

SEDIMENTATION ANALYSIS ON STEEP SLOPE AREAS

DEVELOPMENT:

Western North Carolina

by

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Abstract:

This project focuses on the rapid development and its concomitant environmental consequences that threaten water resources and the quality of life in Western North Carolina (WNC). The growing popularity of WNC, coupled with the region's topography means that builders are increasingly developing on steep slopes. The influence of steep slope development on sedimentation pollution and corollary hazards is investigated. In particular, the focus is on land development and its potential link to the probability of landslides. . A detail analysis was conducted for potential factors that induce landslides, particularly concentrating on Macon County and Watauga County. Most of the analysis applies Geographic Information System (GIS) technology, therefore gathering data, analyzing them, making them compatible to ArcGIS and developing intuitive map making for ease of visualization. How to expand the conclusions from this project to other steep slope areas are briefly described. Slope is analyzed by different percent degree categories, with a lens on the current legislation of 40 percent degree as the initial point of steep slope definition.

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GENERAL BACKGROUND:

Wherever grasslands and forest are replaced by rooftops and roads, the movement of water across the landscape is radically altered. Some of these changes can have severe consequences, particularly as a result of disrupted runoff processes. Such effects as flooding, channel erosion, landslides, and destruction of aquatic habitat have been recognized for decades because of the loss of lives and damage to property that can result. With urbanization, stream channels expand catastrophically to consume adjacent land never before affected by either flooding or erosion, sediment inundates low-lying areas seemingly far away from active channels, stormwater facilities are overwhelmed by frequent flows far beyond their design capabilities and population of aquatic organisms are decimated. In small streams, draining lightly to moderately urbanized watersheds, these environmental and ecological consequences of increased water quantity generally overwhelm the effects of impaired water quality¹. Nearly all these water quantity problems result from one underlying cause: loss of water retaining function of the soil in the urban landscape. This loss may be absolute, if the loose upper layers of the soil are stripped away to provide better foundations for roads and buildings, as steep slope development is happening in WNC. The loss may also be functional, if the soil remains but paving or rooftops block absorption of precipitation. In either case, a stormwater-runoff reservoir of tremendous capacity is removed from the stormwater runoff system. Water that may have lingered in this reservoir for a few hours, a few days, or many weeks now flows rapidly across the land surface and arrives at the stream channel in short,

¹ Field evaluation of permeable pavement systems for improved stormwater management, Derek B. Booth, Jennifer Leavitt
Journal of the American planning association, Vol. 65, 1999 [pages]

concentrated bursts of high discharge.

Degradation of soil water and water quality appear to be two of the biggest problems associated with environmentally insensitive development operations. The goal of a developer is usually to remove runoff from the altered area as quickly as possible, regardless of where the water goes or what it passes through along the way. There are state-approved runoff protection plans that are often followed; however, their effectiveness remains in question. A sample case is pictorially shown below, where a runoff protection system composed of a sequence of nets meeting the state standard, was installed though its functioning on a rainy day is questionable.



Figure1: A photograph of the failure of the net system in July 17th, 2007, Asheville. The rainfall event inducing this sediment erosion was usual for this summer period. Note the sequence of nets and the large sediment erosion passing through the nets. Currently, this kind of protection meets the state ordinance.

This particular case occurred in north Asheville City, on a day where the rain intensity was lower than 30 mm/h and the duration was less than 120 min and well below the 25-year storm water design value. Erosion is the process by which the land surface is worn by the action of water, wind, or ice. In contrast to geologic erosion, the erosion accelerated by the disturbances of humans, through agriculture and non-agriculture uses of the land, has caused several inches of erosion over the last 100 to 150 years. Sedimentation is the process that describes soil particles settling out of suspension as the velocity of water decreases.

Why are we interested in sedimentation. Sediment transport affects water quality and its suitability for human consumption or use in various enterprises. Numerous industries cannot tolerate even the smallest amount of sediment in the water that is necessary for certain manufacturing processes, and the public pays a large price for the removal of sediments from the water it consumes every day.

Sediment not only is the major water pollutant, but also serves as a catalyst, carrier, and shortage agent of other forms of pollution. Sediment alone degrades water quality for municipal supply, recreation, industrial consumption and cooling, hydroelectric facilities, and aquatic life. In addition, chemicals and waste are assimilated onto and into sediment particles. Ion exchange occurs between solutes and sediments. Thus, sediment particles have become a source of increased concern as carriers and storage agents of pesticides, residues, adsorbed phosphorus, nitrogen, and total organic compounds, and pathogenic bacteria and viruses.

Steep slope, mountain top development means clear-cutting the current forest/vegetation to build housing. Scientific studies for more than twenty five years have proven over and over that clear cutting causes very large increases in landslides. The frequency of mass erosion (landslides, debris flows, earthflows, etc) is strongly linked to the type and intensity of land treatment in the basin. Most mass movement are associated with roads and their drainage system, many originate on open slopes after development has raised soil water tables and decreased root strength.

INTRODUCTION:

The communities in WNC are aware of the dangers steep slope development can have on both human lives and the environment. To control the speed and scale of steep slope mountain developments, the WNC is currently adopting an NC construction act that may not be optimum for WNC given its topography. The NC Slope Construction Act requires special permit for development on slopes exceeding 40 percent. Whether this threshold is adequate or not for WNC has not been rigorously explored, the subject of this work is based on it. The reason the focus of this MP is on WNC is due to the fact that WNC is mountainous yet appears to be the least regulated in terms of zoning ordinance (Figure 2). As table 1 states, under current state ordinance, land with slope between 25 percent and 40 percent are included, which means that nearly 25 percent of the area is 'escaping' steep slope legislation. Those 25 percent of area are free to be developed, with no specific permit concerning steep slope.

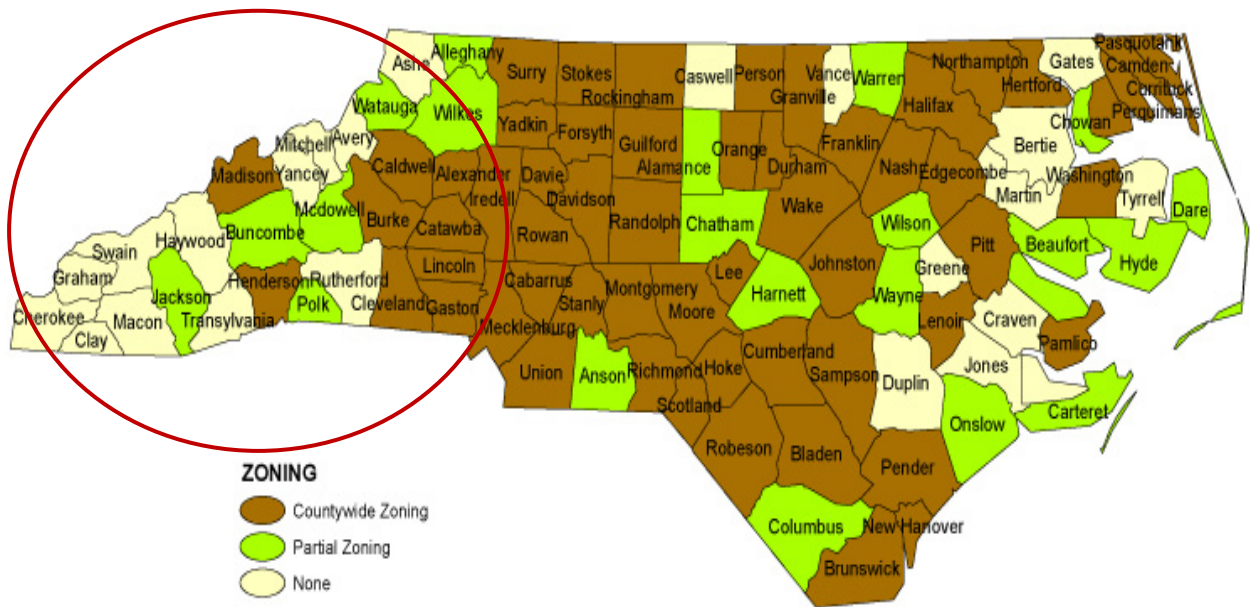


Figure 2: NC counties zoning condition². The red circle defines the general boundary of Western North Carolina (WNC). It shows that many of WNC counties do not have zoning or only have partial zoning regulation, while steep slope development requires zoning legislation for land development restriction.

Macon County	Area (Acres)	Percentage
<15	5083323	14.04
15-25	5034877	13.90
25-40	8946510	24.70
>40	17149274	47.36
	36213984	

Table 1: About 25 percent of area is escaping legislation based on current 40 percent steep slope definition.

THE SCOPE OF THE MASTERS PROJECT

To explore whether the 40% threshold is adequate, the relationship between steep slope development and sedimentation is developed with different factors and inputs. A model utilizing GIS and raster data is constructed to display the results in a manner useful for

² EPA zoning map for North Carolina Zoning: Zoning is a term used in urban planning for a system of land-use.

decision makers and permit identification of 'hot-spots' more susceptible to sediment production in the event of future development.

MATERIAL and METHODS

This preliminary research suggested that one way to move forward is to link hazards (e.g. probability of mudslides initiating) to topographic slope and other parameters (such as soil type, precipitation) so as to replace the 40 percent global threshold. Although state and local governments cited several studies when proposing law or ordinance, none of them was directly concerned with water quality or mudslides initiation. Therefore, an analysis between slope and potential for mudslides is a logical first step.

To analyze the relationship between steep slope development and sedimentation pollution, the conceptual framework in Figure 3 was employed: Land development removes part of the original forest or vegetation, which then leads to soil erosion. For the same stormwater production, the altered land cover and bare road will accelerate surface runoff, with huge sediment load being transported along with the water pathways. Moreover, there is larger possibility for landslides with slope development. In the end, precipitation will transmit sediments into nearby water body, while potential risk of landslides might result in unpredictable debris flowing into water nearby. The whole process is interpreted by the graph below. Based on this conceptual process, detailed analysis was made by different factors.

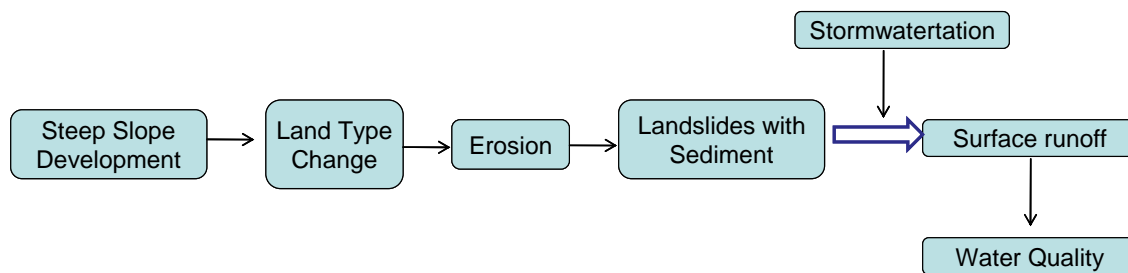


Figure 3: Conceptual framework linking steep-slope development to surface runoff and water quality

It is envisaged that this project will be a capstone experience building on my coursework and intern-ship. I will use the GIS technique to analyze the topography, land development potential landslide hazard in WNC (the red circle area in Figure 2). GIS data and application are major pieces of the analyses. Various information sources, such as NC geo-information center, county geology department and local NGOs, and university research centers were searched to obtain the necessary and compatible data. Moreover, data analyzed and transformation were used by excel and access, with some specific need for python scripts. Finally, with appropriate data already collected at a network of water quality stations, time series that uses such information was developed. Since ArcGIS is linked with R and MATLAB, the necessary data treatment can be carried out first, then it is transform into ArcGIS readable form for spatial analysis purposes.

RESULTS AND DISCUSSTION

1. Development Trends:

Table 2 shows the population and population density in Buncombe Jackson Counties, Macon County and Watauga County, in recent years - all three counties have positive population growth. From the statistics for 1990-2000 we should point out that the population increase did slow down from 2000 to 2006 (the 1990 to 2000 period with nearly 15% percent average increase for most of WNC counties). However, the speed of development did not decrease. Developed land in the Western mountains is projected to increase by 22 percent over the next 20 years, according to a report released by Environment North Carolina. Asheville is expected to see a 29 percent increase in developed land until 2027 while rural mountain areas in the region are projected to see an 18 percent increase in developed land³. The projections are based on development rates in North Carolina over the past twenty years. According to the report, North Carolina has lost 2.37 million acres cropland and forested land, and developed land in the state has grown by 1.86 million acres. Most of this development has taken place near major urban centers, with the biggest increases seen in the Piedmont region. In the mountains, developed land has increased 44 percent in the last two decades, from 591,000 acres to 852,000 acres. During the same time, forest land acreage decreased by 212,000 acres⁴. Combined with increase of population, it will result in more and more requirements for land development, though population growth is not the only reason, as will

³ Asheville is a city in Buncombe County, located in WNC.

⁴ Losing our natural heritage: Development and open space loss in North Carolina, by Environment North Carolina Research and Policy Center, April, 2007

be discussed for Macon County.

Census Population	Buncombe County	Jackson County	Macon County
Persons Per Sq. Mile, 2000	314.5	67.5	57.8
Population, 2000	206,330	33,121	29,811
Population 2006	222,174	35,562	32,395
Population Percent Change, 2000 – 2006	7.7%	7.4%	8.7%

Table 2: Population Growth Analysis and Comparison⁵.

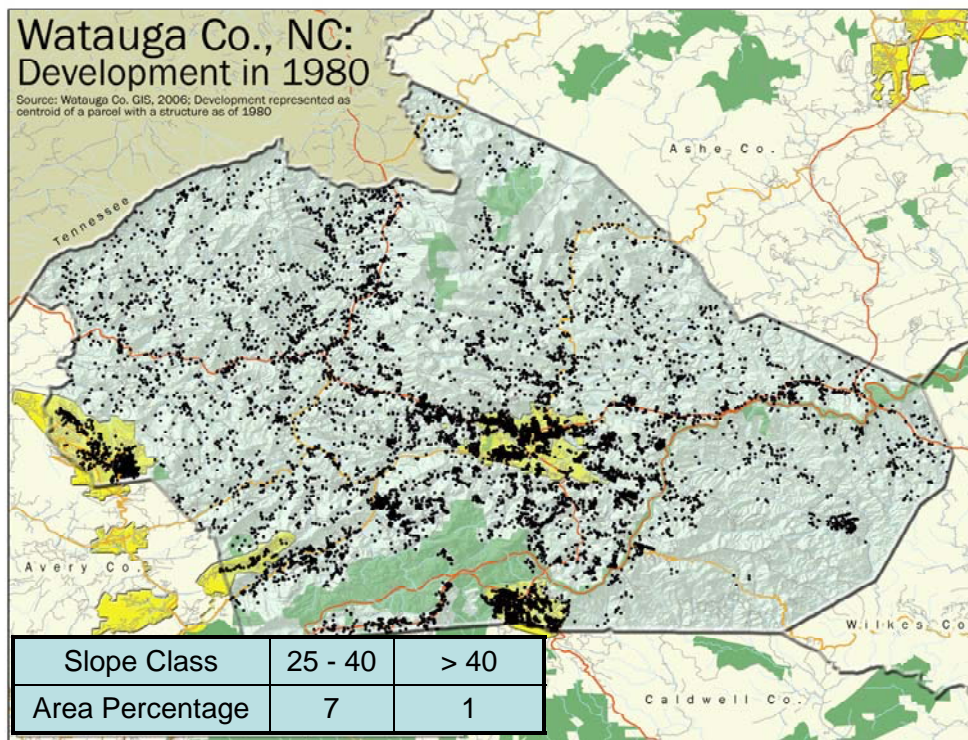
County NAME	Sum of Total Area (acres)	Sum of Developed Area (acres)	Percent of Developed Area (%)
1992			
Haywood	1436517900	84430800	5.877
Henderson	970935300	80221500	8.262
Jackson	1280673900	17431200	1.361
Macon	1346127300	17483400	1.299
Madison	1169457300	11762100	1.006
Swain	1399984200	4484700	0.320
Transylvania	985672800	44697600	4.535
Watauga	809800200	18367200	2.268
2001		0	0.000
Haywood	1436517900	114110100	7.944
Henderson	970935300	158181300	16.292
Jackson	1280673900	80423100	6.280
Macon	1346127300	76177800	5.659
Madison	1169457300	54816300	4.687
Swain	1399984200	42325200	3.023
Transylvania	985672800	71747100	7.279
Watauga	809800200	75100500	9.274

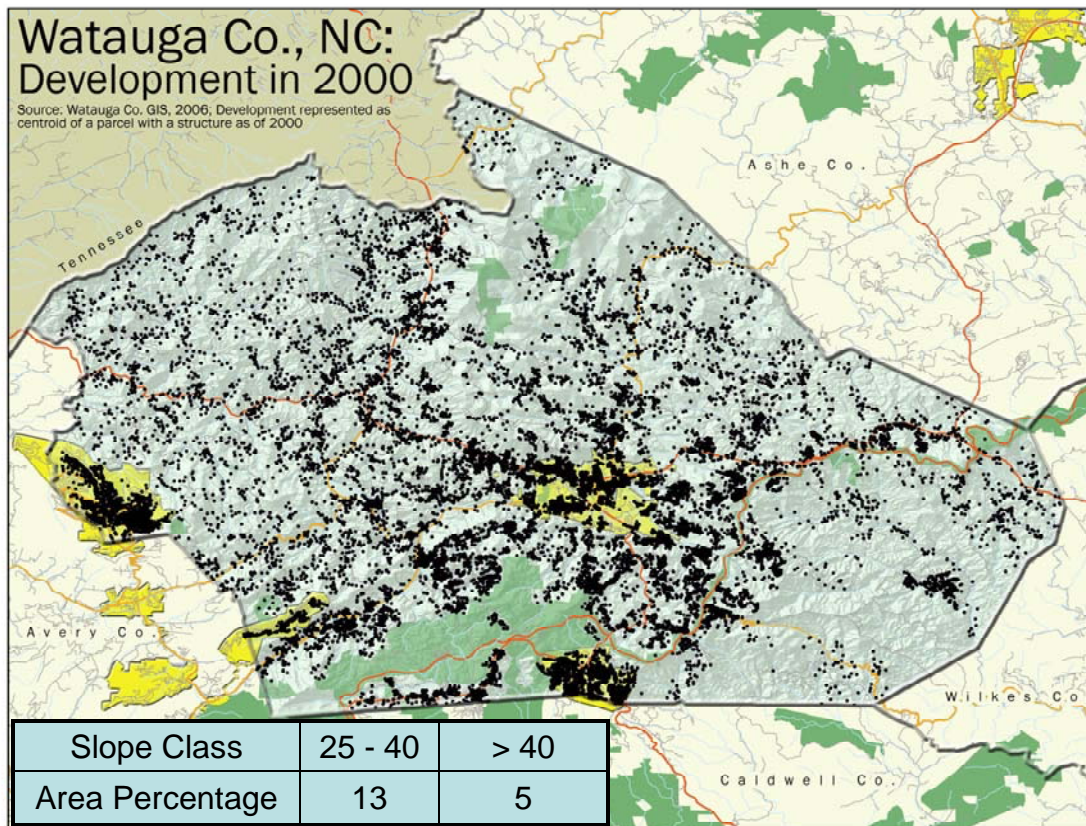
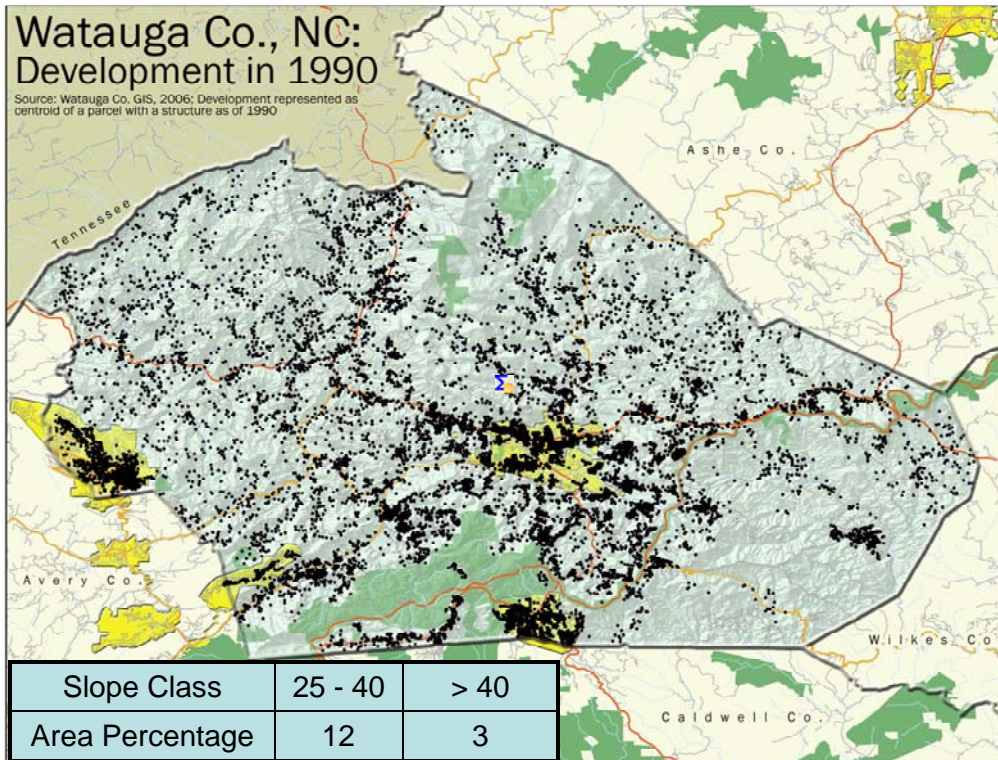
Table 3: Development Trends for most WNC Counties

⁵ North Carolina State Demographics, office of state budget and management, population estimates and projections, http://www.osbm.state.nc.us/ncosbm/facts_and_figures/socioeconomic_data/population_estimates.shtm

Table 3 lists eight major counties in WNC, with their development trend from 1992 to 2001. During that period, the developed area increased sharply, especially for those “rural” counties: The developed area of Swain County has grown ten times during the ten year range, four times for Jackson County. The lowest development rate is Haywood County, with nearly 40 percent increase in development area. Updated land development data are not available for all counties listed in the table.

The next question is where are the new developments occurring? Take Watauga County for example, we can infer from the spatial patterns of land development in Figure 4 that about 2/3 of the new development is occurring on slopes between 25-40%.





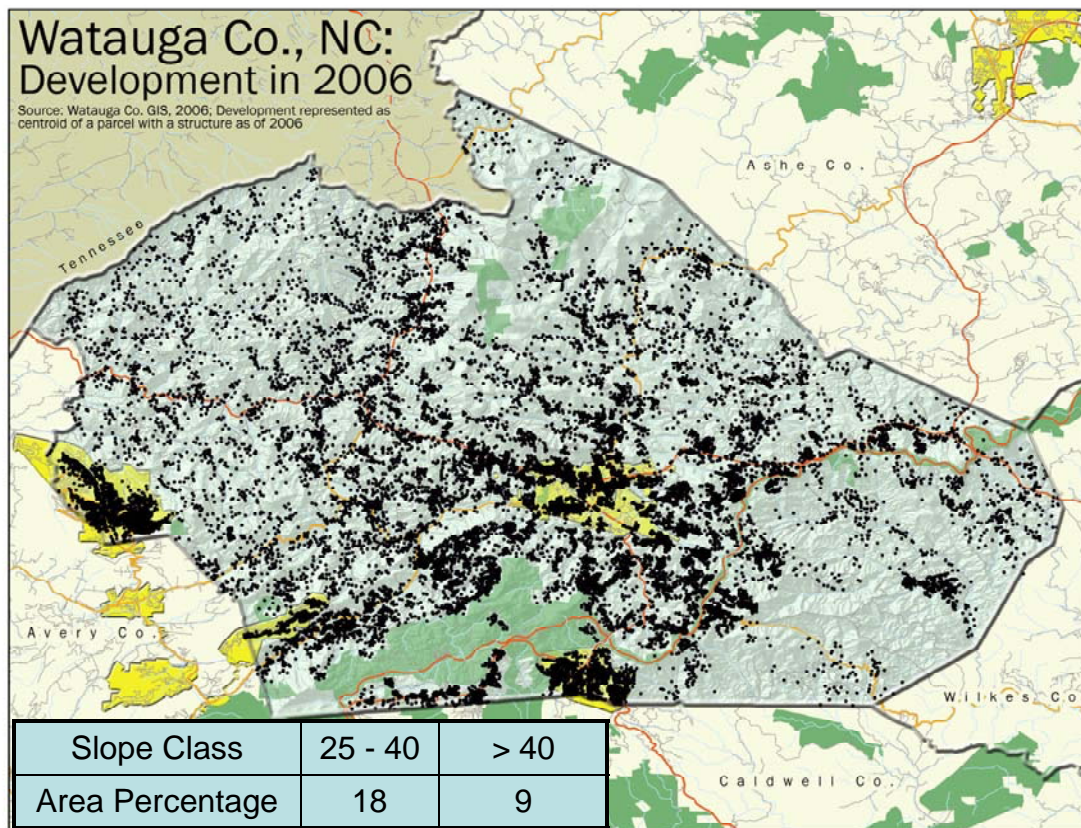


Figure 4: Watauga County development density of structure on steep slope areas from 1990 to 2006. Green areas represent protected land, and yellow areas show major towns. Black dots reflect the development sites.

In Watauga County, the developments from 2005 to 2007, summarized in figure 5 suggests that the number of development on slopes smaller than 25 percent are comparable to developments on slopes larger than 40

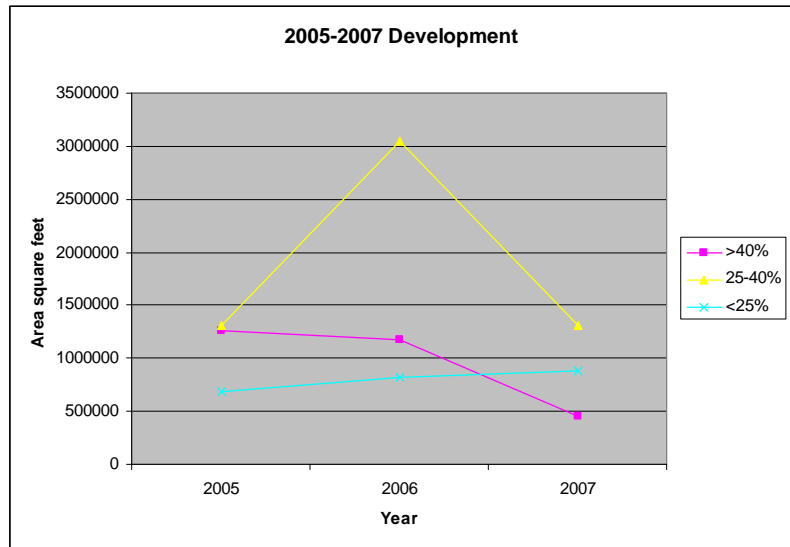


Figure 5: Watauga County Development Area for different slope classes.

percent, while the

developments on slope

between 25 percent degree and 40 percent exceed both. One reason might be because of the State ordinance, which only applies for development on slopes larger than 40 percent.

2. Landslide and Slope

We analyzed the initial points of landslide, which typically occur when the slope material becomes saturated with water, and then develop into debris or mud flow. Based on my research, 94 percent of all slides begin on slopes greater than 15 degree. One of the reasons that Watauga County and Macon County were selected for landslide hazard mapping was the large number of landslides triggered by the August 13-14, 1940 storm that caused fatalities and widespread damage in those two counties.

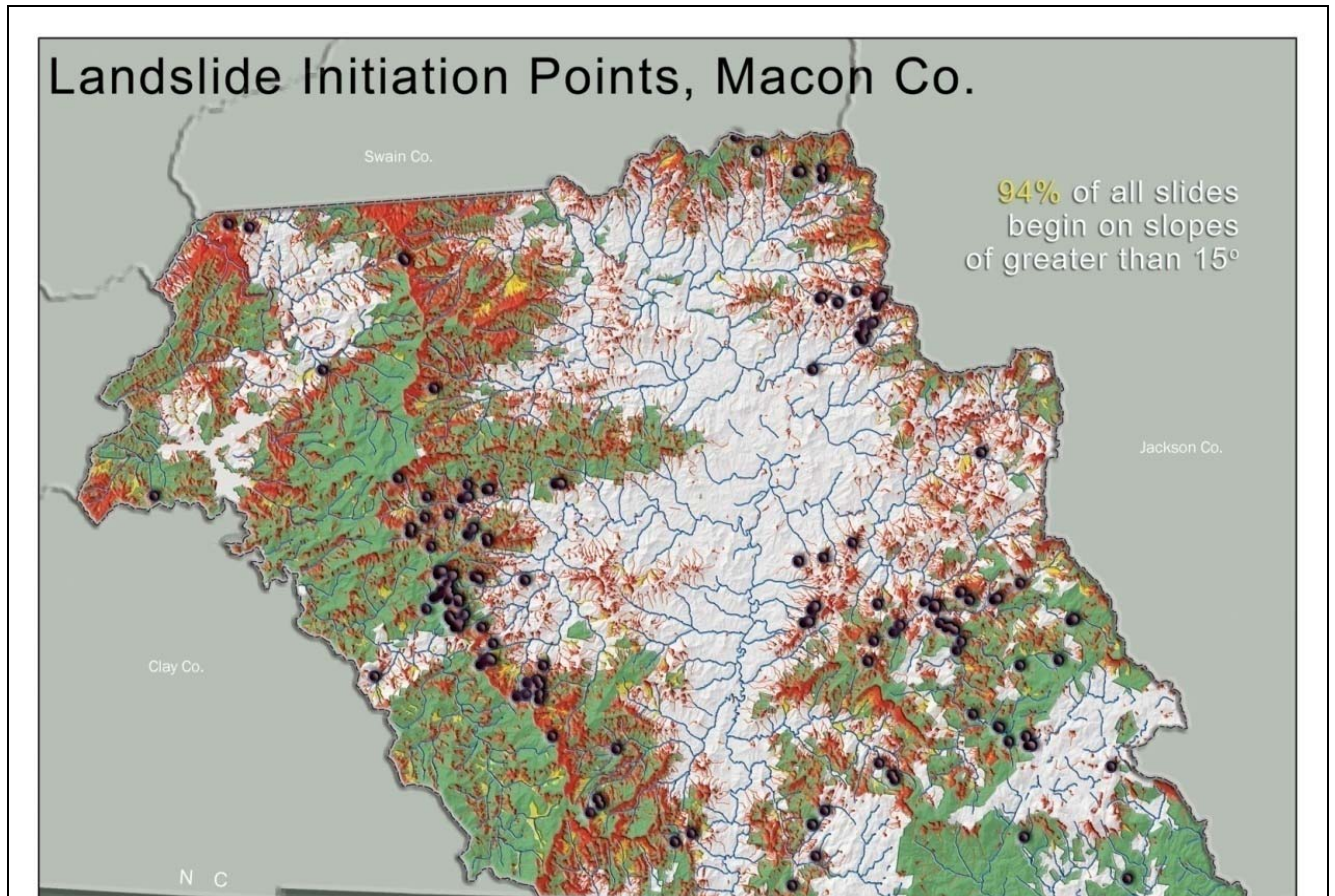


Figure 6: Landslide initiation point in Macon County. Yellow areas represent medium hazards downslope, while red areas reflect high hazards downslope. The green areas show protected lands.

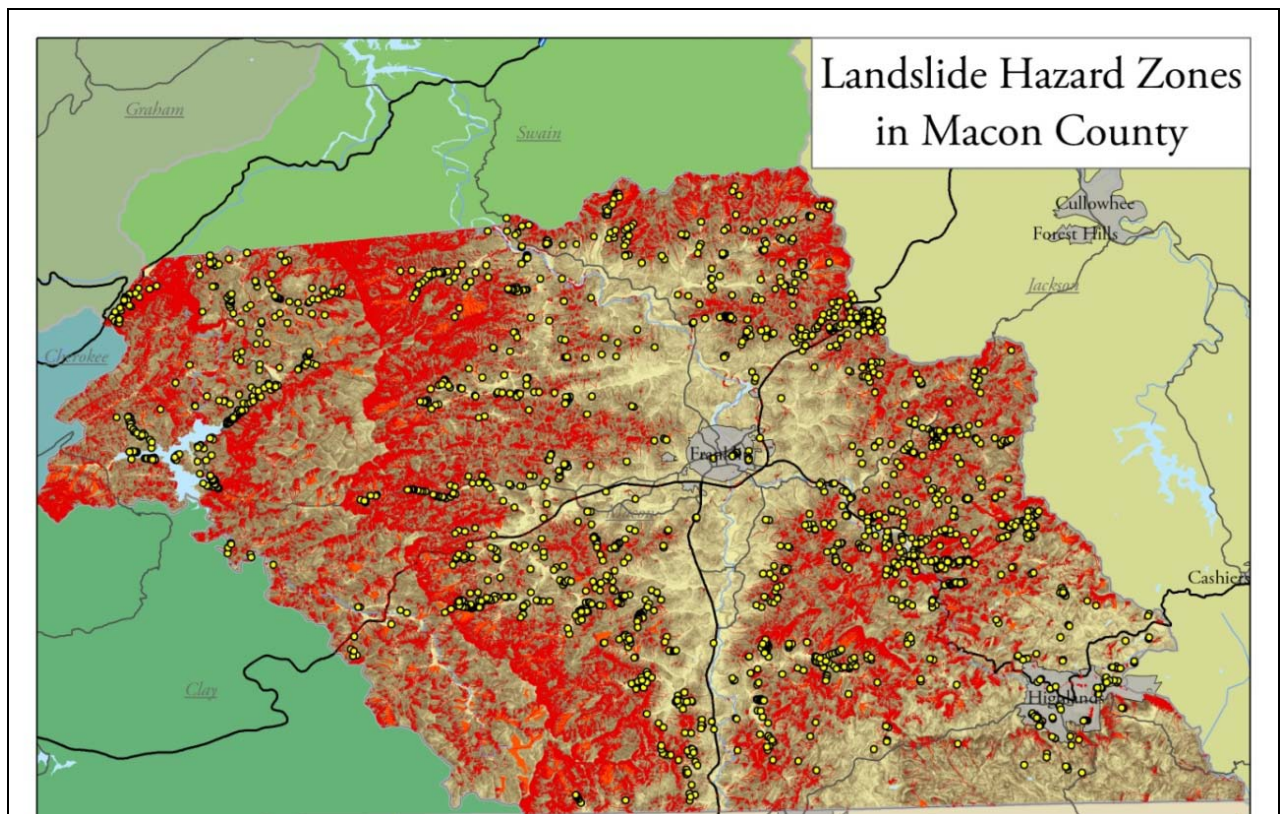


Figure 7: landslide Hazard Zones in Macon County. The red and orange show the hazard class as high and moderate. While the deeper the yellow is, the steeper the slope. Also, the yellow dots are the structures in hazard zones.

According to the figures above, landslide hazard areas occur where the land has certain characteristics, including a slope greater than 25 percent, the presence of impermeable soils, such as silt or clay, which are mixed with granular soils such as sand and gravel, and the presence of an alluvial fan, which indicates vulnerability to the flow of debris or sediments. Considering the three factors mentioned above, the landslide hazardous zone was calculated and shows in Figure 7. The results are presented as follows: high means an event likely to occur within 25 years, medium means an event likely to occur within 100 years⁶. Macon County faces greater danger of landslides. One visual example of the effects of land-slides and their termination point (in the stream) is presented in Figure 8.

⁶ Landslide hazard and risk assessment, department of geography, Makerere University, 12-23 September 2005.



Figure 8: Landslide hazardous Photo Top Left: Maggie Valley home destroyed by embankment failure, December 13, 2003. One occupant of the destroyed home was killed. Photo Top Right: Embankment failure-debris flow along the Blue Ridge Parkway triggered by rainfall from Hurricane Frances, Sept. 6-8, 2004. Photo Center: Home destroyed by embankment failure-debris flow near Jonas Ridge, Burke County during Hurricane Frances in 2004. Photo Bottom Left: Home destroyed by an embankment failure-debris flow in the White Laurel community during Hurricane Frances.⁷

The steep slope development will accelerate the occurrence of landslides. Figure 9 shows the landslide happened in Macon County. More than 60% of the landslides points happened on steep slope areas with slopes larger than 40 percent. However, when calculated in parcel area, more than 65% of parcels are built on area with slope between 25 percent to 40 percent. Therefore, parcel area (or number of developed parcel area) may be another factor for fingerprinting potential risks of landslide along with slopes.

⁷ Macon County View, Macon County GIS home, North Carolina

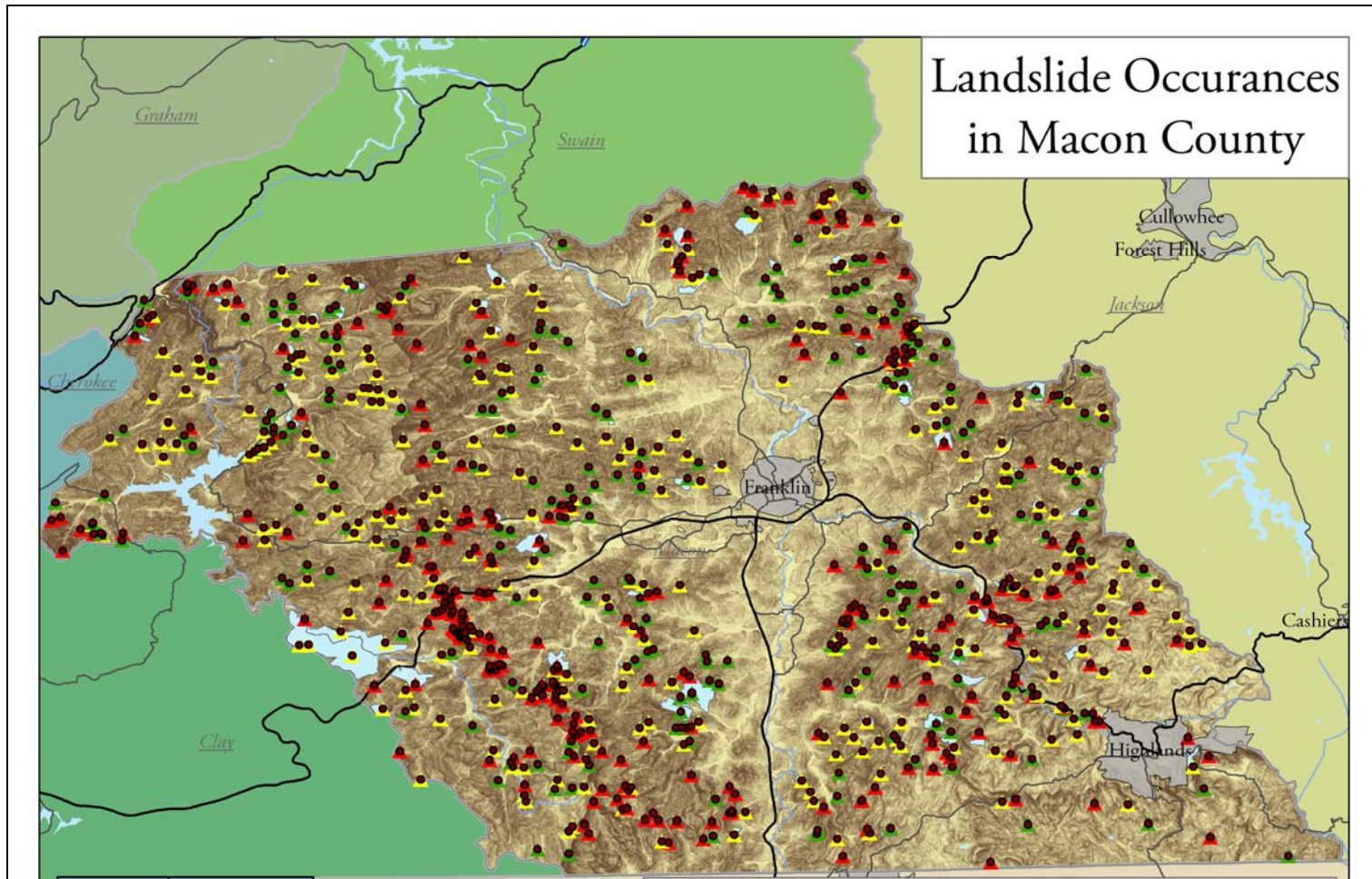


Figure 9: Relationship between landslide and slope of parcels for Mason County. Colored dots represent landslide location and its slope categories, and the background colors show the slope grade, steeper slope with deeper color.

The same methodology for Watauga County was repeated and the results are showed below as figure 10 and table 4.

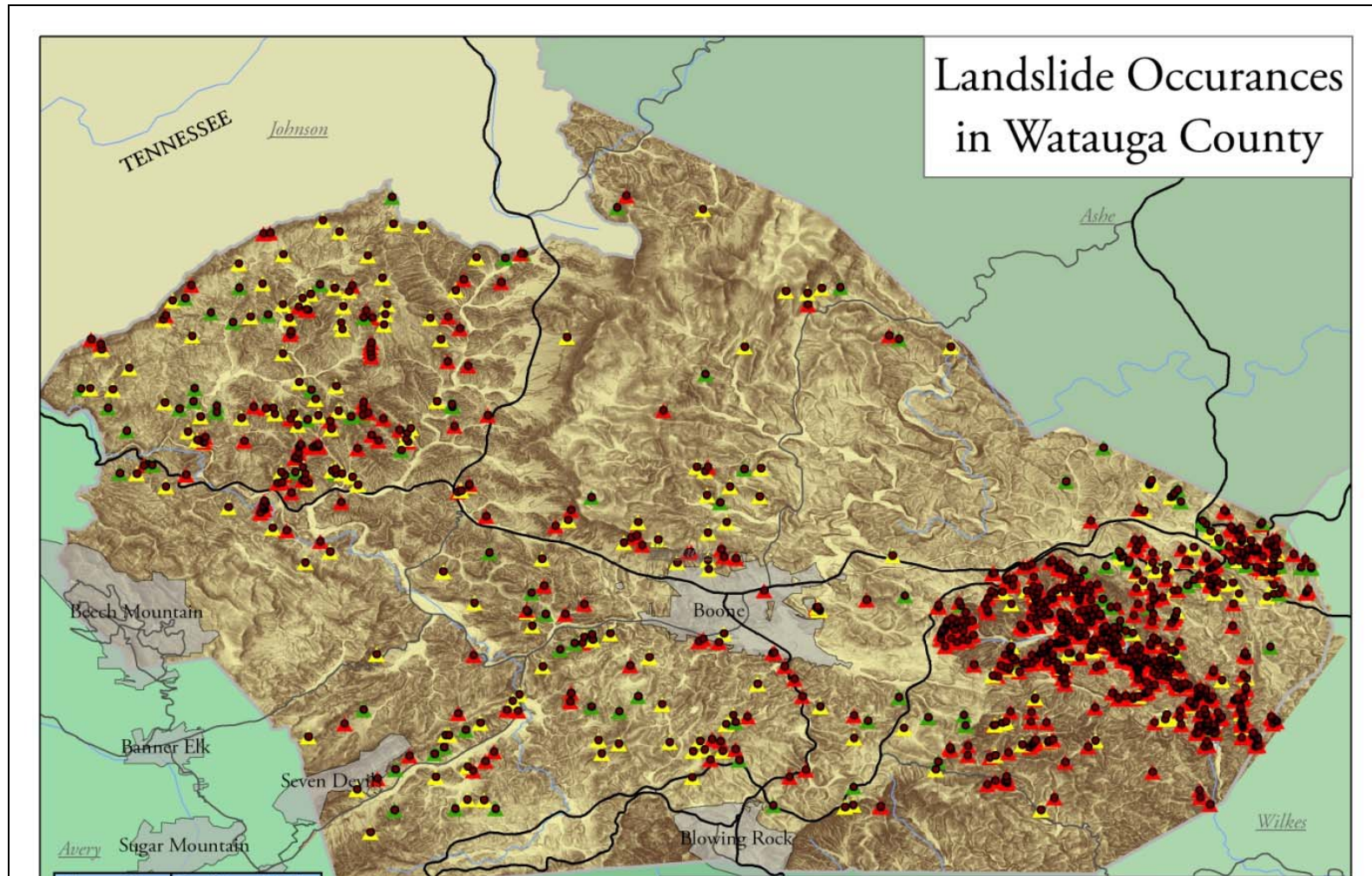


Figure 10: Watauga County Landslide Occurrences. Colored dots represent landslide location and its slope categories, and the background colors show the slope grade, steeper slope with deeper color.

Historical Development Trends				
	All Parcels		Landslide Occurance	
Year Built	No. of Parcels	Average Slope(%)	No.of Parcels	Average Slope(%)
1800-1899	157	26.74	24	34.46
1990-1949	2081	23.38	145	34.01
1950-1959	1295	22.25	52	33.82
1060-1969	2424	23.31	46	31.26
1970-1979	3602	25.54	71	34.5
1980-1989	3243	27.18	83	36.98
1990-1999	3528	27.99	90	37.88
2000-2008	3695	28.99	85	37.82
No Structure	25287	29.51	1042	39.16
Grand Total	45312	28.03	1638	37.79
Parcels by Slope Class				
Slope Class	No. of Parcels	Total Area (%)	No. of Parcels	Total Area (%)
<25%	19211	20.56	241	7.23
25% to 40%	17950	47.14	641	43.76
>40%	8151	32.3	756	49.01
Grand Total	45312	100	1638	100

Table 4: relationship between landslide and slope class

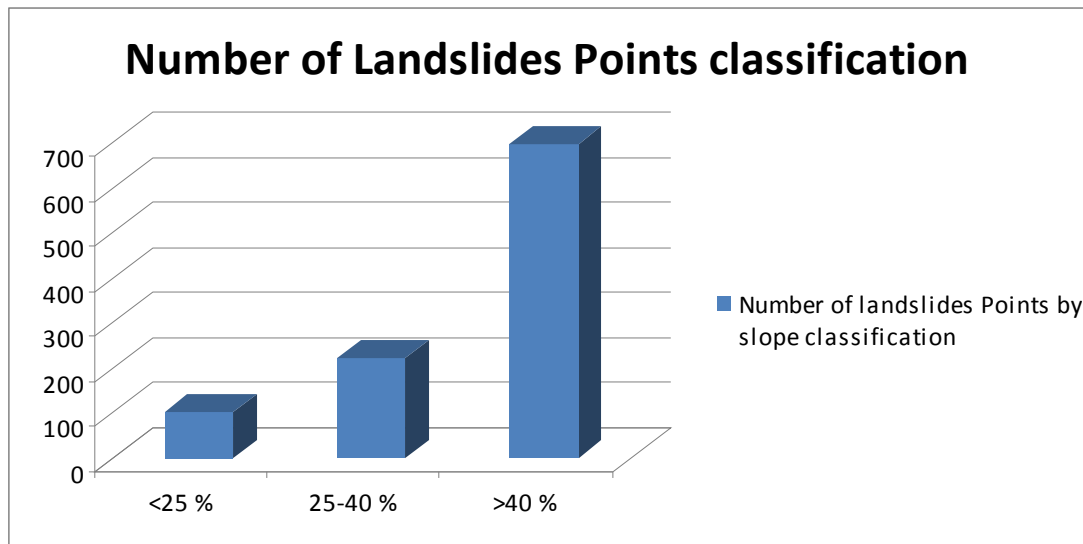


Figure 11: Landslides initial points with slope classification, Macon County, NC

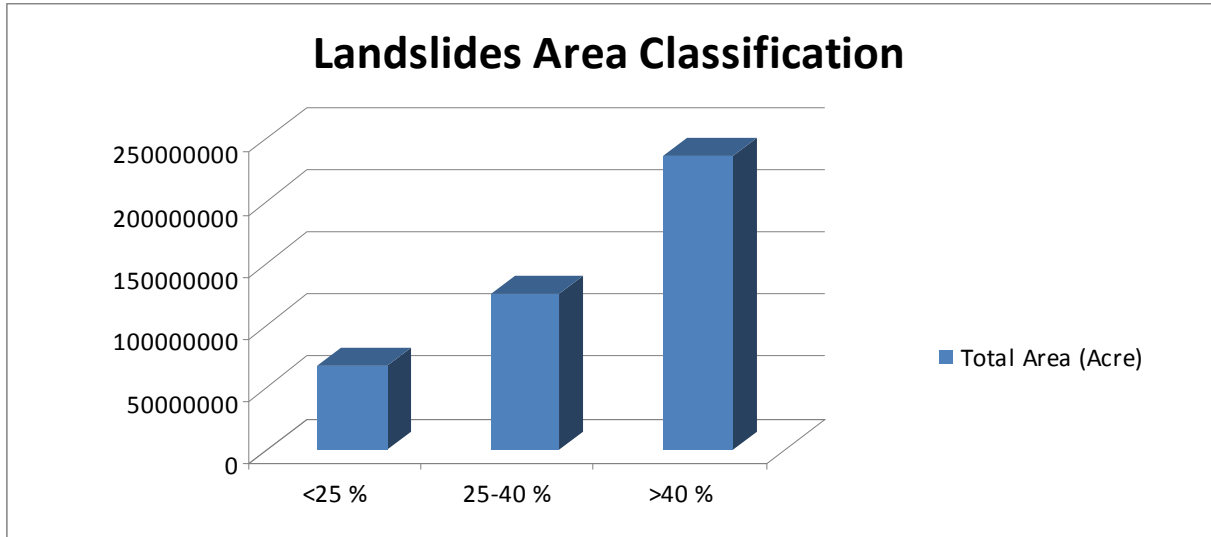


Figure 12: Landslides influenced parcel area (developed parcel) classification by three range of slope, Watauga County, NC

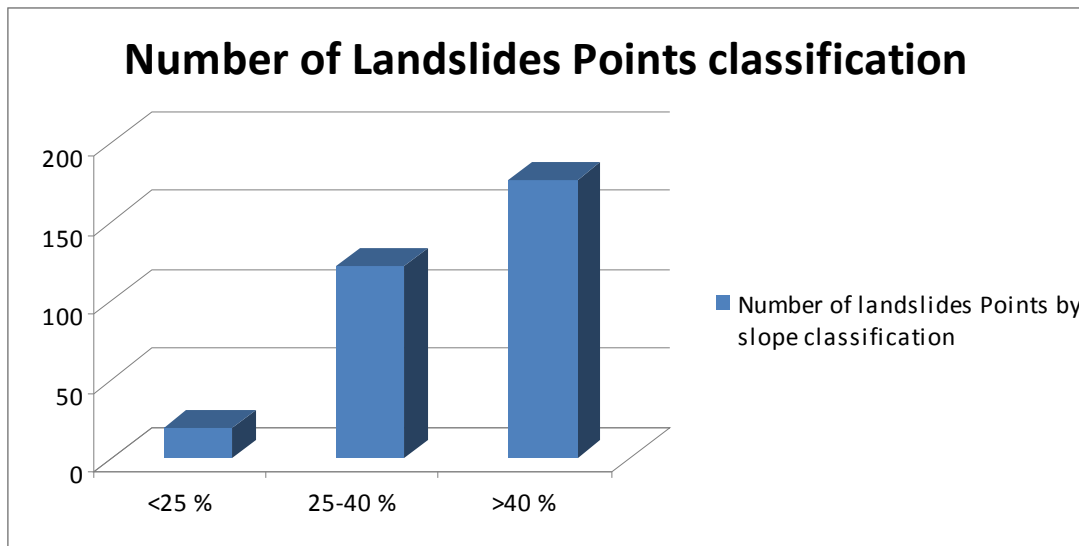


Figure 13: Landslide initial points classification by slope, Macon County, NC

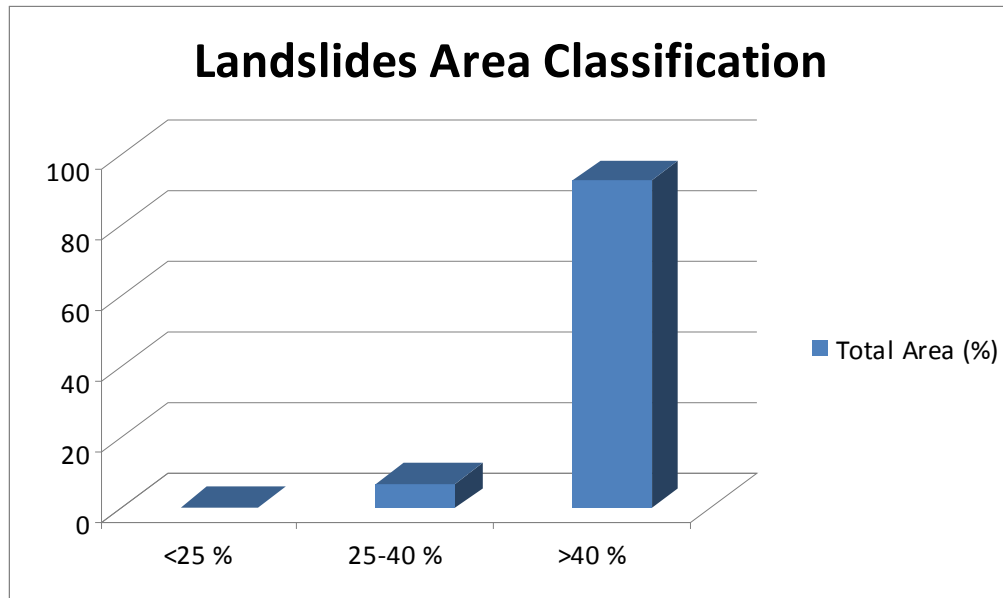


Figure 14: Landslide influence parcel area (developed parcels) with slope classification, Macon County, NC

Figure 11 to figure 14 indicated that for both Watauga and Macon Counties, areas with more than 40 percent slope run the highest risk of landslide. However, the area with slope from 25 percent to 40 percent has comparable probability of landslides as for areas on slope smaller than 25 percent for Watauga County. We compared both the landslides initial points and the landslides influenced area by slope classification and got the consistent results, which proved that 25 to 40 percent degree should not be neglected from the current slope legislation.

CONCLUSIONS

Although NC Slope Construction Act defined 40 percent degree as steep slope starting points, however, our analysis shows that area between 25 percent degree to 40 percent is undergoing

huge development and landslides hazard for some of the counties in WNC cannot be ignored. The development trend analysis shows that there is positive increase in land development for WNC much of it is on slopes between 25%-40%, thereby escaping the existing 40% legislative barrier. Both Macon County and Watauga County landslides analysis confirmed that hazards of landslides at the 25 to 40 percent degree are appreciable. Hence, legislative requirements beyond the 40% slope are warranted to minimize public hazard, especially in Macon and Watauga Counties.

ACKNOWLEDGEMENTS

The research is based on GIS data from Macon County and Watauga County GIS. I would like to thank the referrers for several important suggestions from Clean Water for North Carolina, Southern Environmental Law Center and my advisor Dr. Gabriel Katul at Duke University.