Utilizing GIS for Mapping Reforestation of an Agricultural Landscape, 1939-1993, in Coon Creek Watershed, Wisconsin

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Abstract

The first concerted national effort to address soil erosion problems on private land began in 1933 with the establishment of the Soil Erosion Service. Coon Creek watershed in southwestern Wisconsin, with its dendritic network of creeks and steep slopes, was chosen as the site of the first national Demonstration Project. Clearing for farms began in the 1860s, followed by a shift to dairy farming in the 1880s. Intensive cultivation and over-grazing of slopes cut through the protective layer of sod, exposing the soil to the direct effects of rain and wind. Since 1933, the implementation of conservation practices continues to show significant results in the control of flooding, rill and gully erosion, and floodplain siltation. The planning effort offered an integrated approach. Contour strips, terraces, fencing, streambank stabilization, and tree planting were applied on an individual farm basis. Research on changes in sediment loss rates has been well documented. This study focuses on the reforestation of agricultural woodlots. Using a geographic information system (GIS), a spatial analysis of landcover change can help to understand forest regeneration.

Introduction

Coon Creek Watershed in southwestern Wisconsin was the site of the first national Soil Erosion Demonstration Project. Following the Dust Bowl years and the Great Depression, the need to address the erosion of agricultural land was critical. The Coon Valley project began in 1933, under the direction of Hugh Hammond Bennett, the first head of the newly formed U.S. Department of Interior Soil Erosion Service. Funds were allocated under the Emergency Public Works Law to establish this temporary endeavor (USDA 1983). In 1935, through the enactment of Public Law 46, the service was formalized as a permanent agency, the Soil Conservation Service (now known as the Natural Resource Conservation Service, or NRCS).

Considerable work in the pioneer field of erosion control had begun several years prior in southwestern Wisconsin at the Upper Mississippi Valley Erosion Experiment Station, through a cooperative effort of U.S. Department of Agriculture (USDA) and the Wisconsin College of Agriculture (Sartz 1978). Due to this and to the fact that the Coon Valley watershed was near the top of the list of seriously eroded agricultural regions, the locale was chosen as a suitable site for a demonstration of current conservation practices. Also under the emergency powers mentioned above, the Civilian Conservation Corps (CCC) was enlisted to provide a labor force for the project (USDA 1983). Aldo Leopold, in his role as University of Wisconsin Extension Service advisor, was involved from the Coon Valley project's inception.

Coon Creek Valley is located in the nonglaciated "driftless" region of Wisconsin. It is a narrow steep-sided valley with many side branches, called coulees (a form of the French word for such valleys). The first European settlement was started in 1849. Early settlers found fertile soil interspersed with brush and timber.

After the valleys were cultivated, the upland ridges were cleared. As slopes were grazed (Figure 1), surface runoff increased dramatically. By the 1930s, Leopold (1935) noted that "rain pours off the ridges as from a roof . . . Great gashing gullies are torn out of the hillside." See Figure 2.

Guidelines for terracing, contour strip-cropping, regulated grazing, and planting of trees were prescribed according to slope (NRCS 1939). Land of greater than 40% grade was to be retired from grazing and trees were planted where appropriate. Slopes between 25% and 40% grade were allowed regulated grazing, where the land was not already wooded. Permanent pasture was called at 15 - 25% grade. Areas less than 15% slope were to be farmed in contour strips with crop rotation and terracing for corn (Figure 3). A half-century later, many of these conservation practices continue to show success. Soil erosion loss has been reduced from >40 tons/acre/year to 4 tons/acre/year. Sedimentation in lower floodplains has decreased from almost 6"/year to 0.2"/year (Trimble 1999).

(photo courtesy of NRCS)

Figure 1. Overgrazed slope in Coon Creek Watershed, 1934.

(photo courtesy of NRCS)

Figure 2. Gully erosion in Coon Creek Watershed, 1933. For scale, note the white vertical line in the center foreground marking the height of the man standing just to the left.

Rationale for Study of Reforestation

An indicator of watershed integrity is the landscape's ability to collect and filter water. The relationship between forests and soil erosion has been investigated since the early 1900s. This history of watershed research provides long-term measurements of precipitation and streamflow, along with estimates of how much water forests return to the atmosphere by evapotranspiration (Megahan 2000). Intact vegetation helps to control flooding and retain soil. Riparian habitat functions as a "sponge," greatly reducing nutrient and sediment runoff (O'Neill *et al.* 1997). Extensive research has been reported (Sartz 1978) on the influence of forested slopes on runoff and sediment. Woodlots subject to destructive pasturing show soil compaction and loss of forest floor depth. Prevention of grazing results in rapid recovery, according to the studies.

An additional environmental aspect of reforestation is carbon sequestration. Vegetation sequesters carbon in the biomass and soil layer through photosynthetic conversion of CO_2 to C (Birdsey 1992). Since forested land stores more carbon than agricultural land, reforestation results in a reduction in atmospheric CO_2 concentration. Models of carbon flow and economic costs of land use change are presented in Plantinga *et al.* 1999. A more recent study (American Society of Agricultural Engineers 2001) indicates that reforestation of former farmland over the past century helps reduce greenhouse gases in the atmosphere. The research points to the change in land use as the primary cause of increased absorption, rather than the fertilizing effect of CO_2 as suggested by previous research. USDA scientists and collaborators are developing the first national estimates for amounts of carbon that farm and pasture land are storing (Comis *et al.* 2001).

Because of the historic significance of Coon Creek watershed in soil erosion control, it provides an excellent site to continue assessing corollary effects of early conservation practices. This study maps and

(photo courtesy of NRCS)

Figure 3. Aerial view of contour strips and woodlots, Coon Creek watershed, Hamburg township, 1955.

quantifies the change in forested landcover, using image data from 1939, 1967, and 1993.

Study Area

Coon Creek Watershed comprises 90,400 acres and is part of La Crosse, Monroe, and Vernon Counties. The western end is approximately 10 miles southeast of La Crosse and the eastern end is approximately 6 miles north of Viroqua. Coon Creek begins one mile from the eastern end and flows southwest, entering the Mississippi River at Stoddard. The town of Coon Valley is 14 miles above Stoddard; Chaseburg is midway along the creek's course. The study area for this research was restricted to the township of Hamburg (T14n-R6w). This township is centrally located within the watershed and includes both upland and floodplain acreage (see Figure 4). Also, the proportion of agricultural acreage placed under agreement during the demonstration project is representative of the watershed as a whole.

Data

For landcover data from 1939 and 1967, aerial photographs were used (scale 1:20,000). United States Geological Survey (USGS) Gap Analysis Program data provided the 1993 landcover imagery (Landsat Thematic Mapper). Additional datasets include: USGS digital raster graphics (DRGs) and digital elevation models (DEMs) for Wisconsin quadrangles 043091f1 and 043091f2, Public Land Survey System (PLSS) township boundary T14NR6W, and USGS hydrologic unit boundaries. Figure 5 shows an example of the aerial photography.

Analysis Protocol

Preparing Historic Data

The aerial photographs are stored in the Vernon County Natural Resource Conservation Service (NRCS) office in Viroqua, Wisconsin. A handheld stereoscope was used for interpreting

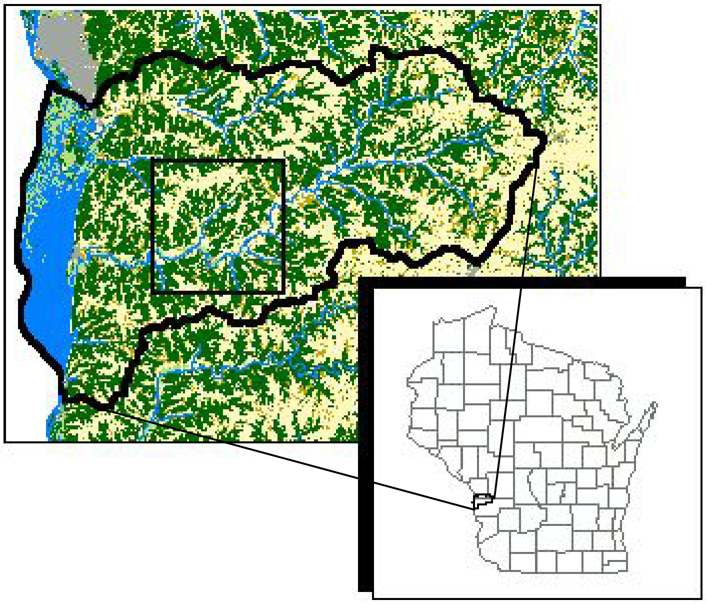
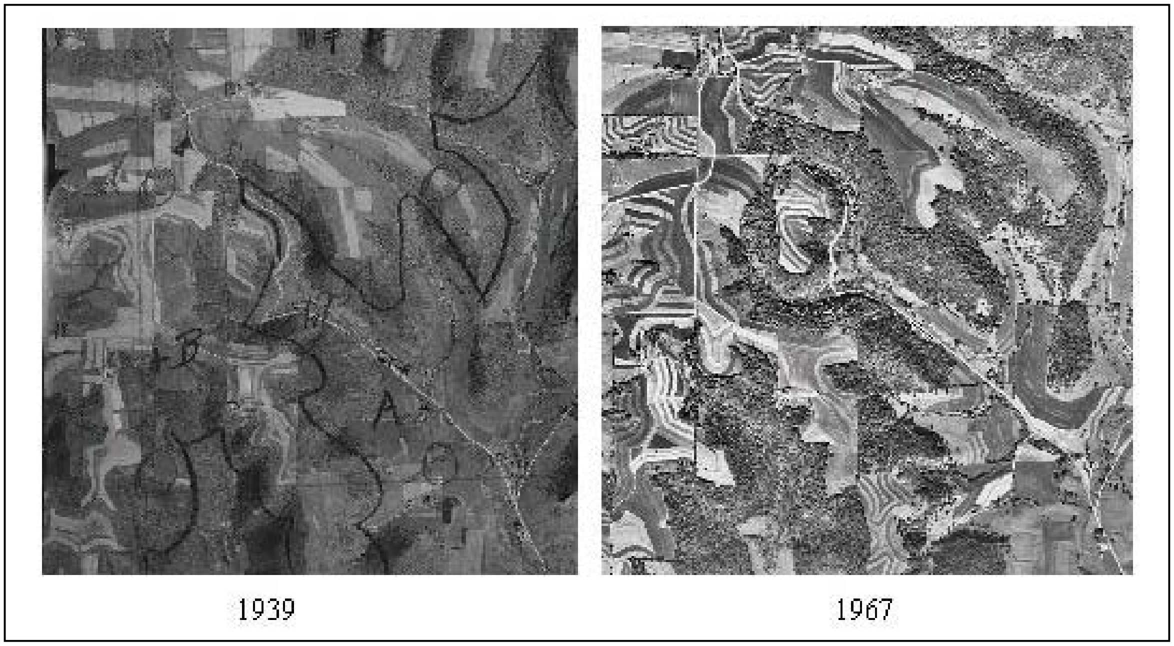


Figure 4. Location of study area within Coon Creek watershed.



1939

1967

Figure 5. Examples of the 1939 and 1967 aerial photographs, showing change in landcover and agricultural landscape pattern. Note: pencil markings visible in the 1939 view are on the original photo.

landcover; the minimum mapping unit was determined with a 0.4 acre grid at 1:20,000. Acetate overlays of the township for 1939 and 1967 were drawn, indicating wooded landcover.

Major road intersections were included for use as control points. Vector coverages were created by digitizing these at a UNIX© workstation, using ESRI© ArcInfo© 7.0.2. The township boundary was appended to each.

The resulting polygon coverages were transformed to Universal Transverse Mercator (UTM) coordinates. The root mean square (RMS) error for the 1939 coverage = 0.009/4.686m, for 1967 = 0.011/6.020m. Finally, the coverages were exported in American Standard Code for Information Interchange (ASCII) format (.e00).

Before proceeding, it is important to assess the accuracy of the data development up to this point. After importing the vector coverages into ArcView©, they were displayed in a view with the DRG as a background. This gave a visual estimation of the polygons' alignment with the topography. Then the two polygon coverages were overlayed in the same view. The aerial photos were examined for identifiable features, known to have remained constant from 1939 to 1967, such as a ridgetop farmstead and adjacent pasture. The digitized boundaries of these were checked for alignment with one another. Figure 6 shows the vector coverages of the entire study area. The inset, which matches the area in Figure 5, provides an overlay view. This method is appropriate for judging accuracy relative to the source data, given the development of the datasets by manual photo interpretation and digitizing.

The greatest potential for error is in the photo interpretation. There has been significant loss of contrast in the 1939 monochromatic photographs. The deteriorated quality of some of these images caused difficulty in discerning woods from valley shadows. Since the objective of this study is to determine trends and cumulative percent change at a landscape scale, the datasets were deemed acceptable for proceeding with analysis.

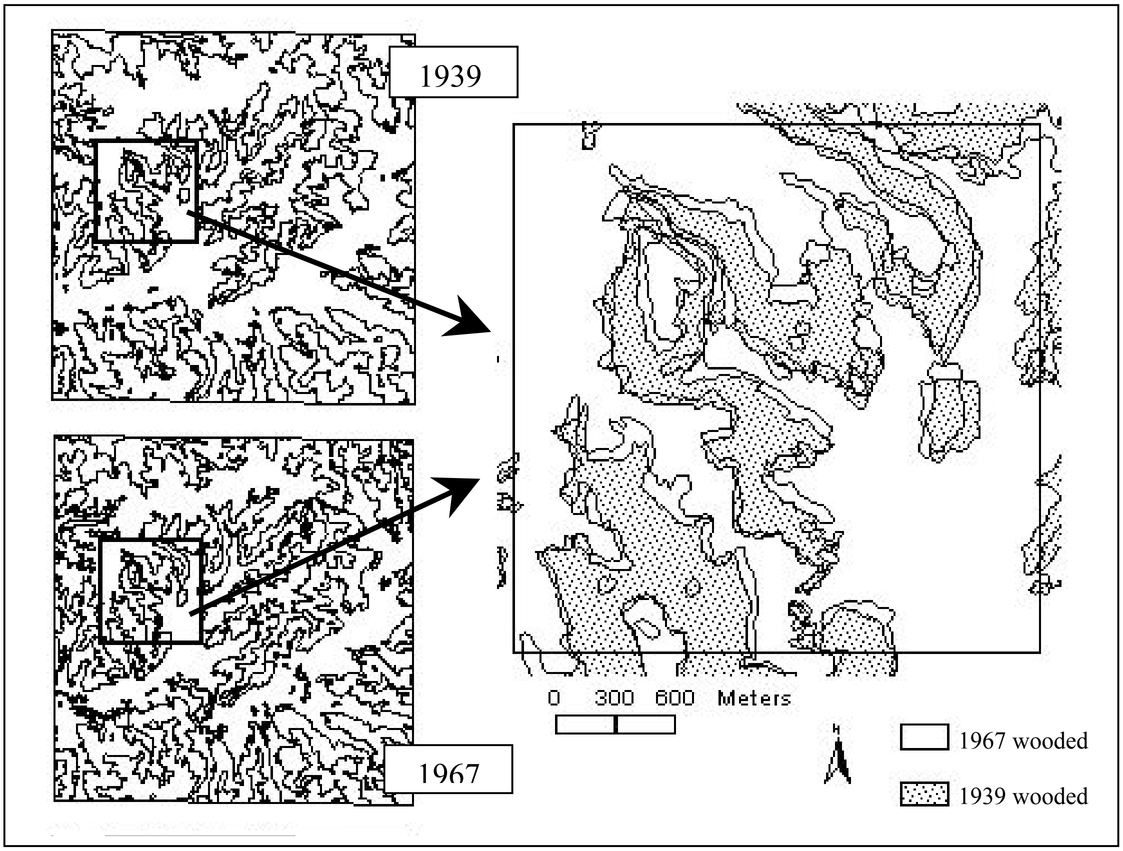


Figure 6. ArcInfo vector coverages. Overlay provides a check for relative accuracy of photo interpretation and digitizing. Note: inset encompasses the same area shown in Figure 5.

Wisconsin Gap Analysis Data

The National Gap Analysis Program (GAP) began in 1989 as a program of the Biological Resources Division of the U.S. Geological Survey. The format of Wisconsin Gap is a 30-meter ArcInfo© grid. Landcover is classified into 38 categories. ArcView© Grid Analyst Extension was used to extract the study area using the township boundary polygon. The tables were joined to reinstate class codes. The study area grid was re-classified into wooded (1) and non-wooded (2) for use in subsequent overlay analyses.

Quantifying Change between Grids using Map Calculator & Map Algebra

To examine the change in wooded landcover over time, the vector coverages were converted to 30-meter grids. The percent of wooded land for each dataset is summarized in Figure 7. Figure 8 provides a geographic overview of the wooded landcover change.

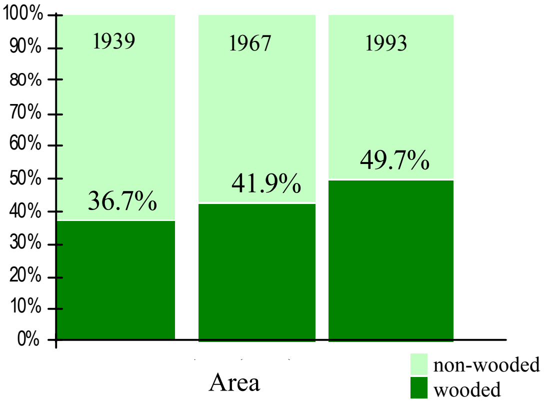
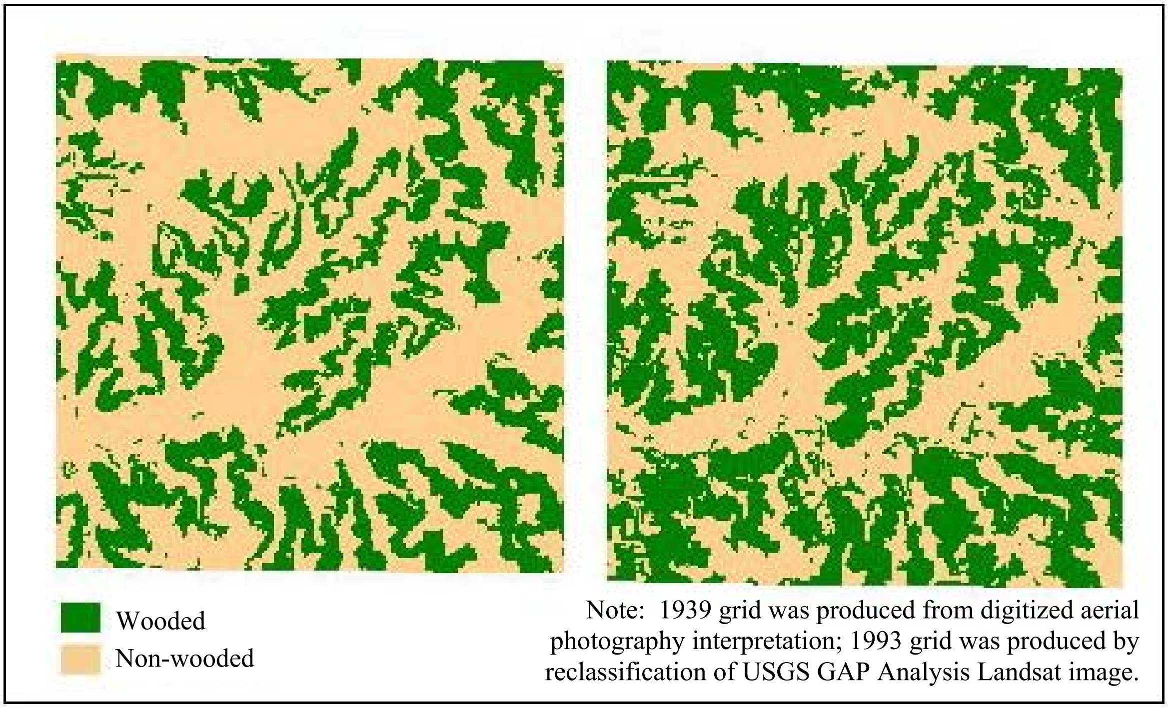


Figure 7. Change in percent landcover, showing reforestation trend during the study time intervals.



Note: 1939 grid was produced from digitized aerial photography interpretation; 1993 grid was produced by reclassification of USGS GAP Analysis Landsat image.

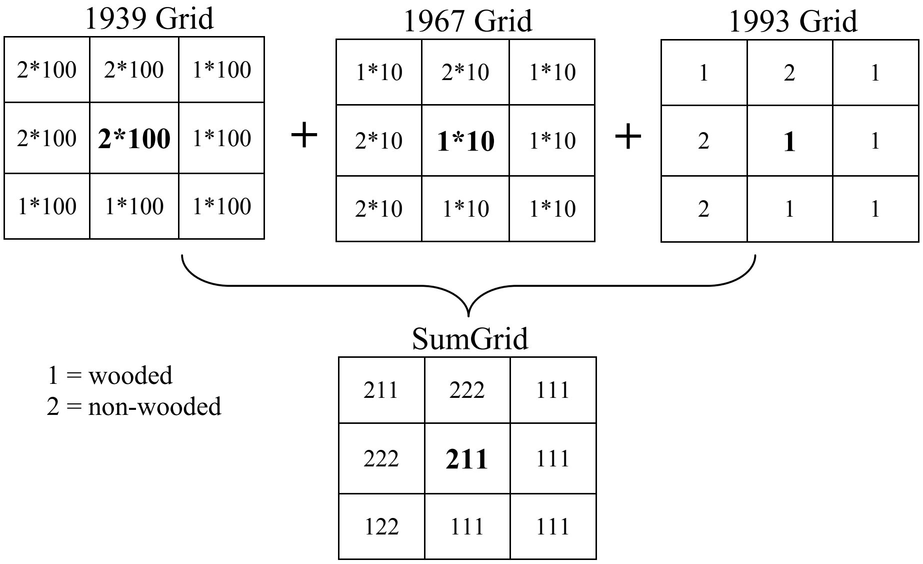
Figure 8. Overview of pattern and extent of wooded land in 1939 and 1993.

The 1939 and 1967 vector coverages had been categorized into two classes: 1 -- wooded, 2 -- non-wooded. After conversion to grid format, the attribute tables were joined. At this point, the three datasets were in appropriate formats to proceed with data queries and conditional processing.

Various queries could be written to extract the information on change between corresponding areas of the grids. However, working with an increasing number of datasets can become unmanageable and makes it difficult to get a picture of the overall change. The optimal solution would be to produce one grid to summarize change over time. This can be accomplished using the Map Calculator in ArcView© Spatial Analyst extension. Using these tools, algebraic expressions based on grid cell values are evaluated to produce a summary grid. Rather than straightforward addition, two of the grids were multiplied by factors of 10, as explained in the following method.

If a grid cell in the landcover grid for 1967 has a value of 1 and the same cell in the 1939 landcover grid has a value of 1, an arithmetic combination of these will yield a cell value of 2. Likewise, a cell in the 1967 grid with a value of 2 added to the cell value of 2 in the 1939 grid will yield a cell value of 4. However, an output cell value of 3 would indicate a change without regard to whether the order was from 1 to 2 or vice versa, i.e., deforestation or regeneration.

An effective method for harvesting this information is to introduce an offset in the cell values before combining the grids via map algebra. This will scale each grid so that the cell values are added together without ambiguous values. Multiplying each of the grids by a power of 10 preserves the relationship between each grid. Figure 9 diagrams an example, showing the cell values that will result in the output grid. Ersts (2001) describes this as a simple but powerful technique for analyzing multiple grids. The following is the Map Calculator



1939 Grid

2*100	2*100	1*100
2*100	**2*100**	1*100
1*100	1*100	1*100

1967 Grid

1*10	2*10	1*10
2*10	**1*10**	1*10
2*10	1*10	1*10

1993 Grid

1	2	1
2	**1**	1
2	1	1

SumGrid

211	222	111
222	**211**	111
122	111	111

Figure 9. This diagram depicts the method of deriving summary data from three grids, while retaining meaningful information from the original grids. The cell value 211 (in bold) indicates a change from non-wooded in 1939, wooded in 1967, wooded in 1993.

equation used in this study to summarize the three grid datasets:

$$\text{SumGrid} = ([\text{Grid39}] * 100) + ([\text{Grid67}] * 10) + ([\text{Gap}])$$

SumGrid is an integer grid; the associated value attribute table (.vat) contains eight records – one for each of the possible cell values resulting from the algebraic equation. Two fields were added to the table to hold values for area. To calculate area in square meters for each value, the cell count was multiplied by the square of the cell size (30 meters); then, acreage was calculated by multiplying area (m^2) by 0.000247 (Table 1).

The histogram of the Sumgrid values (Figure 10) is helpful in visualizing the interaction between the three grids. Of the six categories indicating change, the two with largest total area are those of reforestation. The change from non-wooded in 1939 to wooded in both 1967 and 1993 is recorded as 211. The change from non-wooded in both 1939 and 1967 to wooded in 1993 is recorded as 221. These define the significant areas for continued inquiry. There is obvious evidence of deforestation; however, further investigation of those areas is not in the scope of this study.

Table 1. Sumgrid.vat, showing area for each of the eight possible interactions among the three grid datasets.

Value	*Count*	*Area_m2*	*Acres*
111	26,525	23,872,500	5,896.50
112	3,673	3,305,700	816.50
121	5,032	4,528,800	1,118.61
122	3,220	2,898,000	715.80
211	9,125	8,212,500	2,028.48
212	4,590	4,131,000	1,020.35
221	11,414	10,272,600	2,537.33
222	41,184	37,065,600	9,155.20

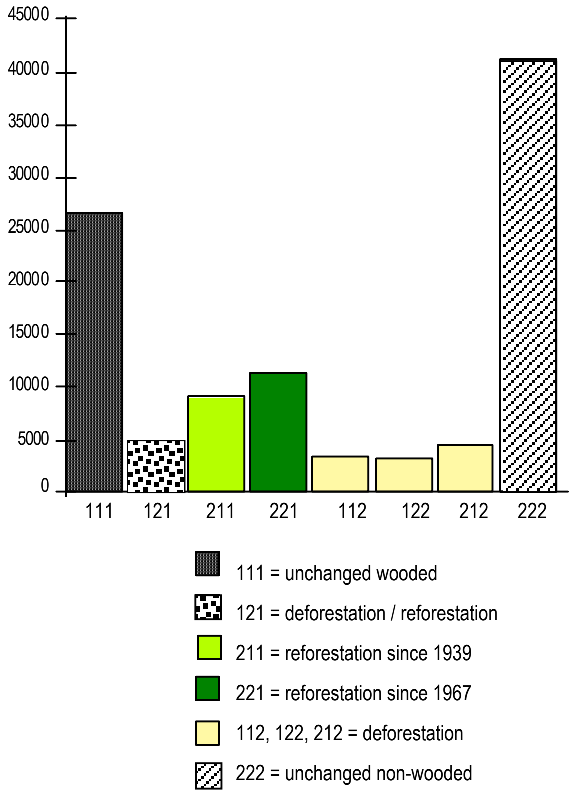


Figure 10. Histogram of values resulting from the overlay of the three grids. The black column (111) indicates the area that remained wooded and the lined column (222) non-wooded. Within the areas of change, the two largest (211 & 221) provide the focus for this study, i.e., reforestation since 1939 and 1967.

The "GRID2PT" Avenue© script creates a point theme in which each cell is represented by a point and an associated Grid_code equivalent to the cell value. A field was added to the attribute table of the point theme for each of the three grid themes. These were populated, using the calculator and the following expressions to restore the original cell values.

```
[1939] = ([Grid_code] / 100).Truncate
[1967] = ([Grid_code] – [1939] * 100) /
              10).Truncate
[1993] = [Grid_code] – ([1939] * 100) –
              ([1967] * 10)
```

As a result, the attribute table of the point theme comprises a record for each cell in the change detection grid and, also, reports the value of each cell in the 1939, 1967, and 1993 grids in separate fields. This data can be exported as a dBASE table for use with statistics applications.

Correlating Reforestation and Slope

Using the Grid Analyst extension, a mosaic was made of the two DEMs. This dataset was projected to match the Gap grid. Contour lines were created at 100-ft. intervals. A slope grid was derived and then classified into 6 equal intervals. Figure 11 illustrates the pattern of reforestation throughout the study area.

The summary grid produced via the Map Calculator was used to assess landcover changes with respect to slope. This form of processing tests grid values and reports true or false in the output grid. The following expressions were evaluated to find areas of change at the percent slopes defined by the 1934 conservation plans:

```
([Sumgrid] = 211.AsGrid) and
                ([Slopegrd] > 40)

([Sumgrid] = 211.AsGrid) and
                ([Slopegrd] <= 40) and
                ([Slopegrd] >= 25)

([Sumgrid] = 211.AsGrid) and
                ([Slopegrd] <= 25) and
                ([Slopegrd] >= 15)

([Sumgrid] = 211.AsGrid) and
                ([Slopegrd] < 15)
```

The same equations were used for the class of cell values 221, i.e., those indicating reforestation since 1967.

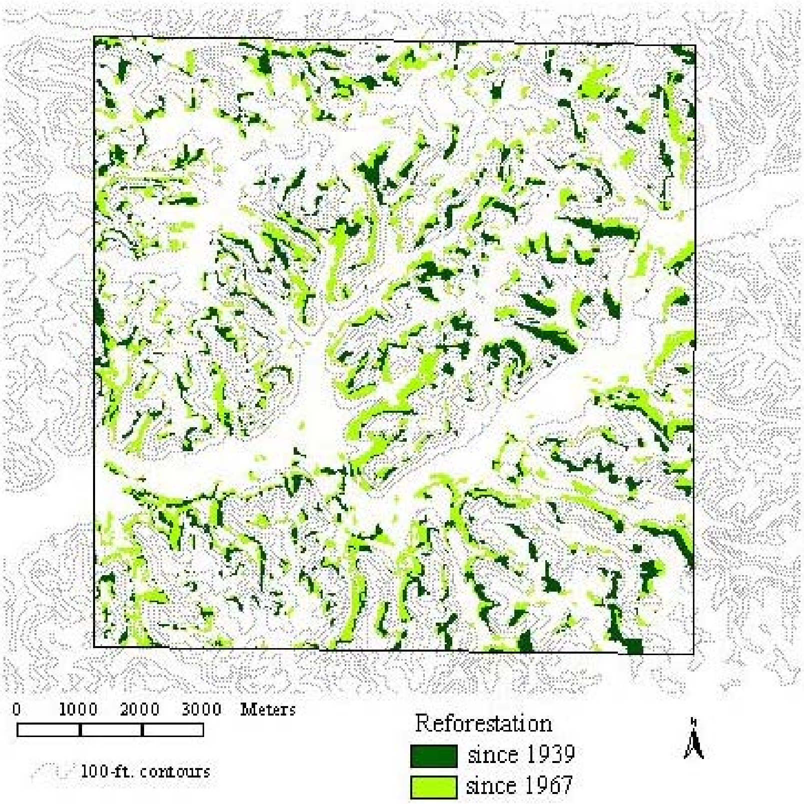


Figure 11. Spatial pattern of reforestation throughout the study area.

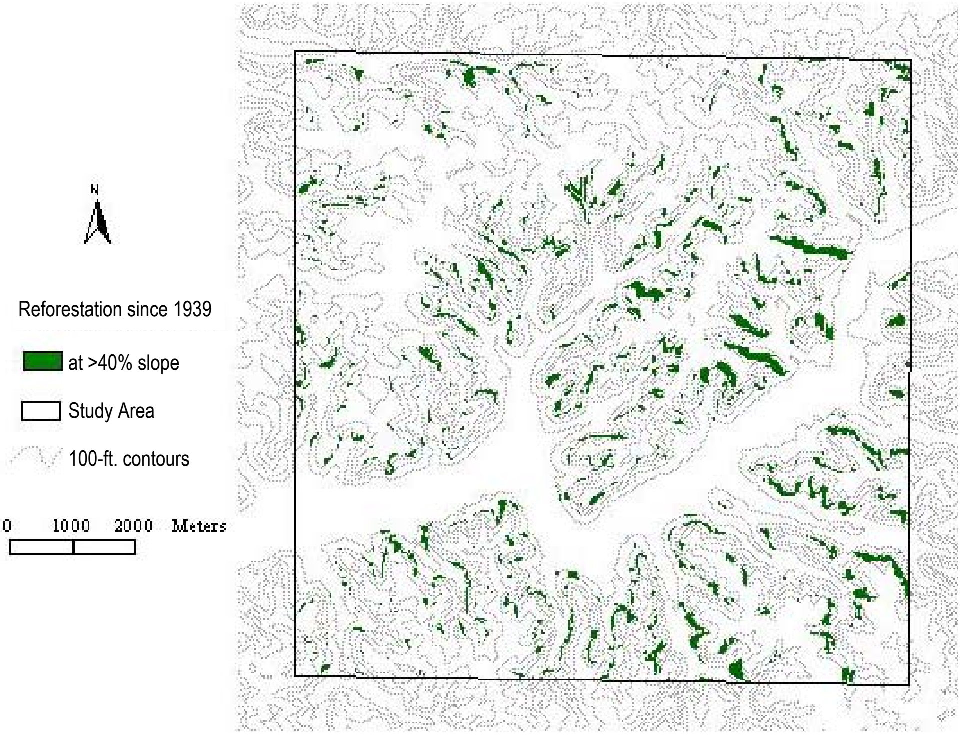


Figure 12. Spatial pattern of reforestation, 1939-1993, on slopes >40%.

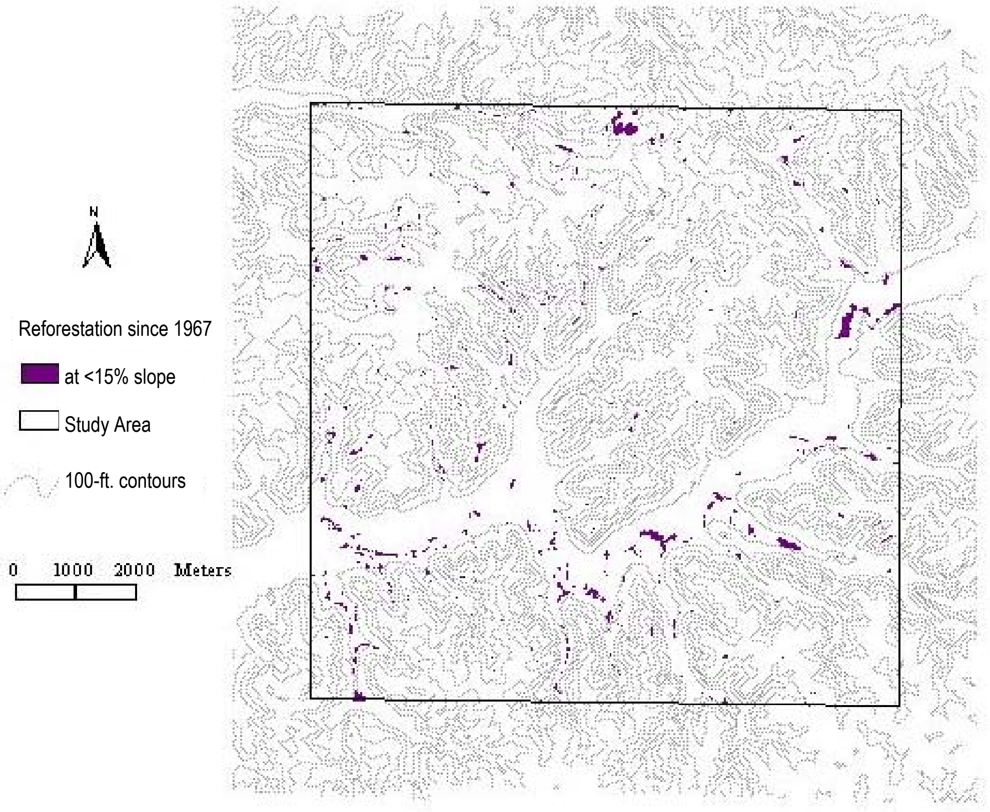


Figure 13. Spatial pattern of reforestation, 1967-1993, on slopes <15%.

Results

The percent areas of wooded land relative to non-wooded for each year in the study are recorded in Table 2. Calculations show a cumulative change of 1220 acres, representing 5.23% of the total area, reforested from 1939 to 1967. The period from 1967 to 1993 indicates a change of 1811 acres, 7.76%.

The greatest amount of reforested acreage is at the slope of 40% or above (Table 3). This corresponds with the intent of the original conservation plans to protect steep slopes from grazing. Resurgence of the forest has continued on the slopes greater than 40% since 1967 and has increased notably at slopes less than 15%. Figures 12 and 13 show the spatial pattern of these reforested areas.

Table 2. Percent and acreage of study area wooded in 1939, 1967, and 1993.

Wooded Landcover	1939	1967	1993
Acres	8,547.41	9,761.83	11,580.92
Percent	36.74	41.97	49.75

The histogram of cell values within various ranges of slope (Figure 14) offers a comparative observation of land reforested since 1939 and since 1967. Areas of reforestation since 1939 are principally on slopes between 20% and 60%, with very little at lower slopes. Examination of the 1967 columns shows a considerably greater extent of reforestation on lower slopes.

The histogram of cell values within ranges of elevation (Figure 15) supplies additional valuable information. The greatest areas of reforestation beginning in 1939 take place at the intermediate and

Table 3. Reforestation at slope categories delineated in 1934 conservation plans.

Year	Sumgrid Value	Slope	Acres
Reforestation from 1939 to 1993	211	>40%	1,196.86
	211	25-40%	522.84
	211	15-25%	186.28
	211	<15%	122.48
Reforestation from 1967 to 1993	221	>40%	992.34
	221	25-40%	821.40
	221	15-25%	383.56
	221	<15%	340.11

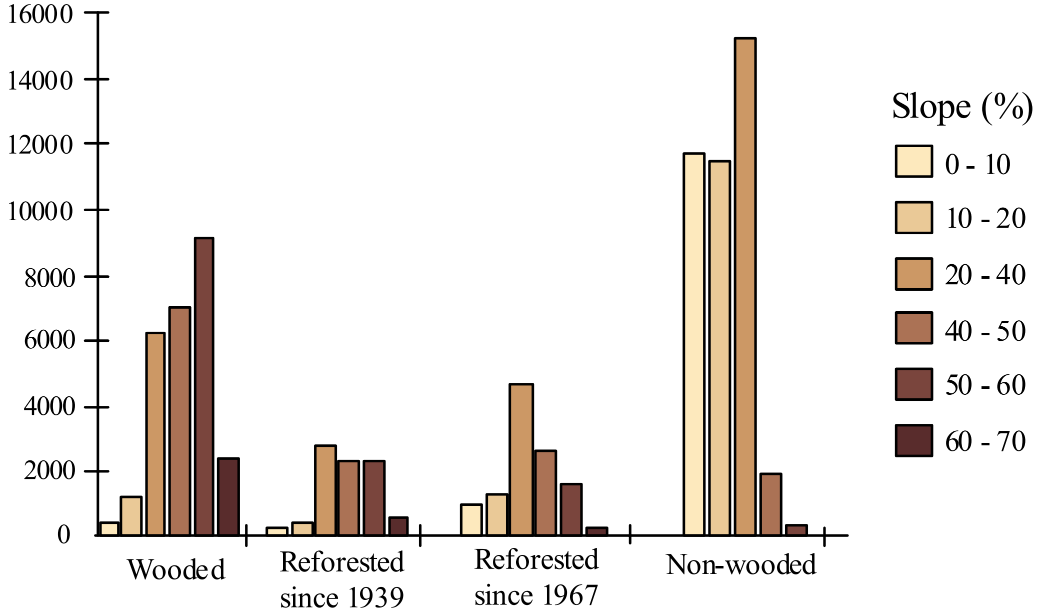


Figure 14. Histogram of Sumgrid values by slope, showing the distribution of wooded, reforested, and non-wooded areas at elevation intervals.

higher elevations. Reforestation since 1967 shows an increase at lower elevations, compared to 1939.

Discussion

The use of ArcView© Spatial Analyst and Map Calculator provides an effective tool for analyzing change among multiple grids.

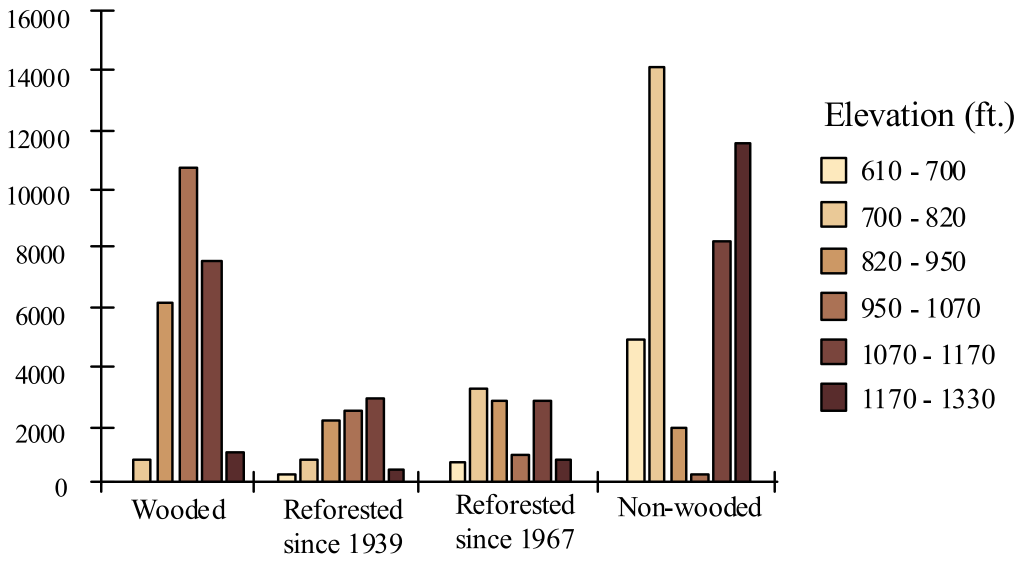


Figure 15. Histogram of Sumgrid values by elevation, showing the distribution of wooded, reforested, and non-wooded areas at percent slope intervals.

The grid produced in this study, and the subsequent database file created by running the "GRD2PT" script, are useful for further queries.

For instance, specific areas where deforestation is indicated could be examined. The maps might prove helpful for field studies investigating particular species. In an article describing the Coon Valley project, Leopold (1935) states that the dry south slopes present special problems, and he questions whether new plantations of conifers will survive.

The results show reforestation that is consistent with both the conservation plans and the topography of the landscape. As is evident in the histograms, the greatest increase in wooded land in the 1939 to 1967 time interval is at steep slopes. This confirms the initial effort to address the critical concern over protecting land of more than 40% slope.

The non-wooded land is principally at the lowest and highest elevations. Farming in this region is practiced on ridge tops and valley floors. The largest acreage of reforested land in the 1967 to 1993 interval is on lower slopes and elevation. This implies a revegetation of the floodplain. A probable cause is the flood control effort during that time. In the years 1958 through 1963, fourteen flood retention dams were built in the upper Coon Creek watershed, under Public Law 566. Prior to that, major flood events occurred 2-3 times per year (Kaap and Radke 2000).

Aldo Leopold was concerned also with the question of public versus private forest lands (Leopold 1939, Leopold and Hickey 1943). Many conservationists thought that public protection was the only answer to community problems caused by erosion and poor land management practices. Leopold's philosophy on the human relationship to the land developed over his lifetime. He recognized that conservation involves a broader view than acquiring and preserving public lands. While formulating the definition of a land ethic, he focused increasingly on the individual farmer and landowner (Leopold 1939).

In a time when deforestation is a global issue, it is crucial to illustrate examples of successful regeneration of

(photo: Martha Kelty Roldán)

Figure 16. Contour strips and regenerated woodlots, Coon Creek Watershed, 2001.

woodlands. Especially noteworthy is this case, where reforestation is one consequence of sound agricultural practices. Since the majority of forested land in the United States is in the private sector and only a small percentage of those landowners have conservation plans (Dombeck 2002), understanding spatial patterns of reforestation is fundamental to devising management practices for the future.

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