Current Results of Landslide Hazard Mapping in Western North Carolina
August 1, 2007

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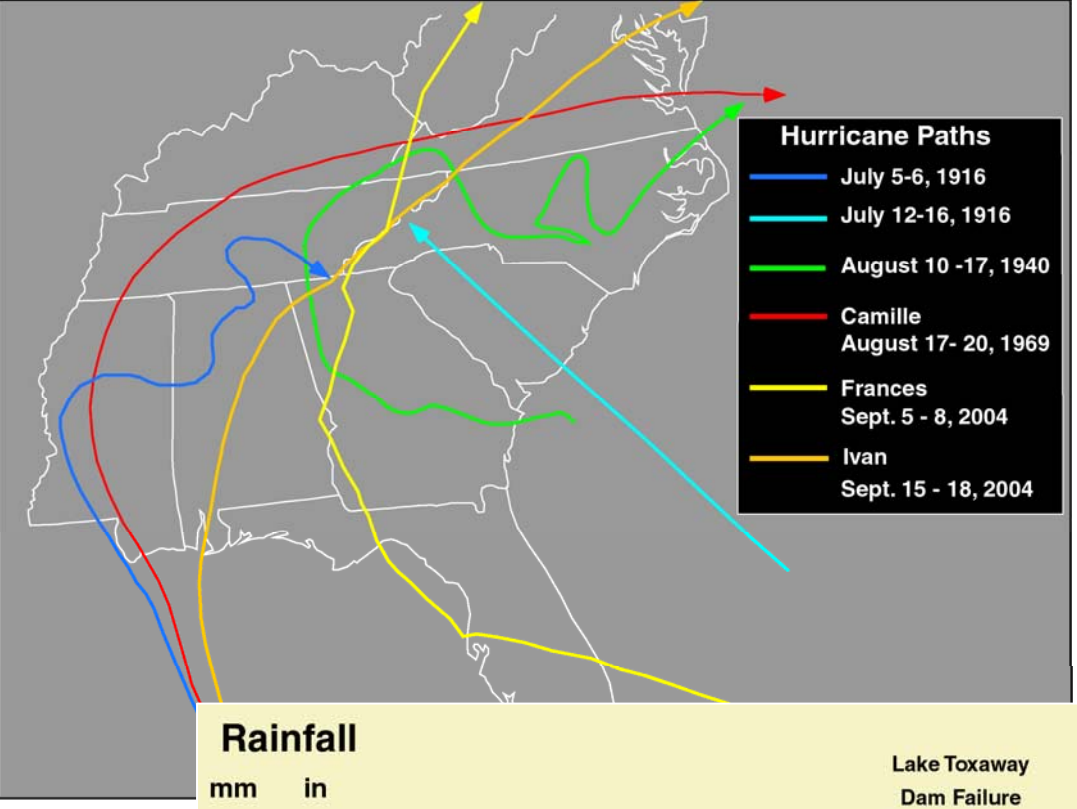
N.C. Landslides 1990 - 2006

Total

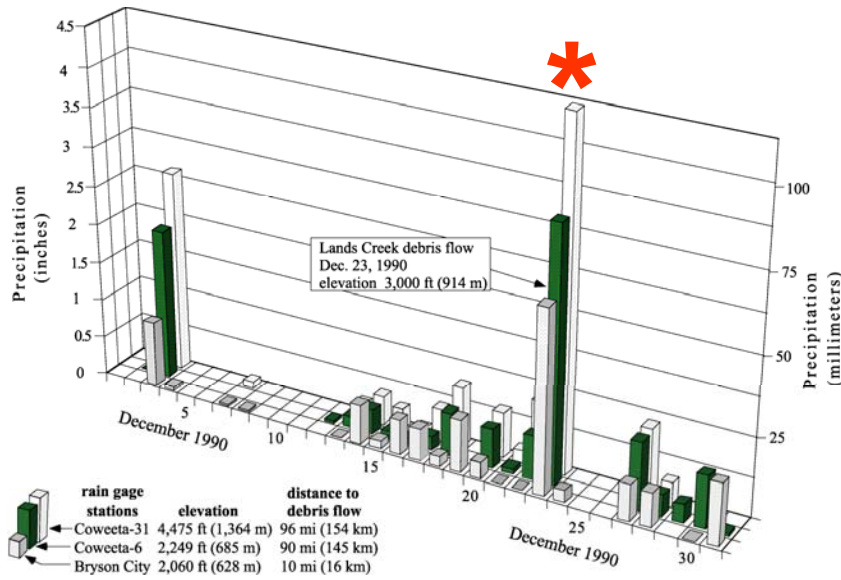
- 6 Fatalities
- 45 Structures Destroyed - Condemned

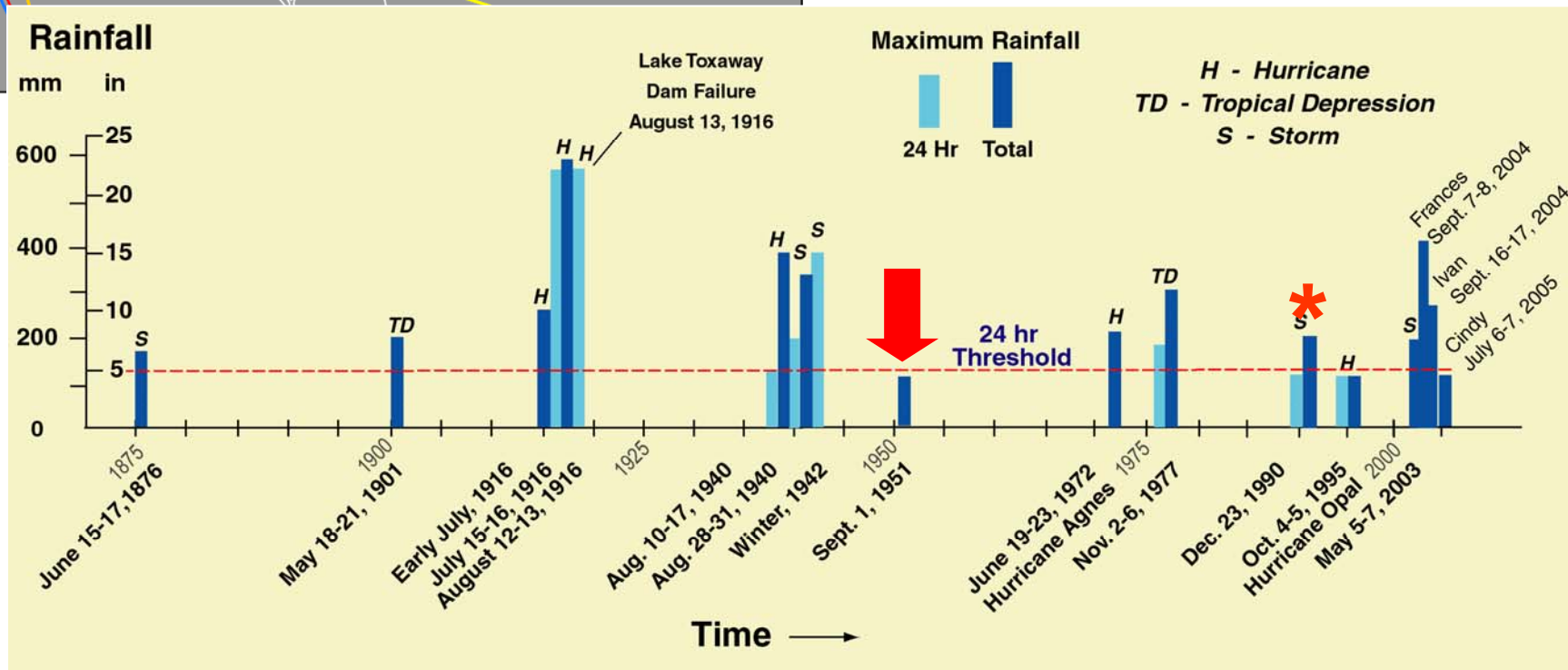
Modified Slopes

- 1 Fatality
- 28 Structures Destroyed - Condemned



Rainfall increases with elevation

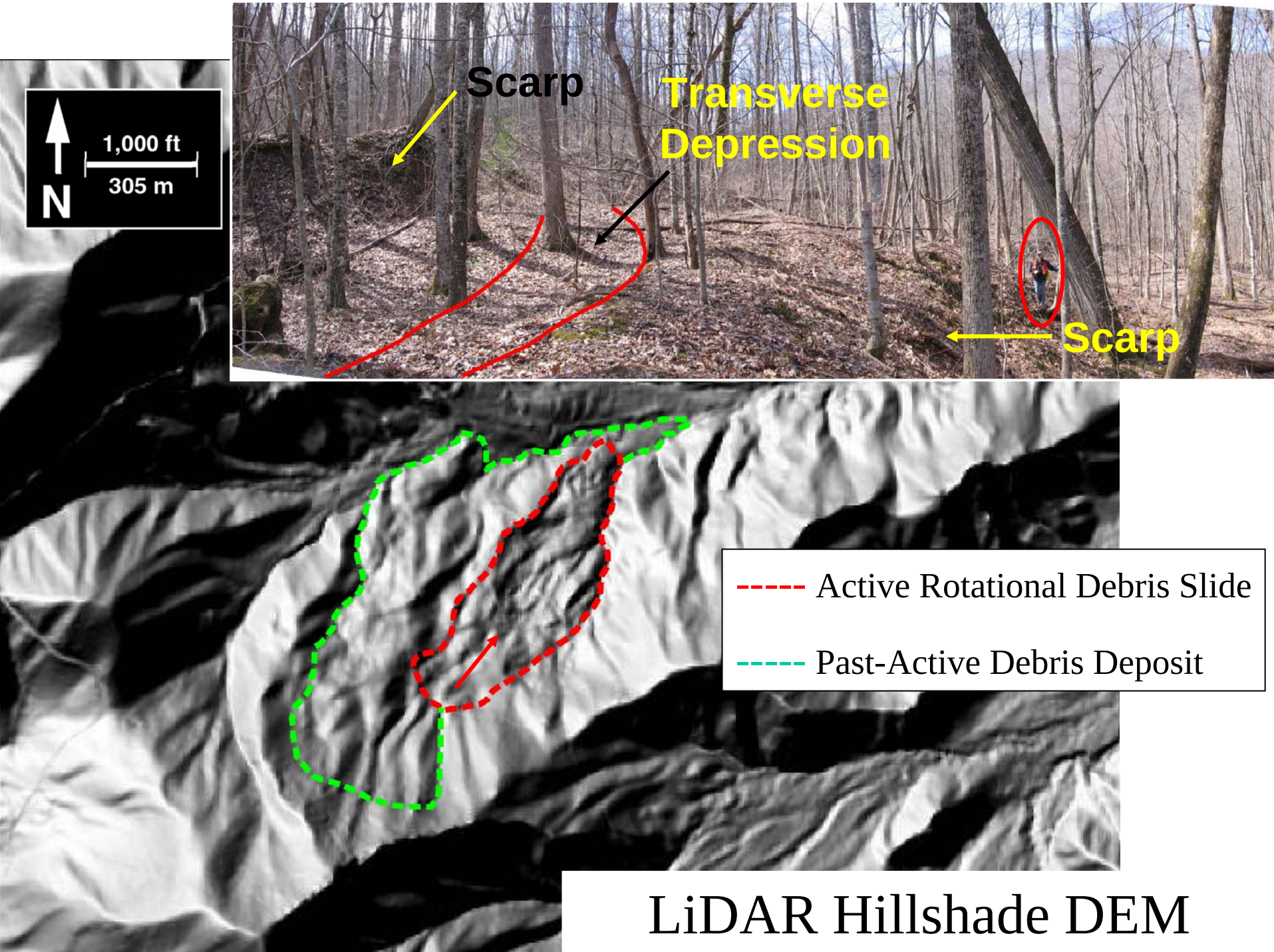




Peeks Creek Landslide – Sept. 16-18, 2004

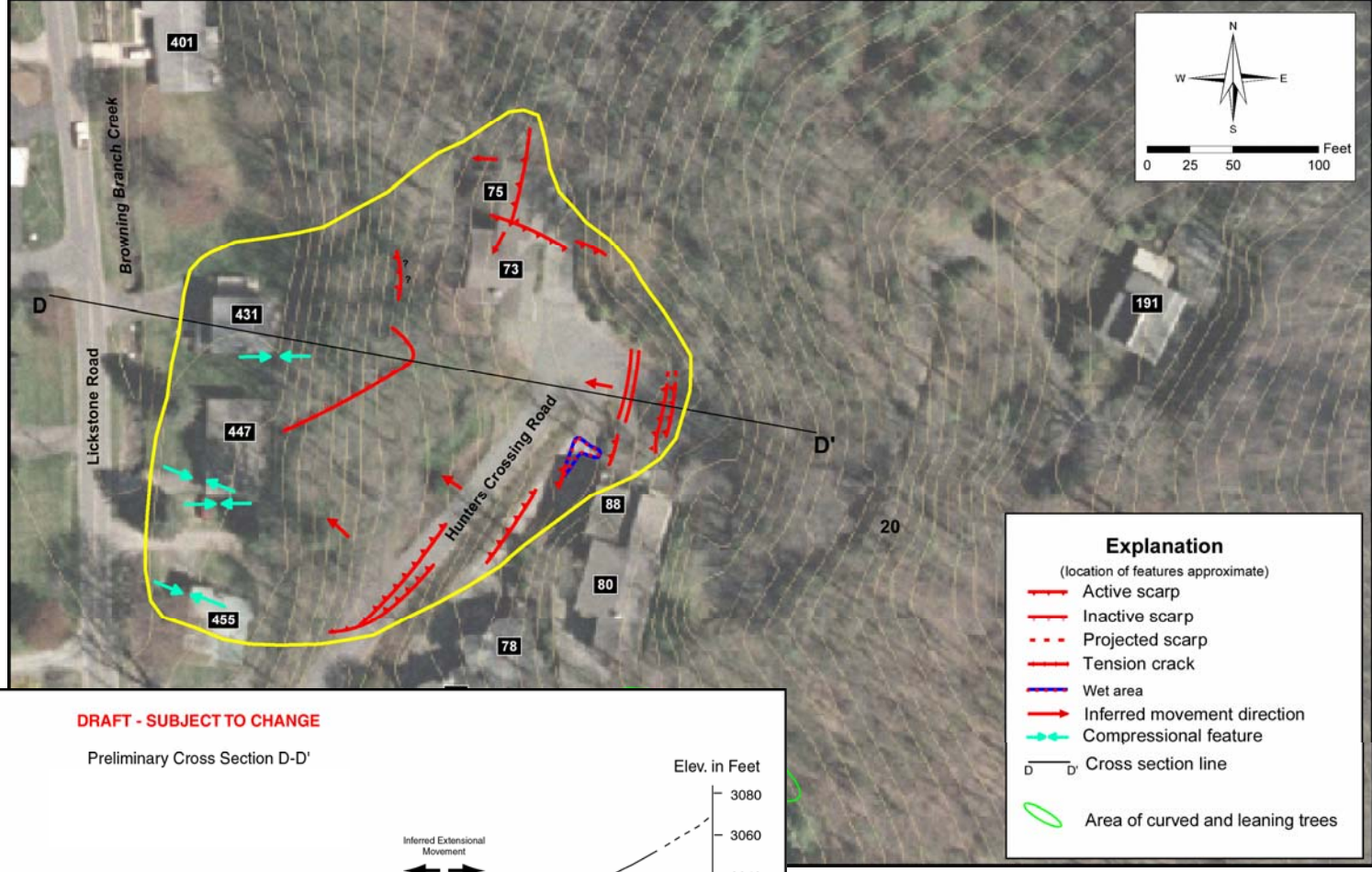
Rock Slides (Blue Ridge Parkway; December 2004 reactivation)

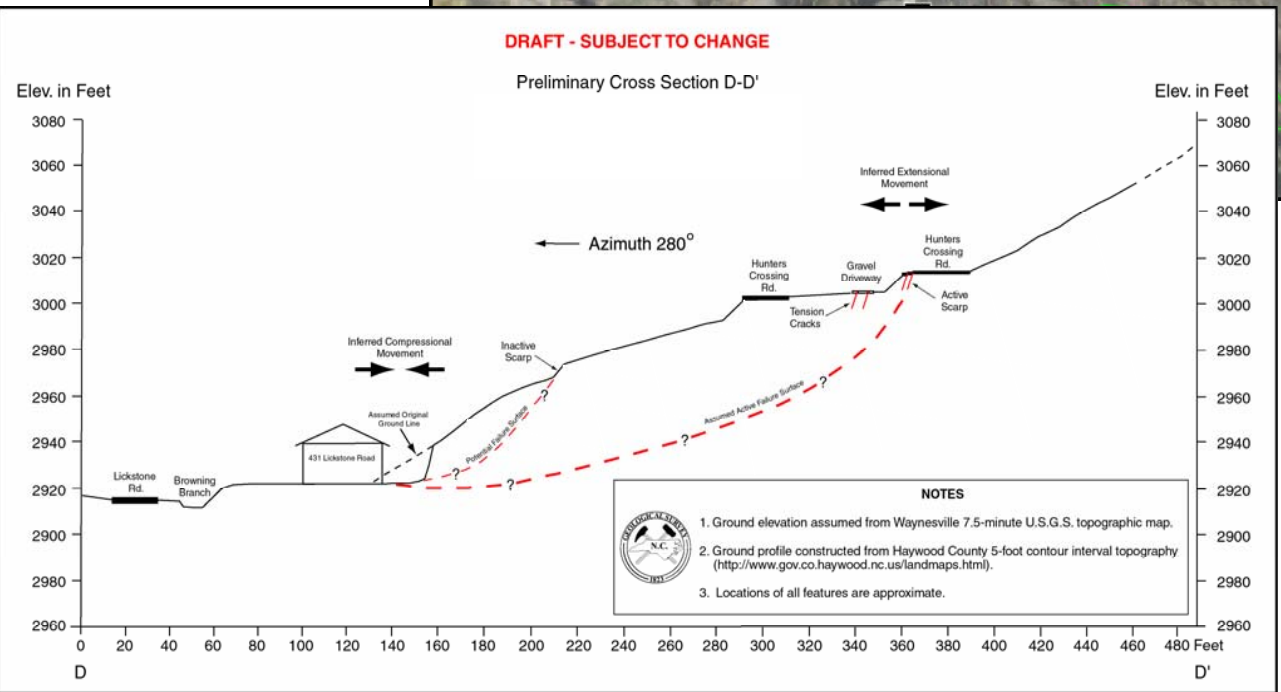
Broad River FD - Buncombe County - TS Cindy



LiDAR Hillshade DEM

Landslides in Weathered Rock

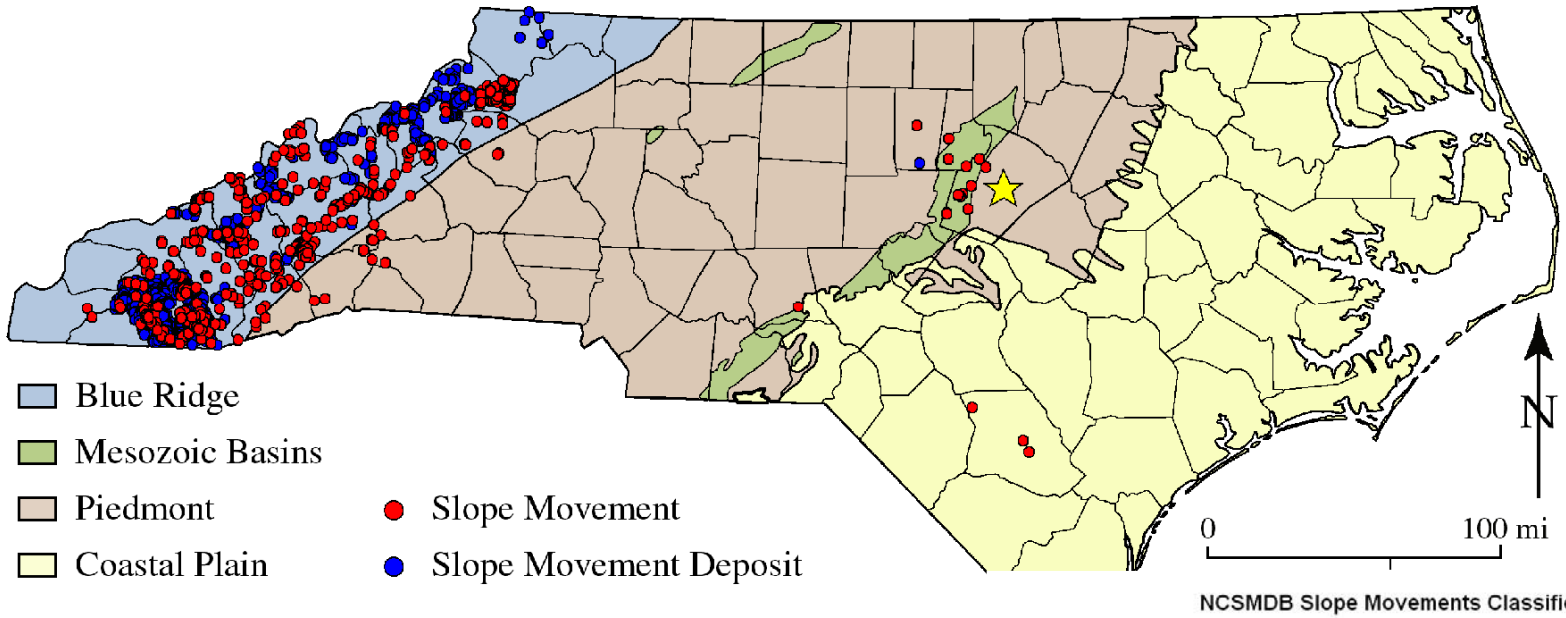




- 1.5 acres
- 50 feet deep
- 64,600 cubic yards
- 4 homes severely damaged
- 4 homes endangered

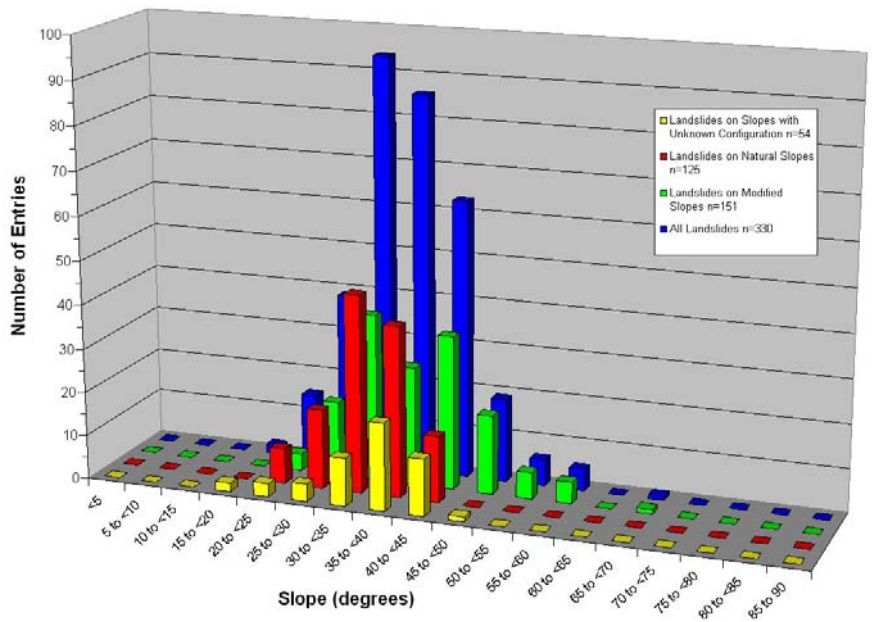
N.C. Slope Movement – Slope Movement Deposit Database

~~2,046~~ 4,550 Entries

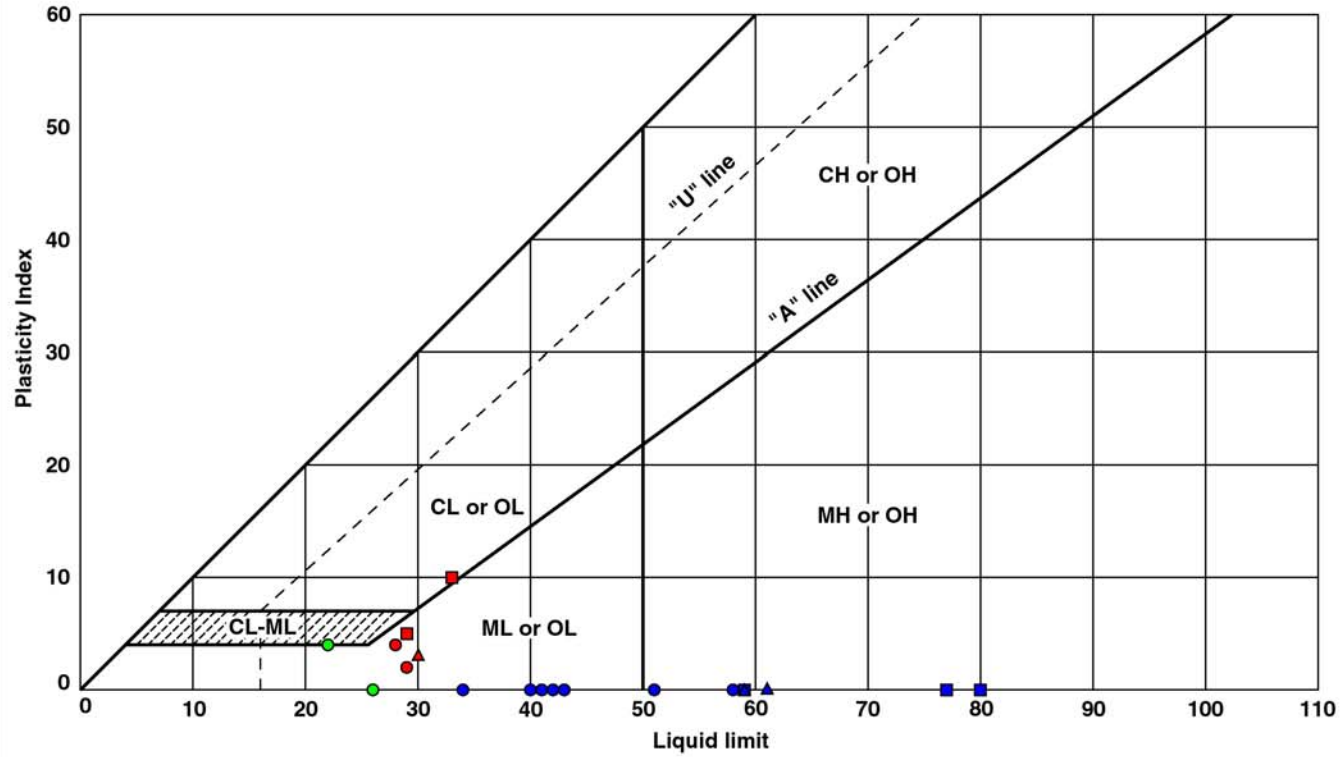


NCSMDB Slope Movements Classified by Slope

http://www.nconemap.com/



Data and analysis for policy decisions



Lands Creek Samples
- Colluvium 1
- Colluvium 2
- Fill

Wayah Debris Flow Samples
- Wayah debris flow

Peeks Creek Samples
- Debris flow track samples/ carbon samples
- Samples taken near headscarp
- Triaxial samples

Soil Sampling, Testing, and Analysis

Stability of Infinite Slopes with Seepage

Angle, β

Angle, β

Soil Properties
Friction Angle, ϕ
Cohesion, c
Unit Weight, γ
Sat. Unit Weight, γ_{sat}

Factor of Safety Calculation (FS_s)

$$FSs = \frac{c}{\gamma_{sat} T \cos^2\beta \tan\beta} + \frac{\gamma_{sat}-\gamma_w}{\gamma_{sat}} \frac{\tan\phi}{\tan\beta}$$

T

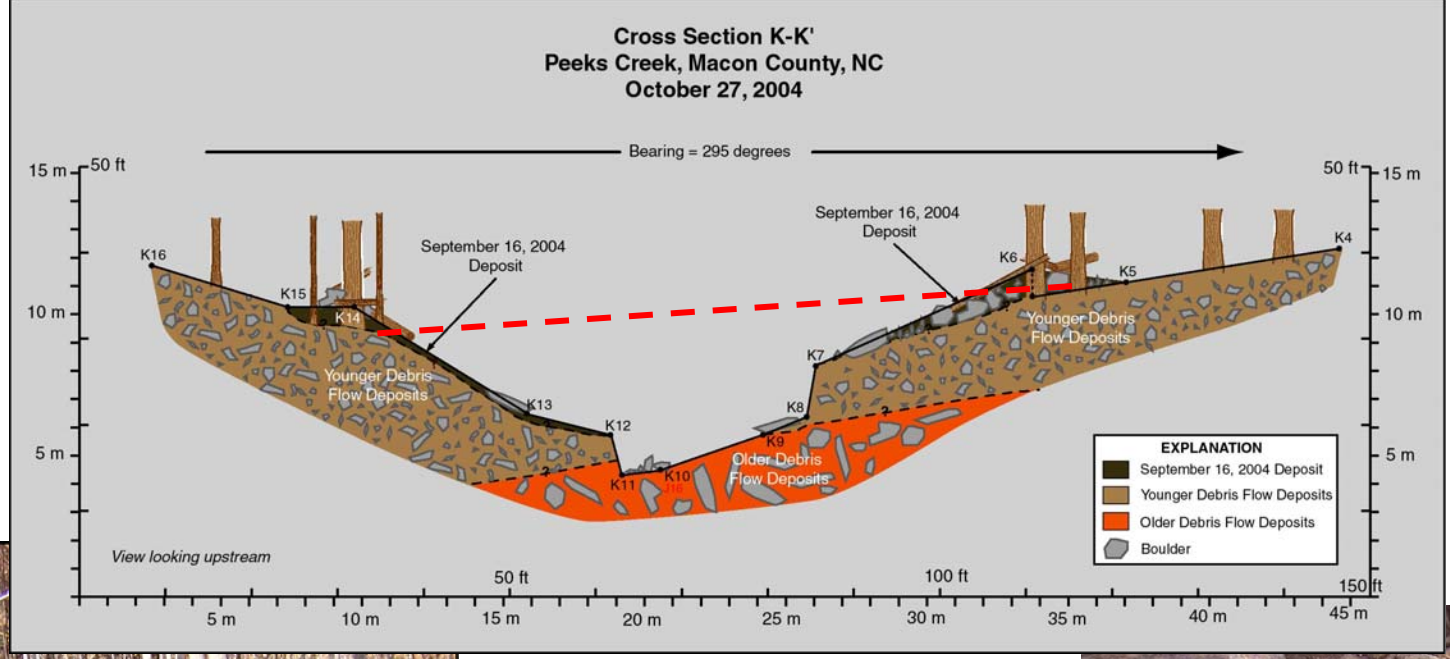
T= Soil Thickness

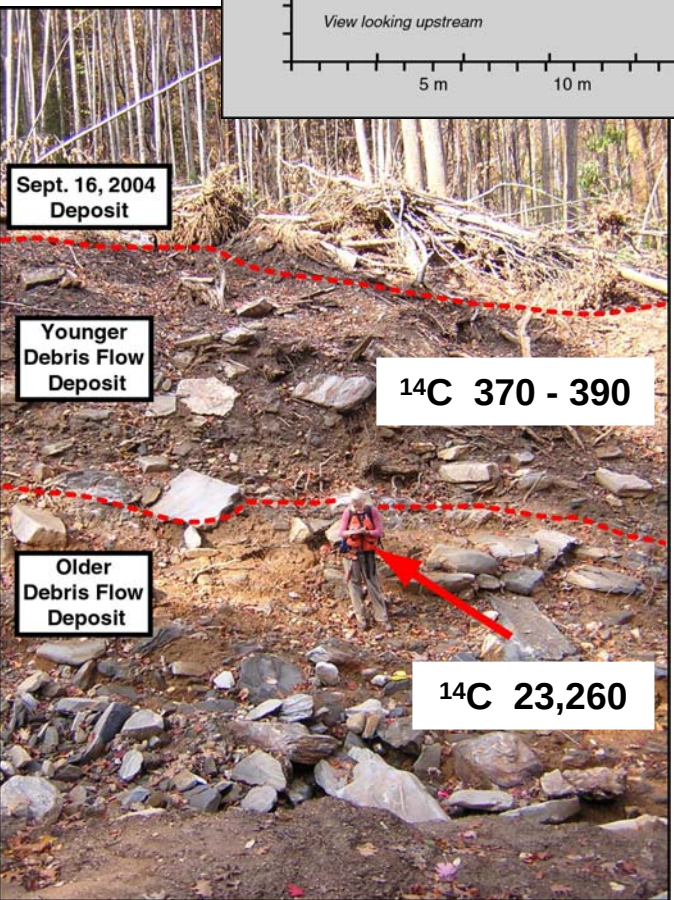
Dw = Depth of Groundwater

γ_w = Unit Weight of Water

Vegetation
Root Cohesion
Root Anchoring
Evapotranspiration

Dw





Macon County

All 33 Frances-Ivan debris flows occurred in areas of past debris flow activity

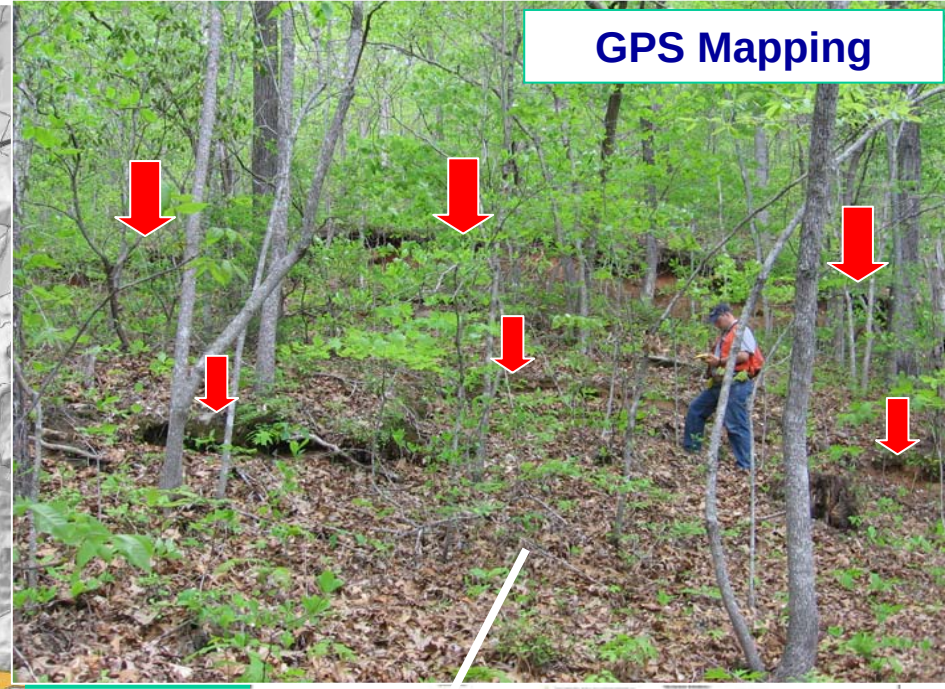
Debris flow tracks – debris deposits

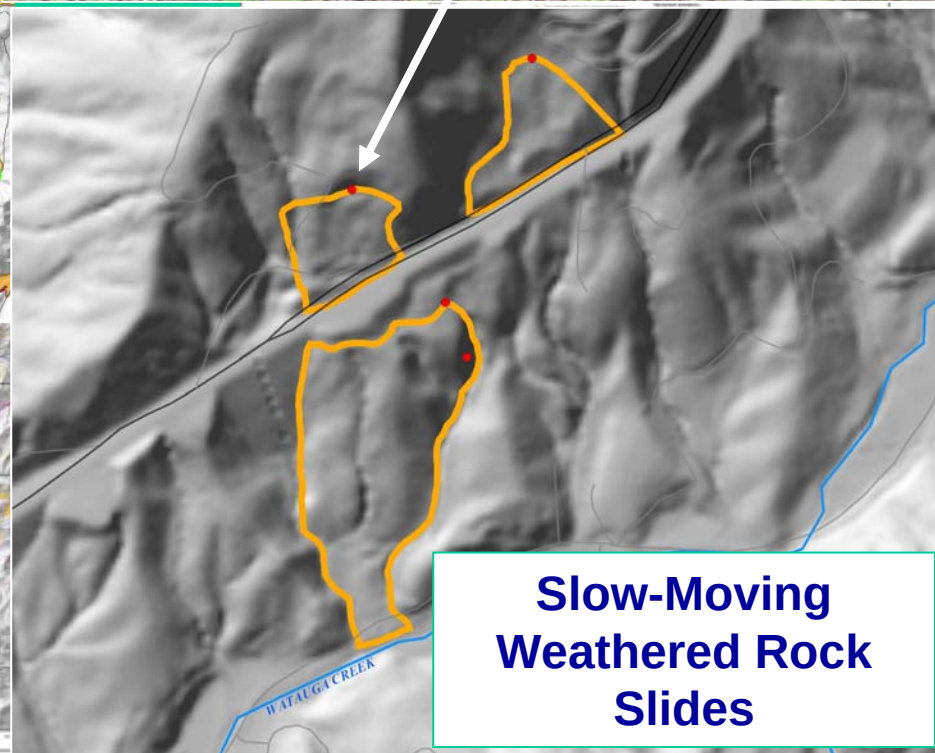
64

River

20 ft - 6m LiDAR DEM Hillshade

GPS Mapping





Slow-Moving Weathered Rock Slides

Data and Mapping Products In GIS

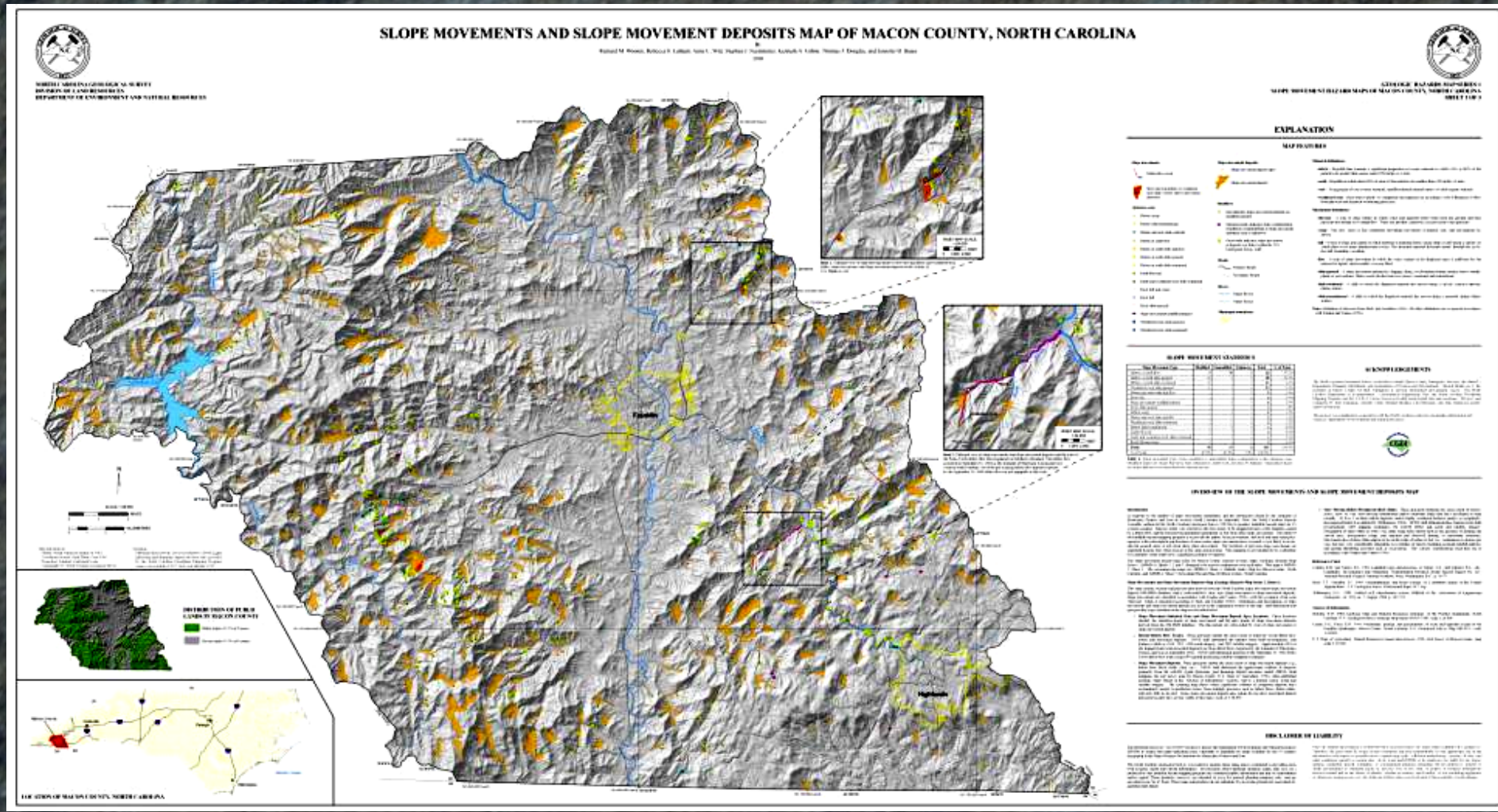
- Slope Movements / Deposits – where landslides occurred
  Slow Moving Landslides – where landslides are occurring

- Stability INdex Map (SINMAP) Results
  - where debris flows-slides might start

- Downslope Hazards – where debris flows-slides might go

- Bedrock Geology – mapped problematic rock units

The Products: 1) Where Landslides Have Occurred - or Are Occurring

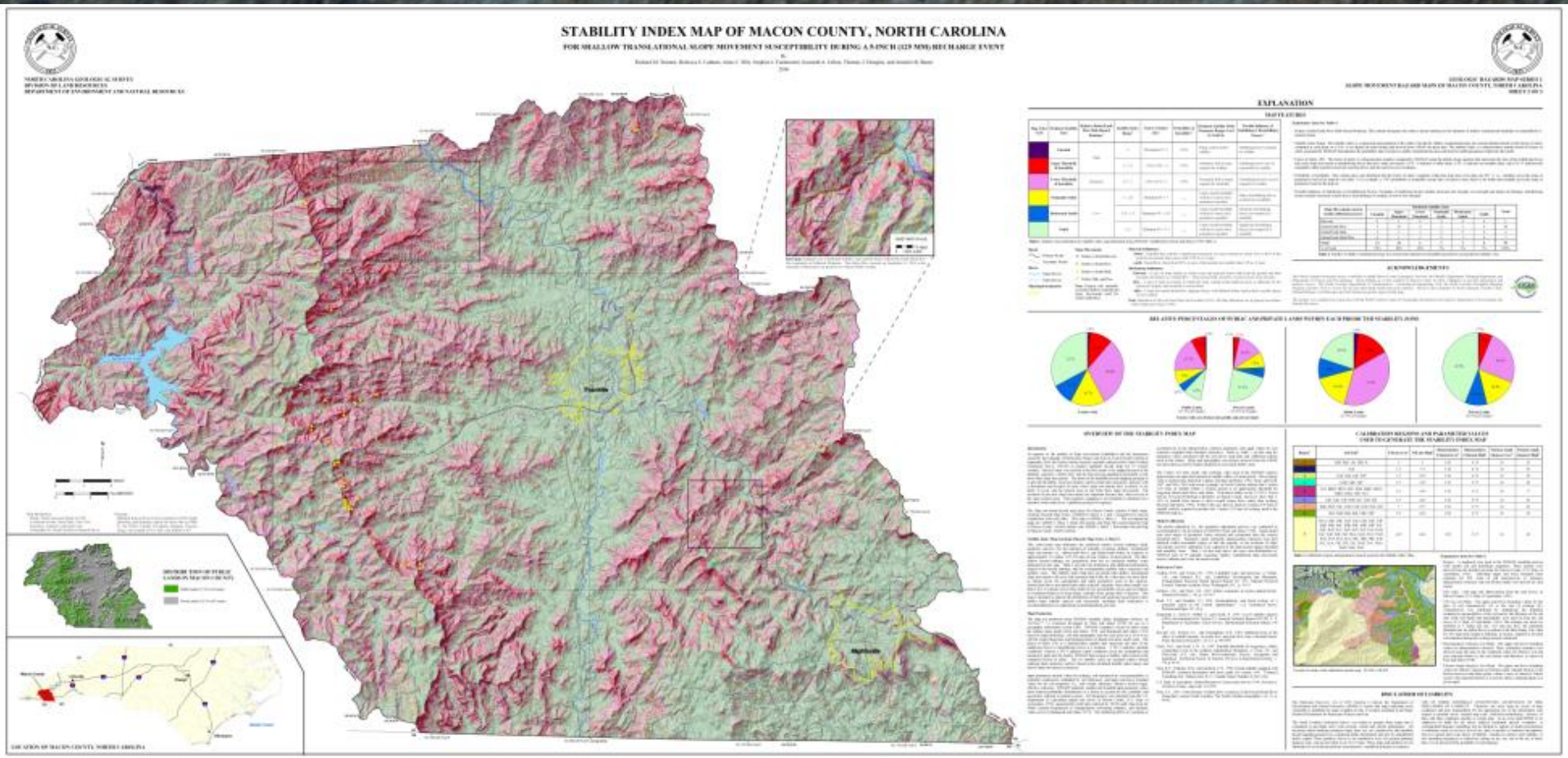


Macon County - 520 mi^2 or 1347 km^2

2) Where Debris Flows and Debris Slides are Likely to Start

Stability INdex MAp

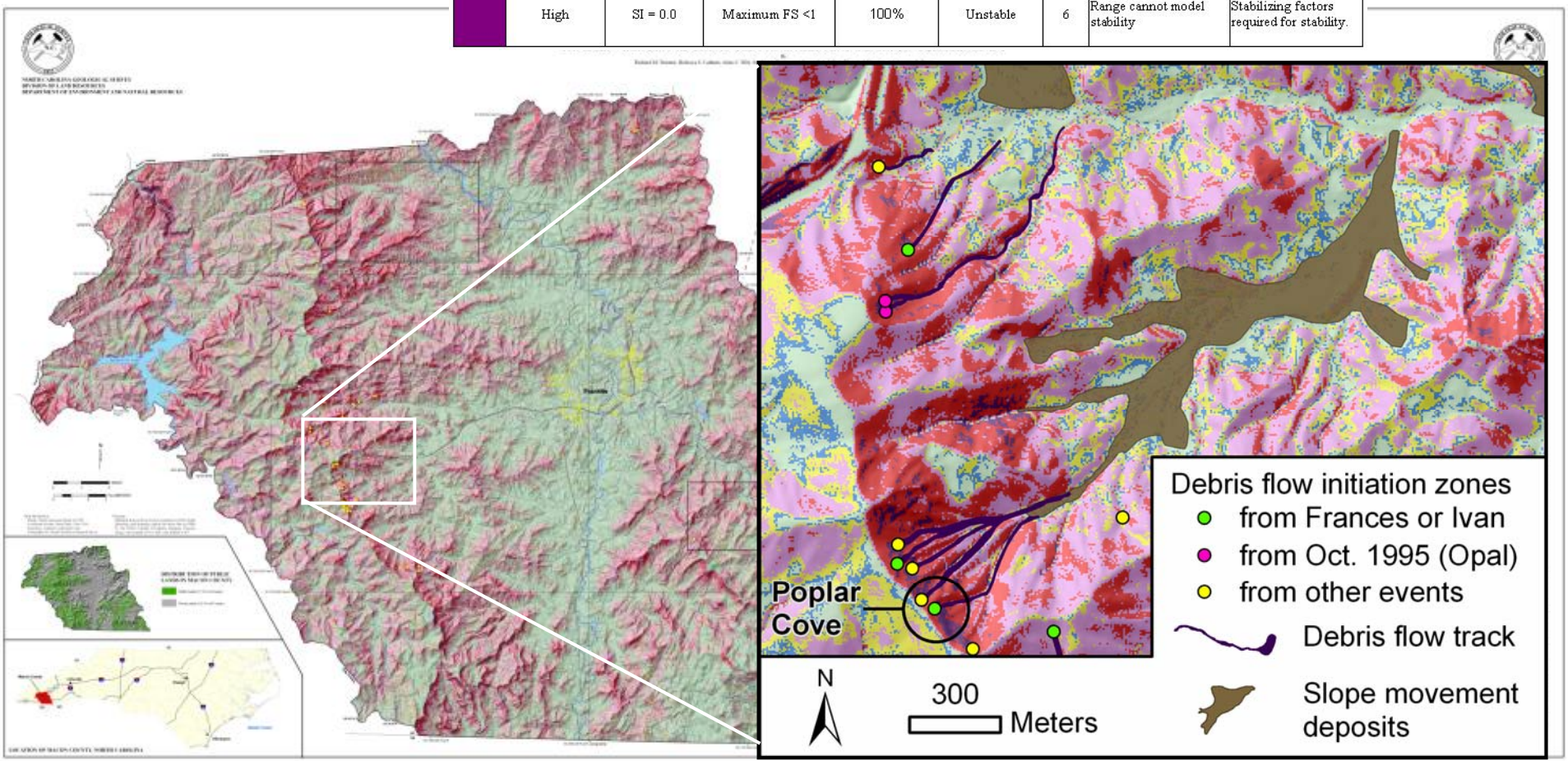
SINMAP – Pack, Tarboton & Goodwin, 1998



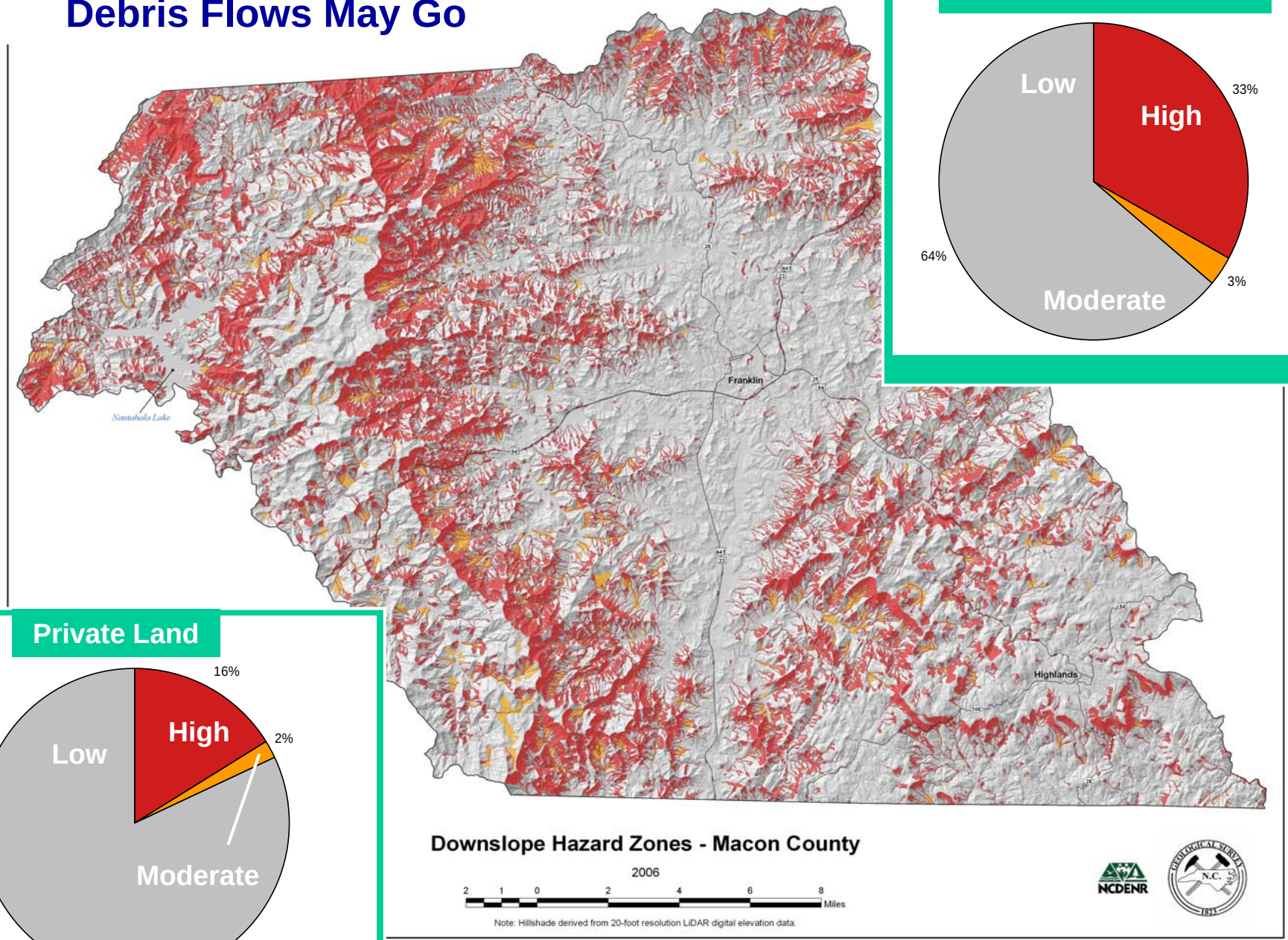
- 5 in / 24-hr 125 mm / 24hr rainfall event
- 11% of county classified as “high hazard” (FS < 1)

- **59 naturally occurring debris flows/slides used for calibration**

Map Color Code	Relative Debris Flow – Debris Slide Hazard [1]	Stability Index (SI) [2]	Factor of Safety (FS) [3]	Probability of Instability [4]	Predicted State of Slope Zone	Class	Predicted Stability With Parameter Ranges Used in Analysis [5]	Possible Influence of Stabilizing or Destabilizing Factors [6]
	Low	SI>1.5	Minimum FS = 1.5	___	Stable	1	Cannot model instability with most conservative parameters specified	Significant destabilizing factors are required for instability
	Low	1.5>SI>1.25	Minimum FS = 1.25	___	Moderately Stable	2	Cannot model instability with most conservative parameters specified	Moderate destabilizing factors are required for instability
	Low	1.25>SI>1.0	Minimum FS = 1	___	Nominally stable	3	Cannot model instability with most conservative parameters specified	Minor destabilizing factors could lead to instability
	Moderate	1.0>SI>0.5	≥50% of FS >1	<50%	Lower threshold of instability	4	Pessimistic half of range required for instability	Destabilizing factors are not required for stability.
	High	0.5>SI>0.0	>50% of FS ≤1	>50%	Upper threshold of instability	5	Optimistic half of range required for stability	Stabilizing factors may be responsible for stability.
	High	SI = 0.0	Maximum FS <1	100%	Unstable	6	Range cannot model stability	Stabilizing factors required for stability.



3) Downslope Hazard Map: Where Debris Flows May Go

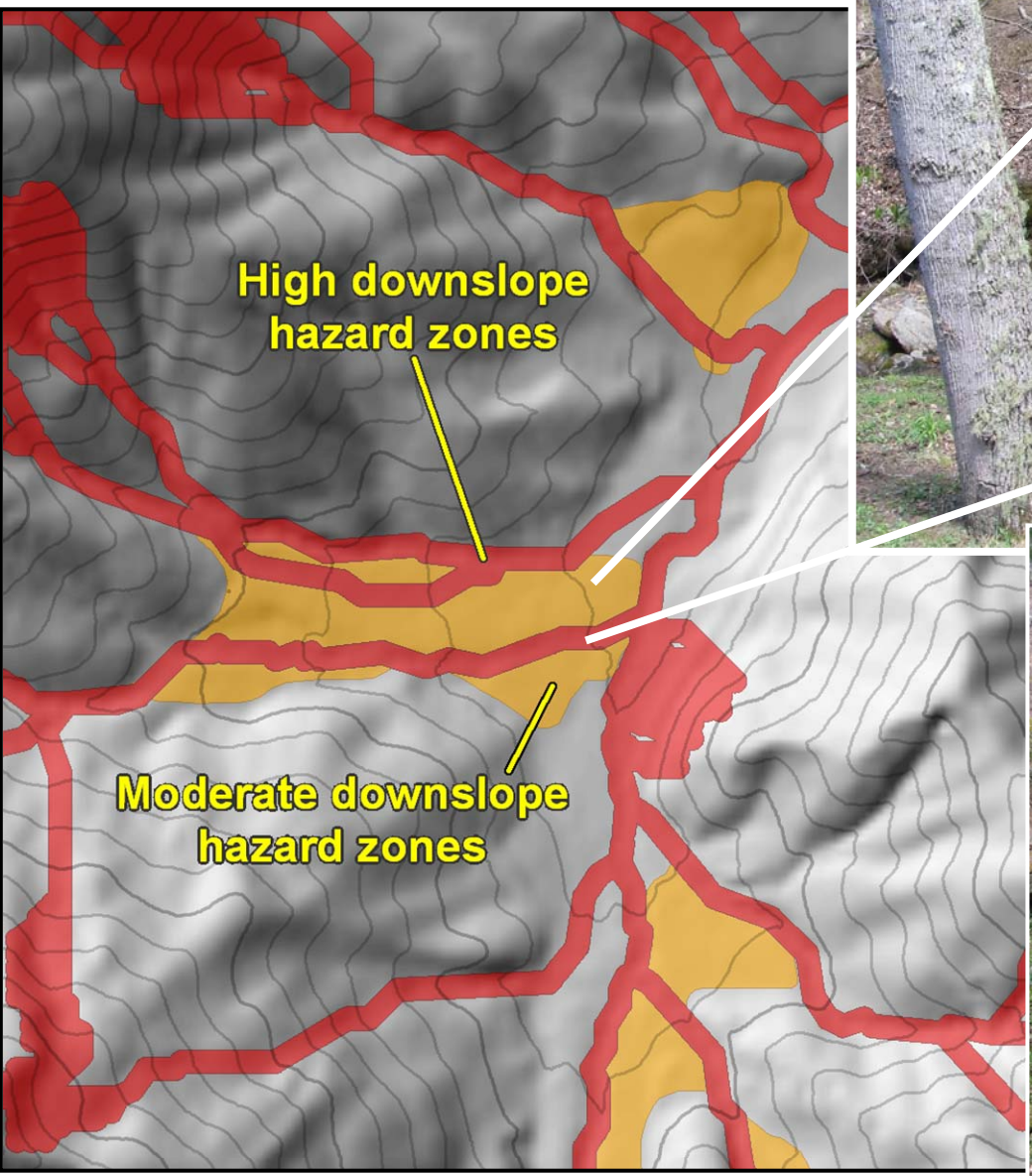


Public Land

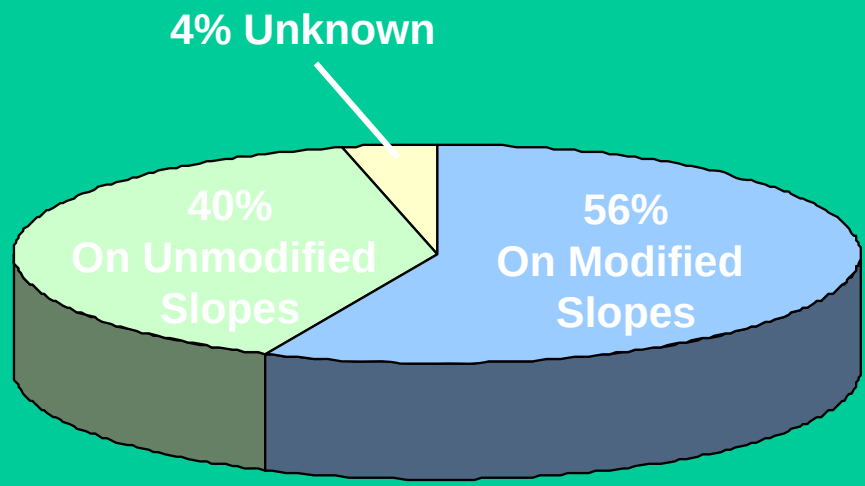
Private Land

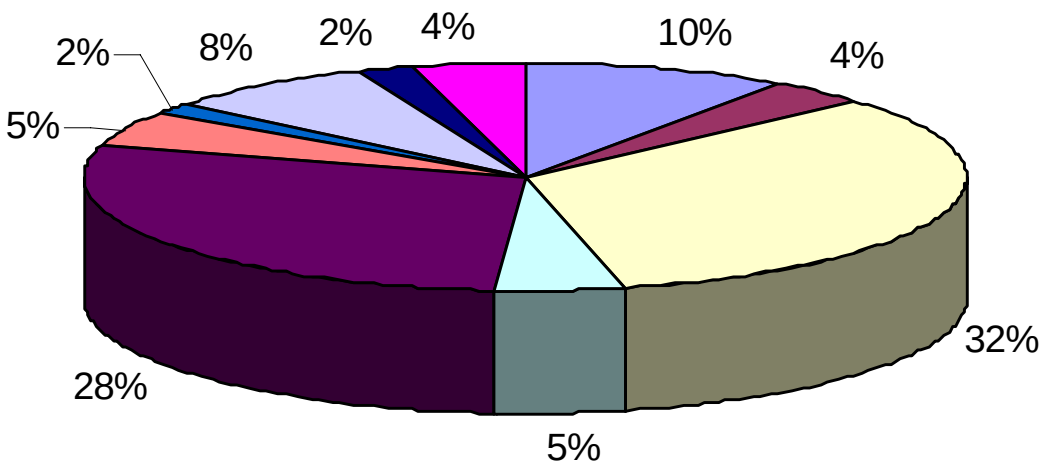
Downslope Hazards

Nickajack Creek



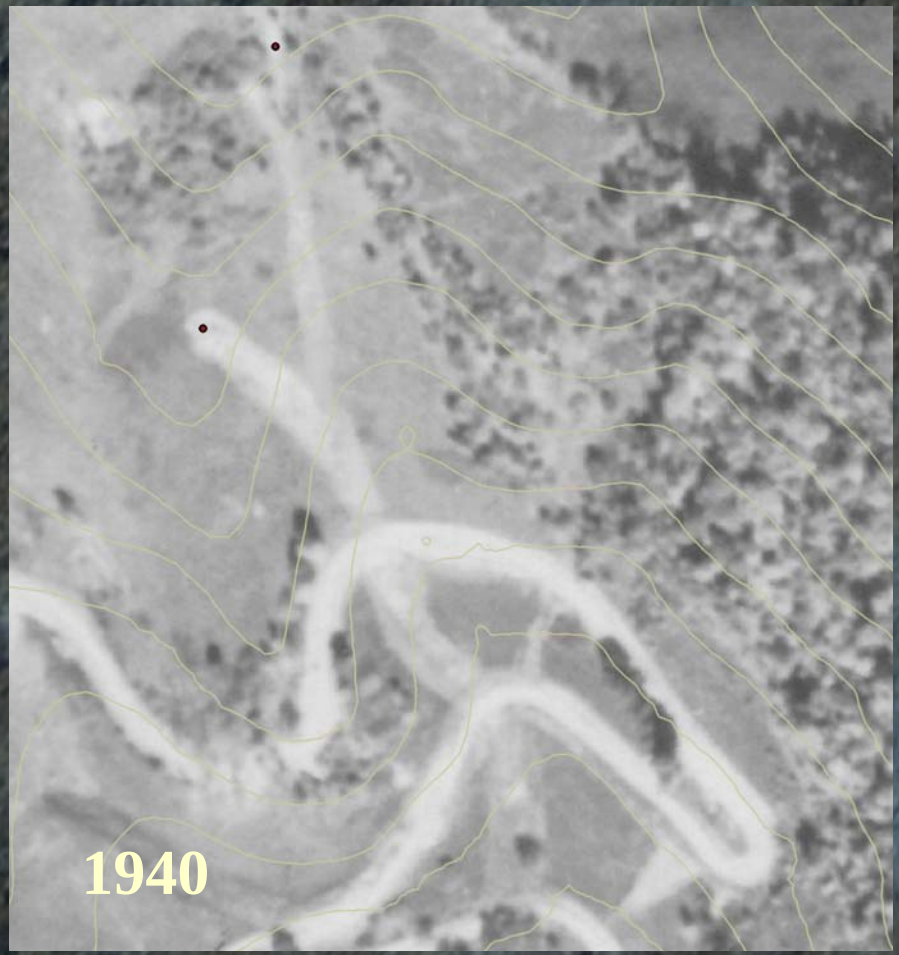
- 171 Modern Landslides
- 3% of county covered by pre-existing debris deposits
- Landslides are more likely to occur on modified slopes

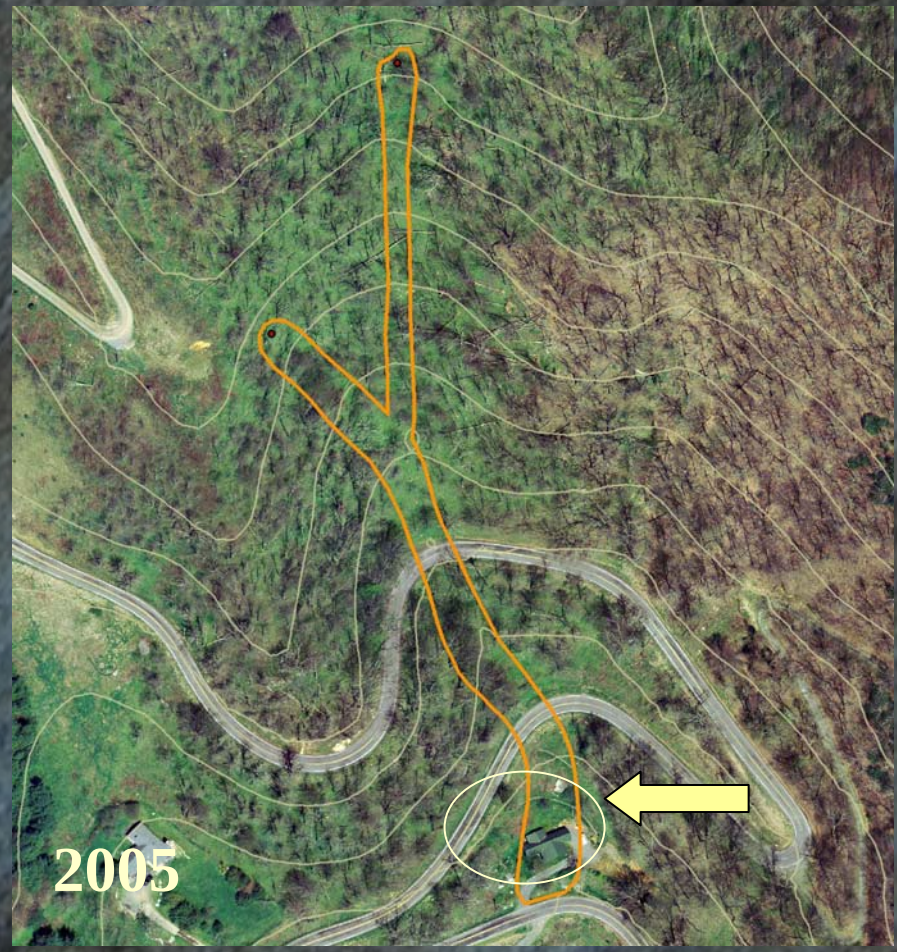




Results of Landslide Mapping of Macon County

Watauga County Landslide Hazard Mapping

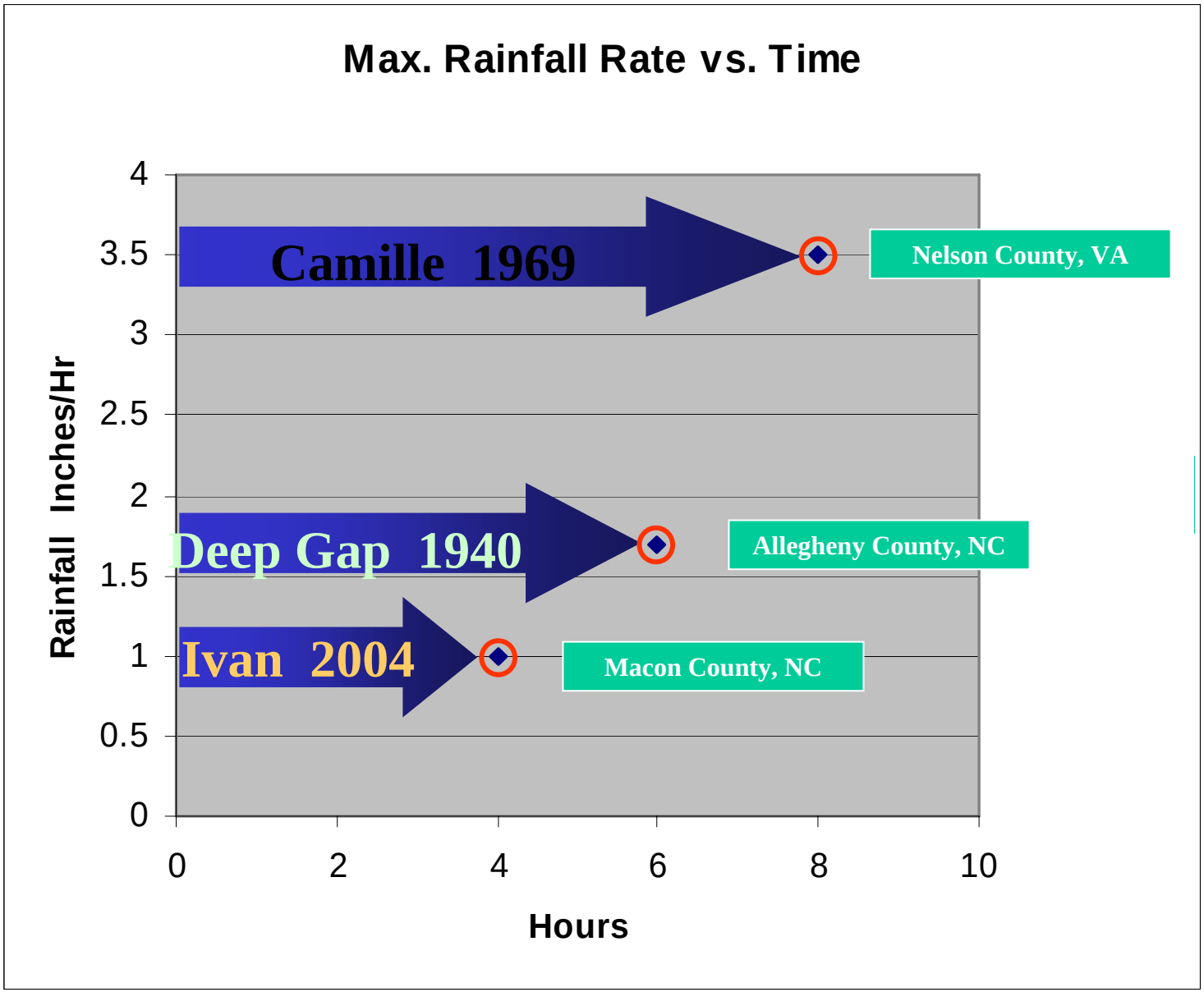




Some Initial Statistics: Over 2000 1940 Landslides Occurred

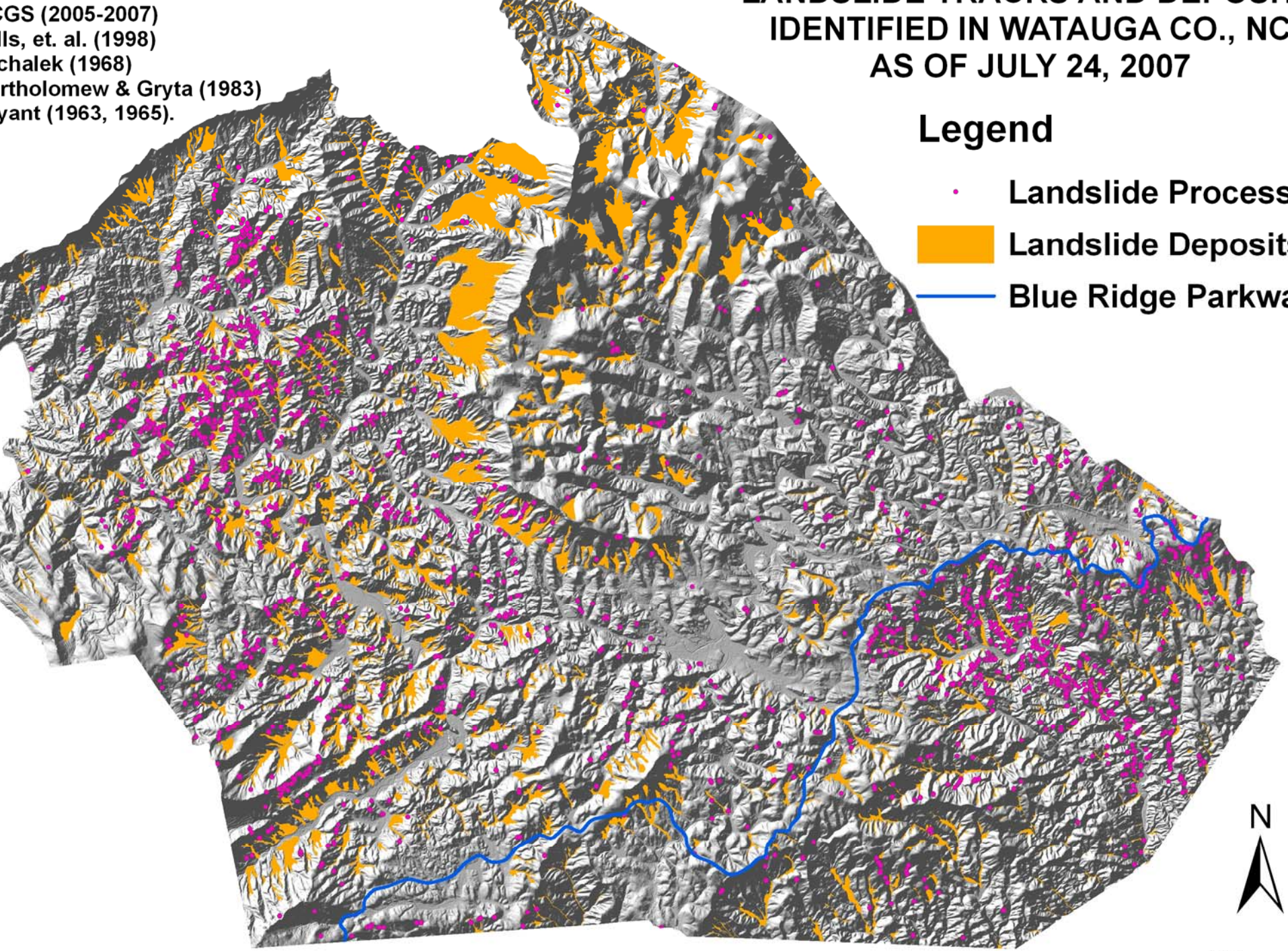
- **139 new structures currently reside on 1940 landslide tracks**
- **521 landslide tracks cross roads visible on 2005 orthophotos**

Maximum Rainfall Rate vs. Duration

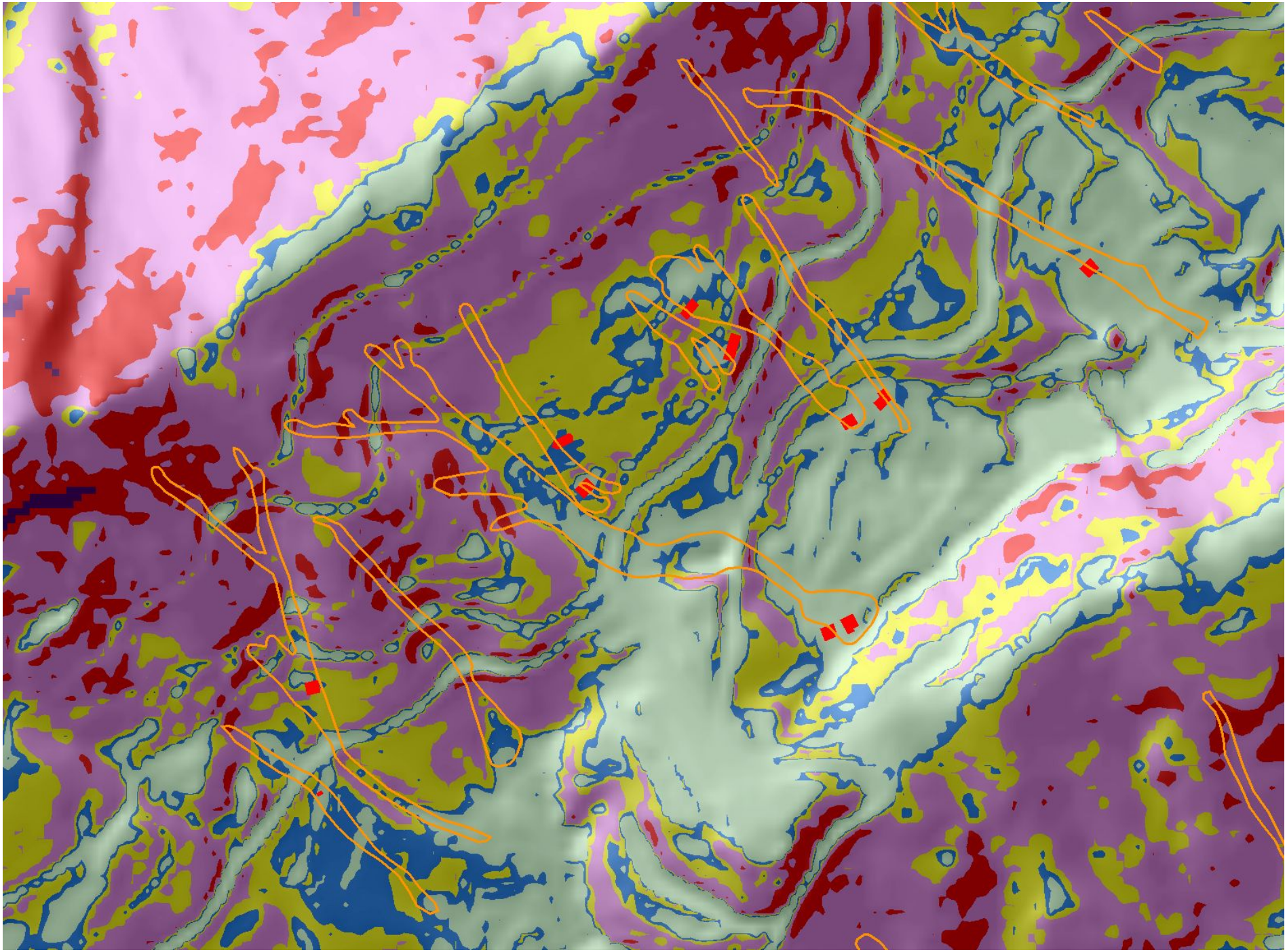


CGS (2005-2007)
lls, et. al. (1998)
chalek (1968)
rtholomew & Gryta (1983)
yant (1963, 1965).

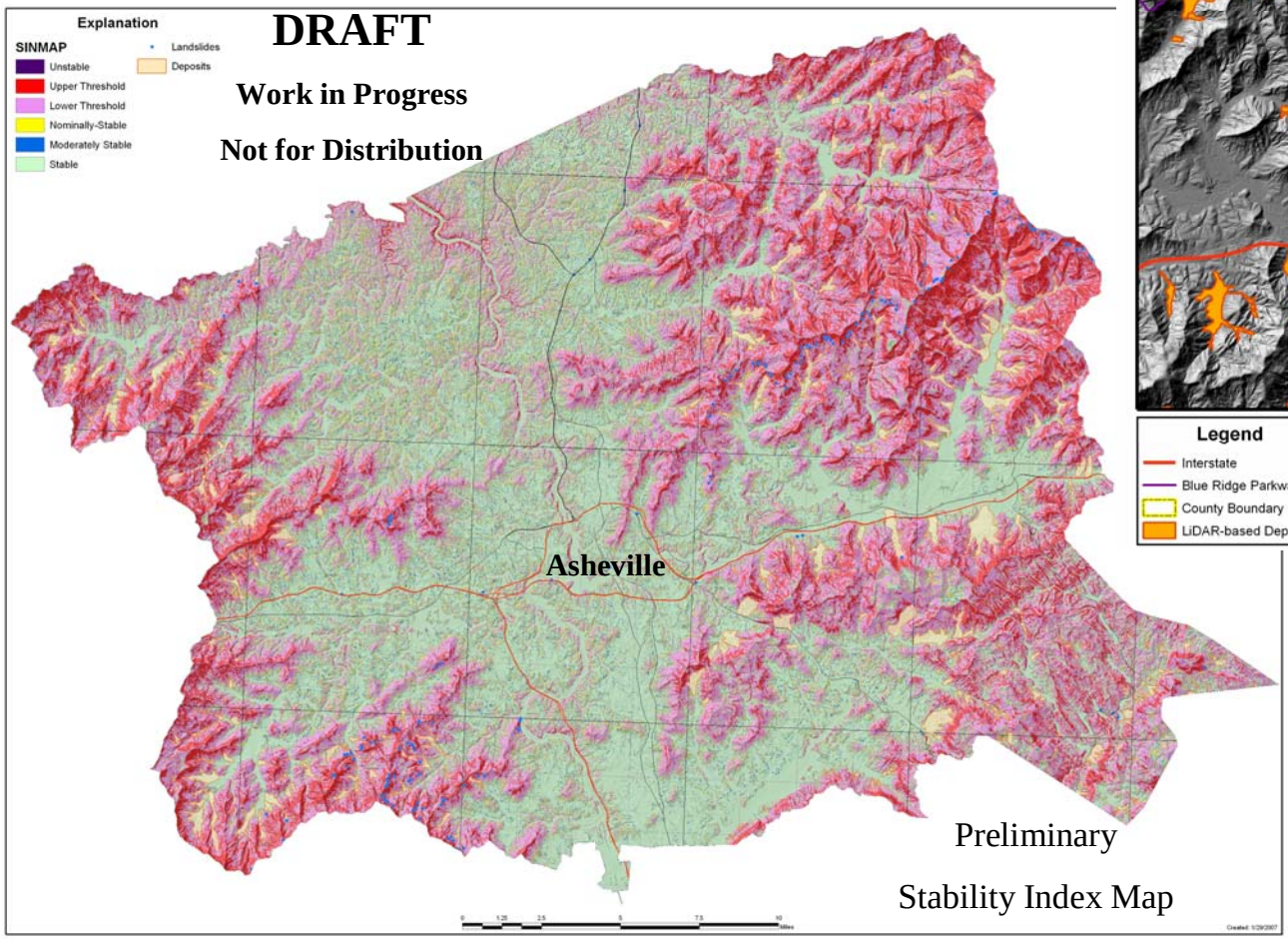
IDENTIFIED IN WATAUGA CO., NC
AS OF JULY 24, 2007



15 1940 tracks reactivated in 2004

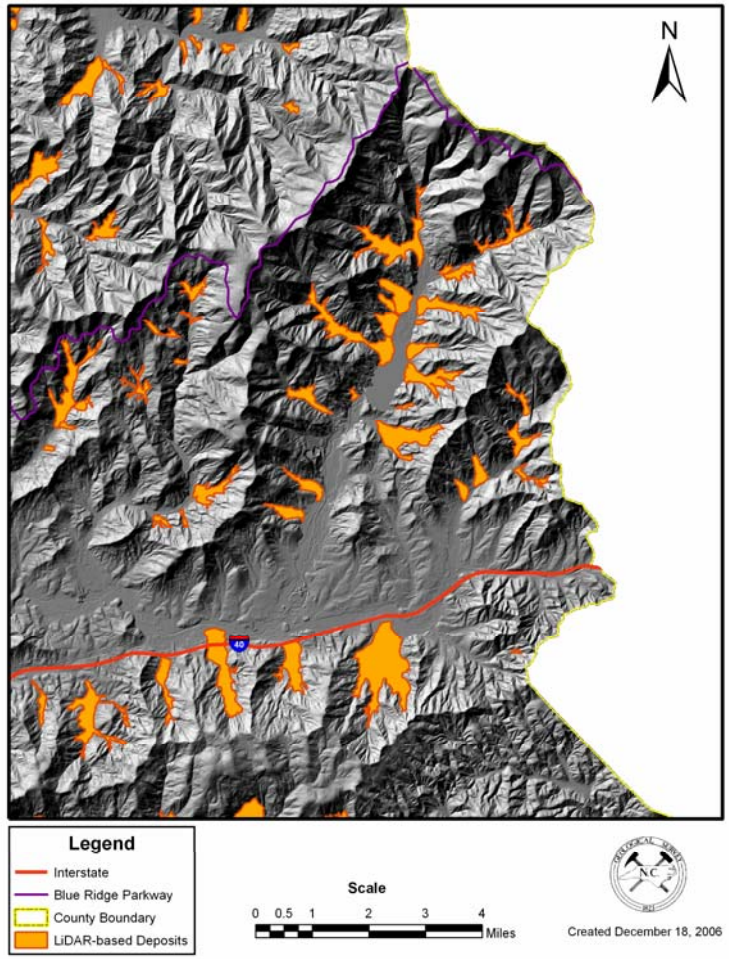


Buncombe County:
Landslide Hazard Mapping In Progress



Preliminary

Stability Index Map



How Can The Maps Be Used?

- Inform public and local governments of potential problem areas - disclosure
- Maps and data - planning tools
- Trigger for more detailed studies
- Emergency Management - Areas of concern when weather conditions favor landslides – landslide advisories
- Landslide point locations on-line at www.nconemap

Summary and Conclusions

- Significant landslide hazard in western North Carolina
- Recurring weather patterns: - Major regional event 22-29 yrs
  - Landslide event in region 9 yrs
- Increasing development on steep slopes increases exposure to landslide hazards
- Increased risk: - destabilizing affects of human activity
  - development in downslope hazard areas

- GIS landslide hazard maps and outreach help mitigate hazard
- Map 2-3 counties per year
- <u>Critical:</u> - LiDAR and remote imagery (new and archival)
  - Geologic and soil survey maps
- Maps not a substitute for site specific investigations

Acknowledgments

USFS – USGS – NCDOT – NWS – NPS
EM & FEMA
Local & State Agencies
JMU – ASU – UNC-CH

Questions ??

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“Landslide Information”