

# Assessing Clearcutting Activities

## *Measuring watershed effects*

—by Glen Jordan

## Introduction

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### Problem

How does clearcutting affect a region's watersheds?

Watersheds delineate the path of water runoff for an enclosed network of streams and rivers. The quantity and quality of water in these watershed networks is ecologically important, because a host of animals, and in many cases people, depend on it.

Forestry activities, such as clearcut harvesting and road building, not unlike natural disturbances of wildfire, windstorms, and disease, can have significant impacts on a watershed. That's not to say the effects are always negative. That depends on the size, intensity, and spatial distribution of these events.

If tree removals occur widely across a watershed in a short span of time, you can expect an increase in stream flows, perhaps leading to flooding and increased sedimentation and general degradation of water quality. Trees, after all, are significant consumers of water in a watershed and have a large influence on the amount of runoff that reaches streams.

In municipalities or communities that rely on a watershed for water supply, the balance between nonforested and forested area is critical. For example, a large amount of clearcut area leads to rapid runoff and loss of water, while a lesser amount decreases water flow and its availability downstream. This balancing act becomes particularly critical in areas where spring snowmelt provides a large volume of water.

Road building is also an issue affecting watersheds. Careless building of roads across or near streams, or a high density of roads within a watershed, increases sediment loads and degrades water quality.

*Keywords: watershed; characterizing with a single number; numerical distribution; map; selecting features by attribute; merging features; creating a raster from polygons; creating polygons from a raster; performing map algebra; overlaying maps (poly-on-line, line-on-line); summarizing an attribute; delineating watersheds*

## Location

A small, 1,400-hectare (ha) woodlot in the Acadian-New England forest region of North America

## Time to complete the lab

Three hours

## Prerequisites

A basic working knowledge of geographic information system (GIS) data, including use of a geodatabase; some experience with rasters and the ArcGIS® Spatial Analyst extension also beneficial (Familiarity with basic forest analysis techniques is important, while familiarity with forest inventory data and terminology is also helpful but not essential.)

## Data used in this lab

- Feature classes and rasters for a forest woodlot (personal geodatabase)
- Geographic coordinate system: NAD 1983 CSRS New Brunswick Stereographic
- Datum: NAD83
- Projection: New Brunswick Double Stereographic Grid (unless otherwise stated)

# Student activity

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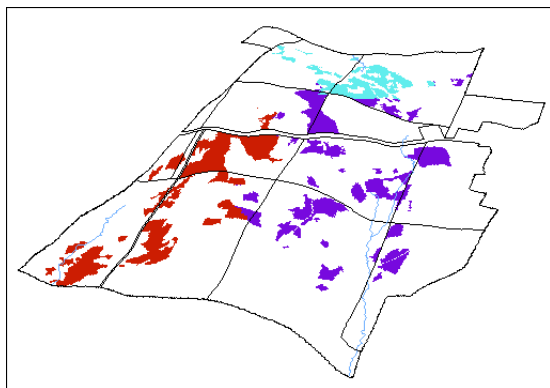
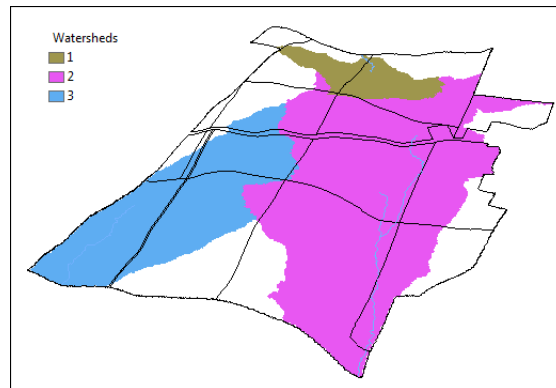
The Woodlot property is surrounded by some highly populated areas, which depend on groundwater for their water supply. Although the Woodlot covers a small geographic area of about 1,400 ha, the condition of its watersheds and frequency of road-stream crossings would be of concern to surrounding communities.

How many watersheds exist in the Woodlot? How much area in each watershed is a recent clearcut? Is there a potential problem with any of the watersheds?

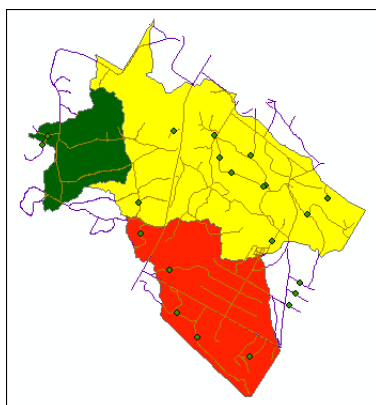
How about roads in the Woodlot? How many kilometers of main and secondary roads exist in Woodlot watersheds? How many stream crossings exist?

## Results expected

- A 3D display of the Woodlot's watersheds
- A tally and map of clearcuts within the watersheds
- A tally and map of roads within the watersheds
- A map of road-stream crossings



OBJECTID *	Watershed	Area (divide by 100 for ha)
1	1	5511
2	2	9426
3	3	8742



OBJECTID *	Watershed	Road Length (m)
1	1	4469.346229
2	2	28623.717135
3	3	14524.276687

## Data available

- Cover types feature class: *cover*
- Digital elevation model (DEM) raster: *DEM\_Woodlot*
- Secondary roads feature class: *roads*
- Streams feature class: *streams*
- Management compartments feature class: *compart*

## Solution steps

1. Examine Woodlot terrain.
2. Delineate Woodlot watersheds.
3. Evaluate watershed clearcutting.
4. Evaluate road building.

### EXAMINE WOODLOT TERRAIN

You'll have to identify the Woodlot's watersheds before you can arrive at an assessment of clearcutting impact. The Woodlot's terrain conditions will define its watersheds, since terrain determines where water runoff flows and in which direction. What's the nature of the Woodlot's terrain?

The Woodlot inventory contains a DEM. Displaying it in ArcScene™ provides a 3D look at the Woodlot's terrain.

### RELATED CONCEPT: CHARACTERIZE USING A GEOGRAPHIC DISTRIBUTION (3D DISPLAY)

1. Open ArcScene and add the *DEM\_Woodlot* raster as a layer. Assign the scene a vertical exaggeration of 10 (right-click *Scene Layers* » *Scene Properties* » *General*). Set base heights using *DEM\_Woodlot* (right-click *DEM\_Woodlot* » *Properties* » *Base Heights*). Last, symbolize *DEM\_Woodlot* with the *Elevation #1* stretched color scheme.
2. Swivel the DEM until the northeast corner is more or less facing you to get the best perspective on Woodlot terrain.

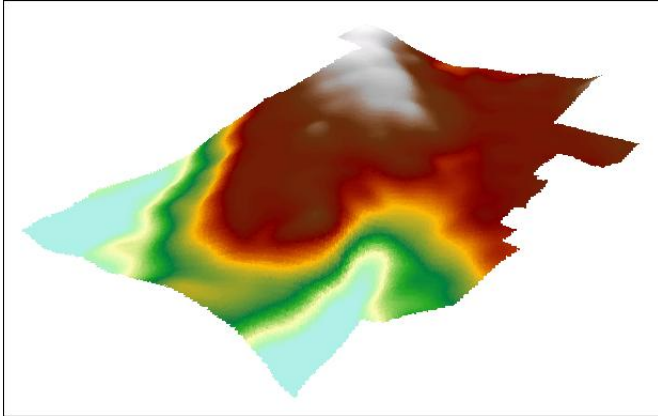


Figure 1. 3D perspective view of Woodlot terrain.

You can see considerable variation in Woodlot terrain, with many possible channels for water flow. Where will flow concentrate to form streams? Where are the high points of land that determine direction of water flow and watershed divides?

There seems to be one obvious ridge that runs more or less diagonally across the Woodlot. Any deep valleys will likely contain streams. Draping the known location of permanent streams over the 3D terrain surface will confirm this.

- 3 Drape the *streams* feature class, using *DEM\_Woodlot* for base heights. Symbolize streams with a bright blue color.

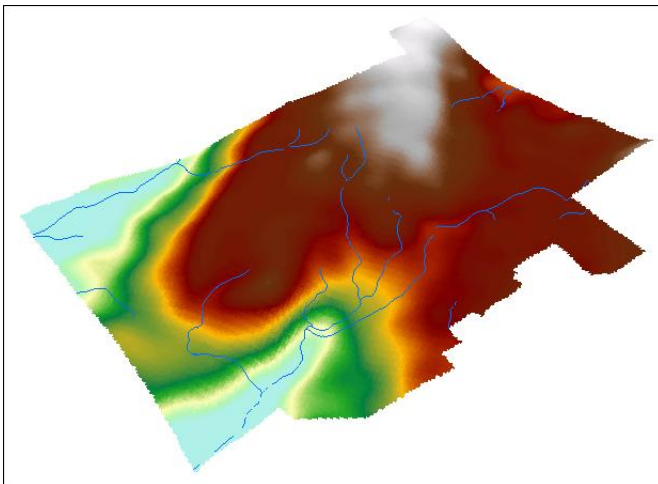


Figure 2. Permanent streams draped over Woodlot terrain.

There appear to be at least three watersheds that channel water runoff from the central areas of the Woodlot to the corners and edges of the property.

Where are the watershed boundaries, exactly? How many watersheds are there? Determining these things is the next step.

## DELINEATE WOODLOT WATERSHEDS


Watershed delineation tools provided by Esri make pretty easy work of what would otherwise be a complex chore.

### RELATED CONCEPT: RECLASSIFY SPATIALLY, USING 3D DATA

- 1 Locate the *Watershed Delineation Tools* toolbox in the *WatershedDelineation* folder. Open ArcToolbox™, right-click in it, and then add the *Watershed Delineation Tools* toolbox.



Figure 3. The Watershed Delineation Tools toolbox.

You'll identify the Woodlot's watersheds using the *Watershed Delineation* tool. This tool is actually a ModelBuilder™ model as indicated by the  icon.

If you want to keep a custom toolbox, such as *Watershed Delineation Tools*, active on an ongoing basis, right-click in ArcToolbox and select *Save Settings » To Default*.

- 2 Examine the *Watershed Delineation* model by right-clicking it and selecting *Edit*.

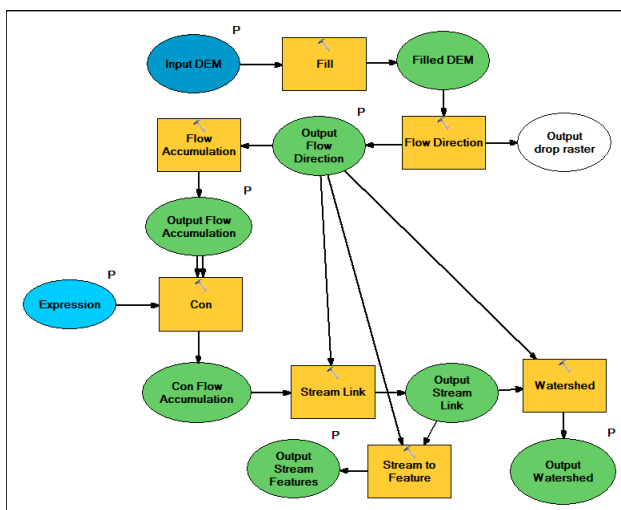


Figure 4. ModelBuilder diagram of the *Watershed Delineation* model.

As you can see, the model strings together a series of inputs and ArcGIS tools to produce a watershed raster. Model inputs and outputs are flagged with a *P*, meaning parameter.

- 3 Close the model.
- 4 Activate the Spatial Analyst extension (*Customize » Extensions*).
- 5 Double-click *WatershedDelineation* and define parameters in its runtime dialog box as follows:

Input DEM	Z:\Desktop\GISData\GIS\ESRI_Labs\Woodlot.mdb\DEM_Woodlot
Expression (optional)	Value >= 10000
Output Watershed	Z:\Desktop\GISData\GIS\Work\Work10.gdb\watershed
Output Stream Features	Z:\Desktop\GISData\GIS\Work\Work10.gdb\stream
Output Flow Direction	Z:\Desktop\GISData\GIS\Work\Work10.gdb\flowdirection
Output Flow Accumulation	Z:\Desktop\GISData\GIS\Work\Work10.gdb\flowacc

Figure 5. *Watershed Delineation* tool set up for calculating watersheds in the Woodlot.

The model may take several minutes to execute but will eventually produce a watershed raster along with several associated outputs—flow accumulation, flow direction, and a stream network.

Drape these rasters over the DEM so you can better visualize the results. Start with flow accumulation, in other words, likely stream locations.

- 6 Turn *DEM\_Woodlot* off, but use it to assign base heights to the flow accumulation raster, *flowacc*. Swivel the image to get the best perspective.

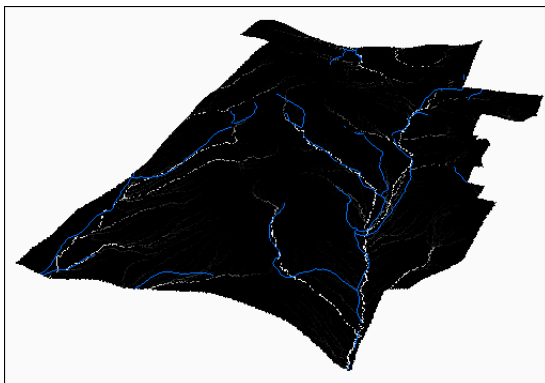


Figure 6. Flow accumulation raster superimposed over the Woodlot's known streams.

The *flowacc* raster, displayed in black and white, shows where water runoff will concentrate and form streams. The lighter areas indicate larger flow accumulations and identify a network

of streams across the Woodlot. The network more or less matches the streams displayed in the *Permanent Streams* layer, although it displays some intermittent streams not shown in *Permanent Streams*.

The flow accumulation raster is the basis for creating a streams feature class—*stream*, in this case.

- 7 Turn *Permanent Streams* off, and then drape *stream* over the DEM again using *DEM\_Woodlot* to assign base heights for *stream*.

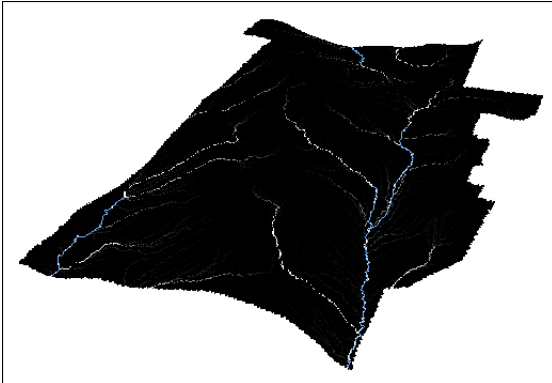


Figure 7. Stream locations, light blue, superimposed over the flow accumulation raster.

The *stream* result is determined by the value entered for the *Expression* parameter in the *Watershed Delineation* model. It was 10000 in this case.

The 10000 value specifies a threshold. A cell would only be considered a stream if the number of cells flowing into it reached this threshold. In this case, it was felt that 10,000 cells—in other words, a 100 ha drainage area—would do a reasonable job of identifying the Woodlot's permanent streams.

How about watersheds?

- 8 Turn *flowacc* off and then drape *watershed* over the DEM.



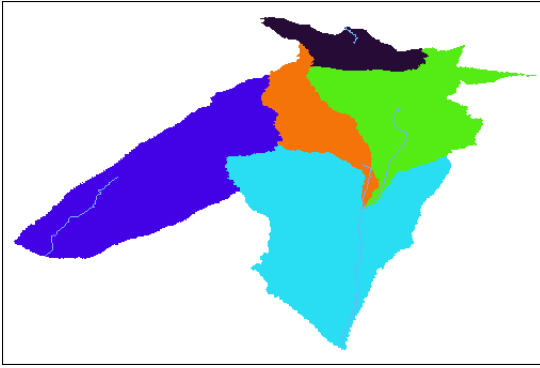


Figure 8. The Woodlot's six watersheds with predicted streams indicated.

From this, it seems there are five distinct watersheds in the Woodlot, each draining to a stream segment.

Of course, watersheds don't stop at property boundaries but extend beyond, depending on surrounding terrain. In fact, if you were to use a DEM covering the Woodlot, as well as surrounding area, you would see changes in the watersheds delineated.

That aside, the light blue, orange, and green watersheds you've identified form a larger watershed for the Corbett Brook network in the Woodlot. It would make sense to combine those three watersheds into a single entity. That would leave you with three watersheds for conducting your analysis of clearcutting in watersheds.

Combining raster categories is not the same as combining adjacent polygons in a feature class by dissolving shared boundaries. Rather, it involves reclassifying.

- 9 Using the *Reclassify* tool (*Spatial Analyst Tools » Reclass*), renumber watersheds 2, 3, and 4 to 2, and 5 to 3, respectively. Name the output *Watersheds*.

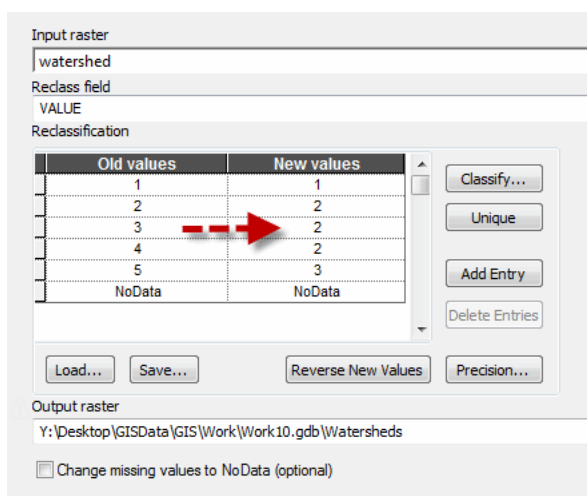


Figure 9. Renumbering Woodlot watersheds to consolidate 2, 3, and 4 into a single entity.

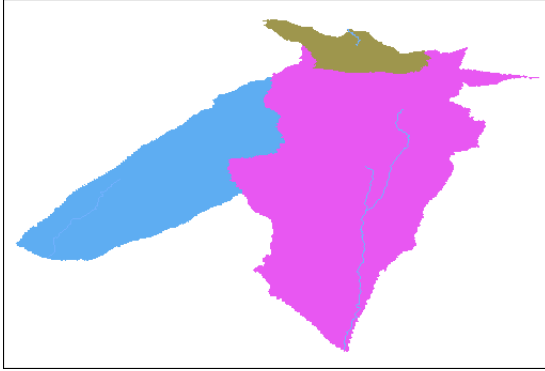
**10** Turn off *watershed* and drape *Watersheds* over the DEM.

Figure 10. Three Woodlot watersheds.

What amount of recent clearcuts is found in these three watersheds? Is it too much? That's what we really would like to know.

**EVALUATE WATERSHED CLEARCUTTING**

As indicated at the outset of this exercise, the balance between clearcut and uncut forest area in a watershed is a critical one. Too much clearcut area leads to rapid runoff and loss of water, while a lesser amount decreases water flow and its availability downstream.

What's the case in the Woodlot? What area of recent clearcuts do we find in each of the Woodlot's three watersheds?

**RELATED CONCEPT: CHARACTERIZE USING A NUMERICAL DISTRIBUTION**

- 1 Add the cover types feature class (*cover*) and use *Definition Query* (right-click *Cover Types* » *Layer Properties* » *Definition Query*) to isolate recent Woodlot clearcuts using the following query expression:

```
[TYPE] <> 'BG' AND [AGE] >= 0 AND [AGE] <= 5
```

- 2 Drape the 121 clearcuts selected over the DEM.

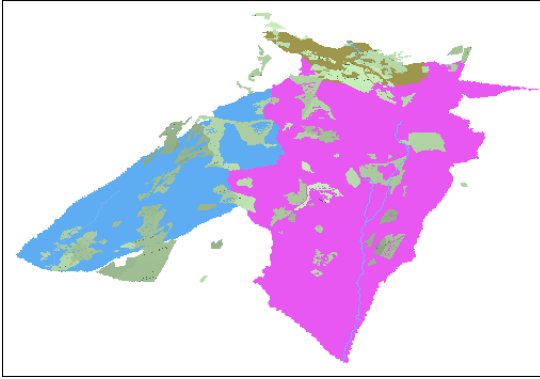


Figure 11. Recent clearcuts draped over the Woodlot's watersheds.

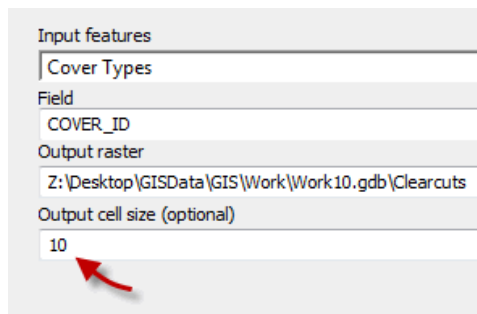
At a glance, it doesn't look good for the westernmost watershed (twelve o'clock). It would appear that more than a third of the watershed is clearcut. Bear in mind, though, that what you're seeing is just the headwaters of the entire western watershed, since your analysis is limited to the confines of the Woodlot. The other watersheds appear to be less affected, although the southeastern watershed (blue) may be problematic, too.

How would you calculate the exact amount of clearcutting in each of the Woodlot watersheds?

For each watershed, you're looking for the tally of its cells that fall within a clearcut. Stated another way, you want to label—reclassify—each of the cells within each clearcut with its associated watershed.

A map algebra *Over* overlay will easily accomplish the latter, but you'll first have to build a raster of the 121 clearcuts.

- 3 Convert selected *Cover Types* features to a 10 m cell-size raster using the *Feature to Raster* tool (*Conversion Tools* » *To Raster*). Name it simply *Clearcuts*.



*Why are you using a 10 m cell size for Clearcuts? It's the same cell size as that of the Watersheds raster. Since you'll be overlaying the two, having the same cell size makes sense.*

Figure 12. Making a raster of the 121 clearcut features.

- 4 Use the *Raster Calculator* tool (*Spatial Analyst* » *Map Algebra*) to enter the following map algebra expression. Name the output raster *CCWatersheds*.

```
Over("Watersheds", "Clearcuts")
```

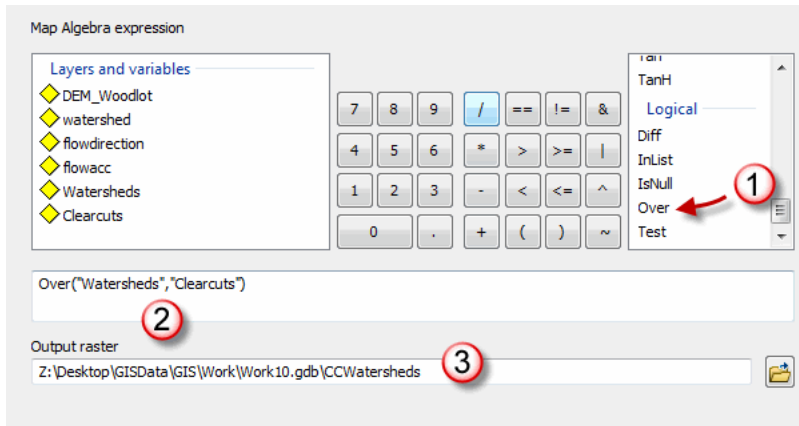


Figure 13. Using a map algebra Over function to label clearcuts with their associated watershed.

Cell by cell, an Over overlay simply replaces values in the second raster (bottom) with those of the first raster (top) wherever nonzero values exist. In this case, it has the effect of labeling clearcuts with their associated watershed.

- 5 Turn the *Cover Types*, *Watersheds*, and *Clearcuts* layers off, and then drape *CCWatersheds* over the DEM.
- 6 As a Woodlot property reference, add the management compartments feature class (*compart*). Drape it over the DEM. Symbolize its features with a hollow fill.

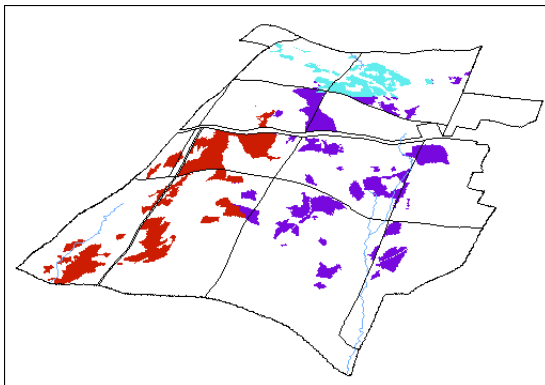


Figure 14. Clearcuts identified by watershed.

If you open the *CCWatersheds* attribute table, you can see the specific number of clearcuts in each watershed.

	OBJECTID *	Value	Count
▶	1	1	5511
	2	2	9426
	3	3	8742

*Divide Count by 100 for hectares. It's easy to assign field aliases that would be more meaningful. Simply right-click a field name and then select Properties.*

Figure 15. Tally of clearcut area (*Count*) by watershed (*Value*).

**Question 1:** *Could you use the Tabulate Area tool (Spatial Analyst Tools » Zonal) to compile the tabular summary of clearcut areas by watershed?*

Remembering that cell size is 10 x 10 m (100 m<sup>2</sup>), watershed 1 has about 55 ha of clearcuts, watershed 2 has 94 ha, and watershed 3 has just 87 ha.

What percentages of watershed area, however, do these amounts represent? How might you determine that, since watershed areas are stored in the *Watersheds* raster?

With the small number of watersheds you're dealing with here, you can do the arithmetic manually; otherwise, a table join would be needed.

You'll find that watershed 1 has 38.5 percent of its area occupied by recent clearcuts, 2 has 15.4 percent, and 3 has 28.4 percent.

As suspected, watershed 1 in the west is heavily clearcut, and likewise watershed 3. On the other hand, the large Corbett Brook watershed has a relatively small number of clearcuts present, at just over 15 percent of its area. Obviously, recent harvest scheduling in the Woodlot has not considered watersheds.

What about roads? You'll recall that they, too, can be an issue in watersheds since their ditches carry runoff and suspended sediment into the streams they cross. What's the situation in the Woodlot? Answering that question is next.

## EVALUATE ROAD BUILDING

What indicators of road building in Woodlot watersheds could you calculate?

An obvious one would be the length of road in each watershed; presumably, more length would indicate more sediment-laden runoff carried to streams.

So how do you determine the length of road within each of the Woodlot's three watersheds?

The road network in the Woodlot is composed of its main and secondary roads, plus a couple of public roads. You can find these in the *clines*, *roads*, and *proads* feature classes. You have a *Watersheds* raster for the Woodlot.

Determining the length of road in each watershed involves an overlay of roads on watersheds, but first you need to combine the roads feature classes into one.

## RELATED CONCEPT: CHARACTERIZE USING A NUMERICAL DISTRIBUTION

- 1 Close ArcScene and start ArcMap™, and then add the main road and public roads centerlines feature classes, *clines* and *proads*, plus the secondary roads feature class, *roads*.

- Use the *Merge* tool (*Data Management Tools » General*) to combine the three road layers into a single feature class named *AllRoads*.

If you remove *Public Roads*, *Centre Lines*, and *Secondary Roads*, you see the complete network of Woodlot roads as a single feature class.



Figure 16. The Woodlot network of power lines; sewer lines; and main, secondary, and public roads.

There are a lot of roads in the Woodlot, although there are two features in *Centre Lines* that aren't roads—the sewer line and power line easements. You should exclude those.

- Using *Definition Query*, exclude from *AllRoads* the sewer and power line easements, `[CLASS] <> 'SE' AND [CLASS] <> 'PE'`, originally from the *Centre Lines* layer.

Now you can overlay the road network and the watersheds to produce a result that associates road segments with the watersheds they lie within. The problem is, you can't overlay a mix of rasters and feature classes. The easy solution is to create polygon features from your *Watersheds* raster.

- Use the *Raster to Polygon* tool (*Conversion Tools » From Raster*) to create watershed polygons in a feature class named *WatershedPolys*.

Input raster	Z:\Desktop\GISData\GIS\Work\Work10.gdb\Watersheds
Field (optional)	Value
Output polygon features	Z:\Desktop\GISData\GIS\Work\Work10.gdb\WatershedPolys
<input checked="" type="checkbox"/> Simplify polygons (optional)	

Figure 17. Converting the *Watersheds* raster to a polygon feature class.

Doing this produces the desired result, although watershed boundaries are not obvious. There is an easy fix for that.

- 5 Symbolize *WatershedPolys* feature class polygons with different fill patterns for the unique values of the *grid\_code* field.

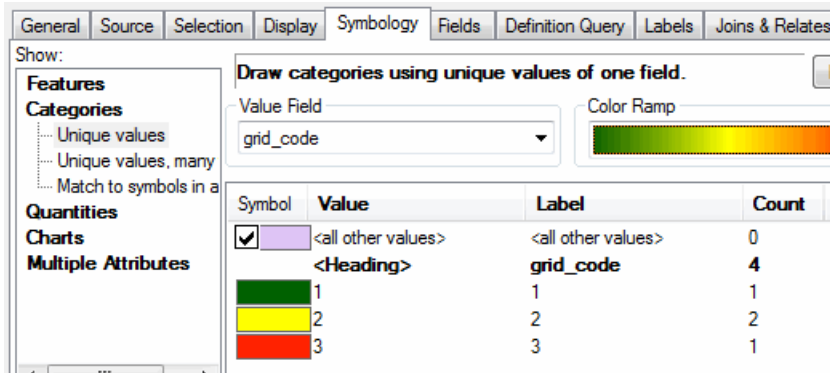


Figure 18. Uniquely symbolizing the three Woodlot watersheds.

**Question 2:** *Why did watershed 2 end up as two polygons (a count of 2) and not as one like the others?*

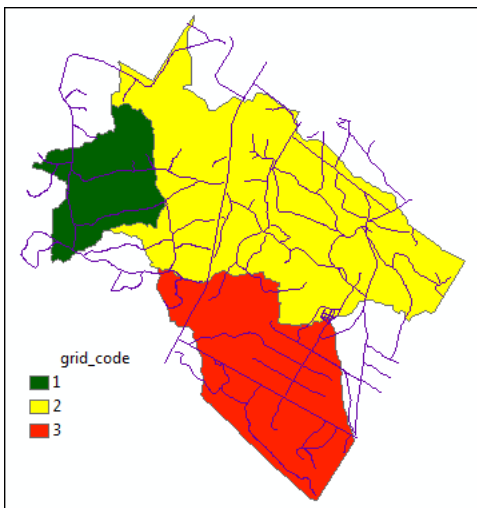


Figure 19. Watershed polygons symbolized uniquely.

Symbolizing the watersheds makes them obvious once again. What's not obvious, although there was a clue earlier, is that watershed 2 (red) is actually two polygons.

- 6 Zoom in to the upper left corner of watershed 2.

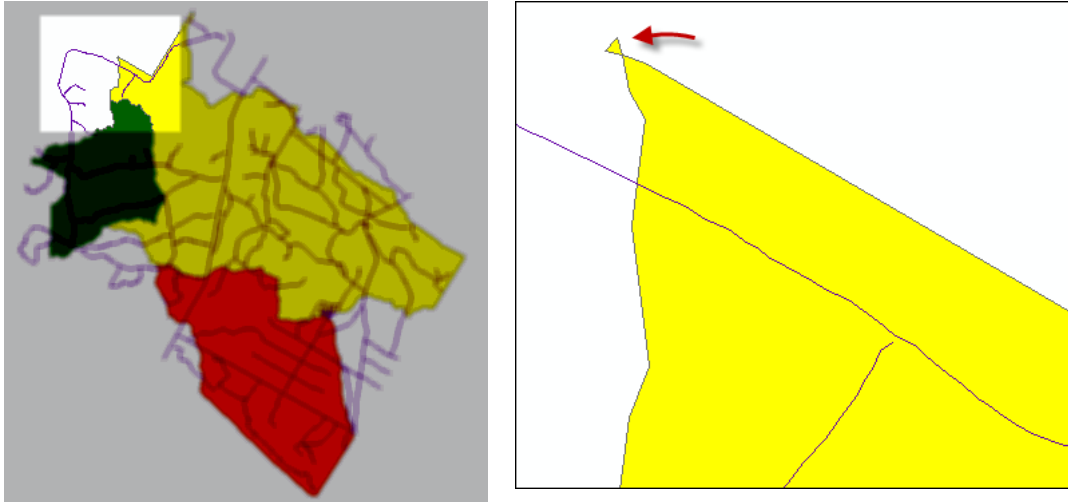


Figure 20. Zooming in on watershed 2 to display its second polygon.

There you can see a very small watershed fragment, a remnant of the raster to vector conversion. Fortunately, it's not going to affect your analysis.

Proceed with the overlay of roads and watersheds as a prelude to tallying up the length of road in each watershed.

- 7 Using the *Intersect* tool (*Analysis Tools » Overlay*), overlay the *AllRoads* and *WatershedPolys* layers. Name the result *RoadsInWatersheds*.

Doing this produces a feature class of road segments identified by their associated watershed. This becomes more obvious if you open the attribute table. You'll see the *grid\_code* field values— watershed IDs—associated with various road segments.

FID_AllRoads	Type	NAME	FID_WatershedPolys	Id	grid_code	Shape_Length
1	Main road gravelled	Near West Rd	3	3	2	20.131425
4	Main road gravelled		3	3	2	93.368388
5	Main road ungravelled		3	3	2	359.196305
6	Main road ungravelled		2	2	1	178.505876
7	Main road gravelled		3	3	2	538.513072
8	Main road gravelled	Blair Road	3	3	2	1430.691112
9	Main road gravelled		3	3	2	335.945955
10	Main road gravelled	Corbett Road	3	3	2	46.76955
10	Main road gravelled	Corbett Road	4	4	3	954.71587
11	Main road gravelled	Corbett Road	3	3	2	900.630392
12	Main road gravelled	Cross Road	3	3	2	1031.985681
13	Main road ungravelled		3	3	2	106.526272
14	Main road ungravelled		3	3	2	273.466821
15	Main road gravelled		3	3	2	33.803705
16	Main road gravelled		3	3	2	70.311466
17	Main road gravelled	College Hill Rd	3	3	2	463.505984

Figure 21. Attribute table of roads intersecting watersheds.

So, how does this information produce a tally of road lengths by watershed?

Rather simple, actually. You can use the *field summarize* function.



- 8 Right-click *grid\_code* and summarize by *Shape\_Length* sum. Name the output table *WatershedRoadLengths*.

	OBJECTID *	grid_code	Count_grid_code	Sum_Shape_Length
▶	1	1	13	4469.346229
	2	2	100	28623.717135
	3	3	35	14524.276687

Figure 22. Summary of road length (m) by watershed.

You could also use the *Summary Statistics* tool (*Analysis Tools » Statistics*) to produce this result.

This summary table tells you exactly what lengths of road exist in each watershed (*grid\_code*).

The large Corbett Brook watershed (2), for example, has 28.6 kilometers (km) of roads. It seems like a lot, compared with the others.

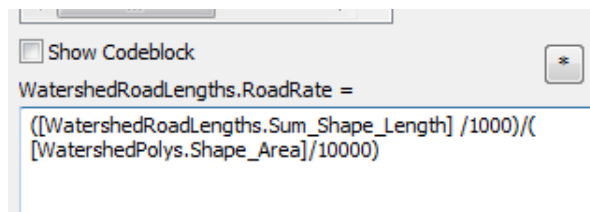
A fairer comparison, though, would use kilometers of road per hectare of watershed. These values should be easy to calculate using *Field Calculator*, simply by dividing *Sum\_Shape\_Length* by watershed area.

The only problem is, watershed area values are not found in the summary table but rather in the *WatershedPolys* attribute table. What's the solution to this problem?

- 9 Join *WatershedRoadLengths* to *WatershedPolys* via their common *grid\_code* fields.

That, of course, makes both the *Shape\_Area* and *Sum\_Shape\_Length* fields available for calculating kilometers of road per hectare of watershed.

- 10 Add a float field called *RoadRate* and then use *Field Calculator* to calculate  $\text{RoadRate} = (\text{Sum\_Shape\_Length}/1000) / (\text{Shape\_Area}/10000)$ .



The divisors of 1000 and 10000 serve to convert m to km and m<sup>2</sup> to ha, respectively.

Figure 23. Calculating kilometers of road per hectare of watershed.

If you examine the calculated *RoadRate* values, you'll note that they are quite small and very similar (except the very large value that appears for that tiny fragment of watershed 2 that arose from the raster to polygon conversion earlier).

grid_code	Cnt_grid_code	Sum_Shape_Length	WatershedPolys.RoadRate
2	100	28623.717135	4180.7373
1	13	4469.346229	0.031585
2	100	28623.717135	0.046859
3	35	14524.276687	0.046878

Figure 24. Kilometers of road per hectare of watershed.

Viewed from this perspective, perhaps the length of road in the Woodlot's watersheds isn't as long as initially thought.

However, a critical issue with forest roads is stream crossings. These locations are, of course, where any suspended sediments are dumped into streams.

How often do road-stream crossings occur in Woodlot watersheds? Given the number of roads and streams in the Woodlot, one might conclude that it's frequent. Is that right?

- 11 Use the *Intersect* tool (*Analysis Tools » Overlay*) to overlay *RoadsInWatersheds* and *streams* to determine the locations of road-stream crossings in the Woodlot. Name the output feature class *Crossings*.

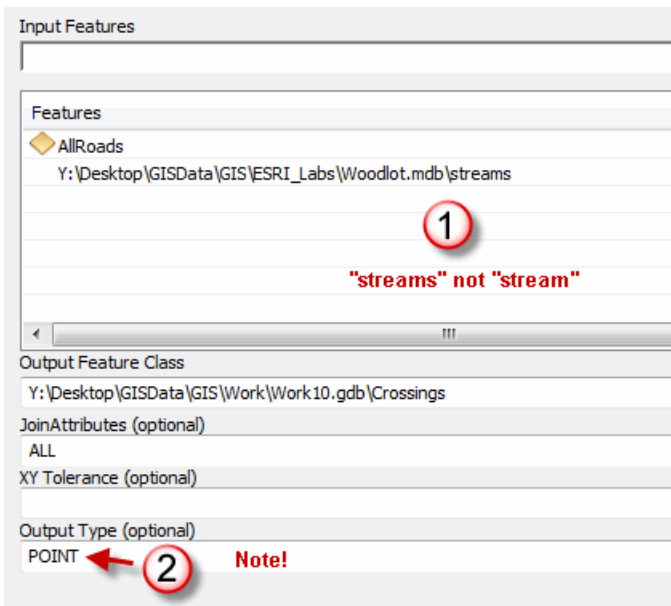


Figure 25. Overlaying roads on streams.

Doing this produces a feature class of points where roads intersect—in other words, cross—streams.

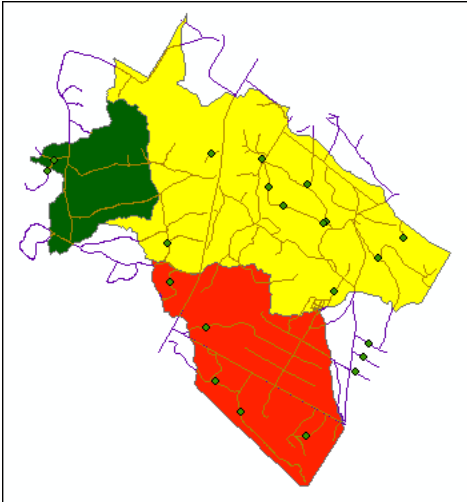


Figure 26. A point feature class captures road-stream crossing locations.

As you can see, there are numerous crossings in the Woodlot. Keep in mind, what you see is only a fraction of actual crossings that exist, since streams in the *streams* feature class were digitized with breaks wherever they crossed main roads. If you zoom in, you can verify this.

This is not really a problem in your analysis, since these main road crossings are most likely to be ones that have been constructed properly; it's crossings at secondary roads that tend to be more problematic.

The small geographic area that comprises the Woodlot (1,440 ha) makes it easy to manually tally the number of crossings in each watershed.

**Question 3:** *How might you accomplish a tally of road-stream crossings by watershed if you were working with a much larger forest property?*

## Conclusion

You've determined that the Woodlot's watersheds have clearcut areas ranging from 15 percent to almost 40 percent at the present time. Road densities in the Woodlot's three watersheds, on the other hand, seem small, at between 0.03–0.05 km/ha.

Based on the results, what's your assessment of clearcutting impact on watersheds in the Woodlot?

# Submit your work

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- A 3D map of the Woodlot's watersheds
- Tally and map of clearcuts and roads within the watersheds
- Tally and map of stream crossings within the watersheds
- Based on lab results, a paragraph detailing an assessment of clearcutting and road construction in the Woodlot (Is it good news or bad?)
- Answers to the questions posed in the exercise:
  1. Could you use the *Tabulate Area* tool to compile the tabular summary of clearcut areas by watershed?
  2. Why did watershed 2 end up as two polygons when the raster to polygon conversion was made and not one like the others?
  3. How might you accomplish a tally of road-stream crossings by watershed if you were working with a much larger forest property?
- A summary of the exercise, indicating where and how related reclassifying and characterizing concepts, as well as analysis techniques, are used (It could take the form of a table that checks off each of these elements.)
- A watershed assessment of clearcutting for a different forest, carried out using techniques similar to those used in the exercise

## Credits

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### Sources of supplied data

#### *Course Data*

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### **Lesson 3: Clearcutting data**

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