Environmental
Protection

DIAGNOSTIC ASSESSMENT OF WARNER CREEK, CATSKILL MOUNTAINS, NY - THREE YEARS OF STUDENT CONDUCTED RESEARCH: CONCLUSIONS AND IMPLICATIONS

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Geological Society of America Northeastern Section

48th Annual Meeting

March 18 – 20, 2013

Bretton Woods, New Hampshire

Overview

NYC Environmental Protection

❖ New York City Water Supply and Filtration Avoidance

❖ Issue of turbidity in the Ashokan Reservoir watershed. Primarily from stream channel corridor sources

❖ Extreme flow events effecting high and low flow stream turbidity in the Catskills

❖Student-based research on Warner Creek to assess impacts of extreme flow events on stream channel morphology

❖ Stream management planning informed by student research

- Surface Water Supply
- Source of water is a 2,000 square mile watershed
- 19 reservoirs & 3 controlled lakes
- System Capacity:
  - 580 billion gallons
- System Serves:
  - 9 million people
  - (1/2 of population of New York State)
- System Delivers:
  - approx. 1.2 BGD
- Operated and maintained by NYC DEP

New York City Water Supply

- New York City Department of Environmental Protection is responsible for the delivery of high quality drinking water to 9 million people.
- About 1 billion gallons of water is used on a daily basis.

New York City Water Supply

- 90% of the source water is from unfiltered surface water stored in 6 reservoirs in the Catskill Mountains of NY.
- The water is delivered via aqueducts and tunnels about 100 miles south to a terminal reservoir prior to treatment and distribution.

Ashokan Reservoir, Ulster County NY

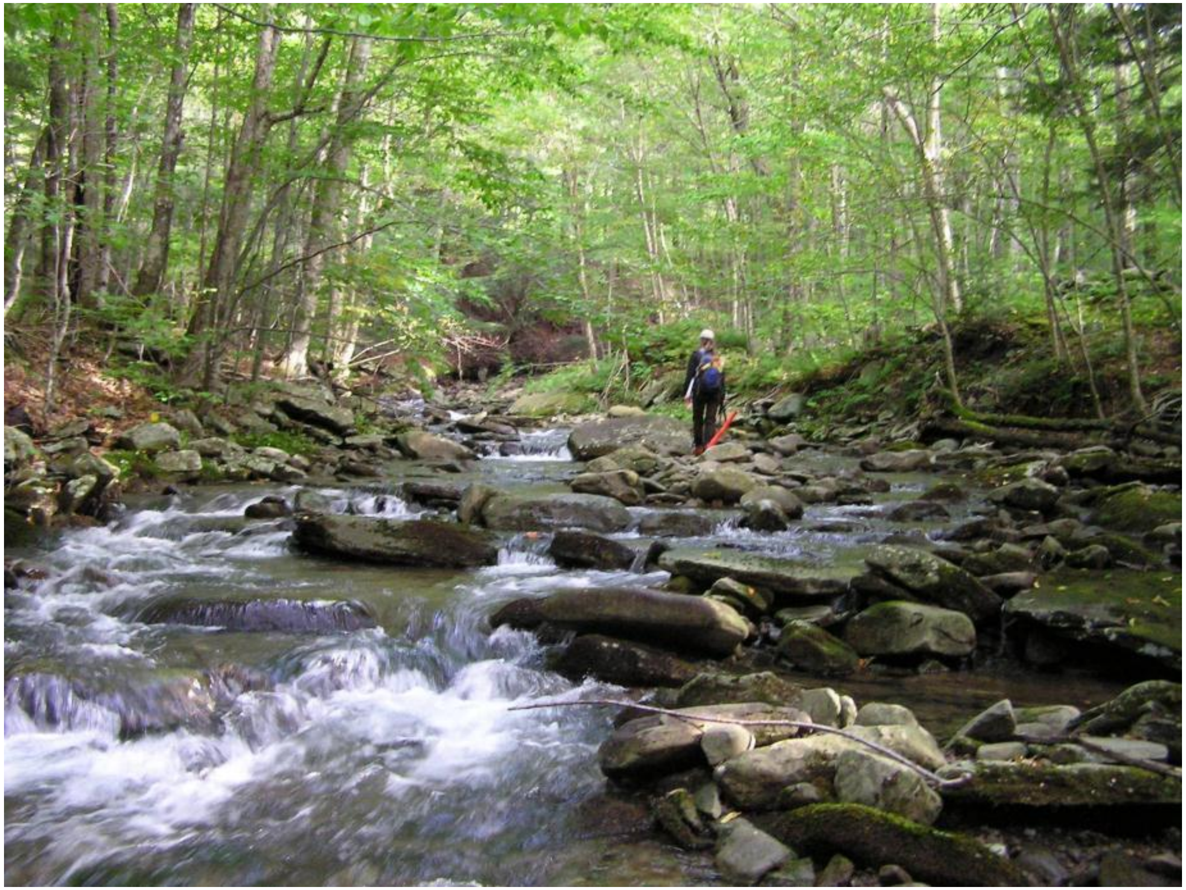
New York City Water Supply

- The source terrain for the West-of-the-Hudson water supply is the Catskill Mountains.
- Approximately 1600 mi^2 of mostly forested watershed with about 250,000 residents in several small population centers.
- The supply is divided into a Delaware System and a Catskill System

Ashokan Reservoir watershed, Ulster County NY

New York City Water Supply

- The reservoirs are supplied by hundreds of miles of mountain streams.
- Most of the headwater streams are in forested settings and are typified by steep gradients and large sediment.
- The higher order streams drain the main valleys and tend to be where the population centers exist.



Esopus Creek headwater reach, Ulster County NY

Turbidity in the Water Supply

Though the water is clean at the tap, the Catskills are subject to periods of extreme turbidity from suspended sediment eroded from the mountain landscape. This presents a serious challenge to water supply management.

In lieu of building a filtration plant

for the Catskill/Delaware water supply,

NYC works to

<u>prevent pollution at the source</u>

by working with watersheds stakeholders

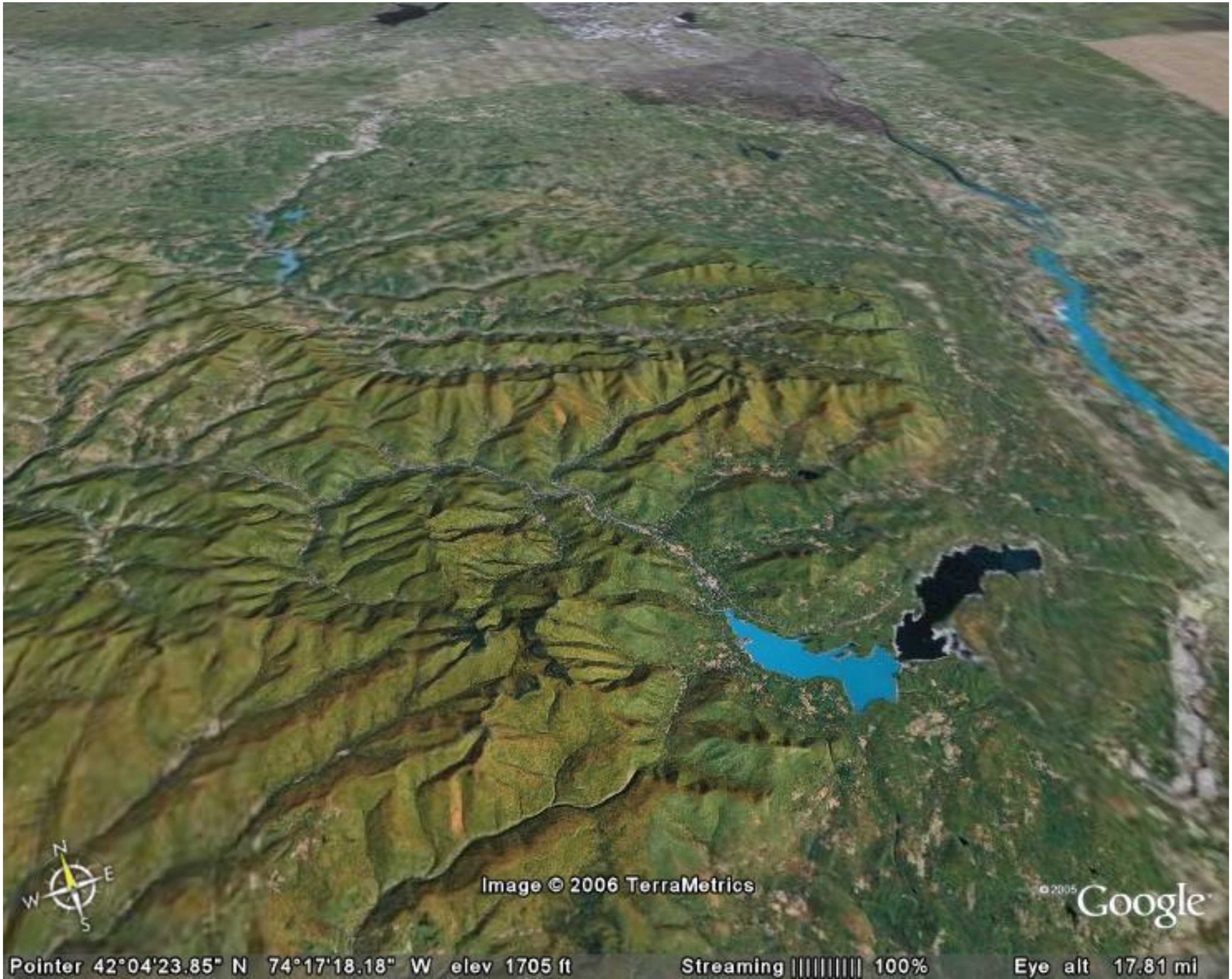
in a partnership arrangement to achieve

watershed protection.

The Catskill System

- Catskill System
  - Catskill geology + hydrology = periodic high turbidity
  - Designed to handle turbidity
- Schoharie Reservoir
  - Schoharie Creek impoundment (1926)
  - 19.6 BG Capacity
  - Diverting System
  - Shandaken Tunnel
- Ashokan Reservoir
  - Esopus Creek impoundment (1915)
  - 127.9 BG Capacity
  - West and East Basins

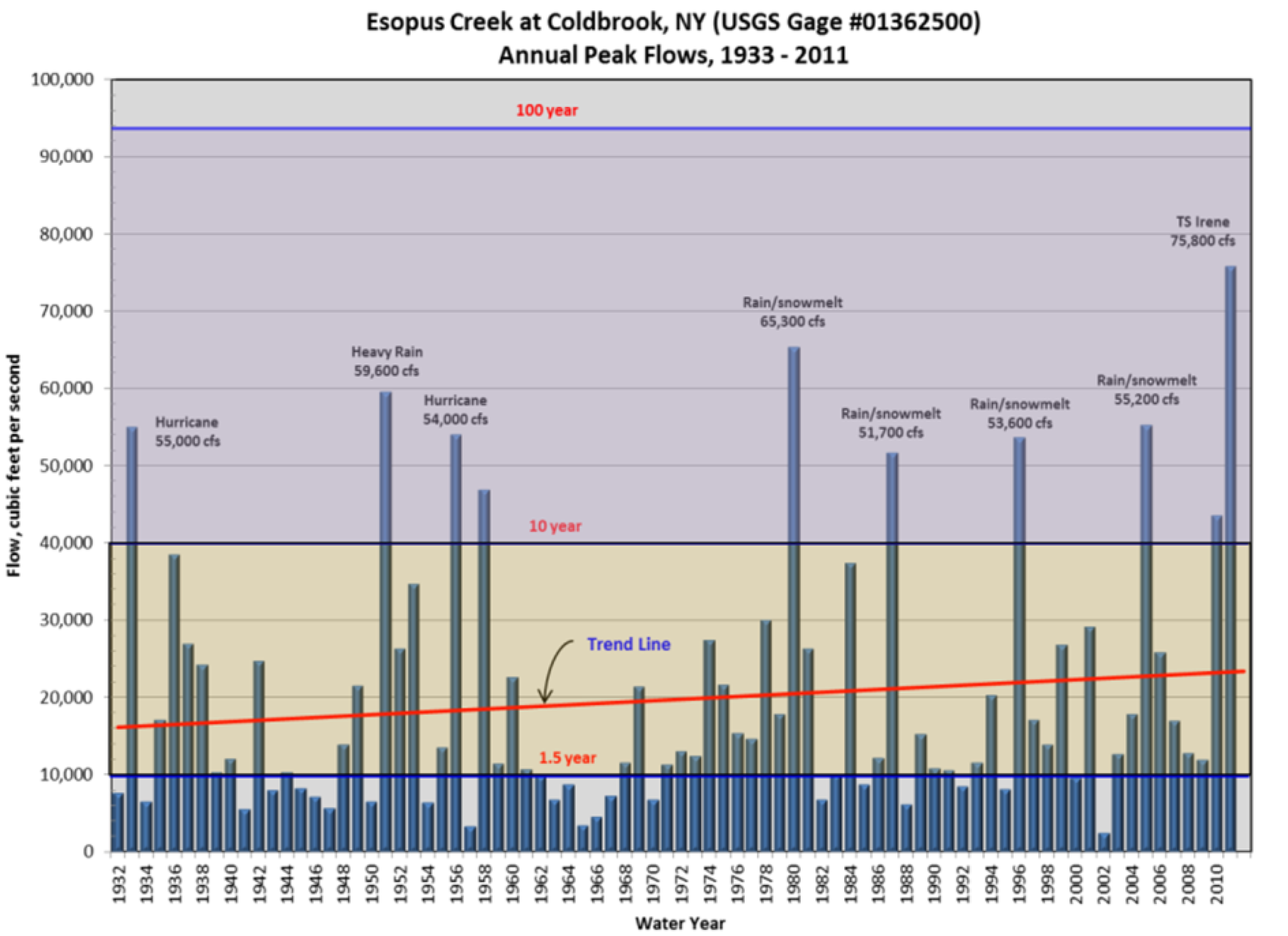
Esopus Creek and Ashokan Reservoir



Turbidity in the Ashokan Watershed

Turbidity in the Water Supply

HYDROLOGY



Esopus Creek at Coldbrook, NY (USGS Gage #01362500)
Annual Peak Flows, 1933 - 2011
100 year
10 year
1.5 year
Trend Line
Hurricane
55,000 cfs
Heavy Rain
59,600 cfs
Hurricane
54,000 cfs
Rain/snowmelt
65,300 cfs
Rain/snowmelt
51,700 cfs
Rain/snowmelt
53,600 cfs
Rain/snowmelt
55,200 cfs
TS Irene
75,800 cfs
Flow, cubic feet per second
Water Year

GEOLOGY

Turbidity in the Water Supply

GEOMORPHOLOGY

All kinds of geo-action going on along the Chichester Reach of Stony Clove Creek, Fall 2010

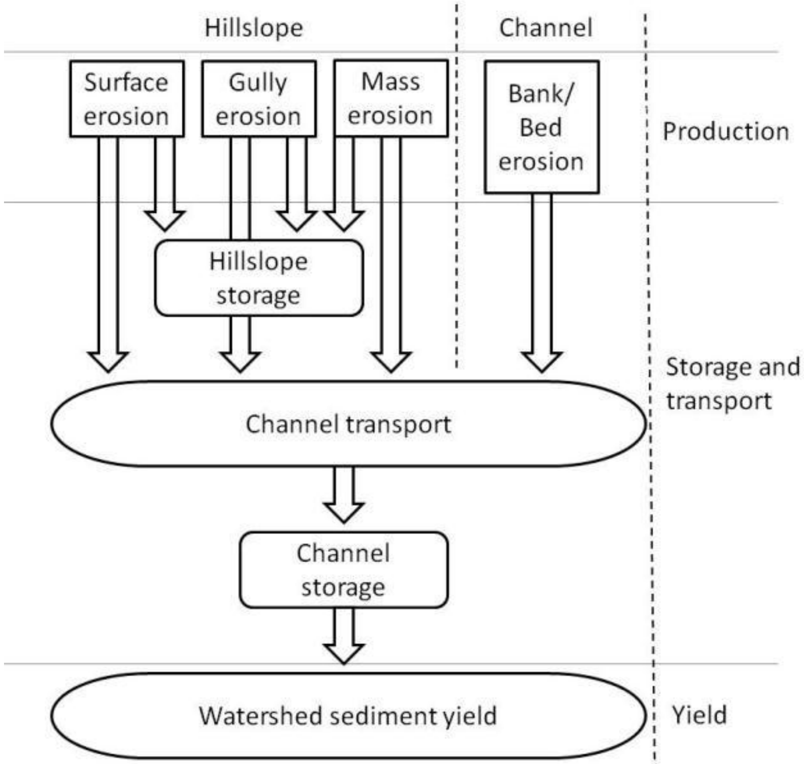
Stream Turbidity

Some general questions

- ❖ What are the dominant sources?

  eg: hillslope erosion, streambank/bed erosion, dirt roads, construction sites etc.

- ❖ Impact on water quality
- ❖ Potential for remediation

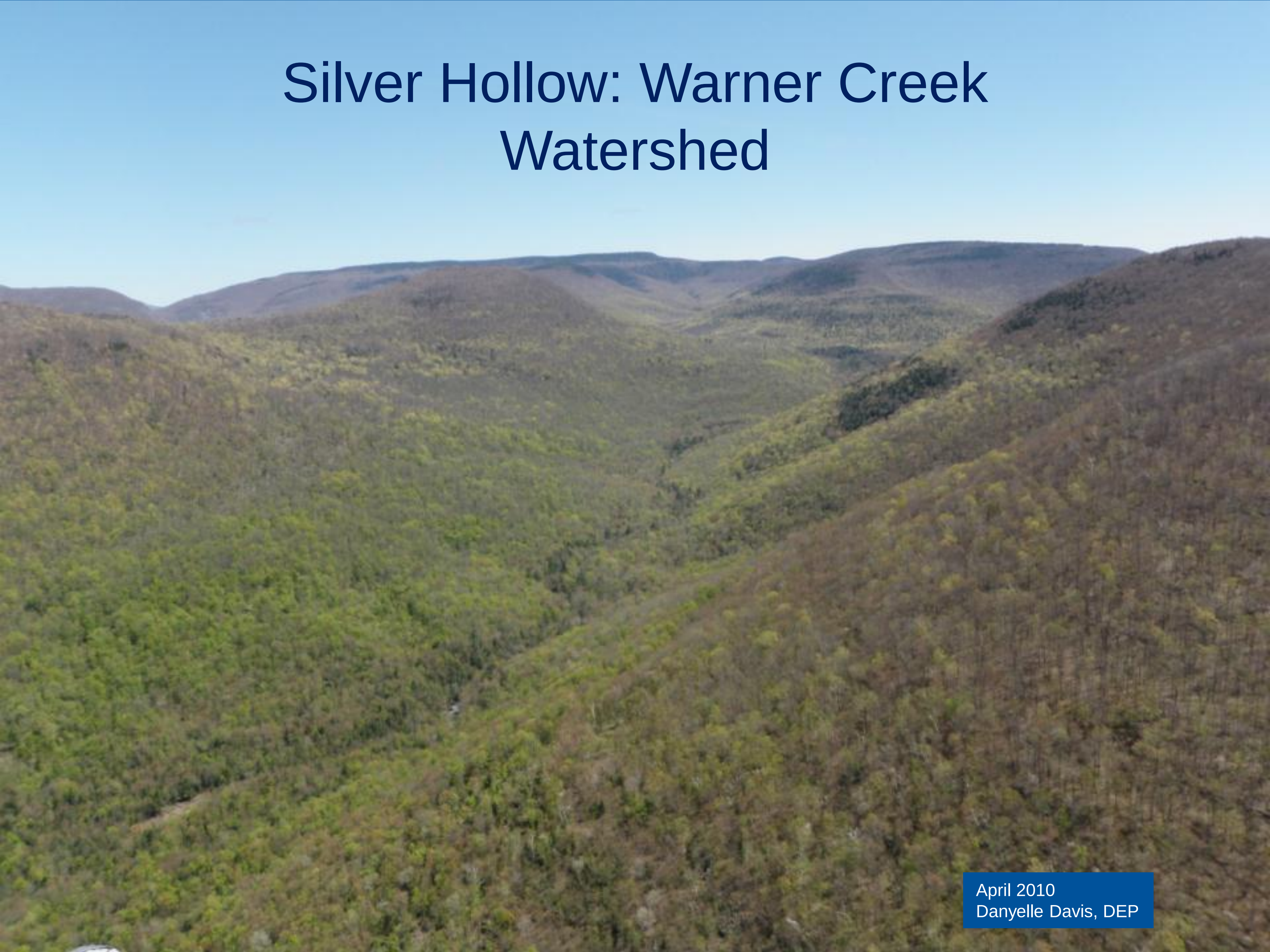


Sedimentation process (Modified from EPA,1999)

SUNY New Paltz REU Program

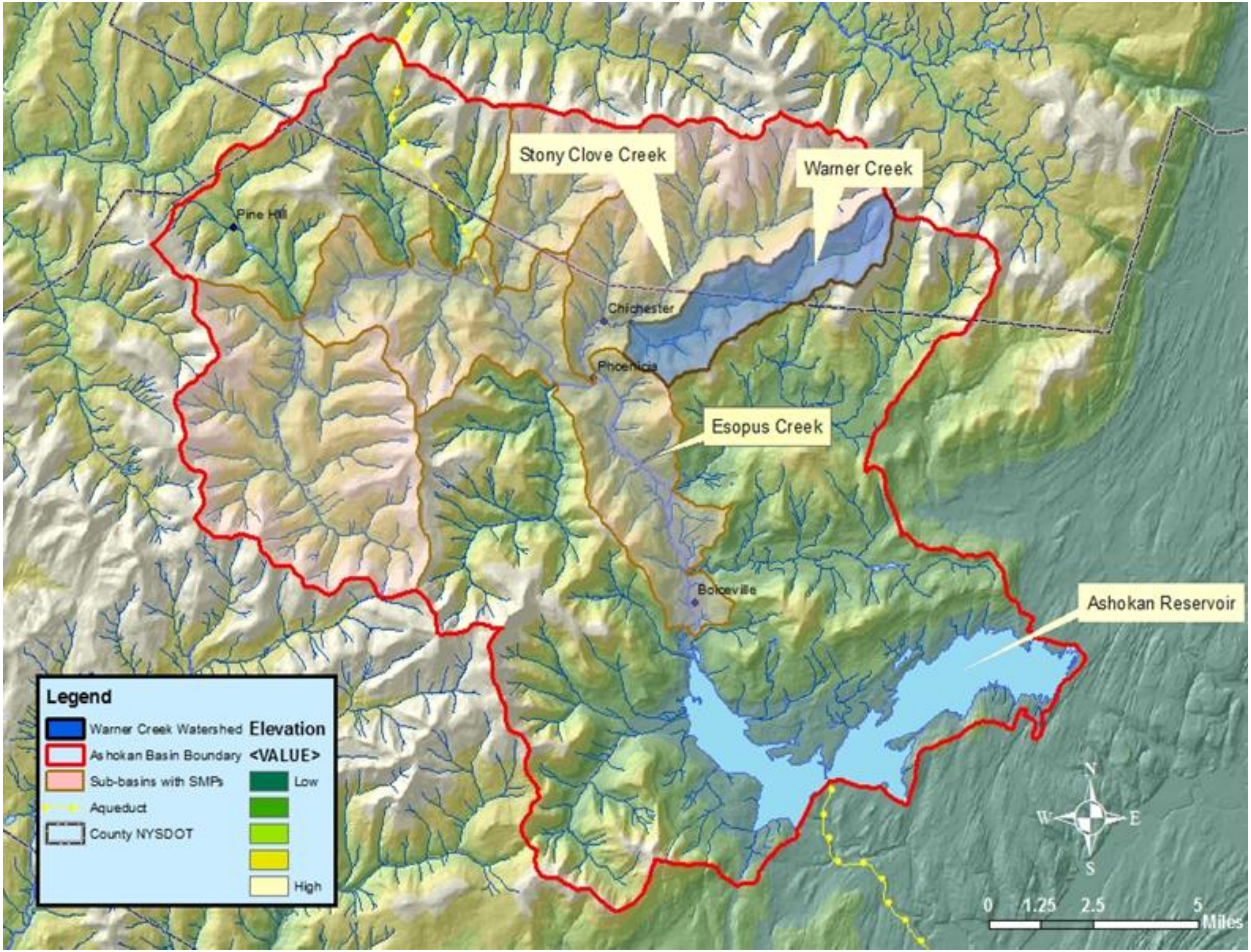
- 2010 – 2012: SUNY New Paltz EGS Department hosted a 3 year Research Experience for Undergraduates (REU) Program
- Twelve students/year participated in 8 weeks of research designed to provide a comprehensive, multi-disciplined characterization of the Stony Clove Creek watershed in the Catskill Mountains, NY.
- Research projects included:
  - diagnostic assessment of Warner Creek
  - mapping glacial geology
  - examining various aspects of water quality
  - studying an invasive periphyton
  - groundwater-induced hillslope failures
  - GIS-based modeling of aspects of the watershed.

Silver Hollow: Warner Creek Watershed



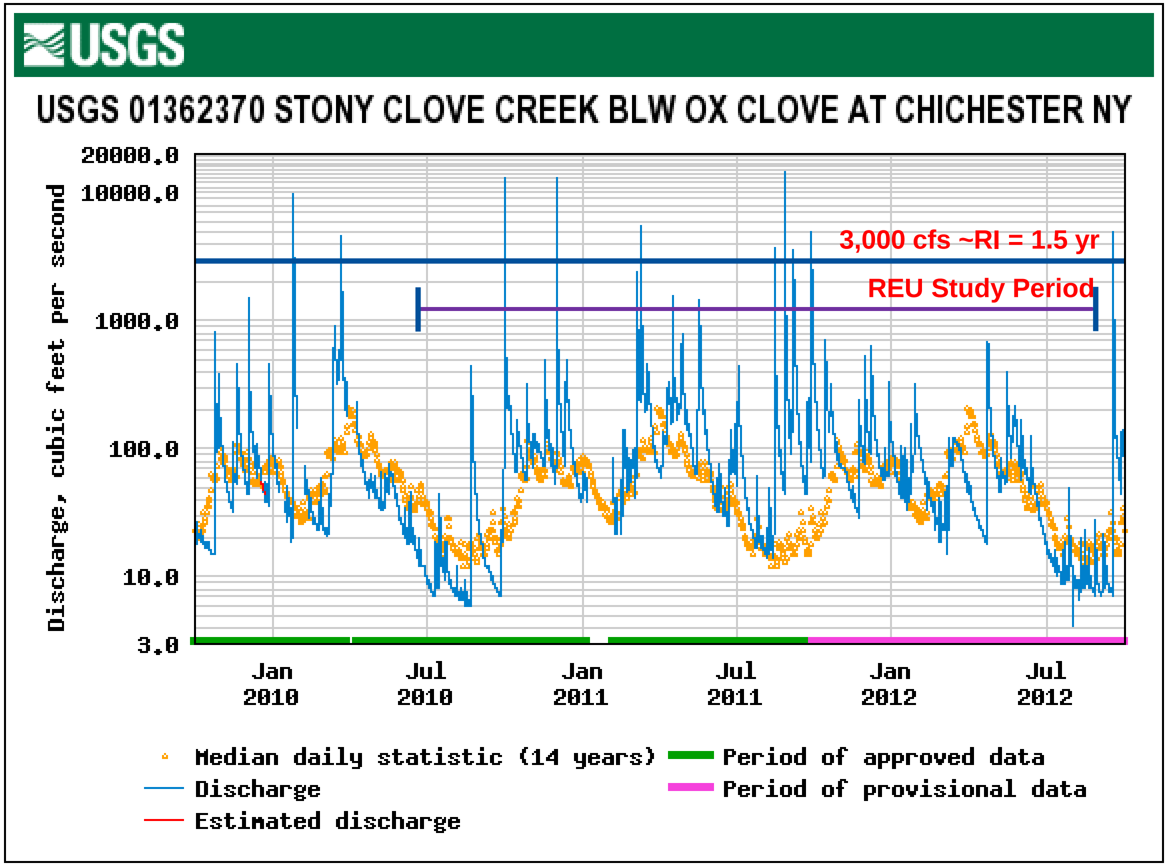
April 2010
Danyelle Davis, DEP

Warner Creek



Study Period Hydrology

Prior to the first year's field season, Warner Creek experienced a geomorphically significant flood in January 2010. Following that there were 7 high flow events ($Q_{1.5}$) over the course of the three study years.

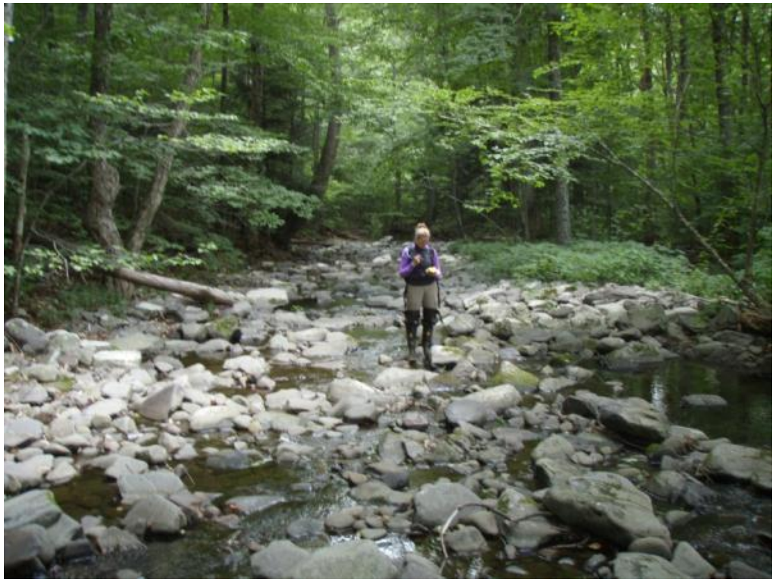


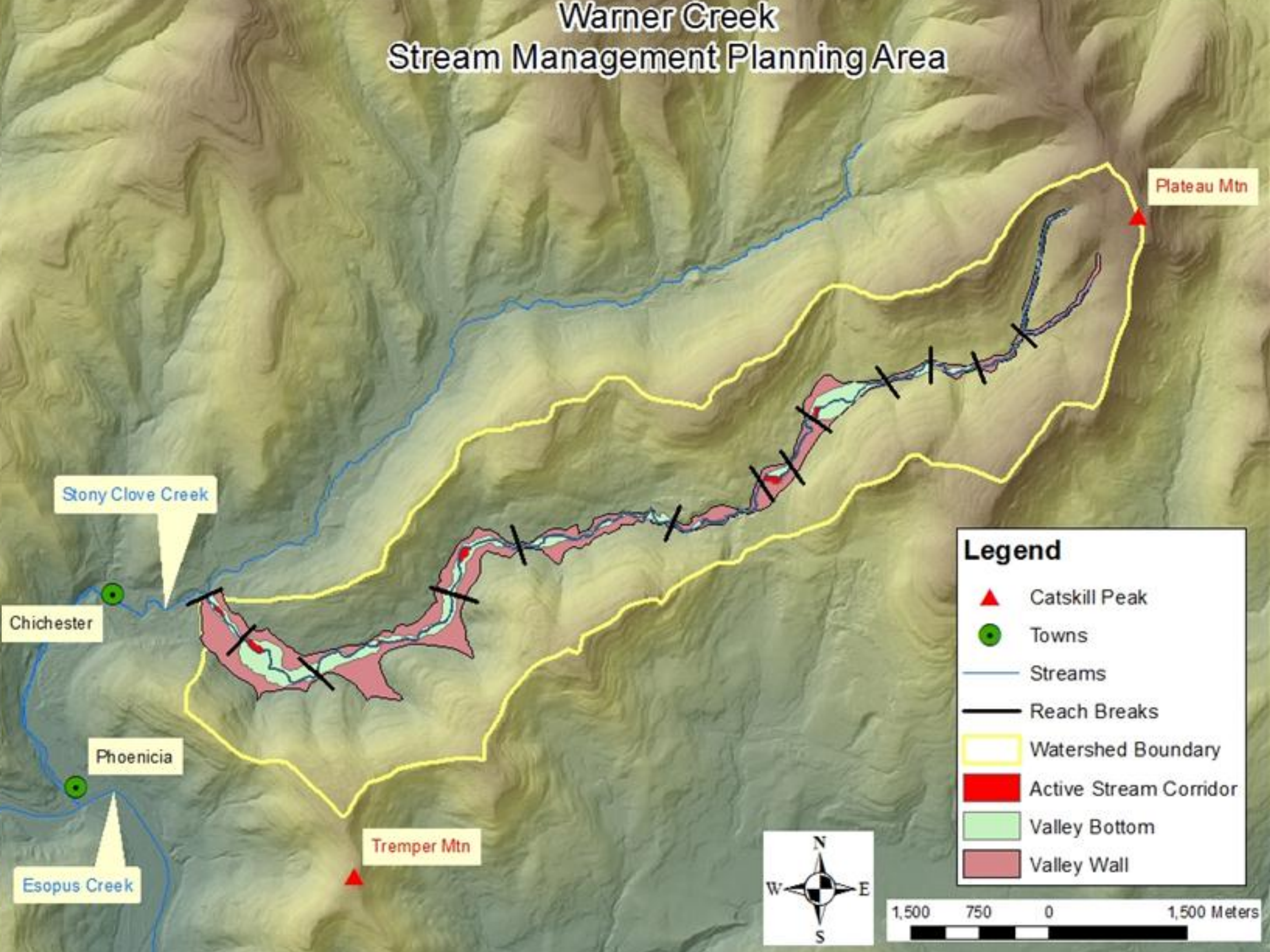
- A period that included 7 flow events greater than the probable bankfull flow (~3,000 cfs from FFA)
- Three of the events during and one preceding the study period had the potential for high geomorphic adjustment with flows in Stony Clove Creek at ~10,000 cfs – 14,000 cfs.
- Presented a unique opportunity to observe through repeat measurements the stream channel's geomorphic response to extreme hydrologic conditions

2010: The Baseline Studies

- 2010: (Wai Allen, Emily Davis, Katrina Morelli, Alison Voelker; Emily Arnold; Chris Oliver)
  - Completed the GIS analysis to
    - Delineate the stream into geomorphic reaches
    - Define the active and past stream corridor
  - Completed a stream feature inventory (SFI) of almost all of the 14.5 km of stream creating baseline data for subsequent years
  - Mapped the surficial geology of an actively eroding reach
  - Completed an isotopic sediment fingerprinting study to identify principle geologic source of suspended sediment

2010 REU Program





Warner Creek
Stream Management Planning Area
Plateau Mtn
Stony Clove Creek
Chichester
Phoenicia
Esopus Creek
Tremper Mtn
Legend
Catskill Peak
Towns
Streams
Reach Breaks
Watershed Boundary
Active Stream Corridor
Valley Bottom
Valley Wall
N
W
E
S
1,500
750
0
1,500 Meters

NYC Environmental Protection

Characterizing the Fluvial Geomorphology of a Mountain River Watershed Using Multi-Scale Methods

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Introduction

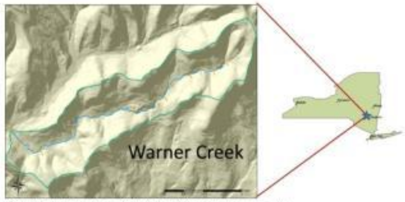
The Ashokan Reservoir is one of two reservoirs located in the Catskill Watershed within the New York City water supply system. Approximately 40% of New York City water comes from the Catskill watershed , and there is currently no filtration system in place to treat the surface water (CCE 2007). Due to the high cost of development, installation, and maintenance of such a system, the city is able to provide unfiltered water to its residents through a renewable Filtration Avoidance Determination and the 1997 Memorandum of Agreement from the Environmental Protection Agency and the New York State Department of Health (Ashendorff et al. 1997). Large storm events prompt flooding, and result in an increase in suspended sediment within the Ashokan Reservoir. Chlorine is used to kill pathogens in water, but turbidity decreases the effectiveness of chlorination as pathogens adhere to the suspended sediments. The New York City Department of Environmental Protection (DEP) ensures high quality water standards are met through watershed management and protection, making turbidity reduction a main goal for the DEP.

Warner Creek is located within the Ashokan watershed, and has been identified by the DEP as a major contributor of turbidity (GCSWCD 2005). The geology of the area is remnant of the past ice age with both glacial and lacustrine sediment deposits. Fluvial sediment deposits are found adjacent to much of Warner Creek, creating a series of terraces within the valley. The 14.5 km stream is bordered by undeveloped land as well as developed land.

Objectives

- Collaborate with the DEP and SUNY New Paltz throughout the summer of 2010 to collect data as groundwork for an ongoing Research Experience for Undergraduates program.
- Characterize the fluvial geomorphology of Warner Creek through a preliminary stream assessment.

Study Location



*Orange lines indicate reach breaks used during stream assessment

Methods

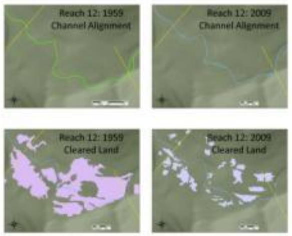
Watershed Scale

- Identified watershed boundary and calculated drainage area using ArcGIS
- Delineated reaches using ArcGIS
- Predicted hydraulic geometry using the USGS StreamStats program
- Digitized stream channel center alignment and forested vs. cleared land using georeferenced orthoimagery spanning 50 years

Stream Scale

- Stream feature inventory using Trimble Pathfinder GPS units
- Cross section surveys with Total Station equipment

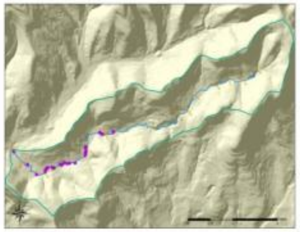
Results



The majority of cleared land was found in the lower reaches adjacent to Warner Creek, where the majority of residents along the stream are located. This is also where the channel center alignment displays the greatest variances. Notice the sharp angles in the channel meander due to human involvement. The amount of cleared land is decreasing.

Warner Creek Watershed		14.5 km²
Year	Percent Cleared	Percent Forested
1959	1.2	98.8
2009	1.1	98.8

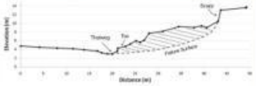
The pink dots represent sources of fine sediment which occur primarily in the lower reaches. These locations have fine silt or clay sediment exposed in either the river bed or in its banks making it easy for the sediment to become mobilized during large storm events.



Large woody debris (LWD) entrains sediment in Warner Creek. Locations of LWD were mapped along Warner Creek. Scouring and entrained sediment were often found at these locations.

The green dots represent locations where LWD is either partially or fully spanning the width of Warner Creek. These locations are found throughout the river system and do not seem to be localized. In some cases, build up of LWD did alter flow patterns.

A cross section was surveyed at a rotational clay slump along Warner Creek. The dotted line indicates the failure surface (position estimated). The tilting of the clay beds is represented in the area between the cross section and failure surface (estimated). The stream is located at the toe of the slump. Geomorphic processes such as this contribute to large amounts of sediment load into the system.



Reach 2	Predicted Values	Actual Values
W_{bf} (ft)	13.3 – 22.3	31.5
D_{bf} (ft)	1.1 – 1.3	0.9
A_{bf} (ft²)	16.1 – 30.3	29.2

Reach 11	Predicted Values	Actual Values
W_{bf} (ft)	36.3 – 50.0	81.4
D_{bf} (ft)	1.6 – 1.9	1.6
A_{bf} (ft²)	68.7 – 110.2	128.1

Hydraulic geometry was predicted using data collected from GIS maps and the USGS Stream Stats program. Actual values were calculated from cross sections surveyed at different reaches in the stream.

Conclusions

Locations where we identified entrained sediment with channel-spanning large woody debris, and where fine sediment sources are exposed in the streambed or stream bank present a significant risk for sediment loading and erosion during large flood events. Additionally, changes in land use have affected stream migration pattern, and pose a high risk for sediment loading. The DEP can use this information to implement a stream management plan directed towards minimizing sediment loading in the Ashokan Reservoir.

References

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[CCE] Cornell Cooperative Extension – Ulster County, New York Department of Environmental Protection, and U.S. Army Engineer Research Development Center. "Stream Management Planning Area." In *The Upper Esopus Creek Management Plan Volume I*. Ulster County, New York, 2007.

[GCSWCD] Green County Soil and Water Conservation District and New York City Department of Environmental Protection. "Section 4: Management Unit 16." In *The Stony Clove Creek Stream Management Plan Volume II*. Cairo, NY, 2005.

Acknowledgements

We would like to express our sincere gratitude and appreciation to Danny Davis for his assistance, wisdom and guidance during this project.

NSF | Ashokan Watershed Stream Management Program | DEP

2011: Callinan and Shaheen

- 2011: (Chris Callinan, Greg Shaheeen)
  - Completed a SFI of the lower 3 km of Warner Creek for temporal comparison with 2010 SFI
  - Established a cross section monitoring study reach
  - Detailed enhanced mapping of depositional features and LWD

2011 REU Program

NYC Environmental Protection

Dynamic Stream Adjustment: A Study of Warner Creek's Erosive Response to Large Hydrological Events

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[1] SUNY New Paltz, [2] Wesleyan University, [3] New York City Department of Environmental Protection

WESLEYAN UNIVERSITY | New Paltz STATE UNIVERSITY OF NEW YORK | NYC Environmental Protection

Introduction

The New York City Department of Environmental Protection (DEP) must maintain delivery of a high quality of water to 9 million people. Turbidity from suspended sediment in the unfiltered water supply can interfere with the efficiency of disinfection. Warner Creek is a tributary to Stony Clove Creek in the Esopus Creek and Ashokan Reservoir watershed identified as a significant sub-basin source of turbidity due to its erosive interaction with Pleistocene glacial deposits (Figure 1). Stream bank and bed erosion can entrain glacial silts and clays, causing acute and chronic suspended sediment loading.

As part of a multi-year Research Experience for Undergraduates (REU) watershed study, the lower 10,500 ft. of Warner Creek (Figure 2) was assessed in 2011 to determine reach scale response to two geomorphically significant high flow events (Q>25 year recurrence interval), occurring in the previous 9 months (Figure 3). This study interprets fluvial processes in a glaciated mountainous terrain and evaluates stream diagnostic assessment methods. This part of the study investigates erosional response to high magnitude flood events and characterizes consequent stream channel conditions.

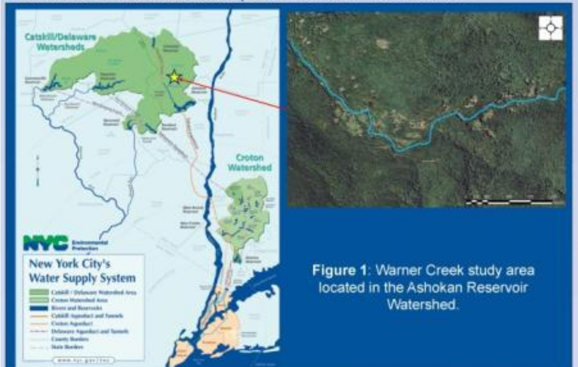


Figure 1: Warner Creek study area located in the Ashokan Reservoir Watershed.

Methods

Field methods included a comprehensive stream feature inventory mapping bank erosion, fine sediment sources, depositional features, large woody debris, and headcuts. These features were recorded using a Trimble GeoXT GPS receiver (with sub-meter accuracy) and were then processed in ArcGIS. This spatial data was compared to similar stream feature data available from a 2010 assessment performed by participating REU students.

Stream channel adjustment was studied by (1) overlaying pre- and post-flood surveyed cross-sections; and (2) comparing mapped eroding stream bank lines. The potential volume of sediment entrained was calculated using GIS-derived area values and bank Retreat measurements. A sub-set of these areas was examined in February 2012 to further quantify the erosive response of Warner Creek to flood flows, incorporating The impacts associated with Tropical Storm Irene (Figure 4).

Figure 2: Percent Slope per Reach (E. Davis, 2010)

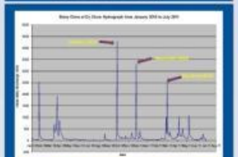


Figure 3: Large Flow Events on Warner Creek from January 2010 to July 2011

Results

Figure 4: Temporal geomorphic change on Warner Creek from a stable boulder dominated reach in 2010 to a deeply incised channel in 2012

Figure 5: Bank erosion caused by various processes including fluvial entrainment of alluvium and cantilever failure due to loading of large woody debris.

- Stream bank and adjacent hill slope erosion account for most of the coarse and fine sediment loading based on the observed increase in erosion and deposition from 2010 to 2011 (Figures 5 - 8).
- The calculated volume of sediment eroded from the banks in the reaches studied was 4,260 m³ between the summers of 2010 and 2011.
- Observed chronic turbidity in Warner Creek originates from entrainment of silt and clay from exposed glaciolacustrine deposits (Figure 6).

Figure 6: Sites of exposed glaciolacustrine deposits along Warner Creek

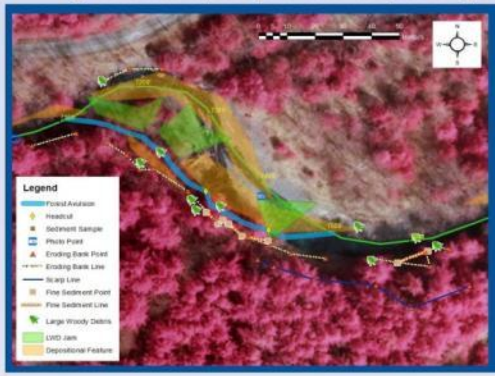


Figure 7: Stream Feature Inventory of a site where an avulsion through the forest occurred during a large flow event in January 2010. Much of this study was focused in this section of the stream.

Results cont.

- Bank profiles and channel cross sections were done in the forest avulsion section of Warner Creek.

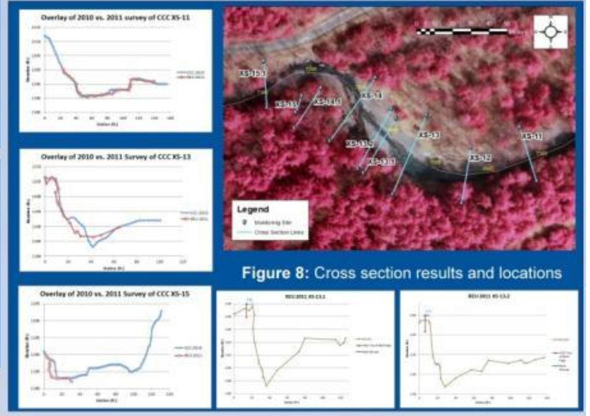


Figure 8: Cross section results and locations

Conclusions

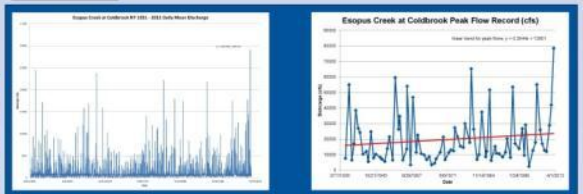


Figure 9: Mean daily discharge and peak flow record hydrographs (D.Davis)

- Warner Creek is responding to a changing hydrologic regime (Figure 9).
- There is no apparent net increase in mean annual runoff; however there is an increasing trend in the frequency of annual peak flows greater than bankfull discharge (as determined for Esopus Creek based on 80 years of USGS stream gage data).
- Warner Creek seems to be adjusting to the increased hydrologic stress by enlarging the channel through accelerated bank erosion and locally degradation evidenced by headcuts.
- Stream erosion in forested high fluvial terrace sections results in excessive amounts of large woody debris entering the stream since many trees' root systems are above the flood stage and do not protect banks from erosion.
- Consequentially, entrainment of these trees locally enhances bank erosion and induces increased sediment entrainment and storage.
- If the hydrologic trend of increasing high flow frequency continues Warner Creek and other Catskill Mountain streams will remain in the current state of dis-equilibrium characterized by increasing erosion rates, excess bedload sediment supply and chronic turbidity.

Acknowledgements

- National Science Foundation for their funding of the REU program and the SUNY New Paltz faculty who ran it
  - Dr. Shafiul Chowdhury, Dr. John Rayburn, Allison Platsky
- NYCDEP for logistical support in the field and ArcGIS expertise
  - Elliot Jordan, Colin Stief, Mark Vian, Chris Tran

2012: Completing the Study

- 2012: (Caitlyn Korren, Abbye Neel)
  - Collected and processed 3rd year of SFI and cross section monitoring data in the lower 3 km
  - Conducted an analysis of bankfull discharge hydraulic geometry

2012 REU Program

NYC Environmental Protection

Not to Steal Their Thunder…

Check out Caitlyn Korren’s poster detailing her work in assessing bankfull discharge hydraulic geometry downstream relations for Warner Creek

Stay tuned for Abbye Neel’s substantive presentation on summarizing some of the findings from the 3 year geomorphic studies

How Can The Ashokan Stream Management Program Use This Research?

- Develop a stream management guide for the developed portions of the watershed intended for landowners as well as stream managers.
- Assist AWSMP in prioritizing site selection for stream restoration projects targeted to reduce suspended sediment loading from chronic loading sites.
- Develop an informed understanding of how these mountain streams respond to extreme conditions in the hydrologic regime.
- Improve our understanding of LWD dynamics in the fluvial system and what level of intervention or preventative maintenance is merited.
- Inform the design hydraulic geometry parameters for stream restoration projects through basin specific bankfull regional curves.
- Inform the formulation and development of conceptual and numerical models to predict Catskill stream channel geomorphic response to floods and consequent sediment transport.

Turbidity Reduction

- Sediment fingerprinting study confirms the assumption that the glaciolacustrine deposits are the principal geologic source of turbidity in the the Stony Clove Creek watershed.
- Glacial geology mapping provides a much improved understanding of the glacial stratigraphy and three-dimensional distribution of the turbidity source material.
- Target restoration/stabilization where glaciolacustrine sediments are chronically exposed, generally associated with stream/hillslope coupled erosion.
- The three year study demonstrated that one site on Warner Creek continues to be the most active turbidity producer. That site is scheduled for a stream “restoration” project in the Summer 2013.
- Preventing headcut migration at the lower end of the valley will potentially inhibitt further channel degradation and contact with suspended sediment sources.

Warner Creek Site 5

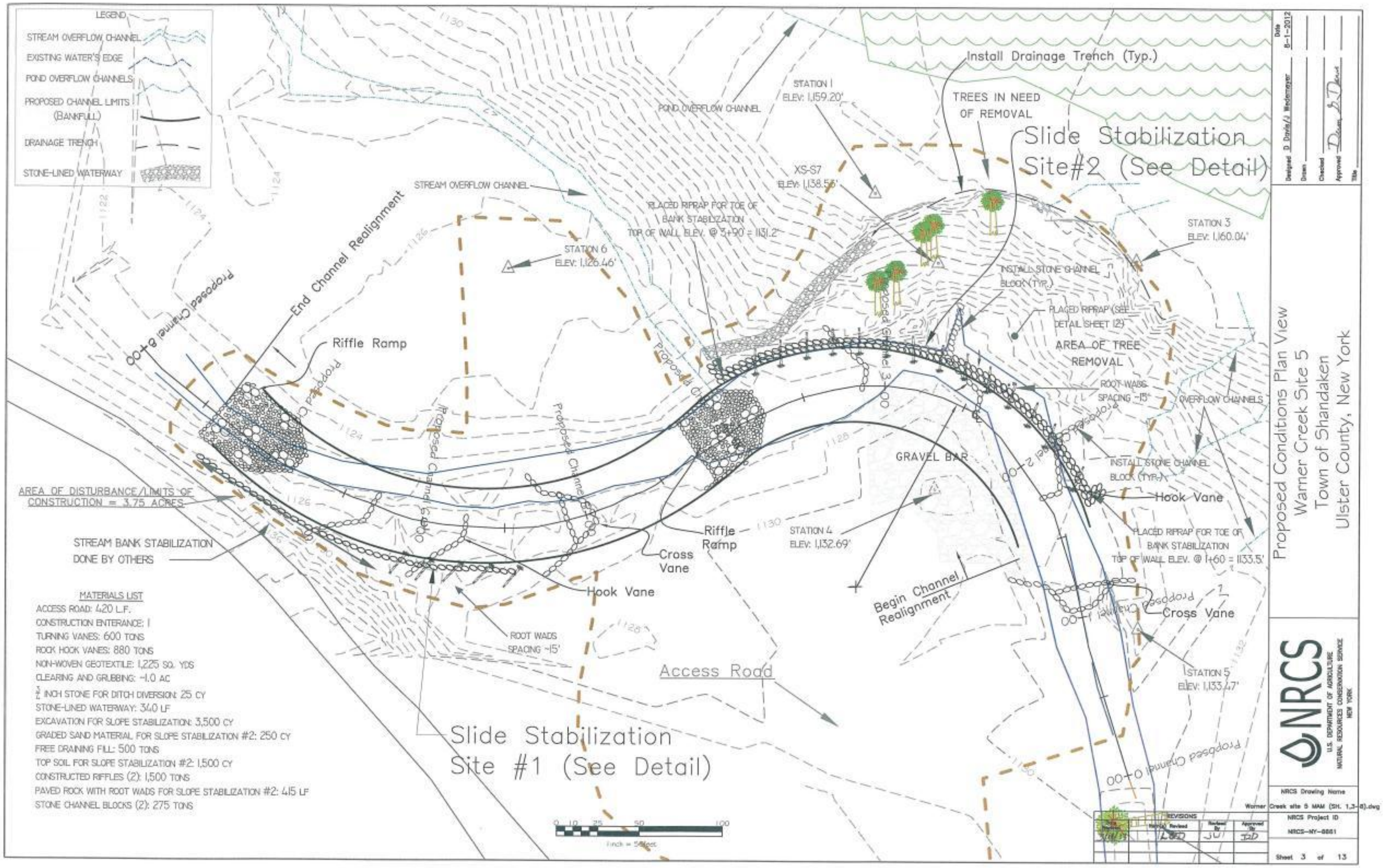
Ground-Penetrating Radar Survey Adjacent to Warner Creek Reach 12 (July, 2010)

Scale = 1:800

25 12.5 0 25 Meters

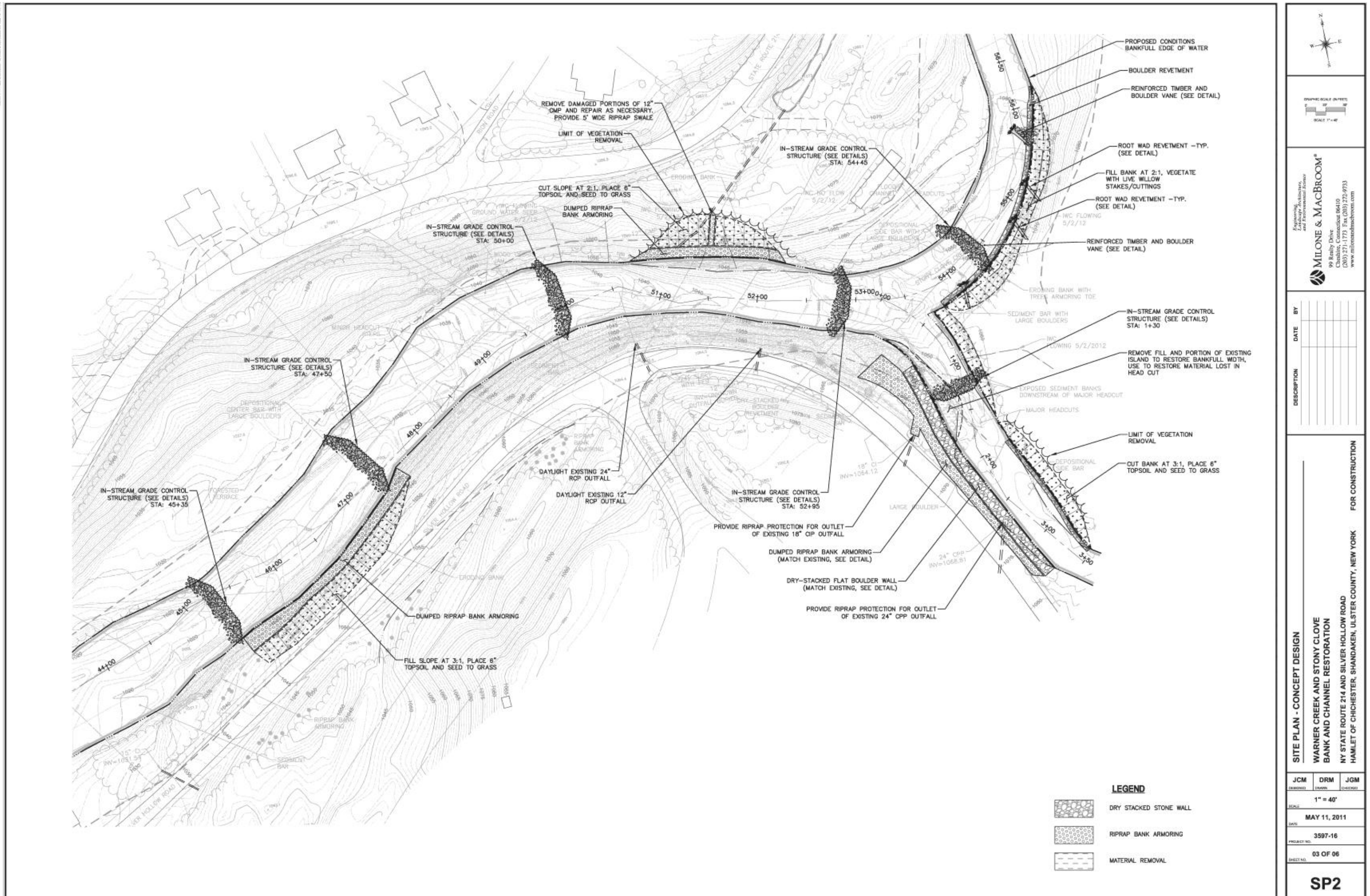
NYC Environmental Protection

Warner Creek Site 5 Stream Restoration Design



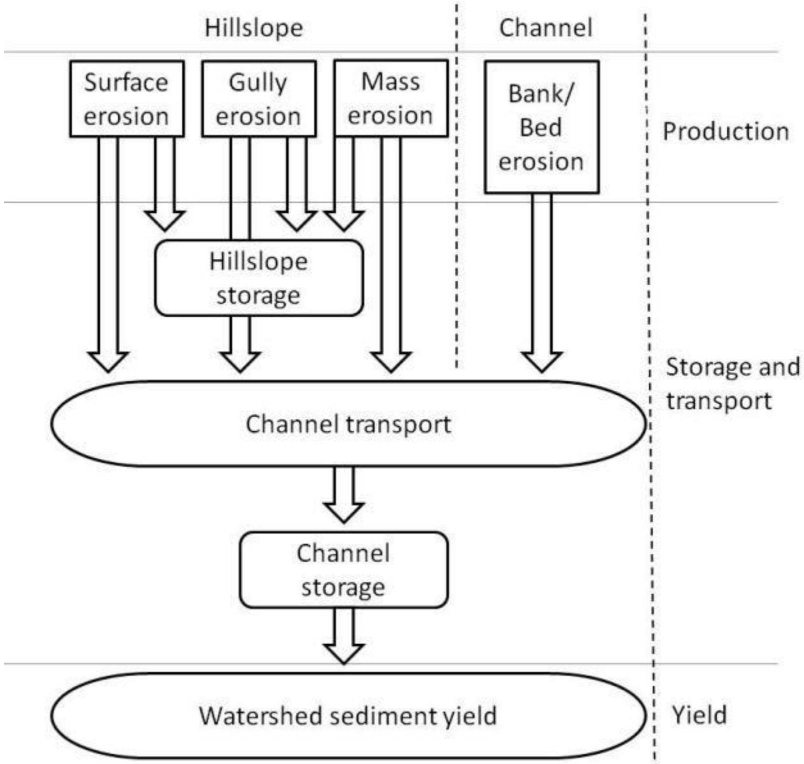
Warner Creek/Stony Clove Creek Confluence: Headcut Mitigation

Warner Creek/Stony Clove Creek Confluence: Headcut Mitigation



Stream Turbidity

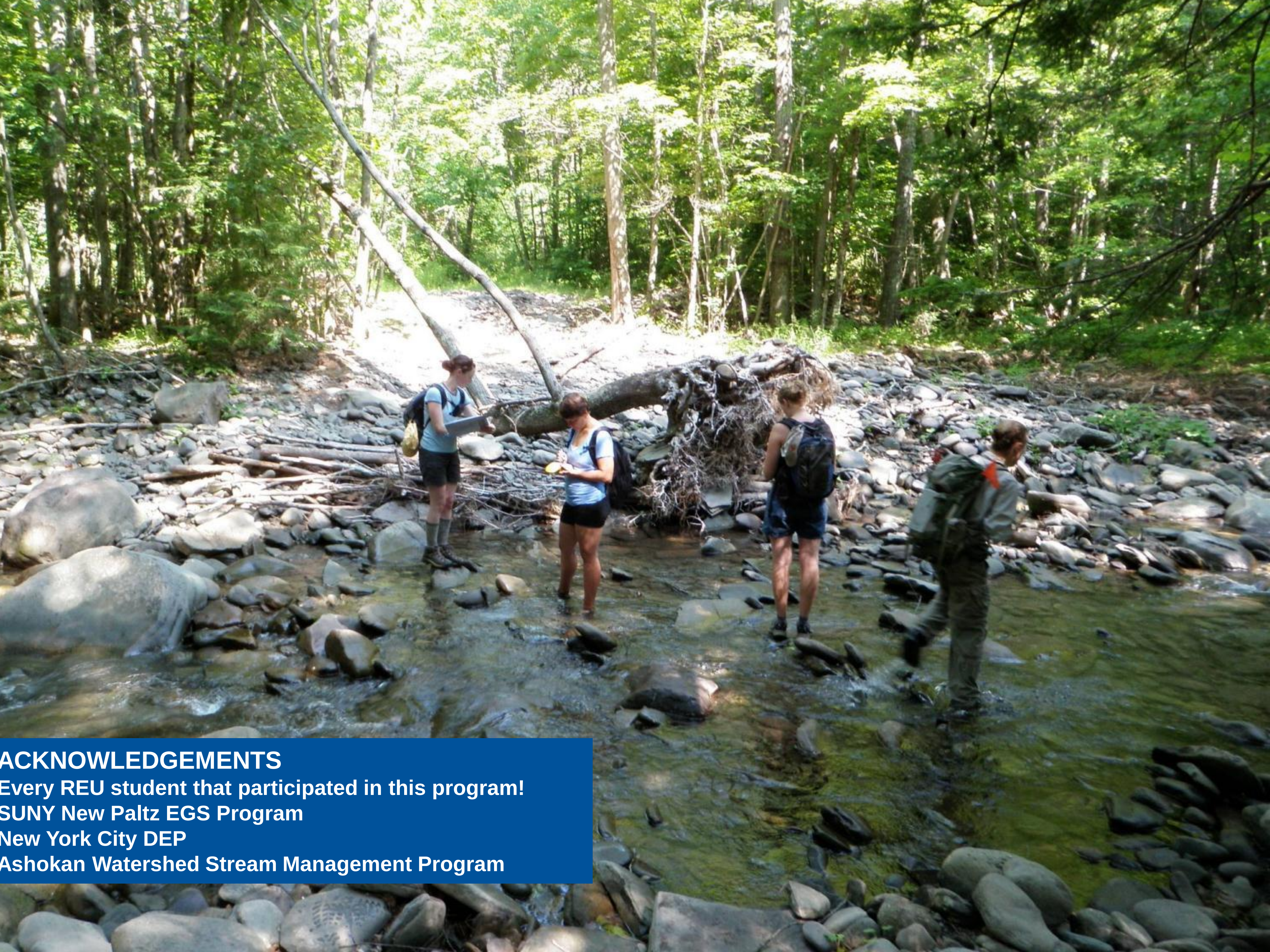
- What are the dominant sources?
  - Stream channel and adjacent hill slope erosion into glacial legacy sediments
- What are some of the processes we need to model?
  - Bedload and suspended load transport
  - Headcut migration with channel evolution
  - LWD dynamics
- Can we develop management strategies to reduce turbidity?



Sedimentation process (Modified from EPA,1999)

Modeling and Monitoring

- We can predict the likelihood of stream interaction with turbidity sources far into future given the geology of the watershed.
- We can inform planned suspended sediment entrainment and transport (channel process) modeling efforts with improved source distribution for model parameterization, and on developing temporal data sets for geomorphic response to evaluate model predictions.
- We can work with the various ongoing and planned water quality monitoring efforts to help interpret loading source distribution and inform future monitoring locations for finer resolution, as needed.



ACKNOWLEDGEMENTS

Every REU student that participated in this program!

SUNY New Paltz EGS Program

New York City DEP

Ashokan Watershed Stream Management Program