Two Decades of Collaborative Landslide Research in Vermont

George E. Springston [1]

Jonathan Kim [2]

Benjamin Dejong [2]

Julia Boyles [2]

Keith Klepeis [3]

1. Norwich University Department of Earth and Environmental Sciences, Northfield, VT 05663

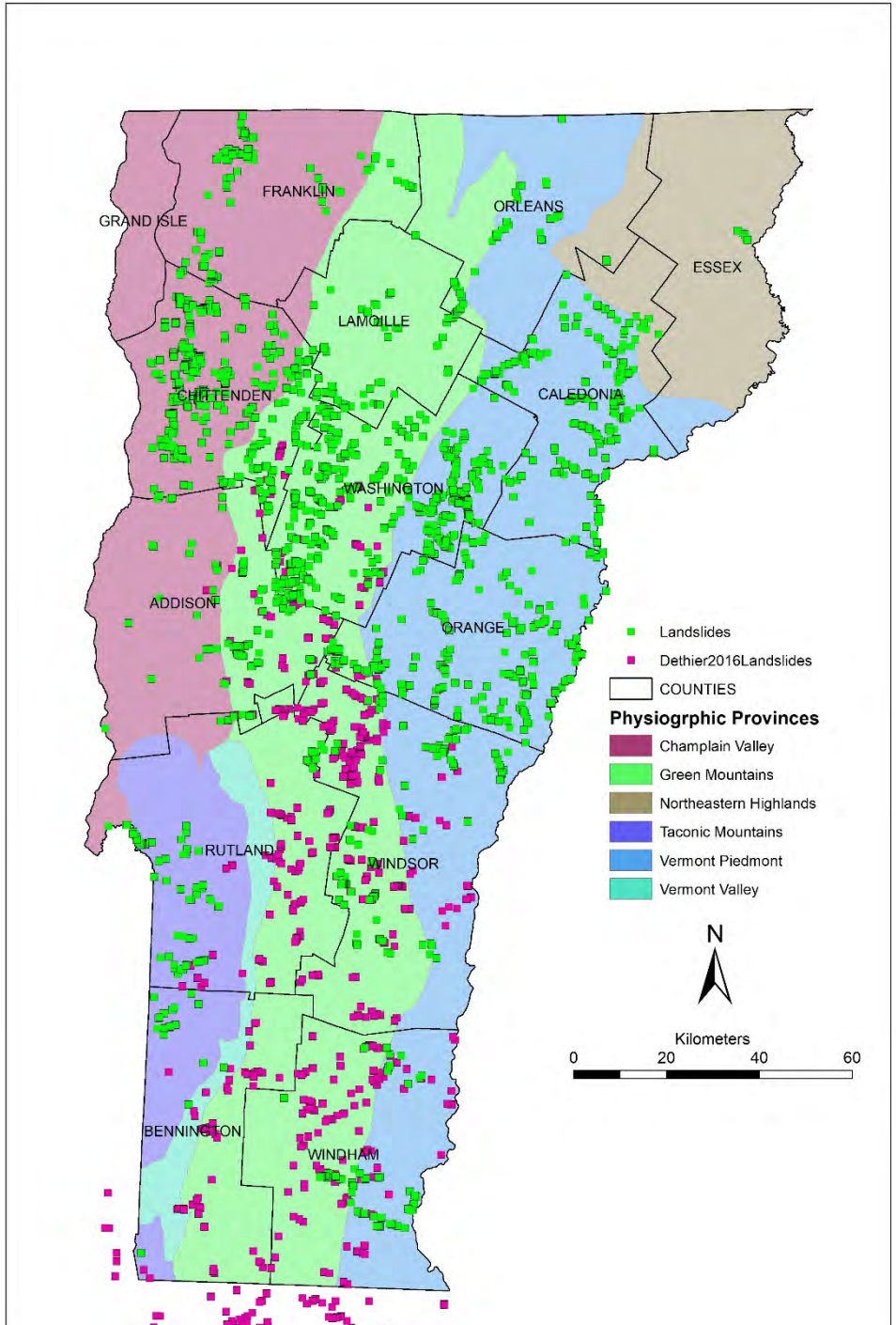
2. Vermont Geological Survey, Vermont Agency of Natural Resources

3. Department of Geography and Geosciences, University of Vermont

Presented at the Joint Southeastern & Northeastern Section Meeting of the Geological Society of America in Reston, VA on March 17, 2023

What We've Learned About Landslides in Vermont

- Over 3000 features identified in Vermont to date. Inventories for 5 counties.
- Most of these slope failures are located in close proximity to rivers.
- Most are driven at least partly by heavy rain events and/or snowmelt.
- Landslides tend to recur in the same locations. Reactivation can be expected after future large floods.
- Active gullies are more common in developed areas.
- Geology Matters: surficial materials, bedrock locations, landscape position….

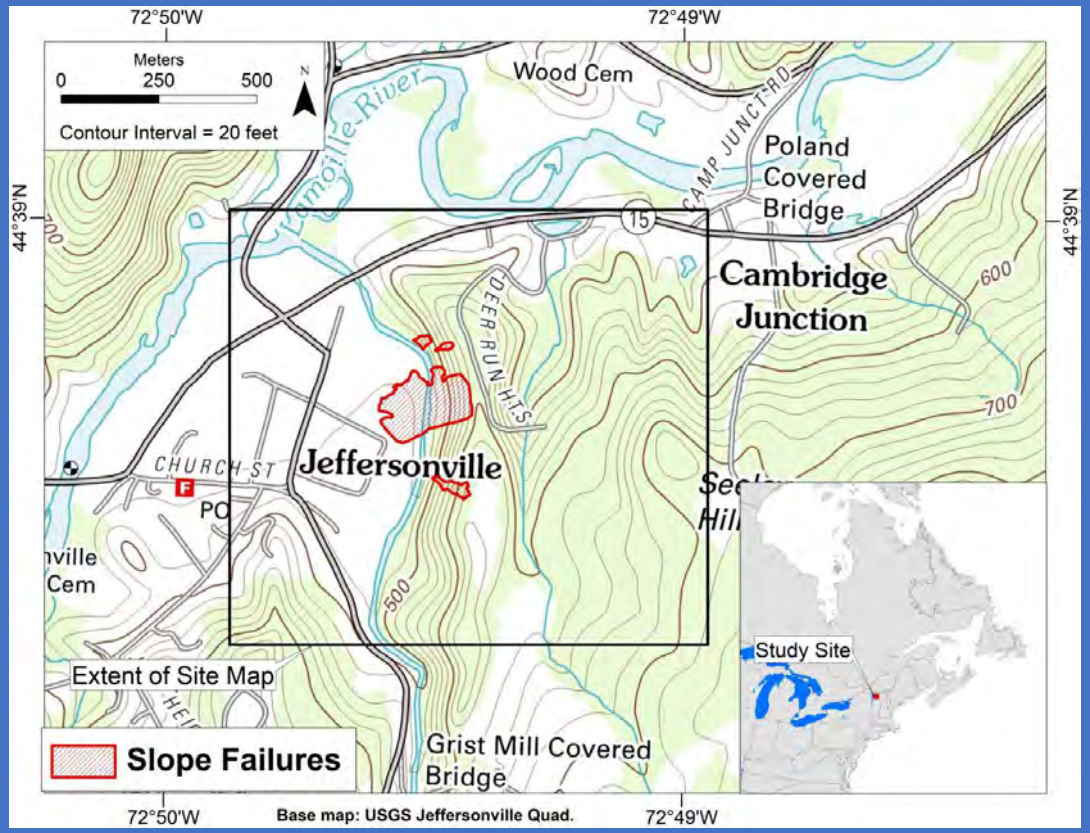


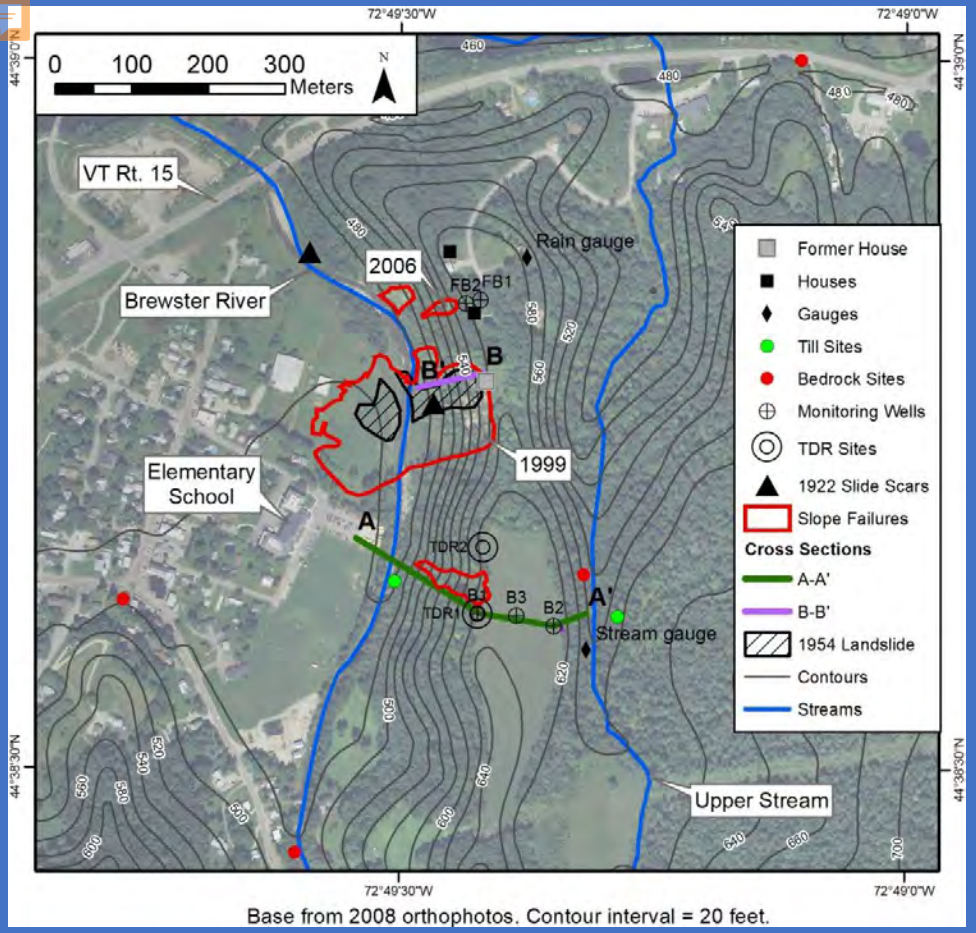
Landslide in Village of Jeffersonville, 1999

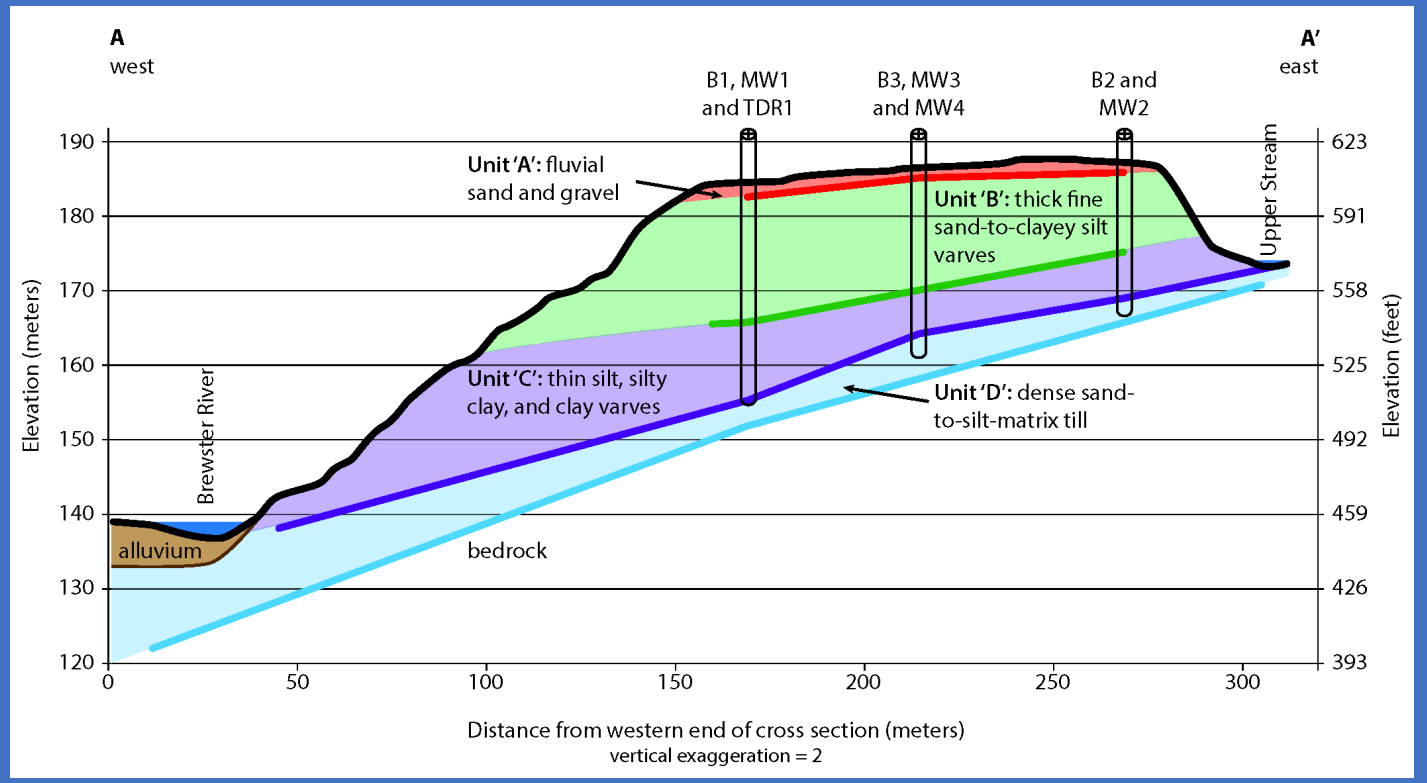
Photo: University of Vermont Landscape Change Program #LS21623_000; P. Bierman

Landslides on April 11 and 18, and July 4, 1999. Note house at top of slope at left. This was abandoned after the first landslide.

Three complex earth slide-flows in 1999, totaling ~27,000 cubic meters, 43 m high, Runout length ≈233 m, Travel angle of 11.2°.







Above: Jeffersonville landslide site map.
Above right: Stratigraphy.
Bottom right: Mud from 1999 landslide splashed up against house at southwest corner of landslide deposit.

Landscape Change Program photo LS21615_000 used courtesy of Paul Bierman, University of Vermont.

A Complex Landslide

Photo: University of Vermont Landscape Change Program #LS21620_000; P. Bierman

History of slope failures: pre-1922, 1954, 1999, 2006, 2011.

1999 Events:

1. Toe erosion by river.

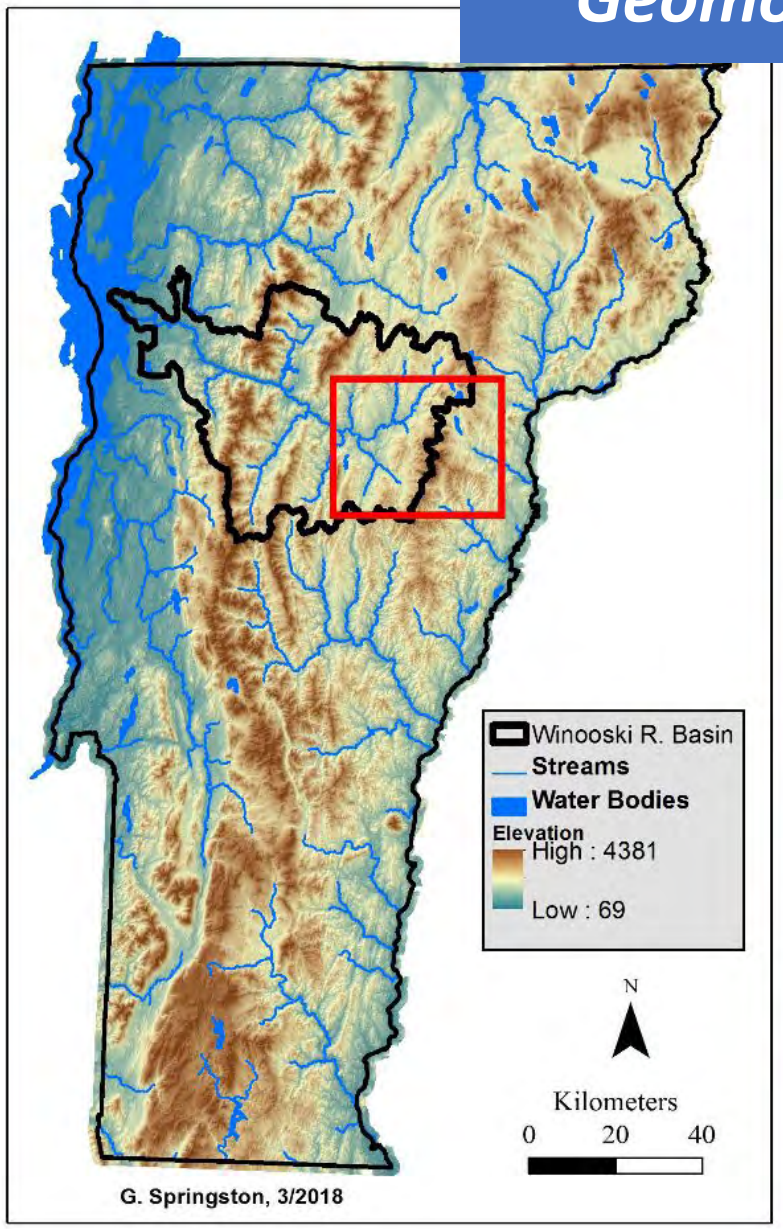
2. Translational slide due to removal of support at base +/- high pore pressure

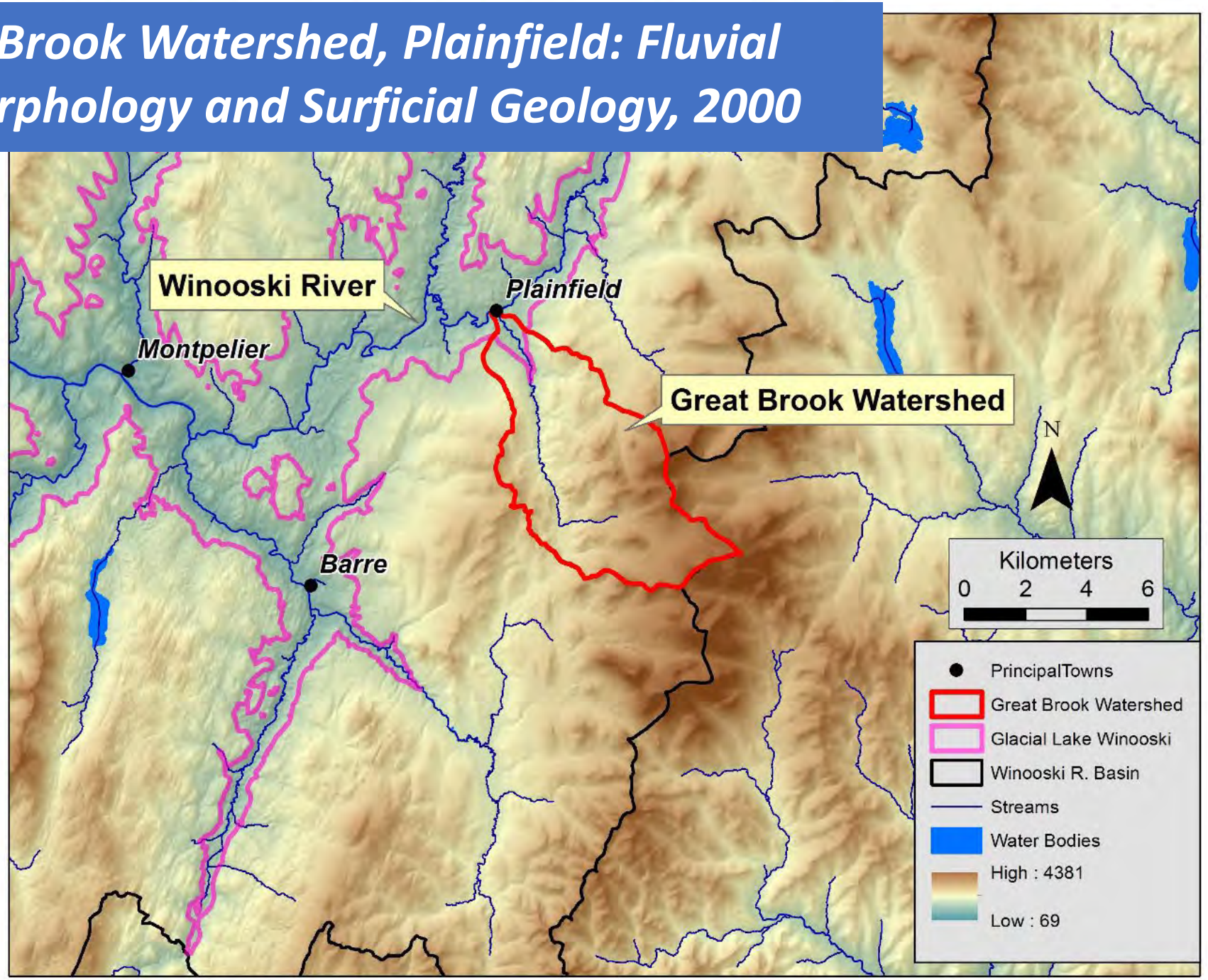
3. Subsequent slides: rotational slides/flows on deformed zone in varved lacustrine deposit (top of gray zone, left).

Failures perhaps due to high pore pressure from losing stream to east.

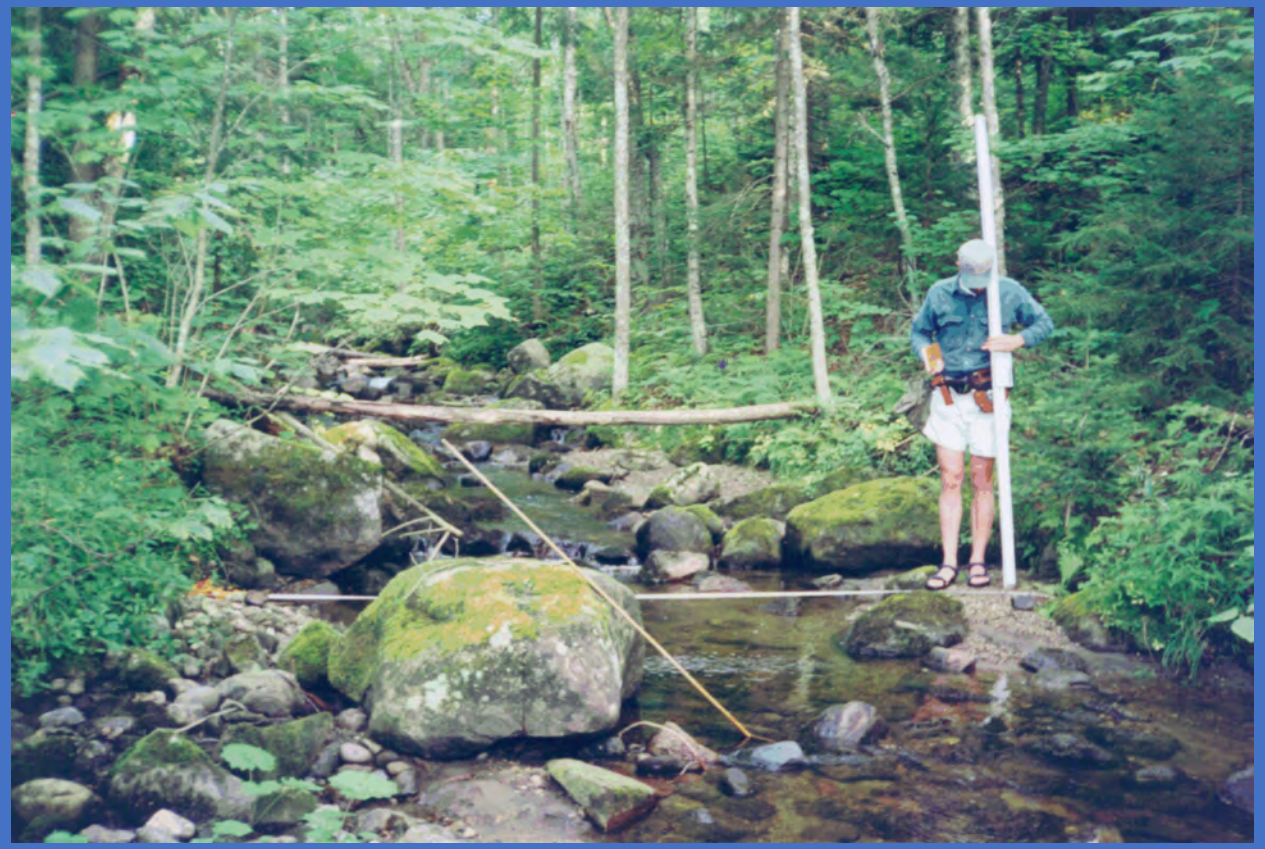
First FEMA buyout of a property in Vermont due to a landslide rather than flood inundation

Great Brook Watershed, Plainfield: Fluvial Geomorphology and Surficial Geology, 2000



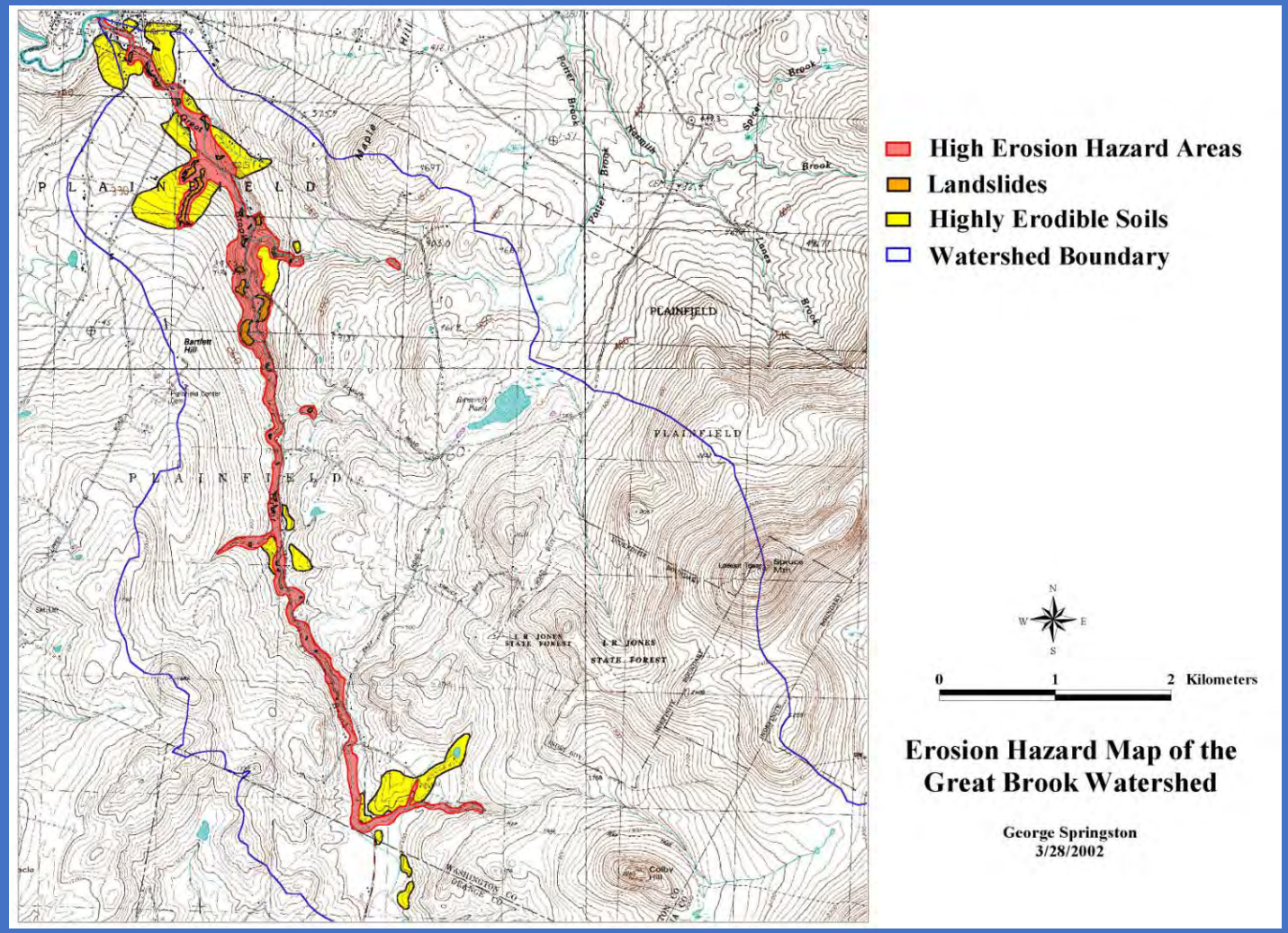


Great Brook: complete characterization of a watershed: Fluvial geomorphology, surficial geology, detailed flood history, plus a 3-year hydrologic study by the Plainfield Conservation Commission. Below: A stable upstream reach. Right: One of many large landslides along the unstable lower reaches of the brook.



Photos by Lori Barg

Below: Site of a house destroyed in the 1984 Flood. Note well casing still standing in center of photo.



Great Brook Was Site of the First Fluvial Erosion Hazard Zone in Vermont, 2002

Hardwick Landslide, 2003-4

An unstable slope above a heavily traveled State highway (VT Rt. 15).

Left: Looking up at slide on November 10, 2003, prior to any major slope failure. Note raw scarp in woods and central mudflow. Right: Top of slope at main scarp. Surface material is recent artificial fill. May 4, 2004 (after major slope movements).

Photos by George Springston

Hardwick: The major slope failures occurred in the spring of 2004

April, 2004. Looking up at slide from Vt. Route 15 prior to first slide across road in 2004. Note slide scarps. Some trees have been cut.

G. Springston
Photo 1-020Aa 4/2/2004

Same view after first of two slides across road in April of 2004.

G. Springston
Photo 7451-020 4/22/2004

Hardwick Landslide

Rt. 15 was clearly at risk (left).

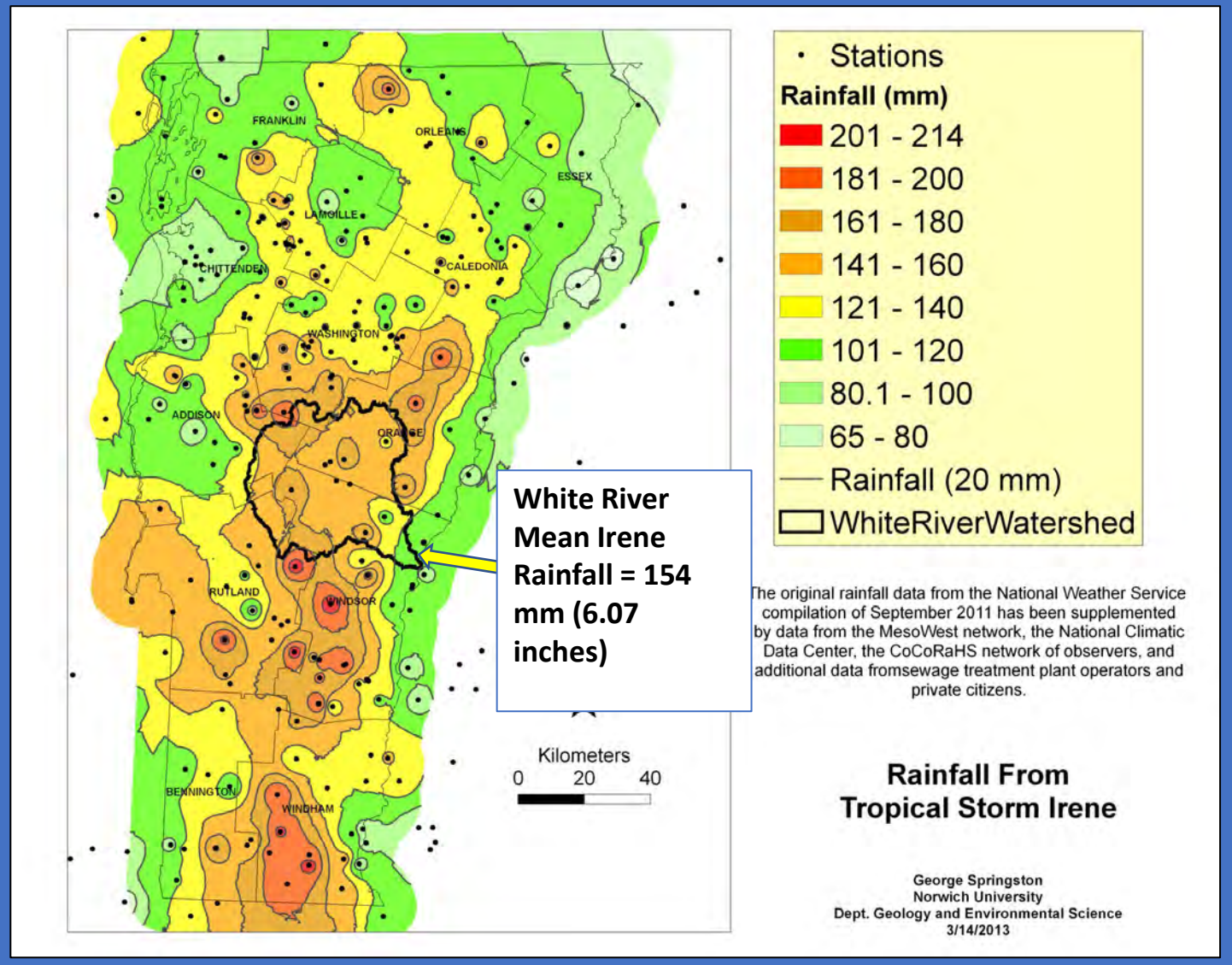
Geologic interpretations played key role in understanding the nature of the failure. Photo below shows dense glacial till exposed beneath a skim of silt-clay on sliding surface.

Fix by VTrans:
-Remove fill
-Install subsurface drains
-Reinforcement of toe of slope with retaining wall

2011: An extremely wet spring: Thick snowpack, heavy rains, high groundwater tables, Lake Champlain stood at record levels for weeks

Then, thunderstorms over central Vermont on the night of May 26 caused flash floods, resulting in heavy damage to roads and property and many landslides. Saturated soil resulted in many slope failures in Barre, resulting in FEMA buyouts of two houses. Still, the damage was localized.

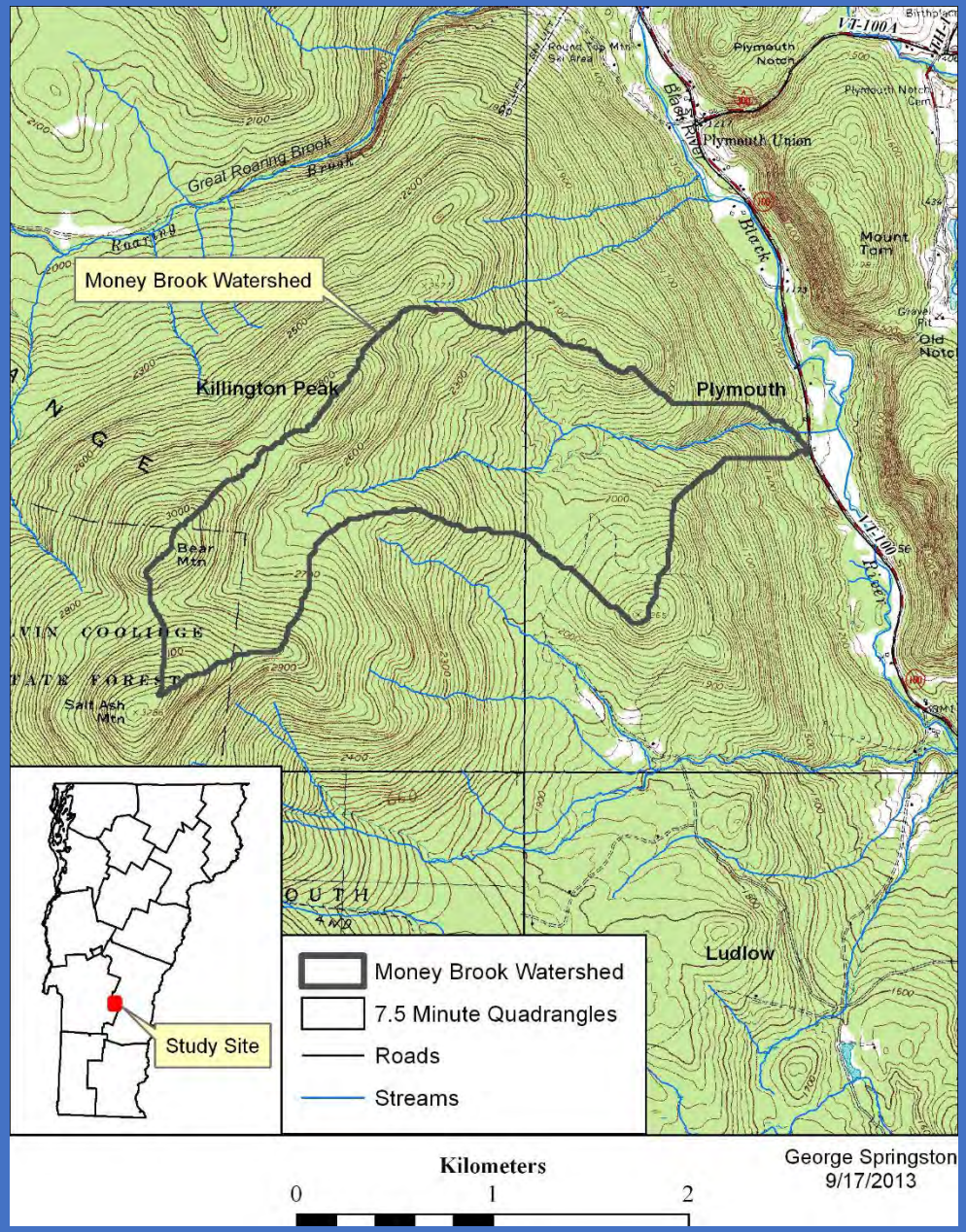
TS Irene in August was a different animal altogether: A regional geomorphic event. Many FEMA buyouts of damaged properties.

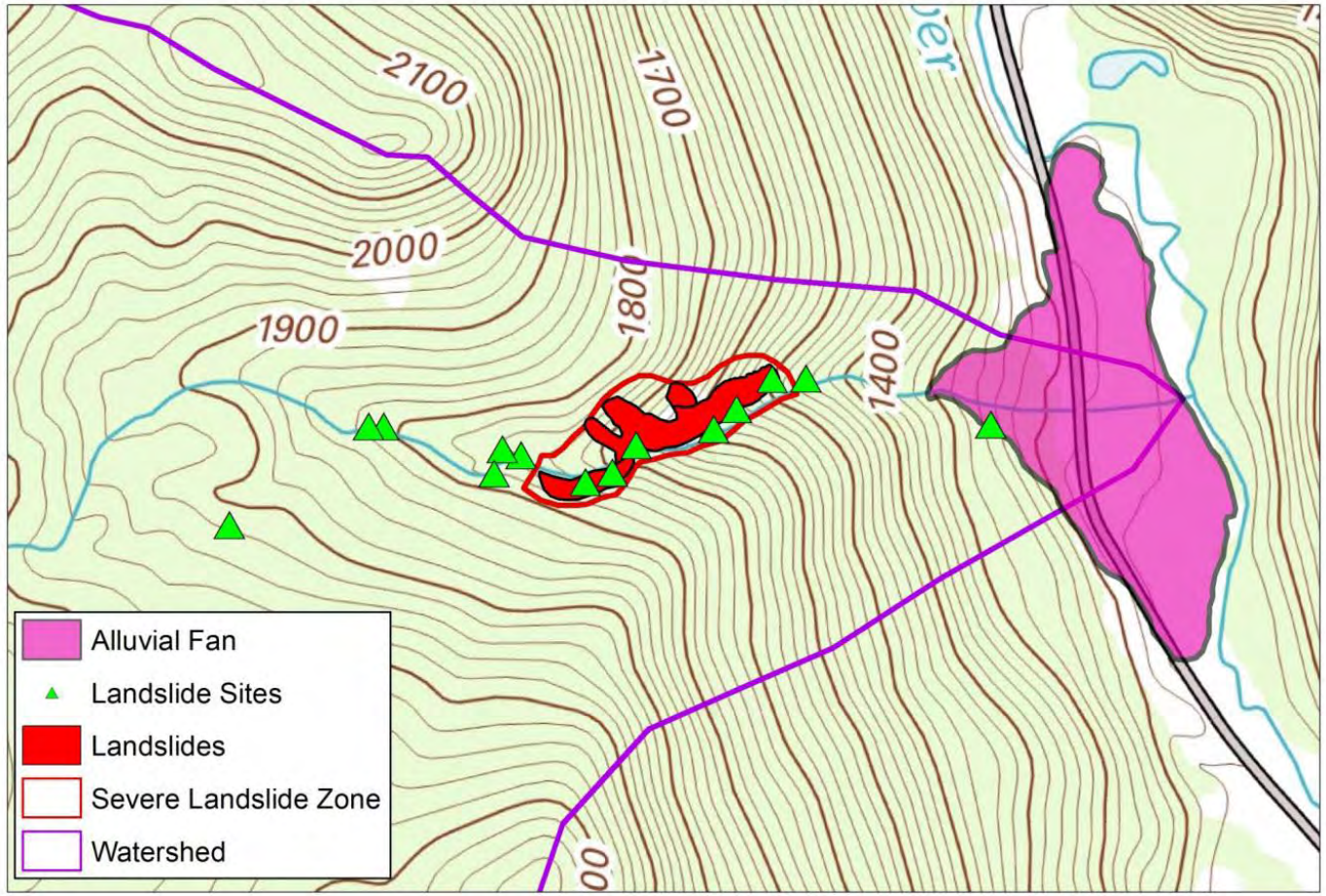


Geomorphic Impacts of Irene in the White River Watershed

Floodplain Scour and Deposition, Landslide, and Bank Erosion on the White River Downstream of Gaysville, Looking Northwest.

Landslide and Alluvial Fan Activation at Money Brook, Plymouth, TS Irene, 2011





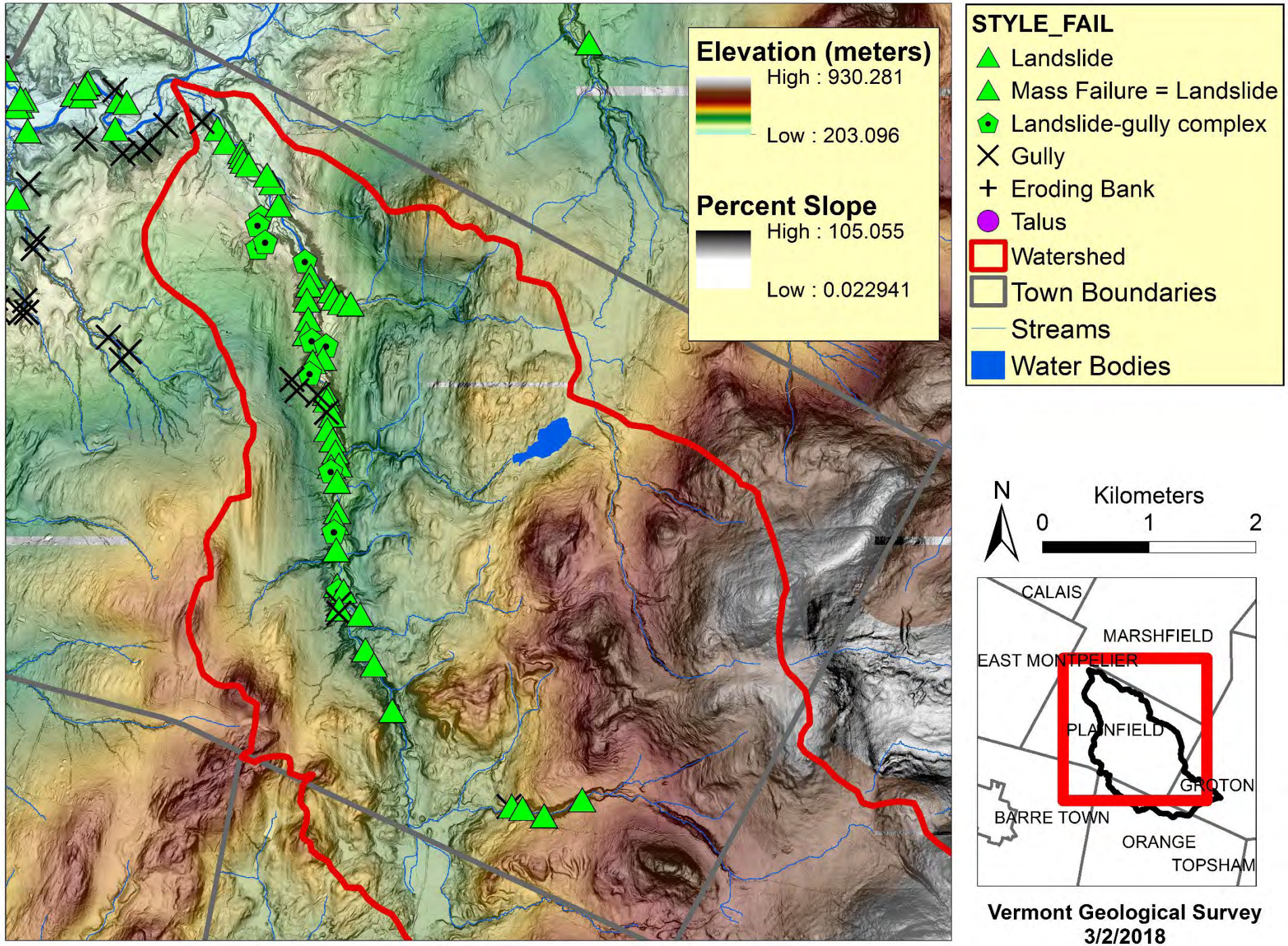
Flood Competence Estimates (after Costa, 1983)

- 7.5 m/s (25 ft/sec) peak velocity

Above: Large landslide in bouldery till, the source material for the boulders on the alluvial fan.
Top right: Boulders moved during flood.
Lower right: Alluvial fan and Vt Route 100.

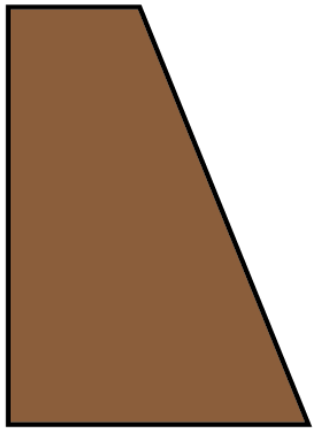
In the Wake of the 2011 Floods, Revisit Landslides and Gullies in the Great Brook Watershed, 2013

Study identified 47 active landslides, 3 inactive ones, 7 streambank erosion sites, and 15 + sites with gullying.



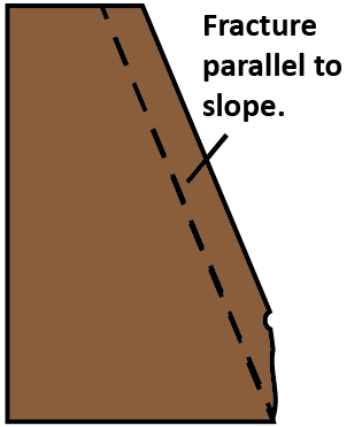
Vermont Geological Survey
3/2/2018

Stage 1



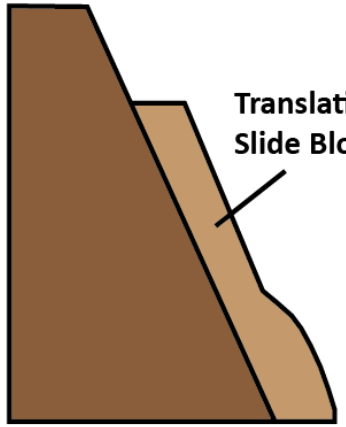
Original forested slope underlain by till with stream at toe.

Stage 2



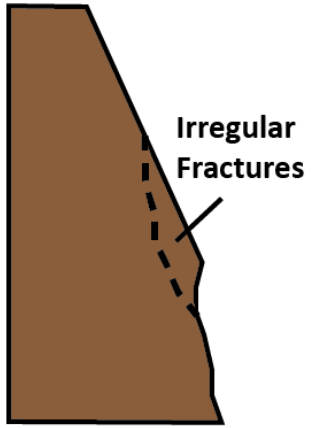
Toe erosion due to fluvial shear. Failure will occur at base of weathered till.

Stage 3



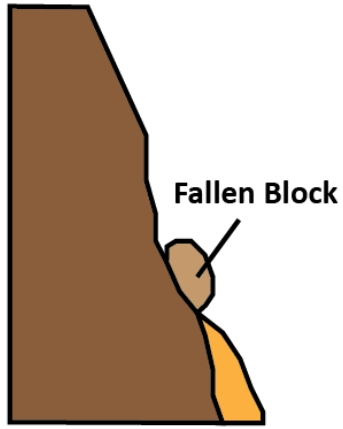
Translational slide of weathered till.

Stage 4A



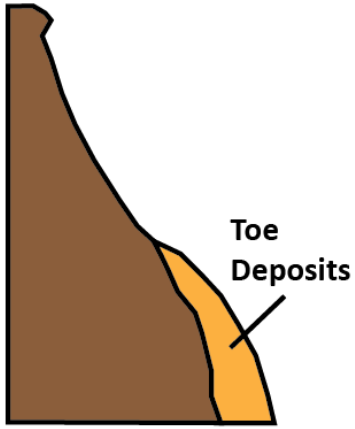
Slope is destabilized by continued erosion at toe. Weathering of fresh material begins.

Stage 5A



Irregular block detachment and sloughing.

Stage 6A



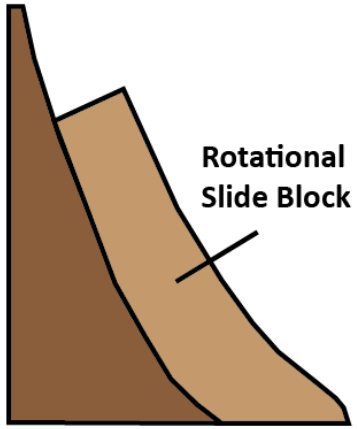
Stream erodes toe deposits and slope fails back to a more stable angle.

Legend

- Toe Deposits
- Slide Blocks
- Till

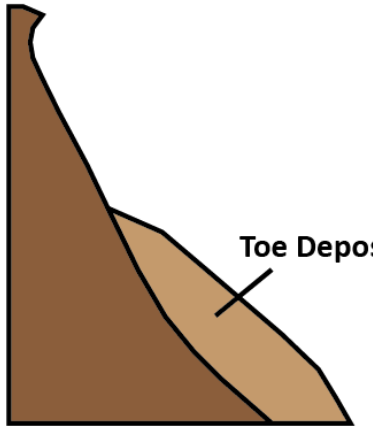
Rotational slides are uncommon on till slopes. If they do occur, it is usually *after* a translational slide has removed soil and trees.

Stage 4B



Rotational slide of unweathered surficial deposits.

Stages 5B and 6B

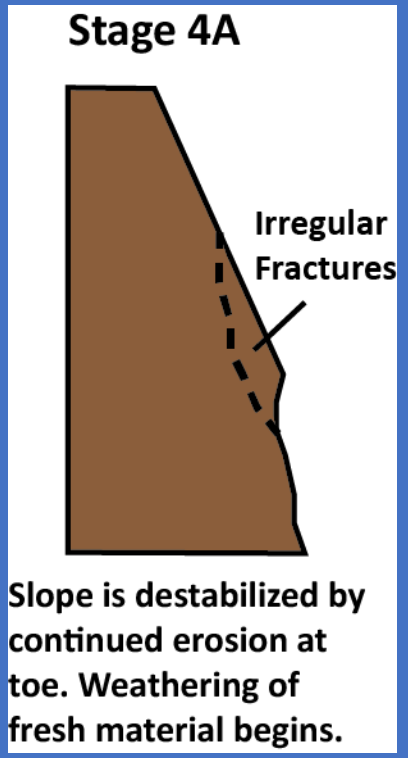


Continued sloughing as stream erodes slide blocks and toe deposits and slope fails back to a more stable angle.

Model for Landslides Developed on Till Slopes in Vermont

George Springston, 3/16/2018

Landslide in dense till, two days after flood of May 26, 2011. Note overhangs at base and fallen blocks of till.



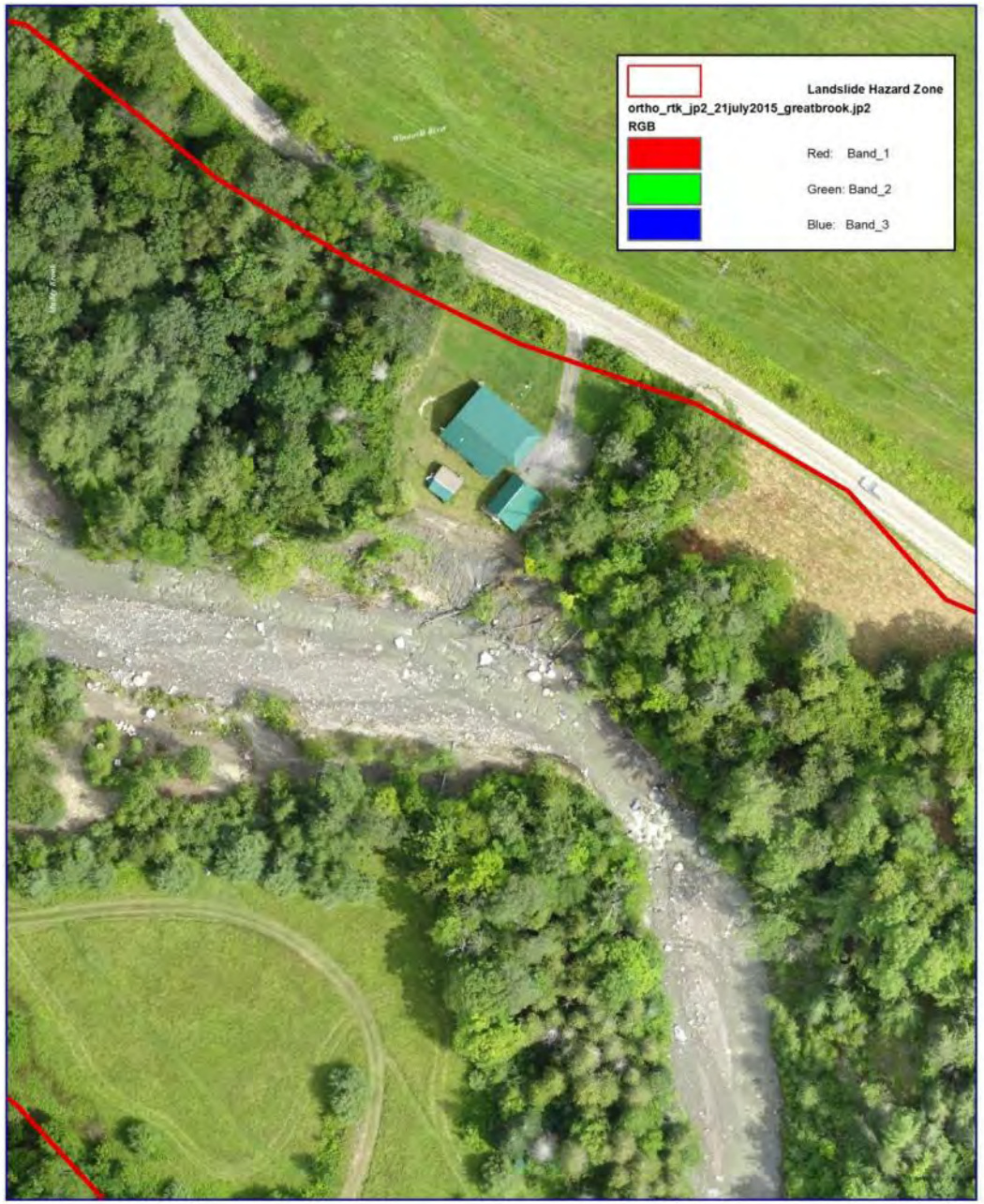
Processes: Undercutting of an existing landslide due to fluvial shear, followed by irregular block detachment.

Site GB-1032, 5/29/2011, Post-Irene. George Springston.

Example of a FEMA Buyout on Great Brook, Plainfield

House perched on the edge of an active landslide is shown in center. Brook flows from right to left. Photo taken after Tropical Storm Irene, September, 2011.

Photo: Staci Pomeroy, Vt. Rivers Program

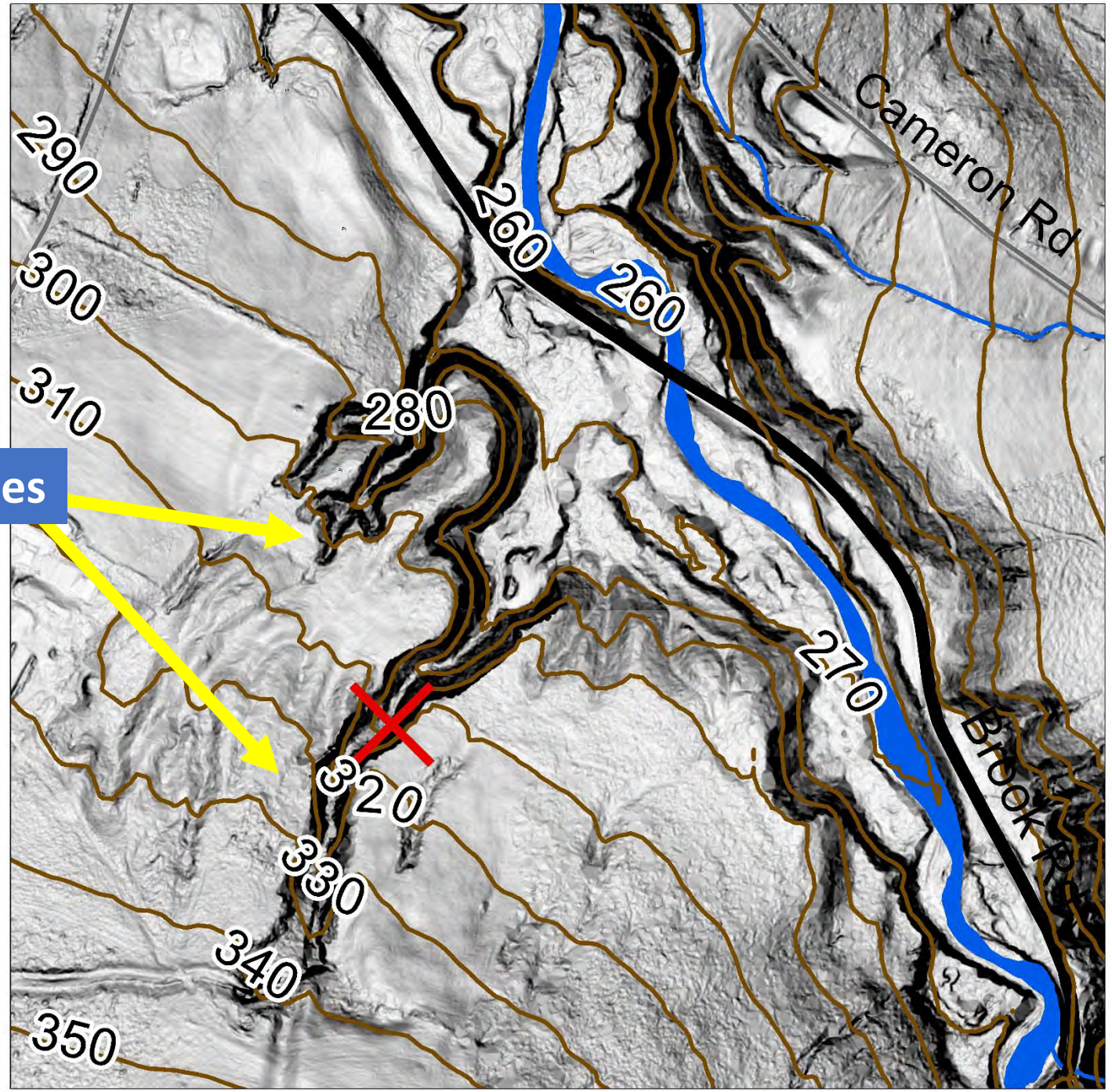


Above: Landslide at Site GB-1025. Note peak of garage roof at top. Slope is 56 feet high and slope angle is 49°.

Left: Aerial imagery of site taken on 7/21/2015, courtesy of Jarlath O'Neil-Dunne of the University of Vermont Spatial Analysis Lab.

Gullies, Great Brook Watershed, Plainfield

Large gullies in highly erodible sand and silt. These features have been reactivated by additional runoff from an agricultural drainage ditch. Site GB-1010.

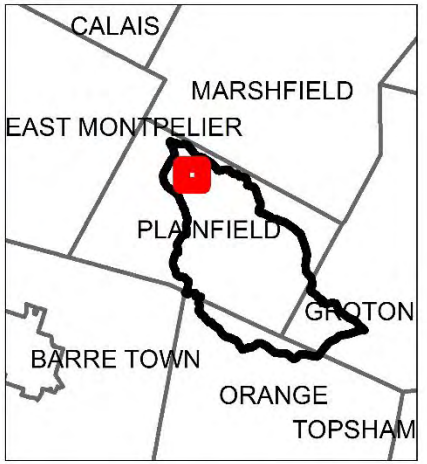


Percent Slope
High : 176.234
Low : 0.172078

- Sites
- Contours (10 m)
- Watershed
- Minor Roads
- Major Roads
- Town Boundaries
- Streams
- Water Bodies

N

Meters
0 100 200



Vermont Geological Survey
3/2/2018

Above: Looking up gully. Note active scour at base of slope on left. Site GB-1010, George Springston, 7/16/2013.

Below: Looking down gully. Material is 21.4 meters (70 feet) of ice-contact fine to very fine sands and silt with gravel lenses. Site GB-1010, George Springston, 7/16/2013.

Smugglers Notch: Rock Slides and Debris Flows in High Elevation Terrain

Above: One of two boulders that reached Rt. 108 in Smugglers Notch, May 30 to June 1, 2020. Right: Source area of rock fall on cliff north of Cass's Gully.

NEWS

Rock slide in Smugglers Notch: What happened when boulders tumbled down to Vermont 108

Ethan Bakuli Burlington Free Press

Published 10:24 a.m. ET Jun. 1, 2020

Once Again, History is Important: Nothing New About Slope Instability in Smugglers Notch

King Rock and the slide scar north of Cass's Gully in 1911.

Left, Stowe Historical Society. Right, from *The Vermonter*, 1911, v. 16, p. 21 – 26.

Rock Slide/Debris Slide Southeast of Mt. Ellen, Warren, ~August 24, 2017

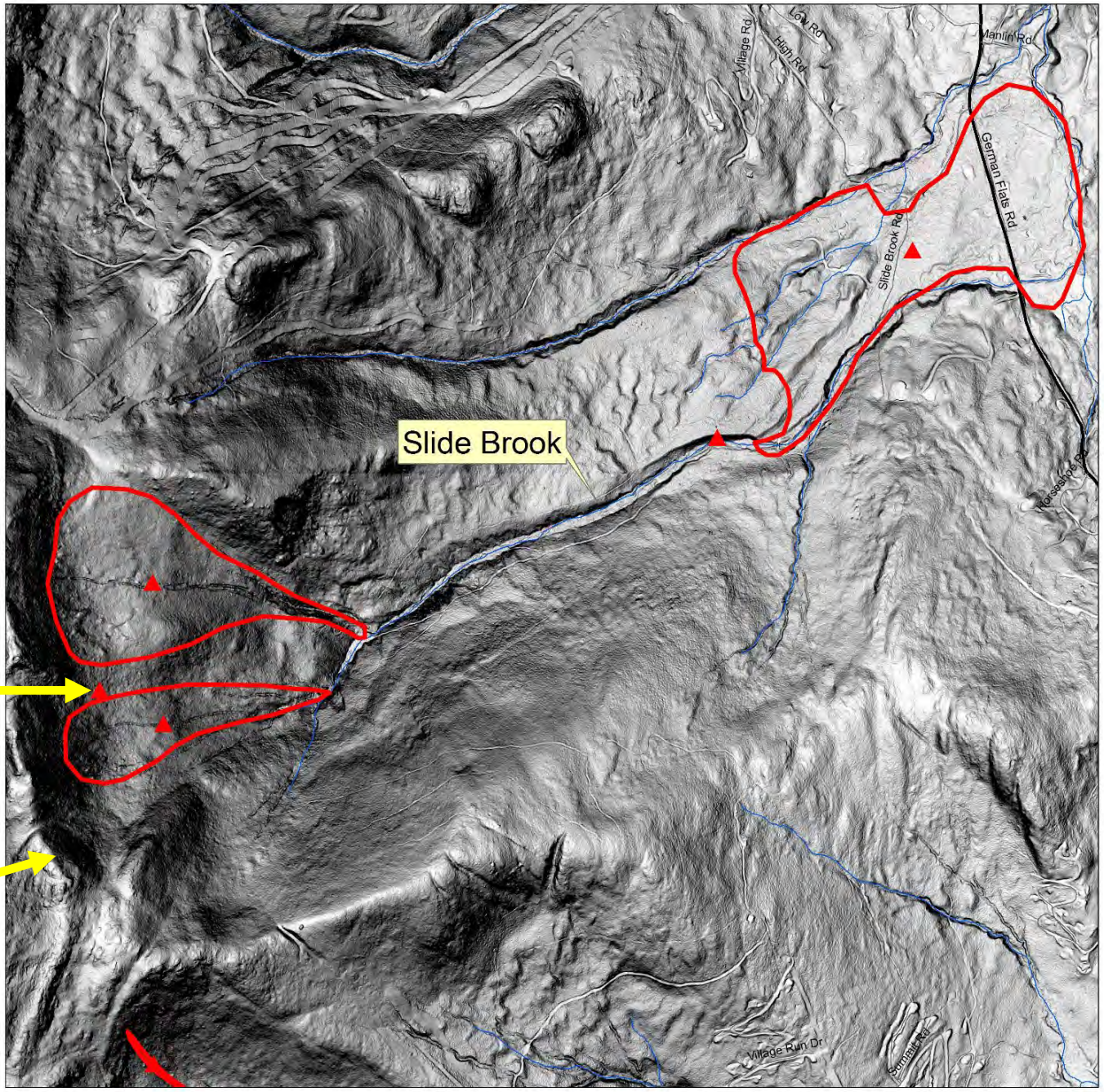
Looking up through broken trees at toe of Mt. Ellen slide. Failure started as a rock slide and transitioned to a debris slide as it moved rapidly down slope.

George Springston, 9/22/2017.

Lidar slope map of Slide Brook, Warren. Two red polygons on left delineate areas of earlier landslides. 2017 slide occurred in area between the polygons.

2017 Slide

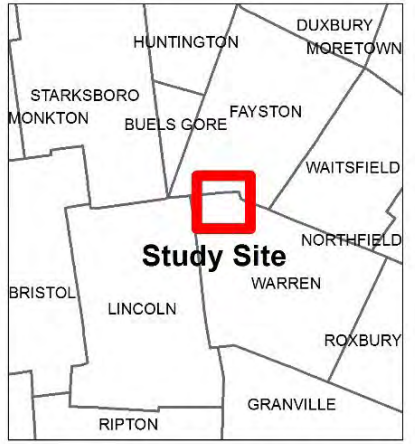
Crest of Green Mountains And Long Trail



Landslides
Landslide Polygons
Minor Roads
Major Roads
Streams
Water Bodies

Percent Slope
High : 178.017
Low : 0.126662

N
Meters
0 200 400 600



Vermont Geological Survey
9/20/2017

Vt. Landslide Protocol, 2010-2013

(Part of the Vermont Hazard Mitigation Plan)

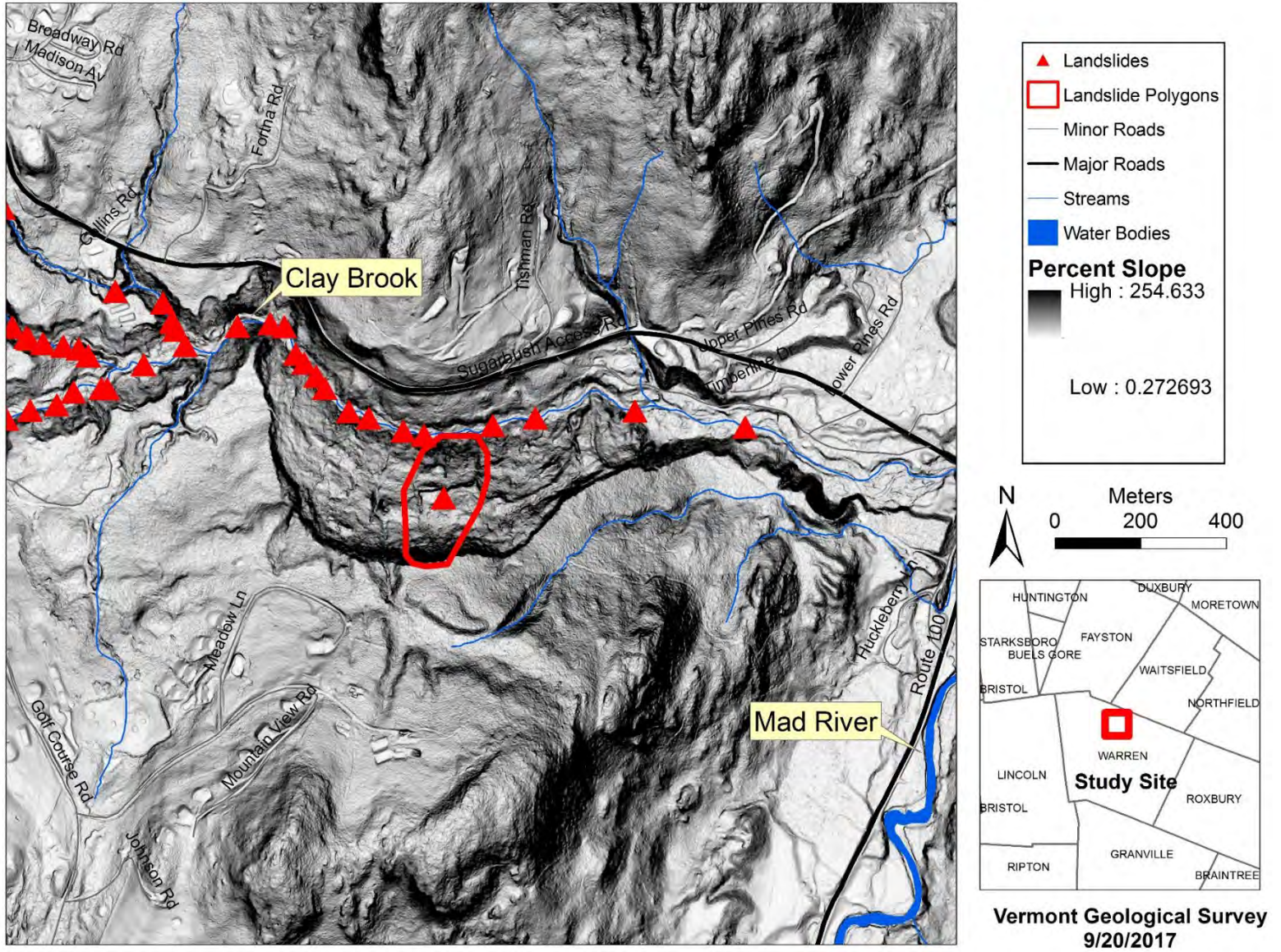
Protocol steps:

1--Map existing landslides

2--Develop models for existing landslides

3--Develop models for potentially unstable slopes (not yet failed)

Inventories available for Addison, Caledonia, Chittenden, Orange, and Washington Counties.



Lidar Slope Map of Landslides on Clay Brook in Warren

Map of Slope Instability Features, Washington County

Includes:

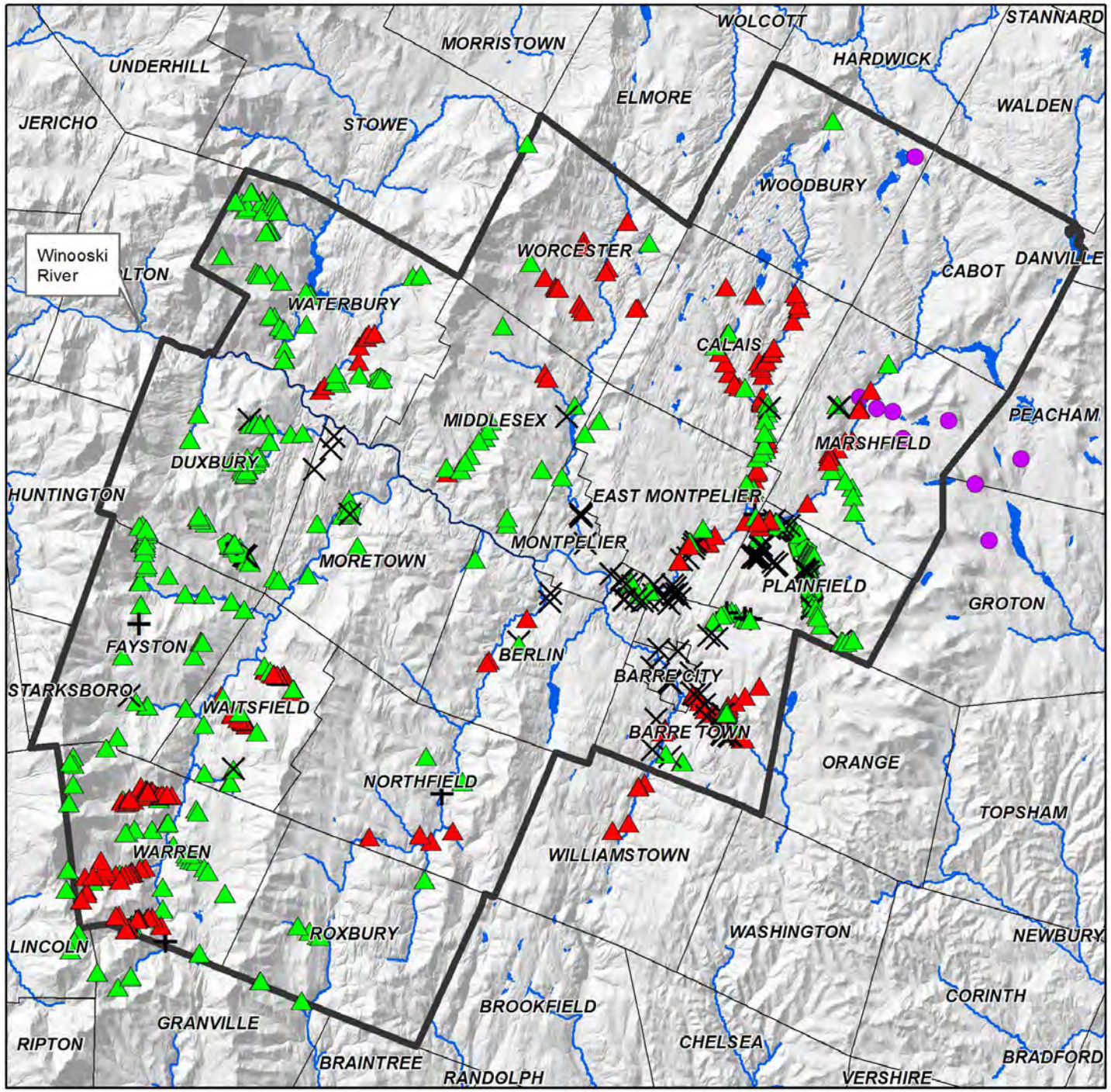
Landslides (in rock, debris, or earth)

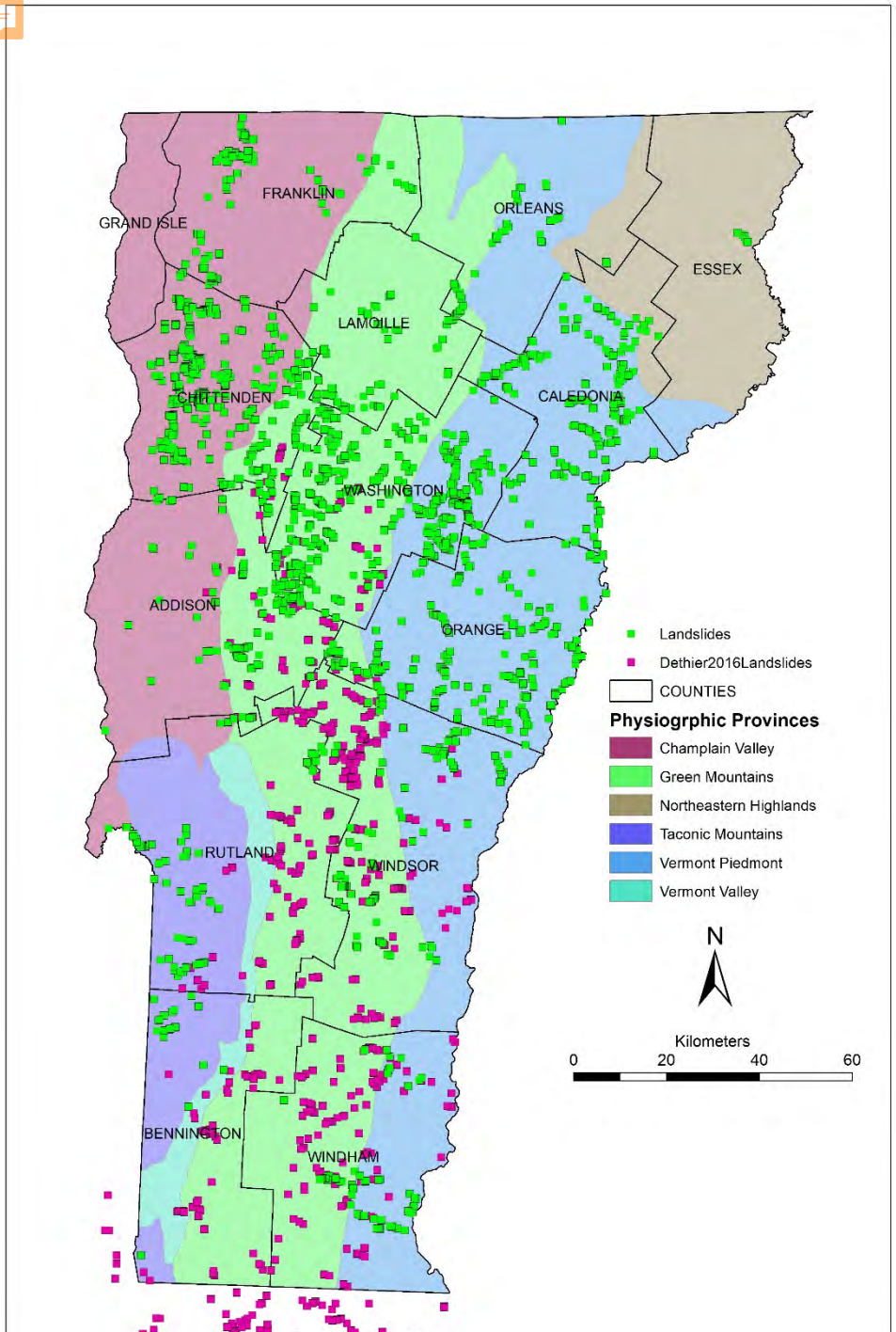
Gullies

Landslide-gully complexes

Mass Failures (= Landslides)

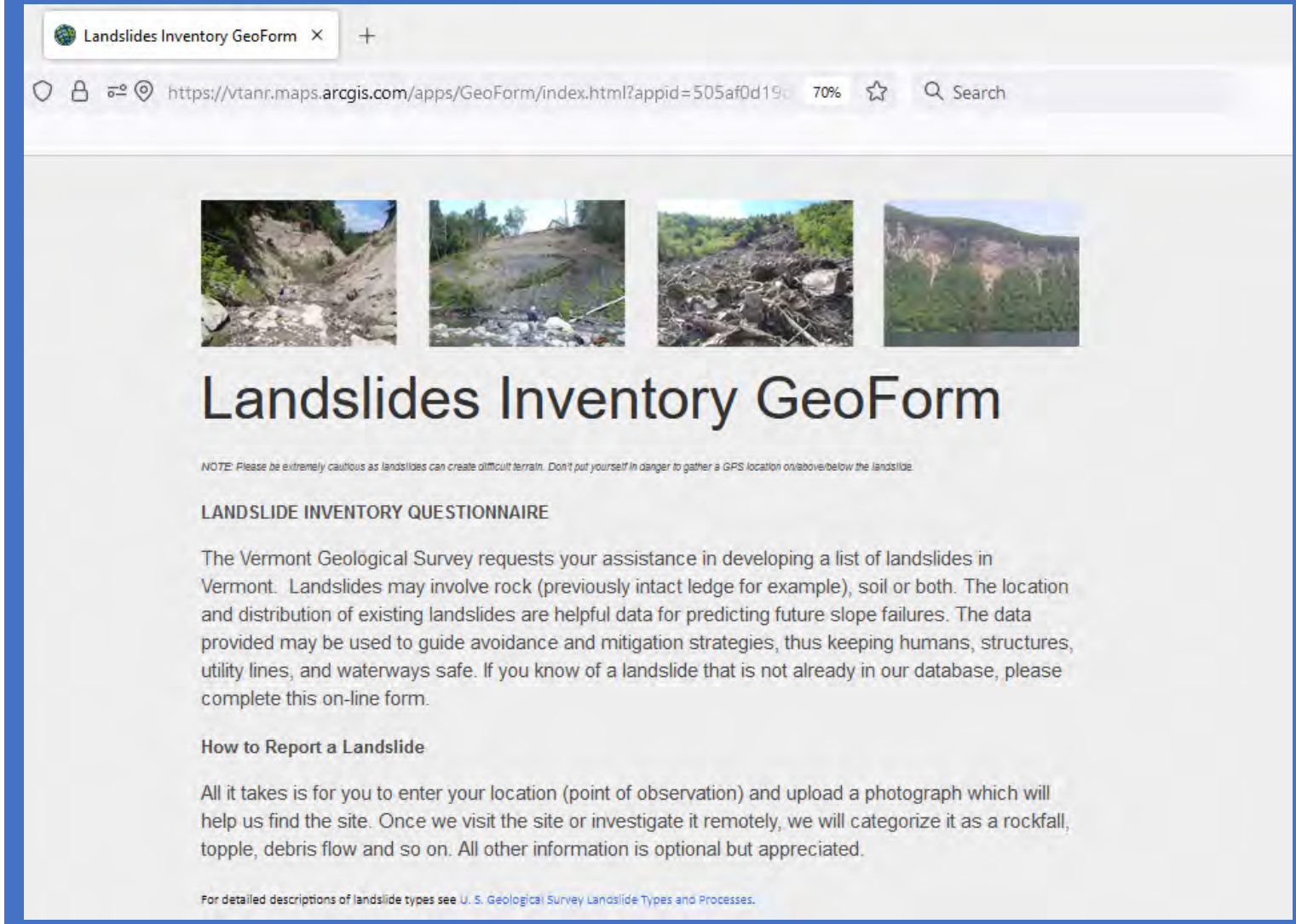
Talus Deposits

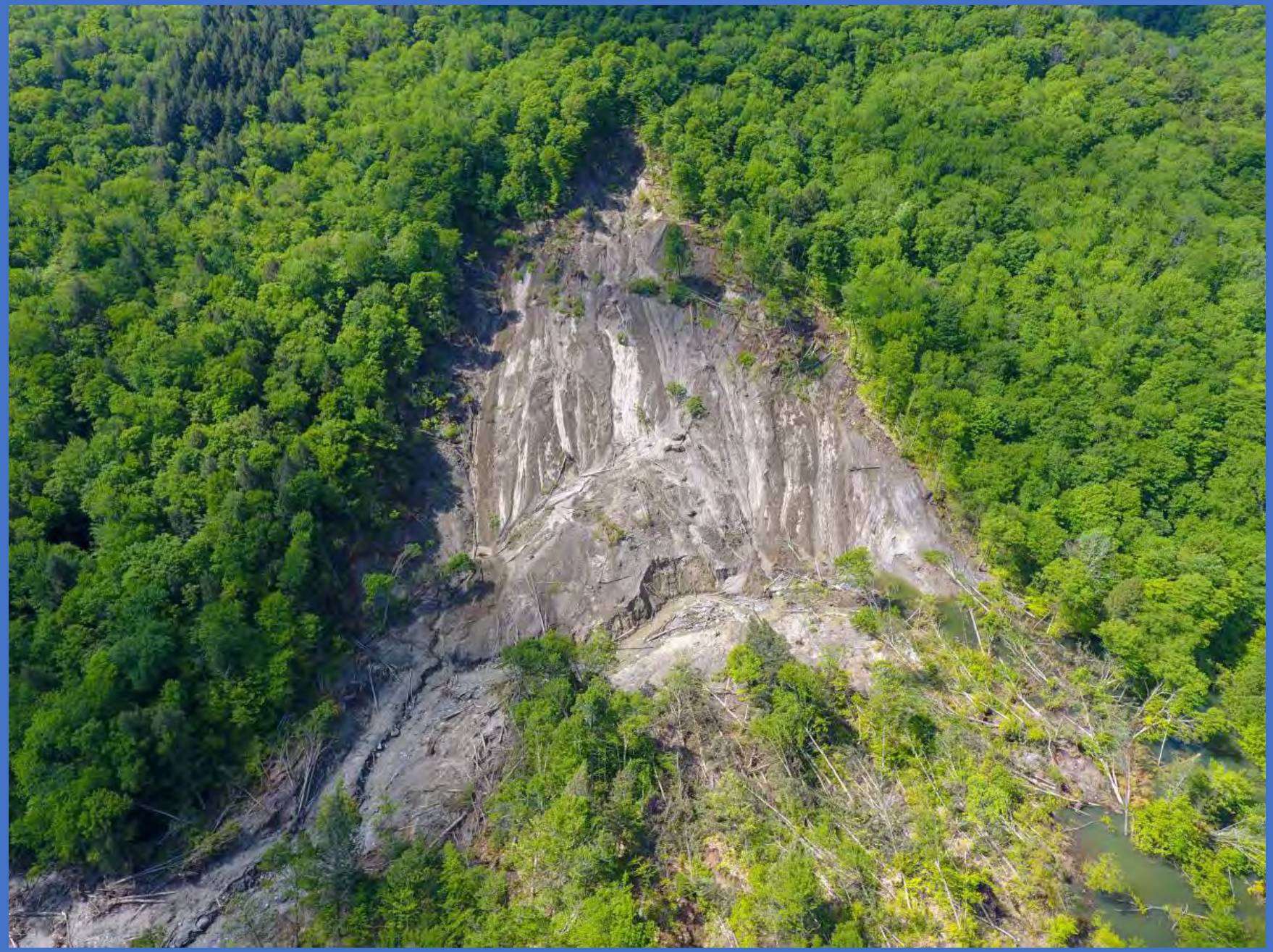




Landslide Database and Report a Landslide

https://dec.vermont.gov/geological-survey/hazards/landslides





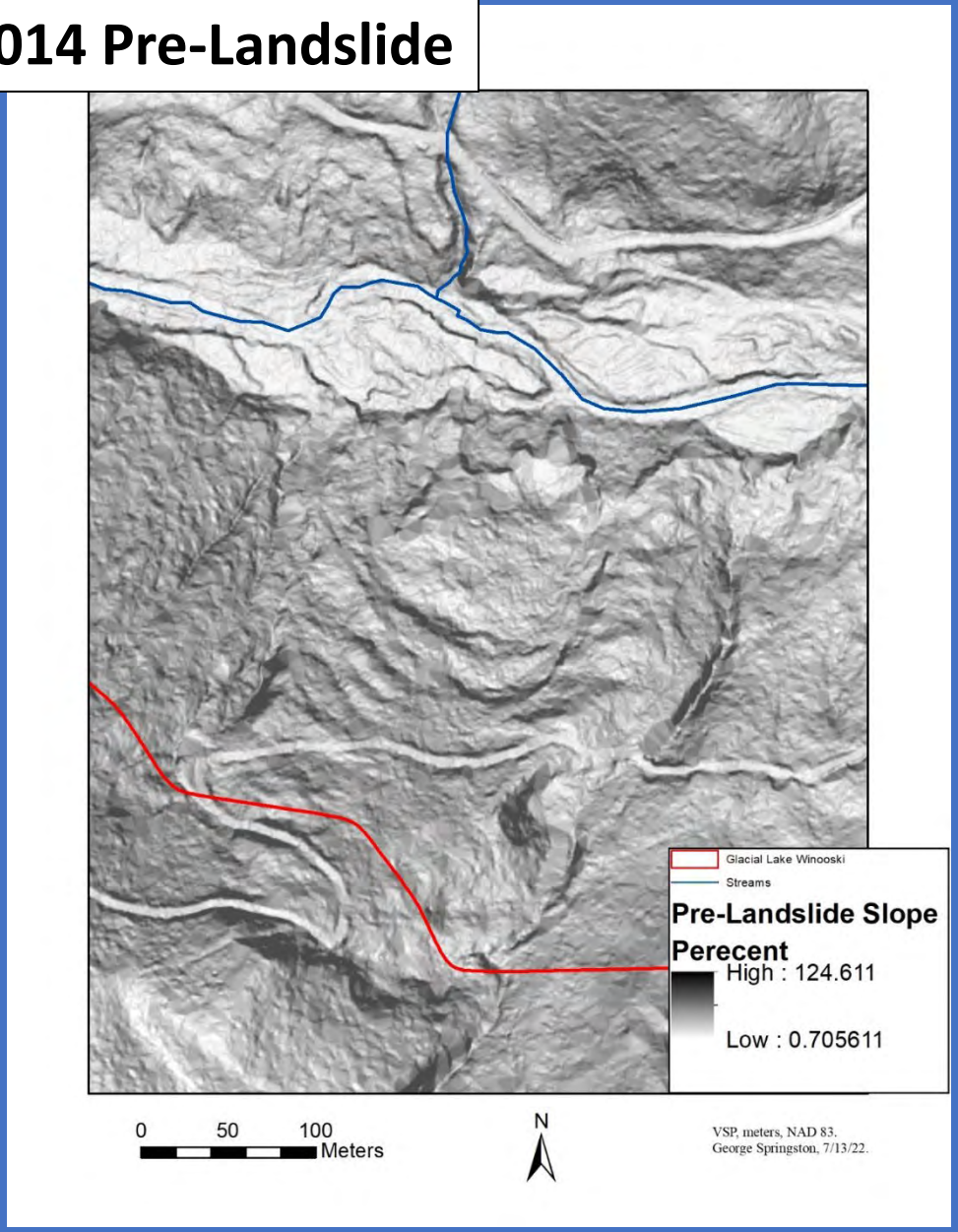
Cotton Brook Landslide, Waterbury, 2019

Looking south. The landslide deposit is at the bottom, center and the ponded area is at lower right. Stream flows from right to left. Photo by Evan Robinson, VTrans Rail and Aviation Bureau, 6/12/2019.

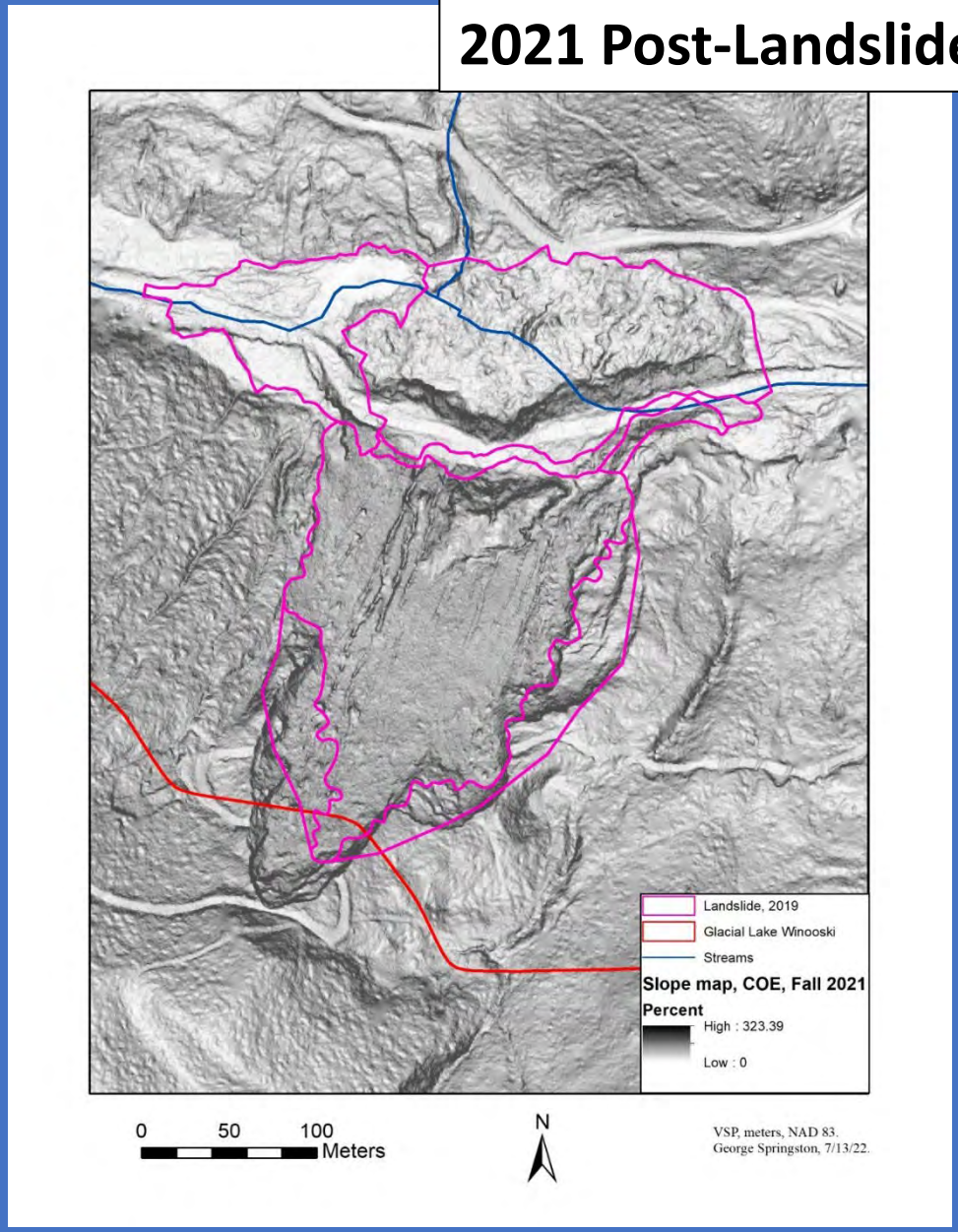
https://dec.vermont.gov/geological-survey/hazards/landslides/cotton-brook

Lidar as a Key Tool in our Hazard Analysis: Example from Cotton Brook

2014 Pre-Landslide



2021 Post-Landslide



What We've Learned About Landslides in Vermont

- Over 3000 features identified in Vermont to date. Inventories for 5 counties.
- Most of these slope failures are located in close proximity to rivers.
- Most are driven at least partly by heavy rain events and/or snowmelt.
- Landslides tend to recur in the same locations. Reactivation can be expected after future large floods.
- Active gullies are more common in developed areas.
- Geology Matters: surficial materials, bedrock locations, landscape position….
- And history matters too!

The 2021 Landslide Team.

For More Information:
https://dec.vermont.gov/geological-survey/hazards/landslides

Acknowledgements

- Funding: Vermont Geological Survey, Vermont Emergency Management Agency, Chittenden County Regional Planning Commission, Central Vermont Regional Planning Commission.
- Thanks to Larry Becker and Marjorie Gale, former Vermont State Geologists, for their leadership, ideas, support and encouragement.
- Thanks to Anne Clift, Ethan Thomas, Kristen Underwood, Leslie Kanat, and Lori Barg for many contributions.
- Thanks to our colleagues Stephen Wright and Rick Dunn for their many contributions to our understanding of the surficial materials.
- Thanks to the staff at the Vt. Rivers Program for generously sharing ideas and information. Particular thanks to Mike Kline, Barry Cahoon, Stacey Pomeroy, and Shayne Jaquith.

Jon Kim with former State Geologists Marjorie Gale and Larry Becker.

NORWICH UNIVERSITY™ 1819
Expect Challenge. Achieve Distinction.

VERMONT
AGENCY OF NATURAL RESOURCES
Vermont Geological Survey

The University of Vermont