. This is one of the values needed to calculate a more sophisticated hydrologic quantity, "time of concentration" for a basin. (To find the longest path, you would use ZonalStats with the Maximum option, with outputs of WaterShed and FlowLength. Discussion of this feature is beyond the scope of this lesson.)

You can use flow length grids to create distance-area diagrams of hypothetical rainfall/runoff events using the optional weight grid as an impedance to downslope movement

Concept

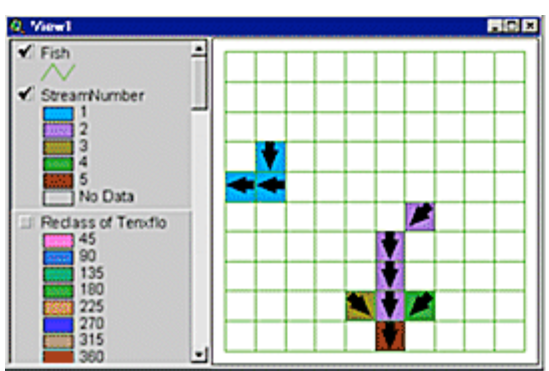
Assigning identities to streams

The most basic hydrologic unit (outside of the individual cell) is the stream segment. A segment consists of all the cells between the junctions of two or more streams or between junctions and the pour points. (The cell that is the junction is considered to belong to one of the streams.) ArcView places the same unique number in all the cells of a given stream segment.

In the discussion of the FlowDirection and FlowAccumulation requests, every cell was considered a contributor to the creeks, streams, and rivers that developed ("Into each cell some rain must fall"). But you do not want to define all the cells in the study area as part of the water network. Instead, you can delineate specific stream channels.

In other words, all of the study area contributes to the total amount of water to be dealt with, but only a small part of the study area carries most of that water. That area is known variously as the water network or the stream channels. This area is defined by including only those cells with flow accumulations greater than a chosen value; that value is called the cell threshold.

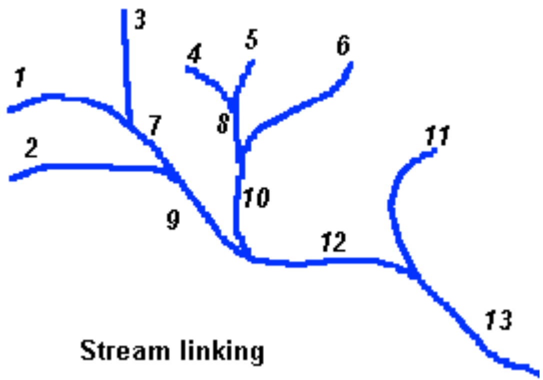
The graphic below shows cells with flow accumulations greater than 7.0. These cells are considered to make up streams. Each stream segment is uniquely numbered, as shown by the color coding.



Each stream is uniquely numbered and represented by color code. [Click to enlarge]

Other than an individual cell, a stream segment is the smallest entity you work with. Generally, streams segments (also called links) run between intersections in the linear network. In the above view, there are five stream links.

The diagram below illustrates how stream segments are numbered.



Stream Linking assigns a unique value to each raster section.

Each section of the raster linear network is assigned a unique value. This process is called StreamLink; the Avenue request syntax is:

```
aStreamGrid.StreamLink(dirGrid)
```

The diagram above shows the difficulties involved in representing the virtually infinite, three-dimensional environment in the memory of a computer, necessarily using only the most fundamental discrete symbols: 0s and 1s. In vector mode, a stream is represented by one-dimensional arcs; the arcs have no width, only length. Attributes of arcs may represent quantities like flow, width, or velocity.

In raster mode, a stream is represented by a sequence of adjacent cells. These cells are two-dimensional--they cover area. The area each cell covers, in basic hydrologic analysis, is the same, whether a mountain creek or a major river is being represented. Again, the geographic representation is only an approximation; even information about quantities such as width must be carried along separately.

This confluence of vector representation and raster representation in storing and displaying information about streams illustrates the challenges of using a computer to represent natural phenomena. In the next concept, an attempt is made to represent the relative "size" of streams and stream channels.

Concept

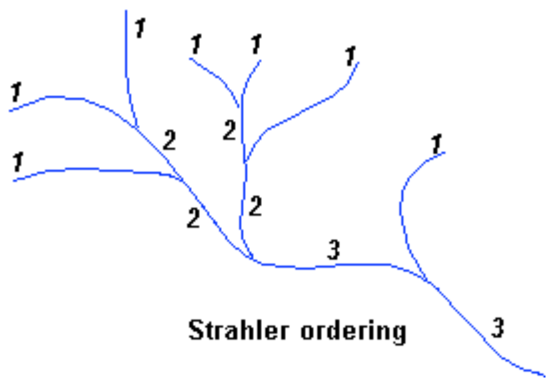
Assigning orders to stream links

You can attach an order number (integer value) to each stream segment or link. Generally, streams with lower numerical values are smaller in volume, but this is not always the case, as you will see.

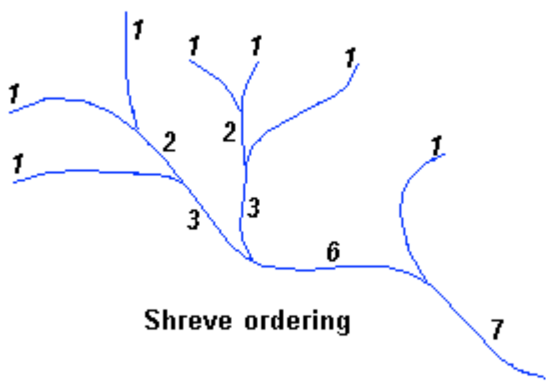
Two ways of determining stream order number have been devised (one by A.N. Strahler in 1957 and the other by R.L. Shreve in 1966--see below). In both methods, the smallest originating streams are numbered 1, up to the first intersection.

In the Strahler method, when (any number of) streams of the same order merge at a point, the downhill stream takes on an order number that is the original stream plus 1. For example, if a stream of order 3 merges with another stream of order 3, the resulting stream is order 4.

In any other case of stream merging, the order number of the downhill stream retains the order number of the larger uphill stream. So, if a stream of order 3 is joined by a stream of order 2, the resulting stream is still of order 3. The diagram below illustrates the Strahler method.



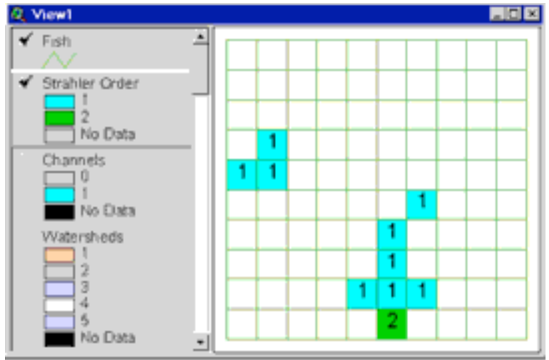
When two streams merge according to the Shreve method, the order numbers of the uphill streams are added together to produce the order value of the downhill stream. When merged, two streams of order 3 produce a stream of order 6. An order 3 stream joined by a an order 2 stream produces an order 5 stream. The diagram below illustrates Shreve ordering.



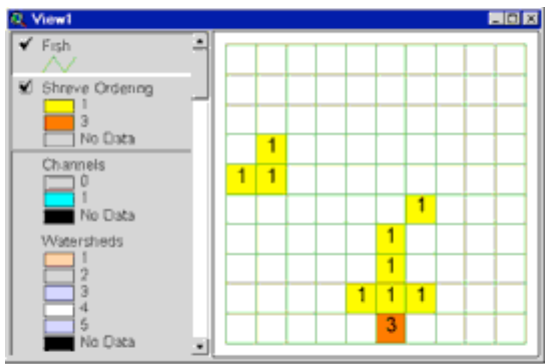
To generate stream orders in ArcView, you use the StreamOrder request:

```
[StreamChannelsGrid].StreamOrder ([DirectionOfFlow],ShreveMethod)
```

where ShreveMethod is a true-false switch: true for Shreve and false for Strahler. Below are the resulting grids from our minimalist example.



You generate Strahler stream order numbers by using a ShreveMethod parameter of False for the StreamOrder request. [Click to enlarge]



Use True for the ShreveMethod parameter to generate Shreve stream order numbers. [Click to enlarge]

For more information on stream ordering see:

- Shreve, R.L. 1966. Statistical law of stream number, *Journal of Geology*. **74**: pp. 17-37.
- Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology, *Transactions of the American GeoPhysical Union*. **8**, 6: pp. 913-920.

Concept

Watersheds and pour points

A watershed is an area that drains water and other substances carried by water to a common outlet as concentrated drainage. Other common terms for a watershed are basin, catchment, and contributing area. The contributing area is normally defined as the total area contributing water flow to a given outlet, also called a pour point.

A delineation of these areas is the output of the WaterShed request. The geographic line between two watersheds is referred to as a watershed boundary or drainage divide. Such a line, as you might imagine, runs along ridge tops and other lines of relatively higher elevation.

An outlet, or pour point, is the point at which water flows out of an area. It is the lowest point along the boundary of the watershed. The cells in the source grid are used as pour points above which the contributing area is determined. Source cells may be features such as dams or stream gauges for which you want to determine characteristics of the contributing area.

The WaterShed request finds the uphill (upgradient) area for streams or other points specified by an input grid. The general syntax is:

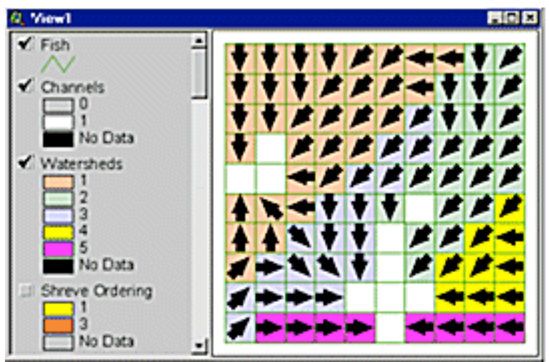
```
[DirectionOfFlow].WaterShed([aSourceGrid])
```

where aSourceGrid may consist of separate points (indicated by cells) or by lines of cells, such as a stream link grid from the StreamLink request.

In this example, we want the watersheds of five streams, so we use:

```
[DirectionOfFlow].WaterShed([StreamNumber])
```

plus some flow direction arrows (created by the Cell Direction tool) to produce:



The CellTool extension was used to show the flow direction for the individual cells in the five watersheds. [Click to enlarge]

In the view above, the five watersheds correspond to five stream links. The arrows indicate the direction of flow from each cell; the cell color indicates to which watershed the cell belongs.

Exercise

Perform surface hydrology analysis

In this exercise, you will use simple grids to learn the fundamentals of hydrologic analysis.

If you have not downloaded the exercise data for this module, you should download the data now.

Step 1 Start ArcView

Start ArcView, if it is not already running.

Note: If you are running ArcView GIS 3.1, you see a Welcome to ArcView GIS dialog. Click Cancel to close this dialog.

Load the Spatial Analyst and the CellTool extensions. Close any open projects. Open a new project.

Step 2 Add a theme to the project

Create a new view. Navigate to the **proxalsa\lesson02** directory and add the theme **fishnet72.shp**. Turn this theme on.

You see lines delineating 72 cells.

VIEW RESULT

Step 3 Add a point elevation theme

Add as a theme the point elevation feature source named **msl.shp**. Turn it on and make it active.

Use the Identify tool to examine the elevations at the points, indicated by the "msl" (mean sea level) attribute. (You must click directly on a point, not just in the implied cell.)

Note the low point in the west. Also note the horseshoe of elevation 9 and the northern border of 8.

VIEW RESULT

Step 4 Create a digital elevation model (DEM)

From the Surface menu, choose Interpolate Grid to generate a digital elevation model. Make the Output Grid Extent the same as Fishnet72 (you may have to scroll down to see it). For cell size, type **50** and press Enter.

The result should be a grid with 8 rows and 9 columns. Click OK.

In the Interpolate Surface dialog, use the IDW method; the Z value should be msl. Accept the default values (Nearest Neighbors, Number of Neighbors: 12, Power: 2, and No Barriers). Click OK.

Rename the grid (Surface from Msl.shp) to **DEM** and turn it on. Move Fishnet72.shp to the top of the TOC.

VIEW RESULT

Step 5 Produce a DirectionOfFlow grid

Open the Map Calculator from the Analysis menu and enter the FlowDirection request with ForceEdge set to False.

The expression should look like this:

```
[DEM].FlowDirection(False)
```

This outputs a grid containing the direction of flow, not forcing water off the edge of the grid. Rename the new grid to **DirectionOfFlow** and turn it on.

VIEW RESULT

REVIEW CONCEPT

Step 6 Make a grid containing compass direction of flows

At this point, it would be nice to see arrows in various cells that indicate the direction of flow. You have at your disposal a CellDirection tool that places an arrow in a cell, pointing in accordance with a compass direction (0 degrees is north, 45 degrees northeast, and so on).

To use the CellDirection tool, therefore, you need to create a new theme that classifies the coded directions (1, 2, 4, 8, and so on) into compass directions.

So that you may draw these flow direction arrows whenever you want, make DirectionOfFlow active and choose Reclassify from the Analysis menu to make a grid that contains compass directions of flow.

Click the Unique button. Modify the table in the Reclassify Values dialog so it looks like this (be sure to press Enter after every entry):

Old Value	New Value
1	90
2	135
4	180
8	225
16	270
32	315
64	360
128	45
No Data	No Data

Click OK. Change the name of the resulting theme to **CompassDoF** and turn it on.

VIEW RESULT

Step 7 Examine some flow directions

Move Fishnet72 to the top of the TOC. Make CompassDoF the only active theme. Both it and Fishnet72 should be turned on; all others should be turned off.

Click the CellDirection tool; don't save the graphics. Click to make arrows in several representative cells.

VIEW RESULT

Notice that some edge cells flow in towards one another while others flow out--the flow direction depends on the slopes between the neighboring cells.

Step 8 Set ForceEdge to true

Now you'll make another flow direction grid from the DEM theme.

Open the Map Calculator and build an expression using the ForceEdge parameter of FlowDirection set to True.

Do not bother to change the name of the new theme. Move Fishnet72.shp to the top of the TOC. Turn the new theme on, make it active, and examine the cells along the edge of the grid by looking at the TOC and the colors of the cells (or use the CellDirection tool).

Notice that all the edge cells flow out of the grid.

VIEW RESULT

When you are finished examining the theme, make (only) the new theme active, then choose Delete Themes from the Edit menu. Click Yes to delete the new theme.

Step 9 Check for sinks

Examine the flow direction (DirectionOfFlow) theme to be sure it has no sinks.

In the Map Calculator, enter the following expression:

```
[DirectionOfFlow].Sink
```

Click Evaluate. If the resulting theme consists entirely of No Data cells, there are no sinks.

Turn on the new theme. Notice that all the cells are black--No Data. Delete the new theme when you are done examining it.

VIEW RESULT

Step 10 Determine the flow accumulation in each cell

In the Map Calculator, enter the Avenue request:

```
[DirectionOfFlow].FlowAccumulation(Nil)
```

Rename the new theme to **AccumFlow**. Make it active and turn it on. Use the DrawCell Value tool V to place accumulation values in some of the cells that have higher flow.

VIEW RESULT

REVIEW CONCEPT

Step 11 Create stream channels

For this exercise, suppose that cells with a flow accumulation of 5 or greater constitute the channels or potential channels during flooding for the flowing water. You will now identify those channels.

From the Analysis menu, choose Map Query.

You will use Map Query to set to 1 (true) those cells in which the value of AccumFlow is greater than or equal to 5. The other cells will be set to 0 (false). The Map Query expression should look like this:

```
[AccumFlow] >= 5
```

Make the new theme active, rename it to **Channels**, and turn it on.

VIEW RESULT

Step 12 Identify individual stream segments

Next, you'll instruct ArcView to display each individual stream segment.

Enter the following expression in the Map Calculator:

```
[Channels].StreamLink([DirectionOfFlow])
```

Turn on the new theme and make it active. Move Fishnet72.shp to the top of the TOC.

What you see is a numbering from 1 to 5 (the numbers arbitrarily assigned) of each individual stream segment. Stream segments 1 and 3 flow together to make stream 2. Segments 5 and 2 make stream 4.

Rename the new theme to **StreamIDs**. Turn off all themes except StreamIDs.

Recall that you made a theme called CompassDoF that contained compass directions of flow based on 360 degrees. It allowed you to place arrows showing the direction of flow.

Find that theme in the Table of Contents and make it active (but don't turn it on). Use the CellDirection tool to place arrows in the StreamIDs cells.

VIEW RESULT

You should now be able to get a good idea of the flow.

Step 13 Determine a stream ordering based on the Shreve method

Building a stream order theme depends on two other themes: the flow directions and the cells (channels) through which the streams run.

Use the Map Calculator to make a new theme, which you will call **ShreveStrmOrd**, by using this expression:

```
[Channels].StreamOrder([DirectionOfFlow],True)
```

Rename the new theme, make it active, and turn it on.

To best see what is going on with respect to stream order, do the following:

Turn off all themes except ShreveStrmOrd and Fishnet72.shp. Move Fishnet72.shp to the top of the TOC. Make StreamIDs active. Use the CellValue tool 

to place the stream number in each cell.

VIEW RESULT

What you see is color indicating the stream order, while the value tells you the stream segment number.

REVIEW CONCEPT

Step 14 Create watersheds

To form the watersheds of the five streams, enter the following expression in the Map Calculator:

```
[DirectionOfFlow].WaterShed([StreamIDs])
```

Name the new theme **Basins**. Turn off all themes except Fishnet72, Channels, and Basins. Arrange those themes in the Table of Contents in that order, from the top.

Make CompassDoF the active theme. Draw flow direction arrows in all the Basin cells.

VIEW RESULT

From this image, you can pick out lines separating the watersheds, both by the colors of the cells in the basins and by the directions of the flow arrows. You have an image of the drainage of the study area.

REVIEW CONCEPT

Step 15 Save your project

From the File menu, choose Close All. Then choose Save Project As from the File menu. Save the project to the **proxalsa\lesson02** directory as **L2_ex1_yi.apr** (where "yi" represents your initials).

If you are continuing on to the next exercise, leave ArcView open. Otherwise, exit ArcView

Exercise

Watershed analysis

In this exercise, you will create an elevation surface from a large number of points, generate a flow direction grid, and then check it for sinks. You will also create a drainage network, assign stream order to linear water bodies, and identify watershed basins.

If you have not downloaded the exercise data for this module, you should download the data now.

Step 1 Start ArcView

Start ArcView, if it is not already running.

Note: If you are running ArcView GIS 3.1, you see a Welcome to ArcView GIS dialog. Click Cancel to close this dialog.

Make sure the Spatial Analyst extension is loaded. Close any open projects.

Step 2 Open the project

Navigate to the **proxalsa\lesson02** directory and open **l2_ex02.apr**.

Note: If you are running ArcView GIS 3.1, you see an Update l2_ex02.apr message box. Click No to dismiss this message.

When the project opens, you see a view called Watershed Analysis, with three themes in its Table of Contents: Elevation, ElevFill, and Pollution Points.

VIEW RESULT

From the File menu, set the project's working directory to **proxalsa\lesson02**.

Step 3 Use the elevation point theme to make a terrain surface grid

Make the Elevation theme active. From the Surface menu, choose Interpolate Grid. In the Output Grid Specification dialog, set the Output Grid Extent to Same as Elevation. Accept the default cell size and number of rows and columns.

In the Interpolate Surface dialog, choose Spline as the Interpolation method and Spot as the Z value field. Accept the other defaults.

A new theme, Surface from Elevation, is generated. Turn it on.

VIEW RESULT

Step 4 Generate a flow direction grid

Using the FlowDirection Avenue request on the Surface from Elevation grid, determine the direction of flow from each cell. Set the parameter for the request so as not to force water off the edge of the grid. (If you need assistance creating the expression, check FlowDirection in the online help or see Step 5 in the previous exercise.)

Change the name of the resulting theme to **Flow Direction** and turn it on.

VIEW RESULT

By looking at the Table of Contents and by clicking on a few cells with the Identify tool, verify that the cells contain the codes for each direction: east (1), southeast (2), south (4), and so on. You may be able to note visually that much of the water in the study area tends to drain towards the west (16), with other directions being towards the southwest, and northwest (values of 8 and 32 respectively).

Look at the Surface from Elevation theme to verify that this makes sense.

You can also look at the preponderance of the direction of flow by looking at the numbers of cells with each flow direction.

Make Flow Direction active and open its theme table.

Note the number of cells assigned to each direction. Of the approximately 50,000 cells, about 33,000 flow towards the southwest, west, and northwest.

REVIEW CONCEPT

Step 5 Identify sinks

As mentioned previously, water needs to ultimately flow to the edge of the grid. If it flows to internal cells from which it cannot exit because the surrounding cells are all of greater elevation, the model does not work. You can check for this situation by applying the Sink request to the Flow Direction theme.

Turn off all themes. Use the Map Calculator to create the appropriate expression to make a theme of sinks.(See the online help files or Step 9 in the previous exercise if you need assistance building the expression.)

Make the new theme, which will be called Map Calculation 1, the only displayed theme.

VIEW RESULT

If this theme consisted only of No Data values, you would be assured that there were no sinks in the study area. But, unfortunately, this is not the case. There are sinks in the study area, or perhaps the surface generated by the Interpolate Grid request has sinks in it where none exist in reality. Or maybe the elevation data was wrong. In any event, to proceed, you need to "fill" the sinks (repair the surface) before proceeding.

To fill sinks you would normally use the ZonalFill and Merge requests or the more extensive hydrologic tools in the hydro.avx sample extension. This is a time-consuming process and requires knowledge you may not have at this point. Filling sinks is an iterative process, meaning that filling one set of sinks may generate others. There are ways of filling sinks effectively but they are beyond the scope of this lesson. So you will use a "repaired" theme, called ElevFill, which has all the sinks filled for you.

First, you'll eliminate themes that you don't need.

Make the Map Calculation 1, Flow Direction, and Surface from Elevation themes the only active themes. (Click on one of these themes, then hold down the Shift key while you click on the other two.) Choose Delete Themes from the Edit menu. Click Yes to All to delete these three themes.

Step 6 Recreate the flow direction theme and check for sinks

Recreate the flow direction theme by applying the FlowDirection request to ElevFill. Call the new theme **Flow Direction** (to complete the next step, the grid must be named Flow Direction).

Check for sinks by using the Sink request on the Flow Direction theme. Name the resulting theme **SinksNow** and turn it on. It should consist entirely on No Data values.

VIEW RESULT

Delete the Sinks Now theme.

Step 7 Trace some raindrops

The ReturnCostPath request can be used to trace a path of a particle as it follows the flow downstream. The elevation grid serves as the cost surface (flow impedance) and the flow direction grid serves as the backlink grid. You could use this technique to trace the probable downhill path of a contaminant spill.

The ReturnCostPath request returns a polyline. This line is the path of the particle from the point you designate to the end of the flow downstream. This capability has been programmed for you and can be accessed with a button.

Looking at the water paths can be quite instructive when you examine them against the background of other themes.

First, turn off all themes except ElevFill and make it the active theme. Use the Path Tracing tool (the button with the "P" icon) and click anywhere in the view on the ElevFill theme. (Important: this tool works only if you have properly named the flow direction theme "Flow Direction.")

When you click with the Path Tracing tool, a script begins executing that invokes the ReturnCostPath request and then draws that line as a graphic on the Watershed Analysis view display.

Click on the view several times.

As you would expect, the path begins in higher elevations and ends in lower ones at an edge of the study area. If you click multiple times in the very highest elevations, you may see that water drains away in several different directions.

VIEW RESULT

Now turn off ElevFill and turn on Flow Direction (you must leave ElevFill active, however). Verify that the raindrop paths follow the flow directions. To see it best, zoom in until you see the individual cells. Click on several areas and on boundaries between areas.

VIEW RESULT

When you are through looking, zoom back to the view's full extent.

Delete the graphics: Choose Select All Graphics from the Edit menu, then press

Delete on your keyboard.

If you want, you may look at the Avenue code associated with the Path Tracing tool; it is contained in Script2 in this project. (Click on the Scripts icon in the project window; double-click on Script2 to open it.)

REVIEW CONCEPT VIEW RESULT

Step 8 Calculate flow accumulation

Recall that the FlowAccumulation request computes the amount of water that flows into each cell from all the upstream cells. In the absence of a weight grid, the request assumes that one unit of water will come from each cell and will flow into one adjacent cell.

The one unit of water for a given cell does not show up in the accumulation of water for that cell. Therefore, some cells which have no water draining into them will have an accumulation value of zero. As you saw from Exercise 1 of this lesson, some cells at the bottom of the drainage can have very large values.

The output grid of accumulation can be used as a measure of runoff for hypothetical rainfall events. The optional weight grid could be a surface of rainfall values interpolated from weather station measurements and modified with a model to adjust for loss from evapotranspiration and soil absorption. With a weight grid, the FlowAccumulation request would return an estimate of actual runoff.

Use the FlowAccumulation request on the Flow Direction theme; for weight grid put Nil (see the online help or Step 10 in the previous exercise if you need assistance building the expression).

Name the new theme **Flow Accumulation** and turn it on. Use the Path Tracing tool (ElevFill must be active) to again look at the watercourse placed arbitrarily on the grid.

Notice how the paths move towards and become coincident with the cells with high accumulation.

VIEW RESULT

Delete the graphics.

REVIEW CONCEPT

Step 9 Determine the stream channels

You can use the Flow Accumulation grid to identify a drainage network. You will identify those cells that have the highest accumulated flow values. The cells that contain the most water are the stream channels. You can create a drainage network of any detail by choosing those cells that have more than a certain minimum threshold value. You will do this with Map Query, since you want only binary values (a cell either is or is not in the drainage network).

In this case, say that a stream exists at a given cell if the flow accumulation is greater than 140, the equivalent of 1 unit of rain over each of 140 other cells that drain to that cell.

In the Map Query dialog, build this expression:

```
[Flow Accumulation] > 140
```

Click Evaluate. Change the name of the new theme to **Stream Channels** and turn it on. Turn off all other themes.

The cells that constitute the stream channels have values of 1; the rest of the cells have values of 0.

VIEW RESULT

Step 10 Calculate steam order

The volume of water flowing through a stream is a function of many things, including the stream's width (number of cells) and its depth. For that and other reasons the number of "width cells" that depict a stream is not a good indicator of its size or volume.

As previously discussed, one way to get an idea of stream size is to assign a stream order number, which indicates the relative volume of water in a stream segment. In this step, you will use the Strahler ordering; you used the Shreve method before.

Use the StreamOrder request on the Stream Channels theme and the Flow Direction theme:

```
[Stream Channels].StreamOrder([Flow Direction], False)
```

Make this theme active, change its name to **Strahler**, and turn it on.

VIEW RESULT

The Strahler method is more conservative than the Shreve--that is, the numbers tend to be smaller. In Shreve, every time one stream joins another, the order number goes up. Not so with Strahler. Notice that there are only four categories of the Strahler theme, even though you had a large number of stream segments.

REVIEW CONCEPT

Step 11 Create a streamlink grid

Now, to individually designate each stream segment, use the StreamLink request. This request operates on the Stream Channels theme and it uses Flow Direction as its single argument. (See Step 12 in the previous exercise for help on building the expression.)

Call the new theme **StreamIDs**, turn it on, and turn all other themes off.

VIEW RESULT

An amazing number of individual stream segments have been produced: 223.

Zoom in on a portion of StreamIDs and use the Identify tool to examine the assigned number (found in the value field).

Click the Zoom to Full Extent button to return the view to full extent.

You need the unique numbers of the streams to define the watersheds, which you will do next. Watersheds are defined from each stream segment, junction, and outlet, indicated by the unique cell values.

Step 12 Delineate the watersheds

Each of the 223 streams has associated with it a watershed. The WaterShed request finds all the upstream cells that flow down to given sets of cells. The given sets of cells are those that depict the stream segments. The WaterShed output theme allocates each cell in the study area to one of the streams.

Generate this theme with the expression below.

```
[Flow Direction].WaterShed([StreamIDs])
```

Rename the new theme to **Unique Basins** and turn it on.

Open the Legend Editor and choose Unique Value as the Legend Type for the Unique Basins theme; for Values Field choose Value. Click Apply and close the Legend Editor.

This produces a rather large number of items in the Table of Contents, so hide the Unique Basins legend by choosing Hide/Show Legend from the Theme menu.

VIEW RESULT

If you now use the Path Tracing tool (with ElevFill active) on a magnified or zoomed-in version of the watersheds, you will notice that the traces of small amounts of water generally respect watershed boundaries, which, as you might imagine, tend to be ridge lines or other relatively higher elevations. Water may cross from one watershed into another only at junction points where a stream designation changes.

REVIEW CONCEPT

Step 13 Determine watersheds of pollution sources

The WaterShed request finds the upgradient cells of a specific set of cells; those cells may or may not be cells in stream segments. It is possible to find the watersheds of points where pollution has been found by monitoring devices. The Pollution Points theme (which means points at which pollution has been found) indicates pollution in streams at two points.

Zoom the view to full extent. Move Pollution Points to the top of the TOC and turn it on.

Only two cells are involved, so red circles have been drawn around the two cells.

Create the following expression in the Map Calculator:

```
[Flow Direction].WaterShed([Pollution Points])
```

Name the new theme **Pollution Candidates**. Arrange the themes in the TOC as shown below.

Pollution Points
Pollution Candidates
Strahler
ElevFill

Turn on these four themes and turn off all other themes.

VIEW RESULT

Step 14 Save the project

When you are finished examining the results, save the project to the **proxalsa\lesson02** directory with the name **L2_ex2_yi** (where "yi" represents your initials).

Close the project and exit ArcView

Summary

Hydrologic analysis of surface water flow is concerned with how water moves over the ground and into creeks, streams, and rivers. The primary force on such water is gravity; therefore, differences in surface elevation determine how water flows.

ArcView Spatial Analyst hydrologic analysis tools assume that you have a grid which is a digital elevation model (DEM). From this DEM, a grid of flow direction is formed; the water that falls onto or otherwise accumulates in each cell is then assumed to flow into one of its eight adjacent neighbors. The flow direction grid must conform to certain requirements, such as not having any sinks (areas lower than surrounding neighbors) in it, in order for the steps that follow to be valid. It is from the flow direction grid that a number of other grids key to hydrologic analysis are calculated.

By selecting the cells that have high flow accumulation, you can depict those linear water bodies that carry enough water, or might carry enough water under conditions of flooding, to constitute real or potential streams or rivers. These streams and rivers can then be assigned an order according to two different methods of developing a hierarchical water network. The Strahler and Shreve methods can be used to assign stream order numbers.

You can determine the upstream flow length and the downstream flow length from any cell on the network. Each stream segment can also be numbered uniquely. For each stream segment, a watershed can be defined. If pollution is found at any point on any stream, you can identify the set of watersheds which might contribute to that pollution

This is the **Using ArcView Spatial Analyst Proximity and Hydrologic Tools - Lesson 2 Self test**.

Please watch your time—you have 2 hours to complete this test.

Use the knowledge you have gained in *Using ArcView Spatial Analyst Proximity and Hydrologic Tools* to answer the following questions. You will need to correctly answer 7 of the following questions to pass.

Netscape Users: Do not resize this browser window. This can cause the page to reload and generate new questions.

GOOD LUCK!

---

1. The Sink request is used to repair sinks.

- True
- False

2. If the Sink request generates only No Data values, you do not need to take steps to repair sinks in your elevation grid.

- True
- False

3. To get a digital elevation model (DEM) from a point elevation grid, you would use the InterpolateSurface request in the Map Calculator.

- True
- False

4. To delineate streams from the rest of the study area, we use Map Query because we want only two values in the result.

- True
- False

5. Strahler stream order numbers tend to be smaller than Shreve stream order numbers.

- True
- False

6. If ForceEdge is true, no water can flow into the grid from the boundary cells.

- True
- False

7. A flow to the north is indicated by:

- N
- 7
- 8
- 64

8. The Flow Accumulation request generates a grid "A." The minimum value a cell in "A" can have is 1.

- True
- False

9. In the last figure of the Lesson 2 exercise, Surface hydrology analysis, the arrows in a given colored field do not all point in the same direction. Why not?

- The colors represent watersheds while the arrows represent flow.
- Watersheds was on while DirectionOfFlow was active.
- Water may flow in different directions within a watershed.
- All of the above.

10. Which of the following does not directly depend on the output of the FlowDirection request?

- FlowLength
- FlowAccumulation
- StreamOrder
- None of the above

Calculate My Grade