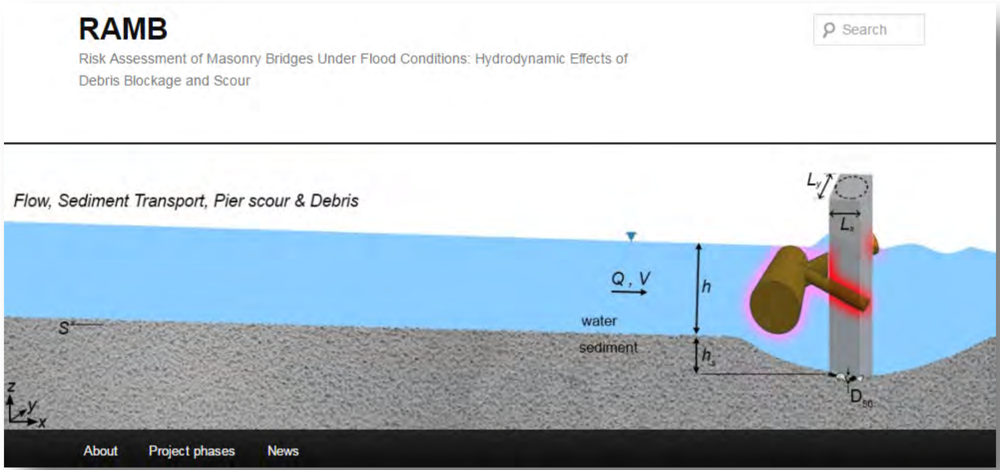
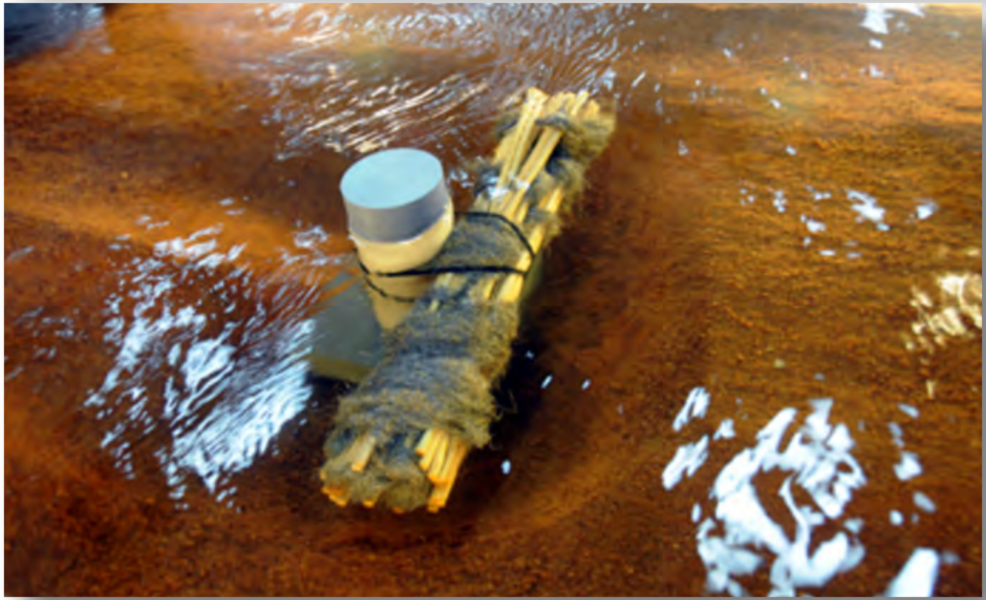
Debris Loads, Bridge/Culvert failure, and Climate Change

Identifying stream reaches most susceptible to climate-exacerbated debris load

Seth Lawler, Mathew Mampara, Kristine Mosuela, Mathini Sreetharan

Debris Accumulation & Scour





- Wears away earth and soil that anchors piers
- Compromises capacity to withstand lateral forces (flow, accumulated debris, cars)

http://blogs.exeter.ac.uk/ramb/tag/debris-blockage/
http://cee.illinois.edu/news/research-helps-optimize-alaska-railroad-bridge
http://www.ayresassociates.com/wp-content/uploads/2016/06/scour-5_sized.jpg

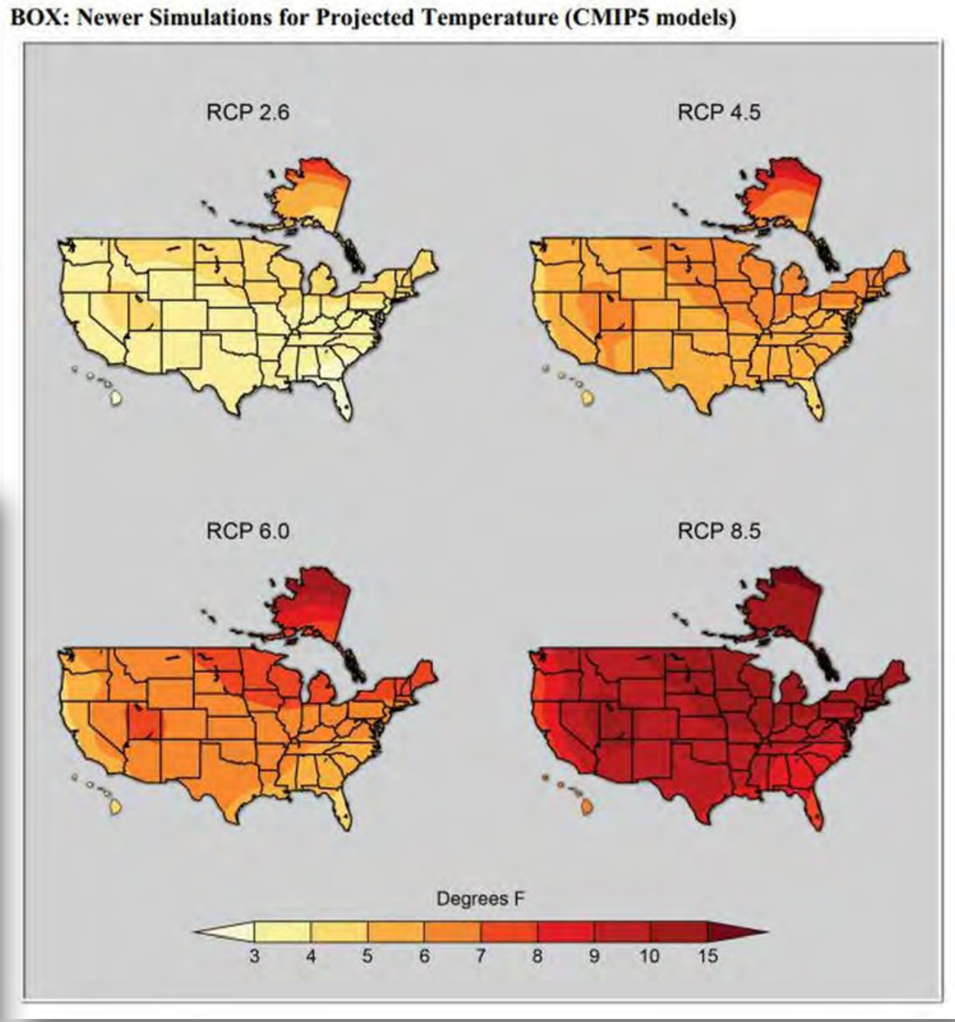
Impact

- Scour and flood cause **~half** of all bridge failures
- FHWA **~$20 million/year** spent on repairing failed bridges

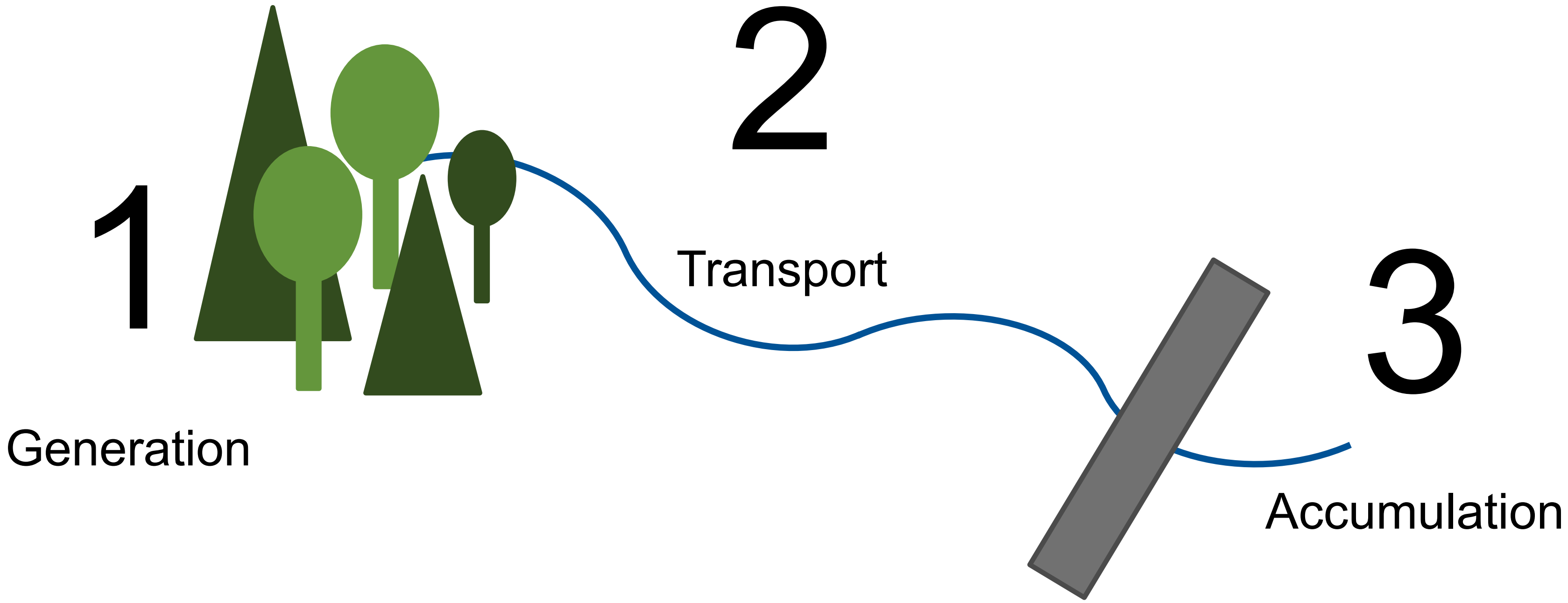
Bradley, J.B. et al., 'Debris Control Structures Evaluation and Countermeasures,' Hydraulic Engineering Circular 9. US Department of Transportation, FHWA. October 2005.
Cook, W. 'Bridge Failure Rates, Consequences, and Predictive Trends,' Utah State University. 2014.
Lee, et. al. 'A Study of U.S. Bridge Failures (1980-2012),' Technical Report MCEER-13-0008. 2013.
Trent, R. 'An Evaluation of Highway Flood Damage Statistics,' ASCE Water Forum. 1992.
Wardhana, K. 'Analysis of Recent Bridge Failures in the United States,' ASCE Journal of Performance of Constructed Facilities. 2003.

NYSERDA & NYSDOT

- Identify HUC-12's most at risk
- Climate Resilience → Increased temperatures& precipitation

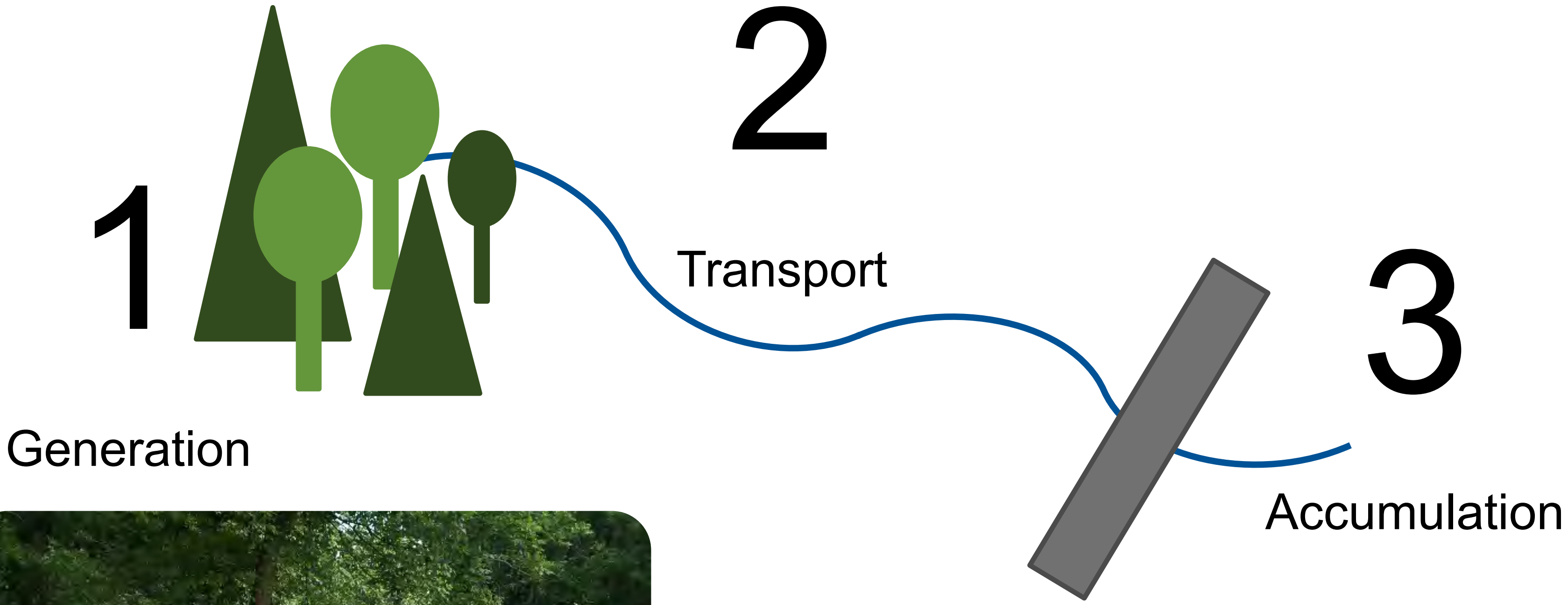


Debris Risk: 3 main components



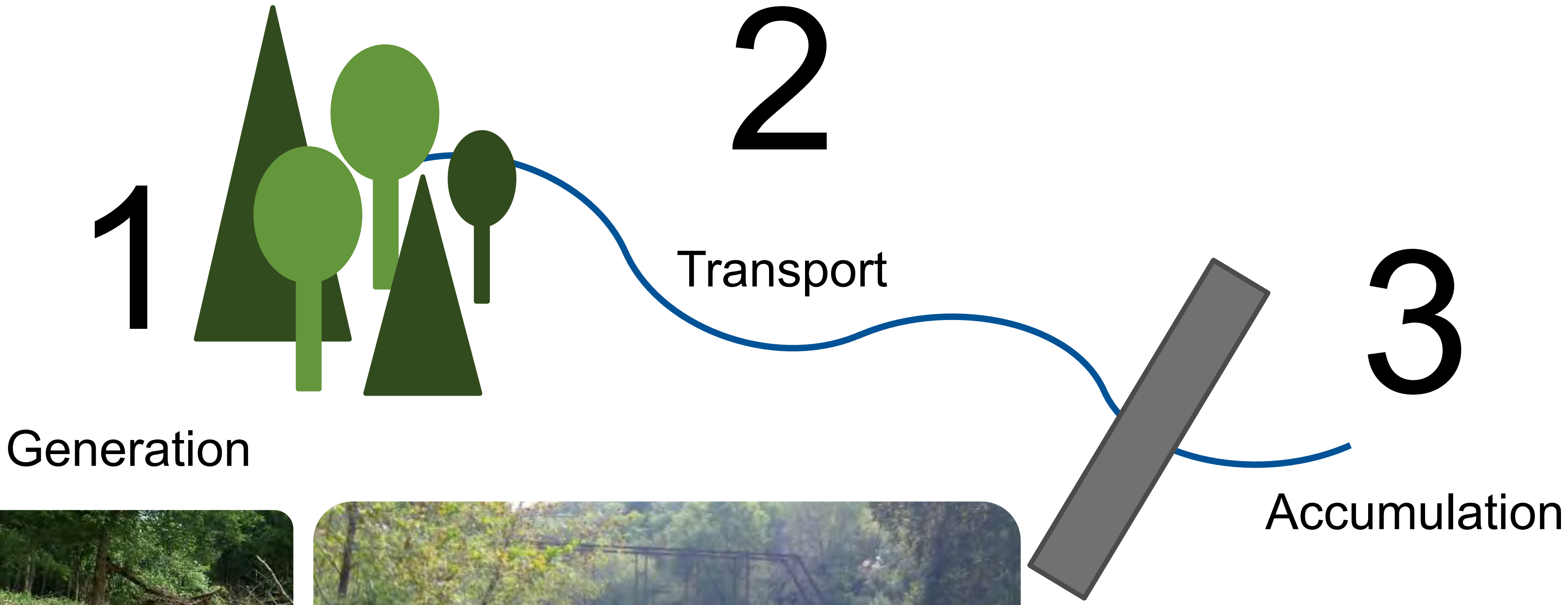
Dewberry

Debris Risk: 3 main components



https://upload.wikimedia.org/wikipedia/commons/8/8f/Pimmit_bank_erosion.JPG

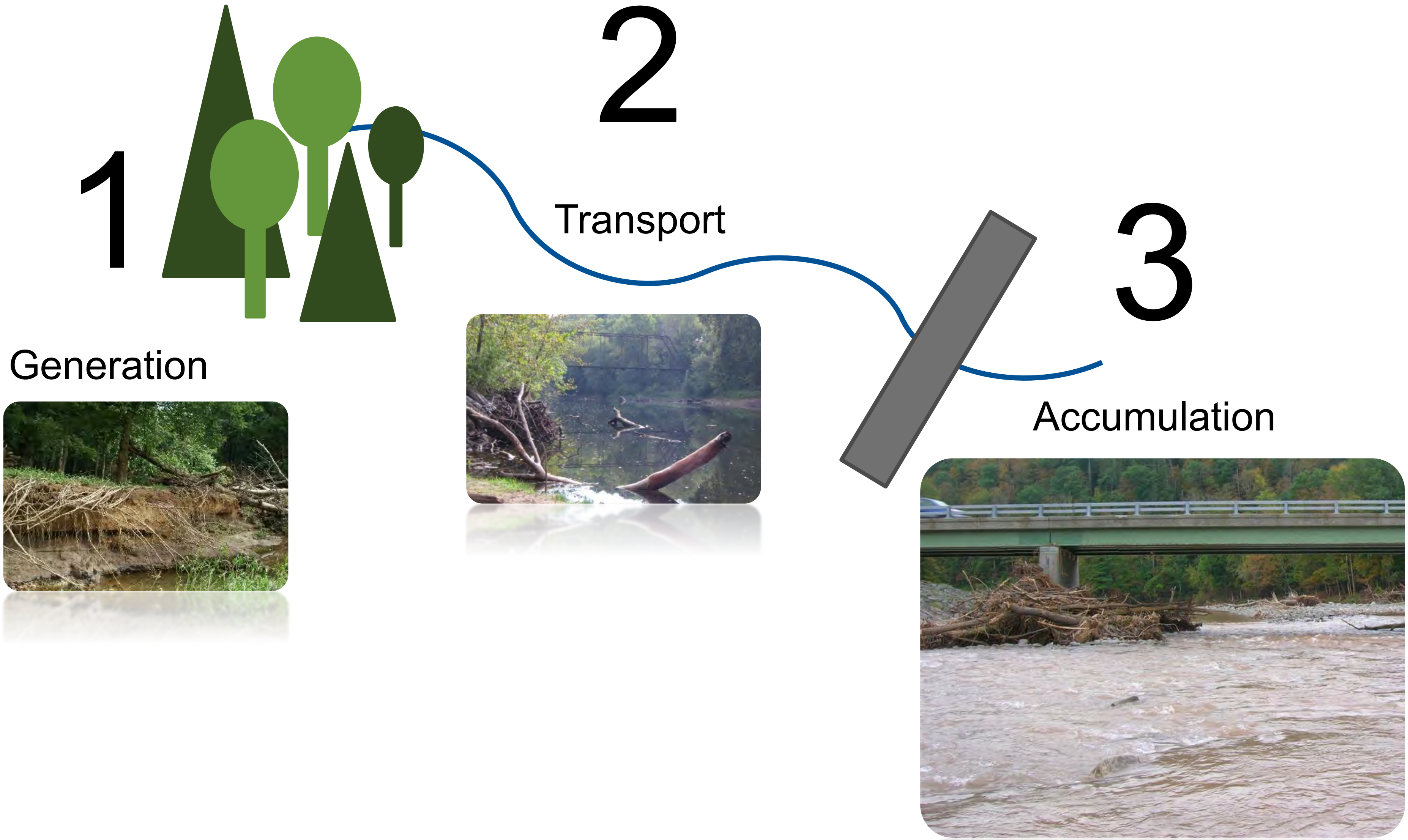
Debris Risk: 3 main components



https://upload.wikimedia.org/wikipedia/commons/8/8f/Pimmit_bank_erosion.JPG

http://nature.mdc.mo.gov/sites/default/files/styles/centered_full/public/images/conservation/Cross%20Timbers%20Access.JPG?itok=GW1m0MdR

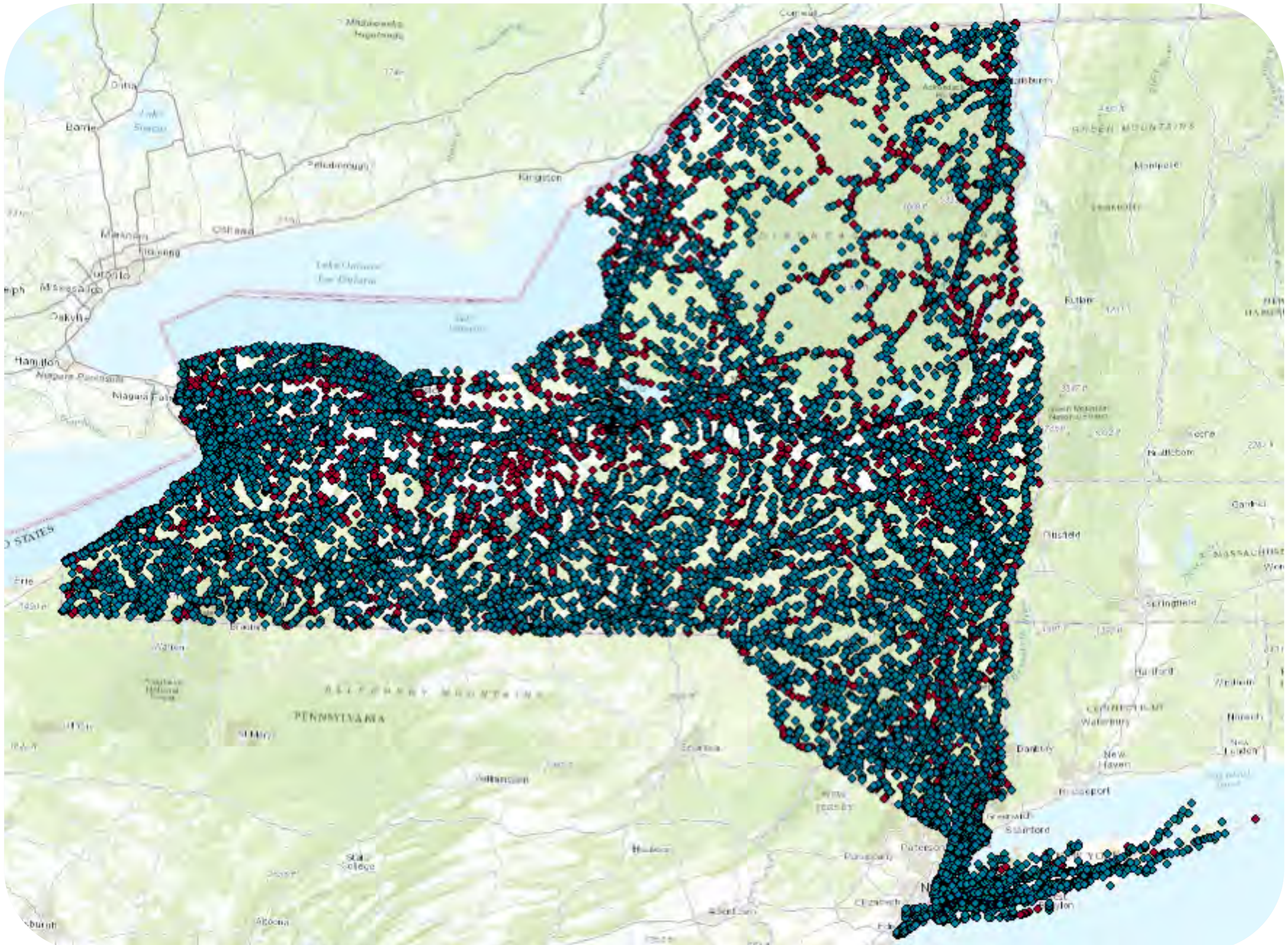
Debris Risk: 3 main components



https://upload.wikimedia.org/wikipedia/commons/8/8f/Pimmit_bank_erosion.JPG

http://nature.mdc.mo.gov/sites/default/files/styles/centered_full/public/images/conservation/Cross%20Timbers%20Access.JPG?itok=GW1m0MdR

Data: Structures

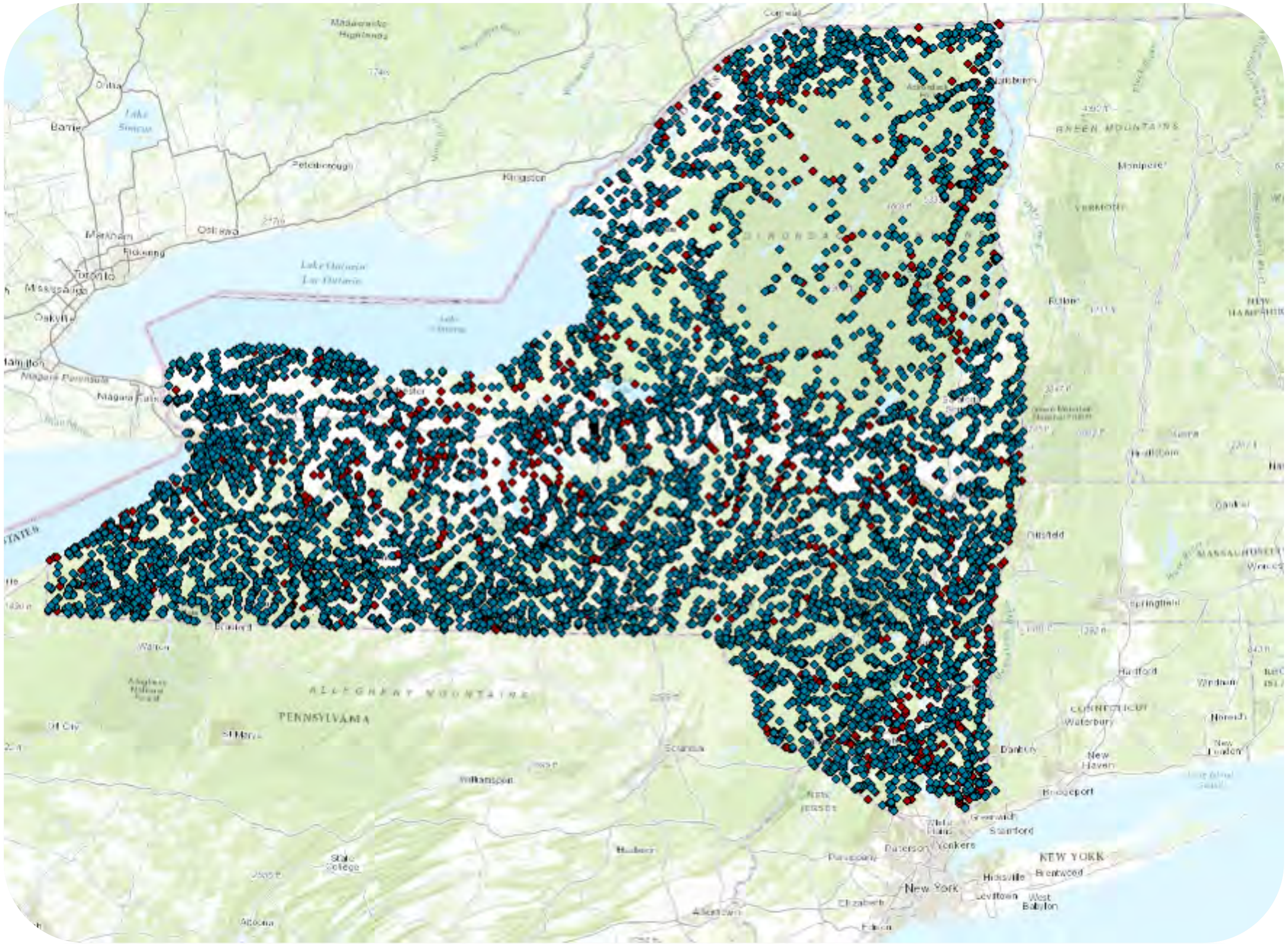


NYGIS Data Clearing House:

1. ~20,000 Bridges (blue)

2. ~10,00 Large Culverts (red)

Data: Structures at Crossings

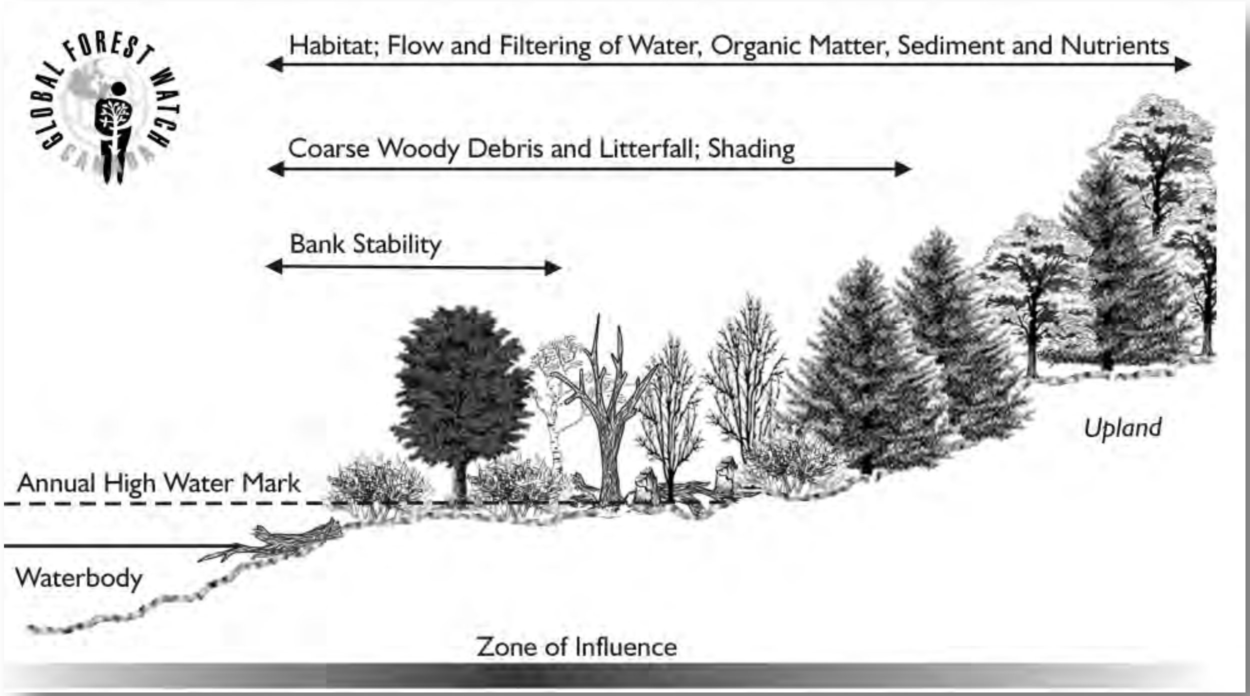


NYGIS Data Clearing House:

1. ~20,000 Bridges (blue)
   - 10,000 crossing waterways
2. ~10,000 Large Culverts (blue)
   - 1,500 crossing waterways

#1: Generation

- Channel bank stability
- Stream power
- Debris type



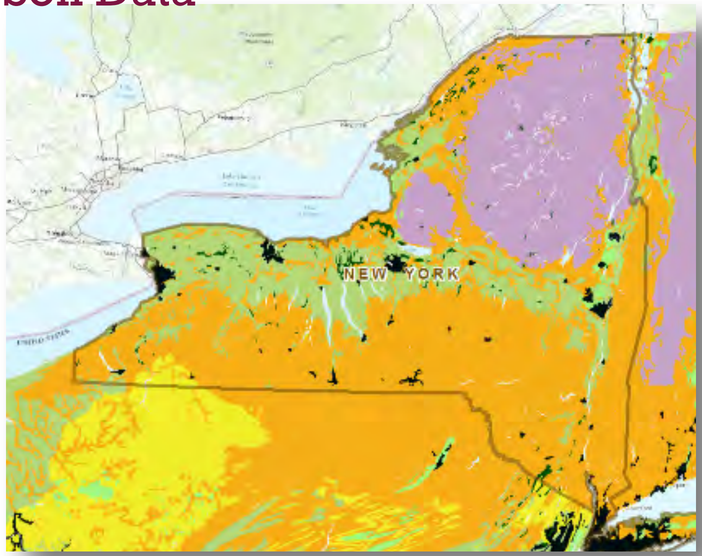
https://upload.wikimedia.org/wikipedia/commons/8/8f/Pimmit_bank_erosion.JPG
http://www.globalforestwatch.ca/sites/gfwc/files/images/20040119A_figure1.png

#1: Generation

- **Channel bank stability**

Initial Data Source

Soil Data



- Stream power
- Debris type

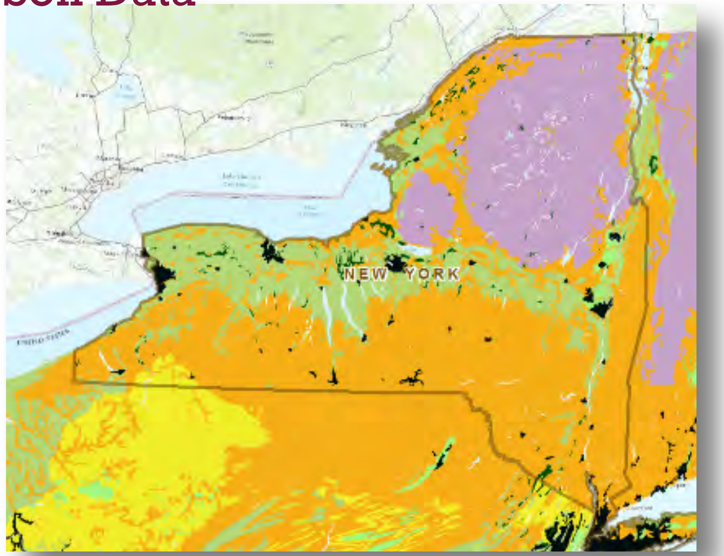
#1: Generation

- **Channel bank stability**
- Stream power
- Debris type

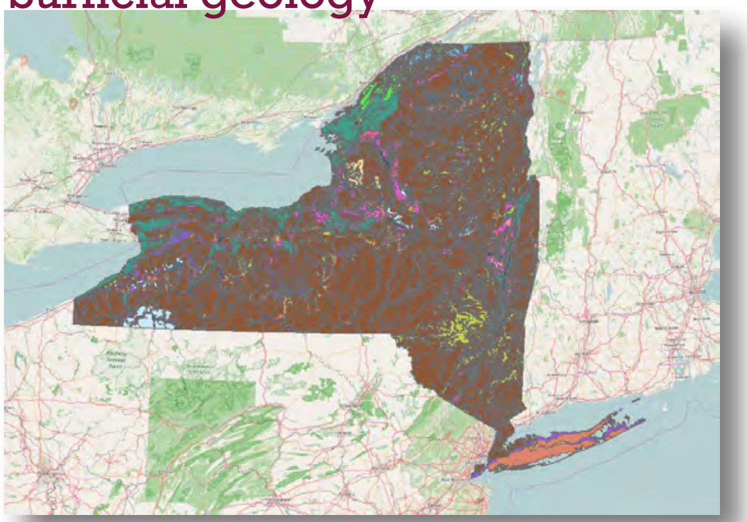
Initial Data Source

Final Data Source

Soil Data



Surficial geology



http://www.nysm.nysed.gov/research-collections/geology/gis

#1: Generation

- Channel bank stability

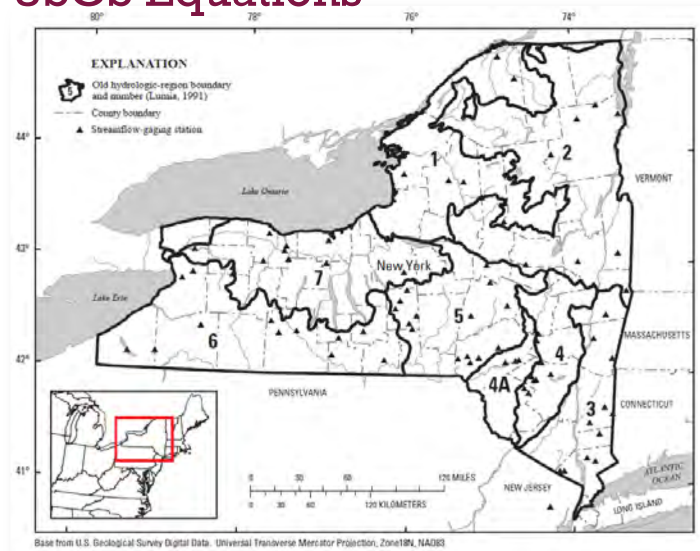
- **Stream power**

$$\Omega = QS$$

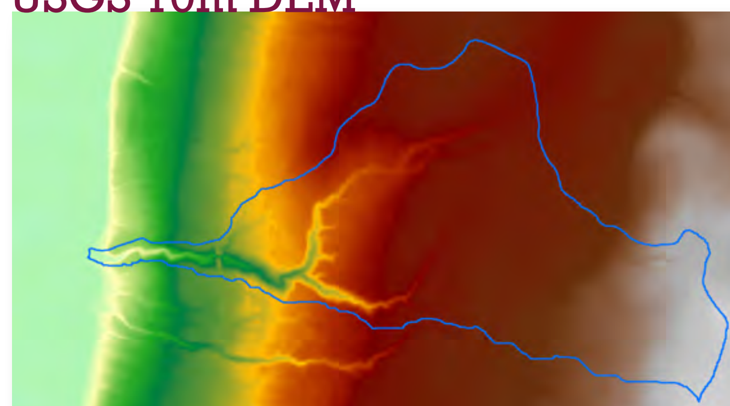
Stream power = Flow x Slope

- Debris Type

USGS Equations



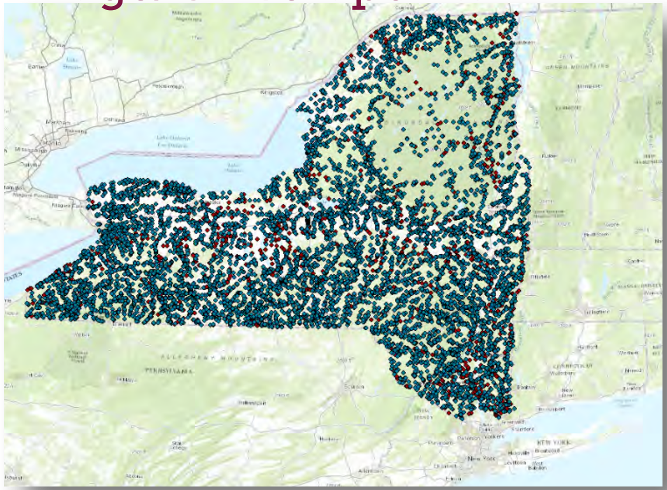
USGS 10m DEM



#1: Generation

- Channel bank stability
- Stream power
- **Debris Type**

Bridge/Culvert points



SSURGO Soil Classification

Soil Class	Vegetation
Holderton	red maple, sugar maple, white ash, wal
Minoa	Aspen, white ash, cherry, white pine,
Wayl	red maple, alder, willow
Unadilla	Sugar maple, American beech, red oak,
Suncook	sycamore, aspen, cotton wood, white oa
Worth	northern red oak, eastern white pine,
Scio	northern red oak, white ash, sugar map
Chautauqua	sugar maple, white ash, northern red o
Tioga	maple, ash, red oak, elm
Sunapee	northern red oak, sugar maple, eastern
Northway	red maple, eastern white pine, yellow
Fremont	sugar maple, oak, white ash, yellow bi

#2: Transport

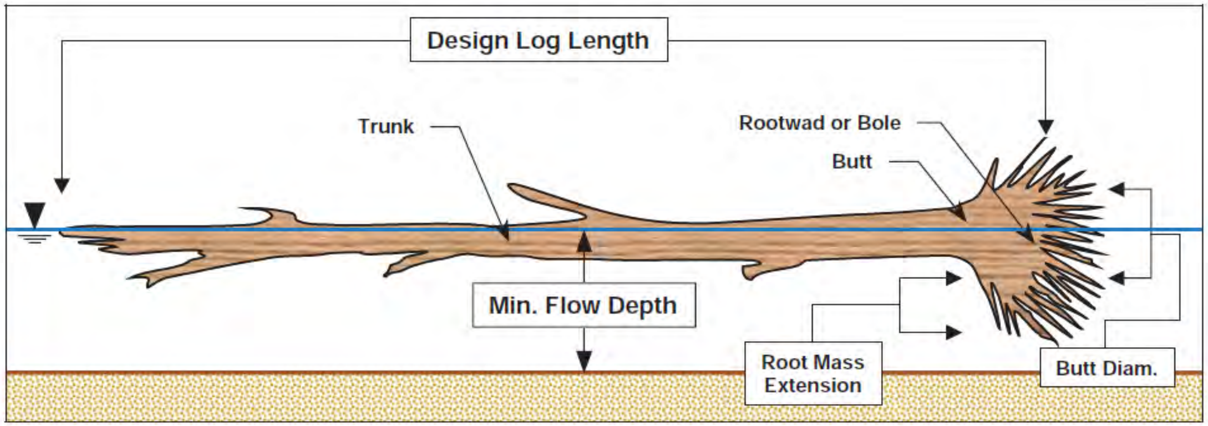
- Debris Geometry & Channel Characteristics
- Flow Index
- Sinuosity

#2: Transport

- **Debris Geometry** & Channel Characteristics
- Flow Index
- Sinuosity

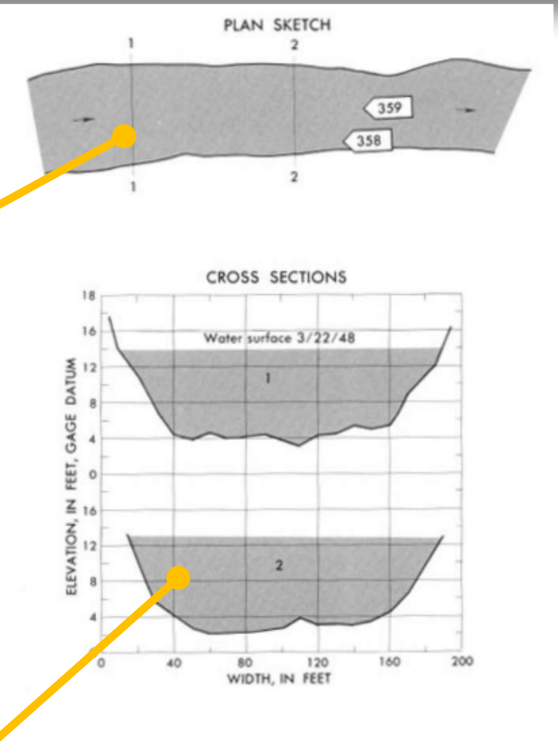
SSURGO

Soil Class	Vegetation
Holderton	red maple, sugar maple,
Minoa	Aspen, white ash, cherry
Wayl	red maple, alder, willow
Unadilla	Sugar maple, American be
Suncook	sycamore, aspen, cotton
Worth	northern red oak, easter
Scio	northern red oak, white
Chautauqua	sugar maple, white ash,
Tioga	maple, ash, red oak, e
Sunapee	northern red oak, sugar
Northway	red maple, eastern white
Fremont	sugar maple, oak, white

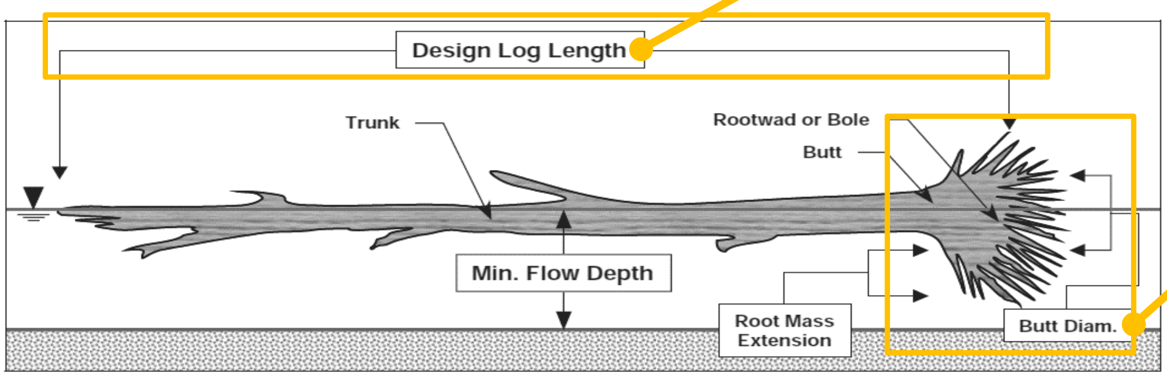


#2: Transport

- **Debris Geometry & Channel Characteristics**
- Flow Index
- Sinuosity



Plan sketch and cross sections, Esopus Creek at Coldbrook, N.Y.



http://il.water.usgs.gov/proj/nvalues/supplementary/pictures/Esopus2_XS.jpg

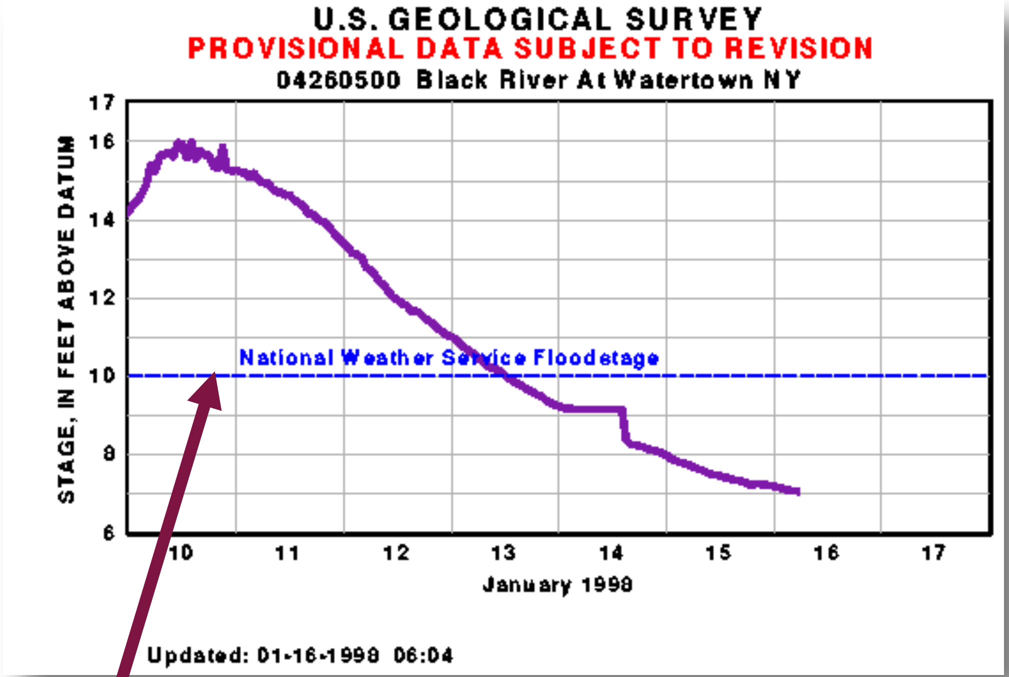
Lagasse, P. F. et al, 'Effects of Debris on Bridge Pier Scour,' National Cooperative Highway Research Program Report 653. Transportation Research Board of the National Academies. 2010.

#2: Transport

- Debris Geometry & Channel Characteristics

- **Flow Index**
  - Current Discharges
  - Bankfull Discharges

- Sinuosity

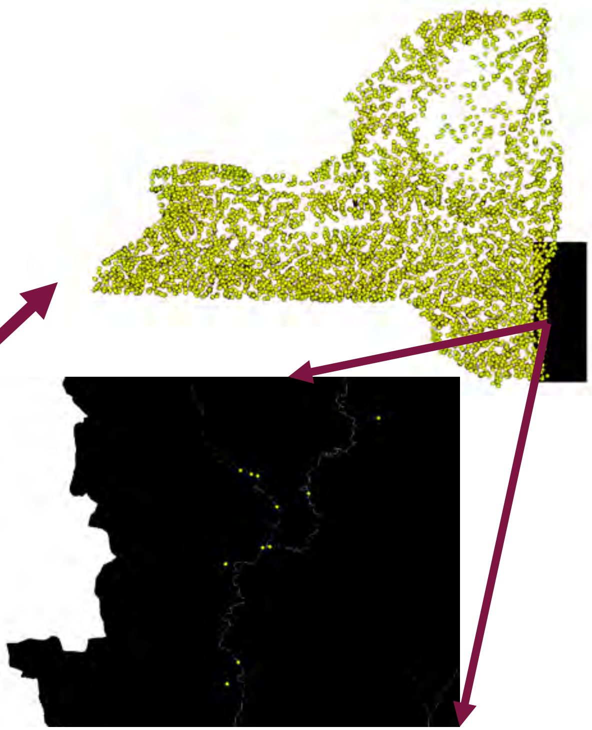


Recurrence Interval Flow Threshold for Debris Transport?

#2: Transport

- Debris Geometry & Channel Characteristics
- Flow Index
- **Sinuosity**
  - Abrupt turns in smaller waterways near the bridge approach

#2: Transport

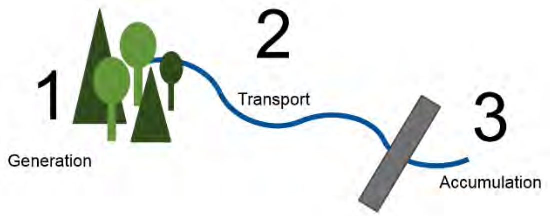


- Debris Geometry & Channel Characteristics
- Flow Index
- **Sinuosity**
  - Abrupt turns in smaller waterways near the bridge approach

#2: Transport

- Debris Geometry & Channel Characteristics
- Flow Index
- **Sinuosity**
  - Abrupt turns in smaller waterways near the bridge approach

#3: Accumulation

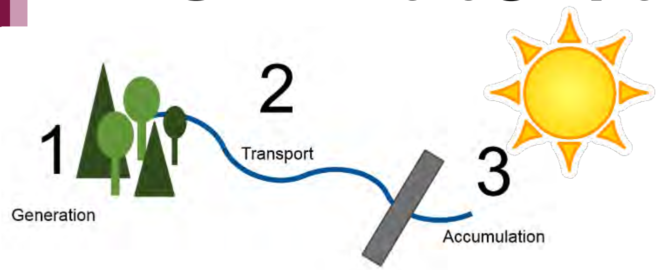


Impediments to flow:

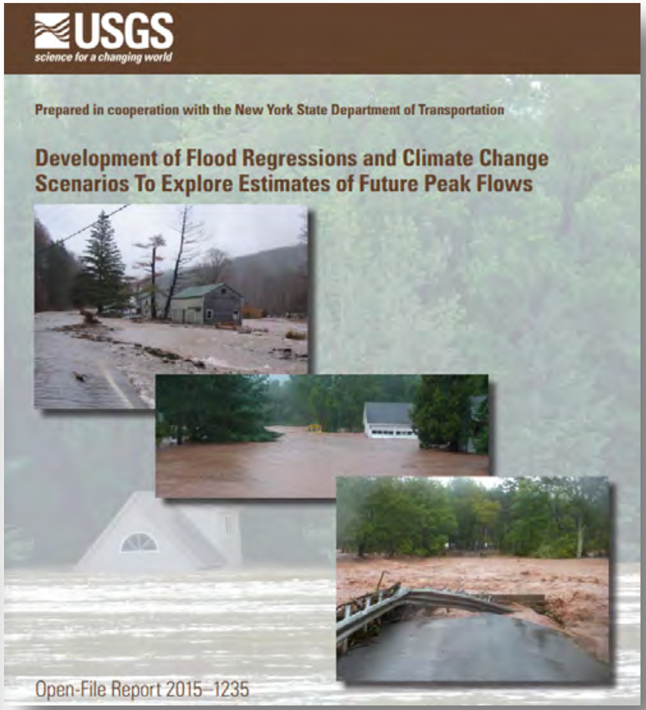
- Piers & Abutments
  - Presence
  - Orientation
  - Span

Bradley, J.B. et al., 'Debris Control Structures Evaluation and Countermeasures,' Hydraulic Engineering Circular 9. US Department of Transportation, FHWA. October 2005.
Parola, A. 'Highway Infrastructure Damage Caused by the 1993 Upper Mississippi River Basin Flooding,' Transportation Research Board. 1998.

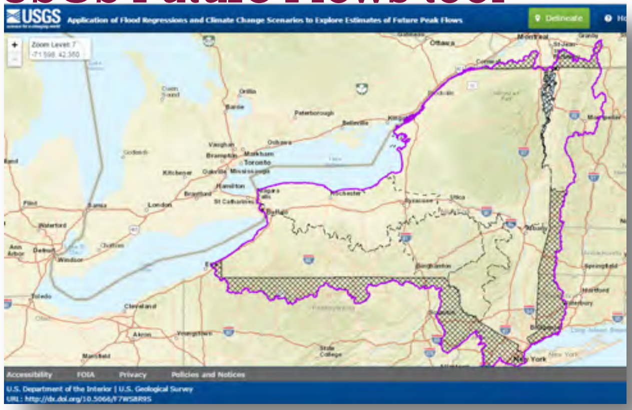
*Climate Variability



Name/description	Abbreviation	Reference
Climate models		
Beijing Normal University Earth System Model	BNU-ESM	Ji and others (2014)
Community Earth System Model with Biogeochemical Cycling Model, Version 1.0	CESM1-BGC	Lindsay and others (2014)
Centre National de Recherches Météorologique Climatological Model 5	CNRM-CM5	Voldoire and others (2012)
Institut Pierre Simon Laplace Climate Model 5A, Low-Resolution	IPSL-CM5A-LR	Dufresne and others (2013)
Norwegian Earth System Model, Intermediate Resolution	NorESM1-M	Bentsen and others (2013)
Greenhouse-gas emissions scenarios		
Representative Concentration Pathway 4.5	RCP 4.5	Thomson and others (2011)
Representative Concentration Pathway 8.5	RCP 8.5	Riahi and others (2011)
Time periods		
Average from 2025 to 2049	2025–2049	USGS Climate Change Viewer
Average from 2050 to 2074	2050–2074	USGS Climate Change Viewer
Average from 2075 to 2099	2075–2099	USGS Climate Change Viewer



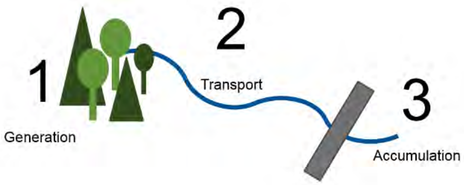
USGS Future Flows tool



http://pubs.usgs.gov/of/2015/1235/ofr20151235.pdf
http://pubs.usgs.gov/of/2015/1235/index.html
http://vignette2.wikia.nocookie.net/clubpenguin/images/f/f7/Sun_Pin.PNG/revision/20130808182600

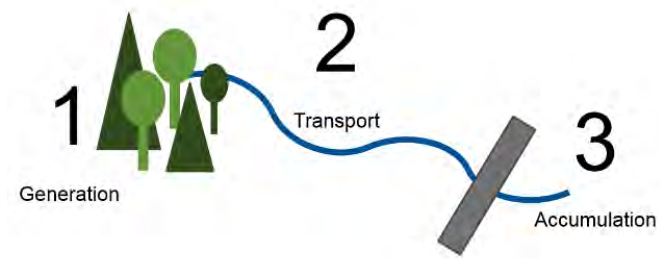
Analysis: Risk Factors

	Risk Factor	Name	Description
	SP	Stream Power	Hydraulic force working on channel banks
	EF	Erodibility Factor	Soil erodibility potential
	LL/CW	Log Length vs. Channel Width Factor	Ratio of log length to channel width
	DRW/CD	Debris Root Width vs. Channel Depth Factor	Ratio of root mass diameter to channel depth
	SI	Sinuosity Index	Degree of sinuosity of reach
	FI	Flow Index	Nearest return interval flow at calculated bankfull discharge
	P	Piers	Presence and orientation of piers
	FFI	Future Flow Index	Projected change in future flow
	CRF	Climate Risk Factor	Climate induced change in risk



Analysis: Weighting & Regression

Risk Factor	Name	Description
SP	Stream Power	Hydraulic force working on channel banks
EF	Erodibility Factor	Soil erodibility potential
LL/CW	Log Length vs. Channel Width Factor	Ratio of log length to channel width
DRW/CD	Debris Root Width vs. Channel Depth Factor	Ratio of root mass diameter to channel depth
SI	Sinuosity Index	Degree of sinuosity of reach
FI	Flow Index	Nearest return interval flow at calculated bankfull discharge
P	Piers	Presence and orientation of piers
FFI	Future Flow Index	Projected change in future flow
CRF	Climate Risk Factor	Climate induced change in risk



Regression Equation

$$DR = \left[1 + e^{-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n)}\right]^{-1}$$

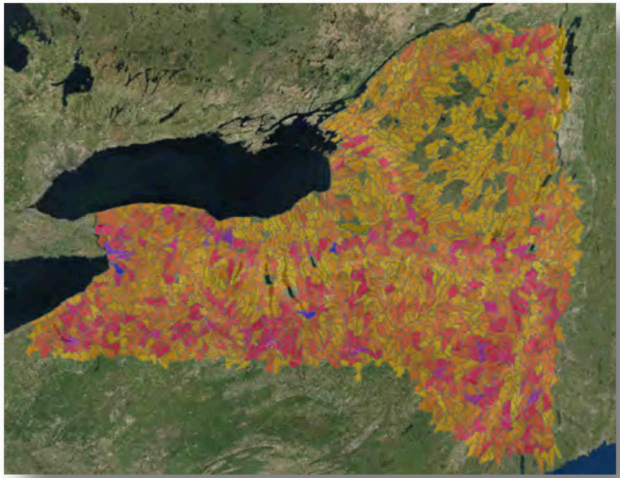
$$DR = X_0 + a_1 X_1 + a_2 X_2 + \ldots + a_N X_N$$

Analysis: Validation & Calibration

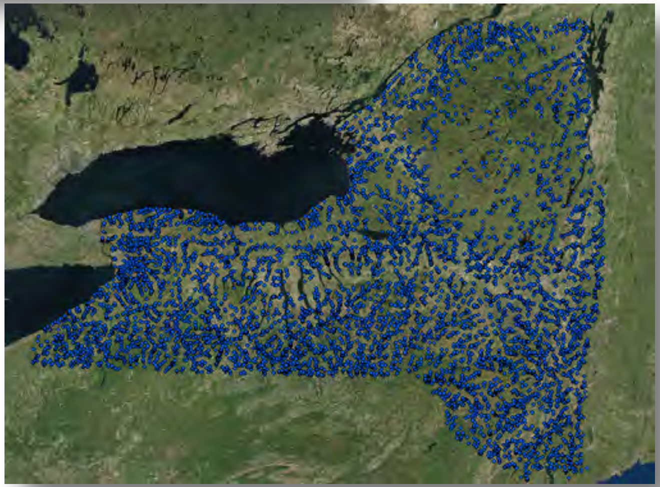
Risk Factor	Name	Description
SP	Stream Power	Hydraulic force working on channel banks
EF	Erodibility Factor	Soil erodibility potential
LL/CW	Log Length vs. Channel Width Factor	Ratio of log length to channel width
DRW/CD	Debris Root Width vs. Channel Depth Factor	Ratio of root mass diameter to channel depth
SI	Sinuosity Index	Degree of sinuosity of reach
FI	Flow Index	Nearest return interval flow at calculated bankfull discharge
P	Piers	Presence and orientation of piers
FFI	Future Flow Index	Projected change in future flow
CRF	Climate Risk Factor	Climate induced change in risk

Final Products

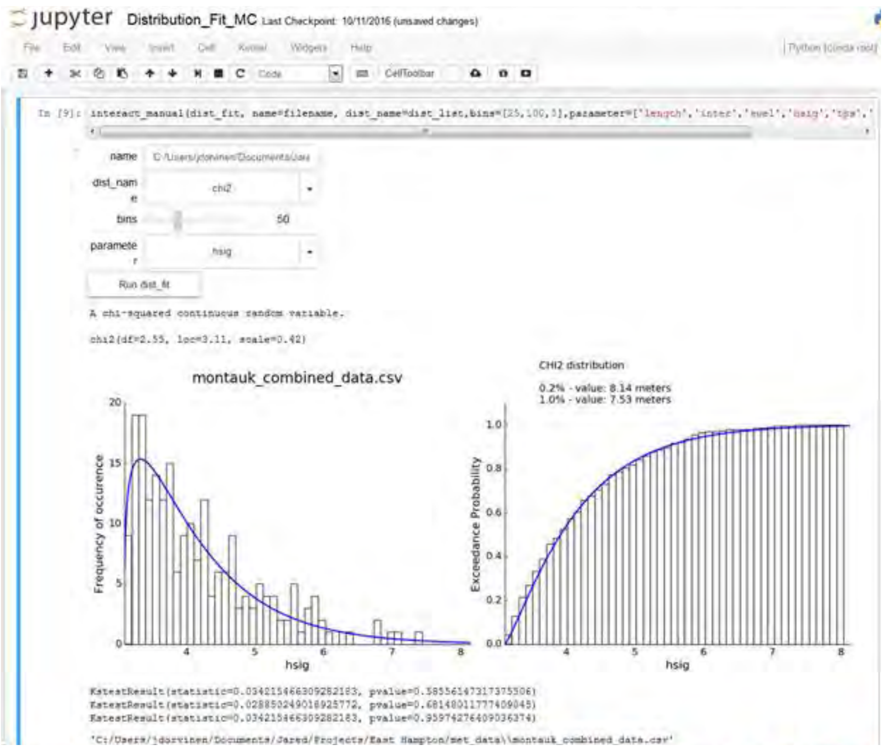
HUC 12 Level Assessment



Attributed data for each Crossing



Interactive Notebooks



Outstanding Tasks

- Finalizing methodology
- Developing regression equations
- Validating methodology on test cases
- Individual and Total risk factor development for NY bridges and culverts
- Statewide application and HUC-12 based risk factor development
- Develop Updated Design Standards to Reduce Debris-caused Failure

Open Source Tools

python™

R

CONTINUUM ANALYTICS

NumPy

RStudio®

pandas

$y_{it} = \beta' x_{it} + \mu_i + \epsilon_{it}$

GDAL

matplotlib

Questions?