From Landslides to Levees

Important Links Among Episodic Sediment Movement, Fluvial Landforms, Geologic Setting, and Aquatic Habitat

By Faith Fitzpatrick

USGS Wisconsin Water Science Center

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Why do we need to track long-term sediment movement?

- Aquatic and riparian habitat
- Stream rehabilitation design and monitoring
- Contaminant transport and source
- Dam removal
- Drinking water
- Nutrient transport

Why do we need to understand long-term geomorphic processes?

- Fluvial features are formed by processes that often work slowly or are responding to events that happened in the past
- Movement of sediment is punctuated by periods of storage
- Cause for a recent change may be an internal adjustment to a past disturbance

Toutle River, WA 2005

USGS

Talk Outline

- Why study episodic sediment movement?
- Geomorphic concepts
- Examples
  - North Fish Creek (fish habitat)
  - Bad River (water quality management)
  - Duluth (stream corridor preservation)
  - Halfway Creek (wetland preservation/restoration)

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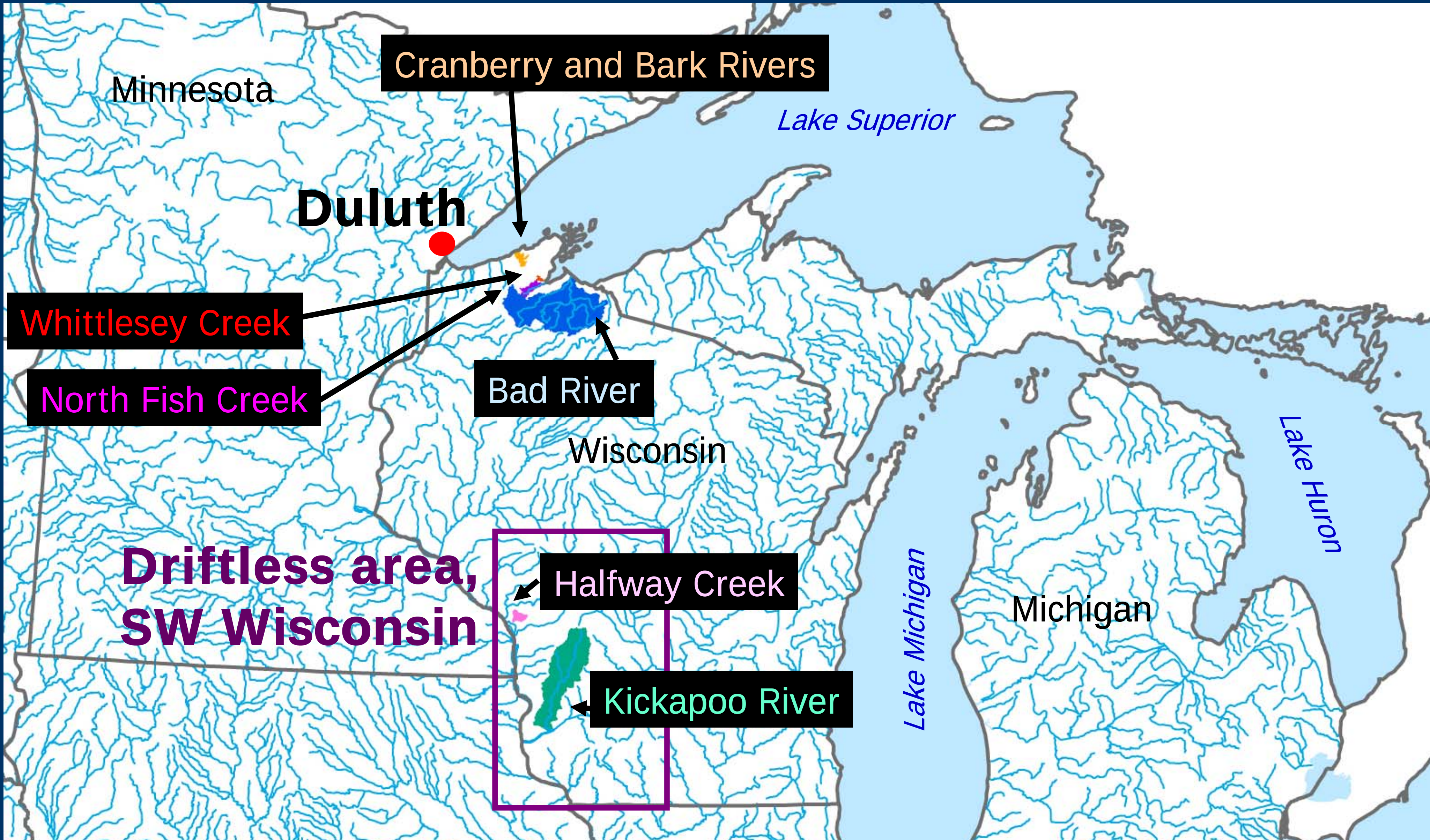

Cranberry and Bark Rivers
Minnesota
Lake Superior
Duluth
Whittlesey Creek
North Fish Creek
Bad River
Wisconsin
Lake Huron
Driftless area,
SW Wisconsin
Halfway Creek
Lake Michigan
Michigan
Kickapoo River

USGS

Landslides = episodic sediment movement

La Conchita, CA 1996

Photo by R.L. Schuster, USGS

McClure Pass, CO 1994

Photo by Terry Taylor, Colorado State Patrol

Landslides near rivers....

Photo by R.L. Schuster, USGS

Stella, WA, Columbia River

Ontonagon River, MI, 2004

Photo source unknown

Tributary mouth near North Fish Creek

North Fish Creek, WI tributary, WI 2005

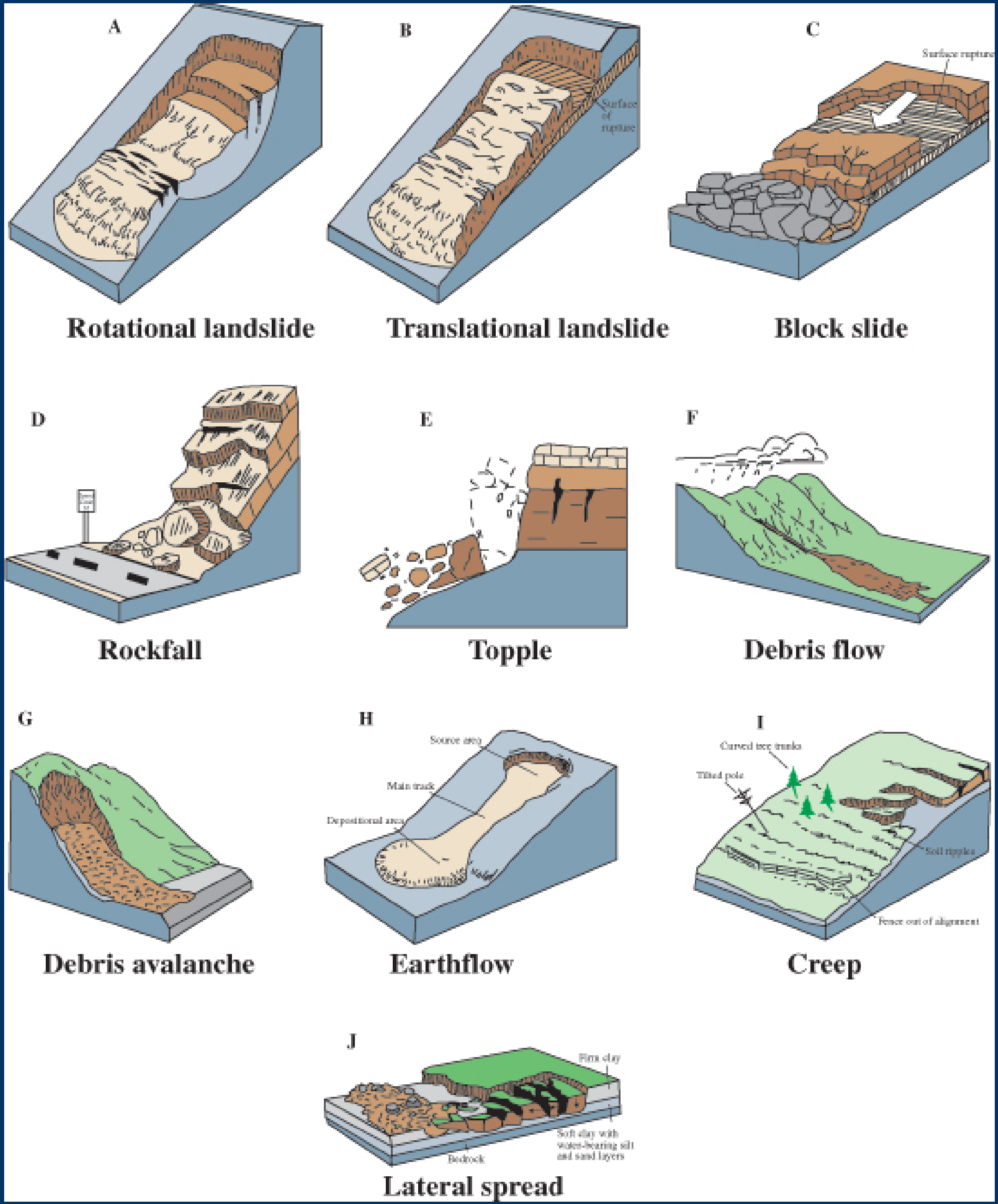
Photo by Dennis Pratt

pre July 2005 flood

post July 2005 flood

post October 2005 flood

Types of Landslides



(Highland, 2004)

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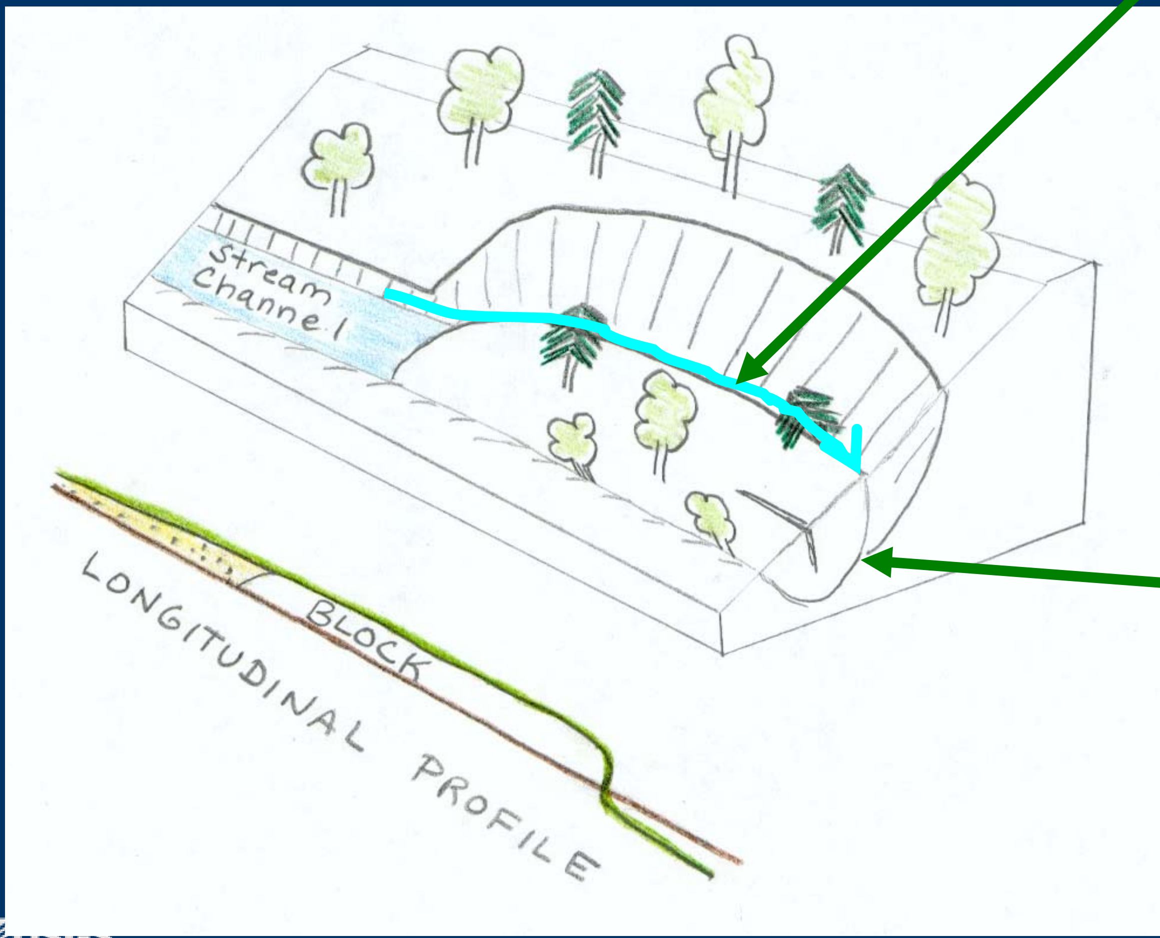
Landslides on ephemeral channels or small tributaries



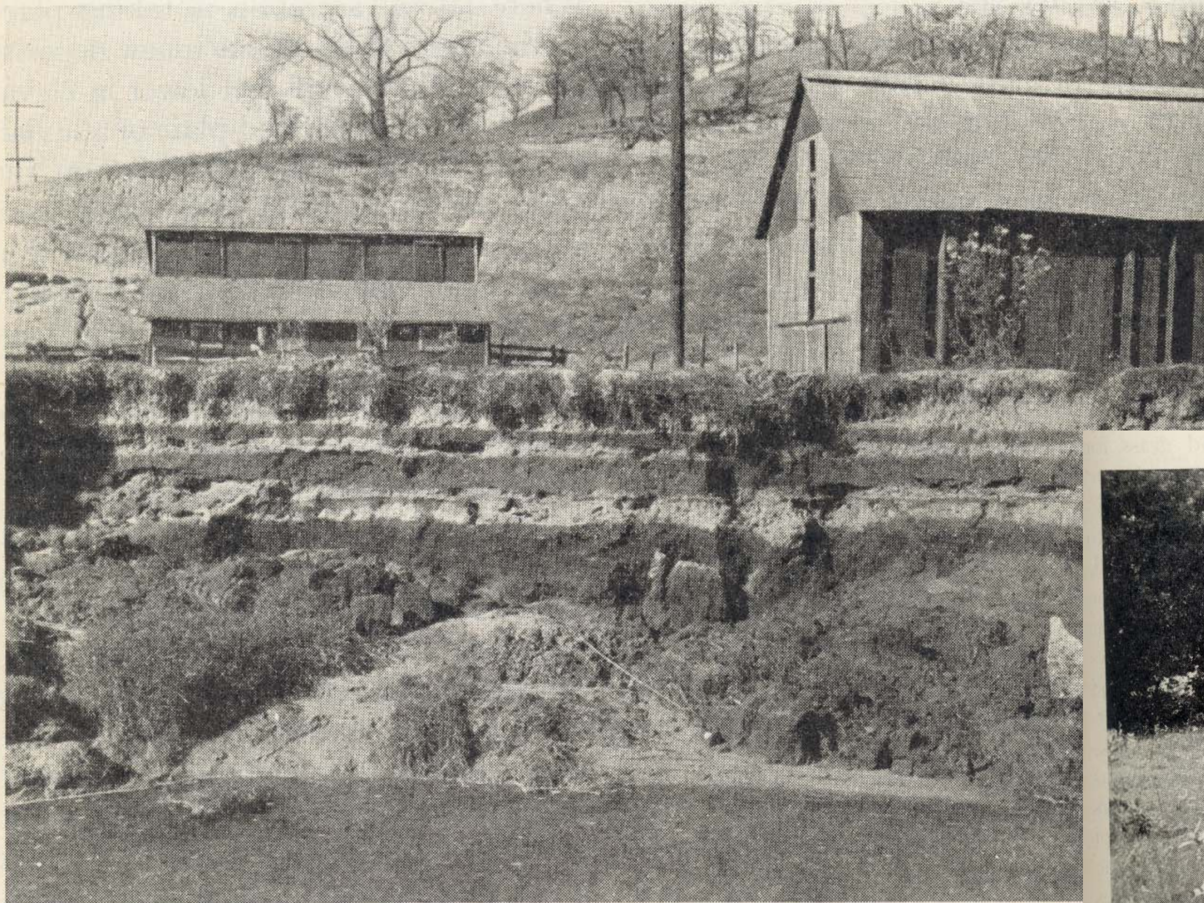


FIG. 4.—Cut-bank exposure showing 3 feet of stratified modern sand and silt overlying t
topsoil horizon. This picture was taken on the alluvial fan of Sand Creek, a tributary of the K
shows more sand (light-colored layers) in the modern alluvium than is common on the main K
plain.

nce posts, with woven wire still attached, partially buried on the Kickapoo River flood plain
southwest of La Farge. The soil auger stands at the site of a post that has been recently
ose beside which the men stand have been buried to within about 15 inches of their origi-

Kickapoo River, WI;
Studies by Stafford Happ, 1940


North Fish Creek, WI, 1993

Signs of rapid overbank sedimentation
Buried root crowns

North Fish Creek, WI

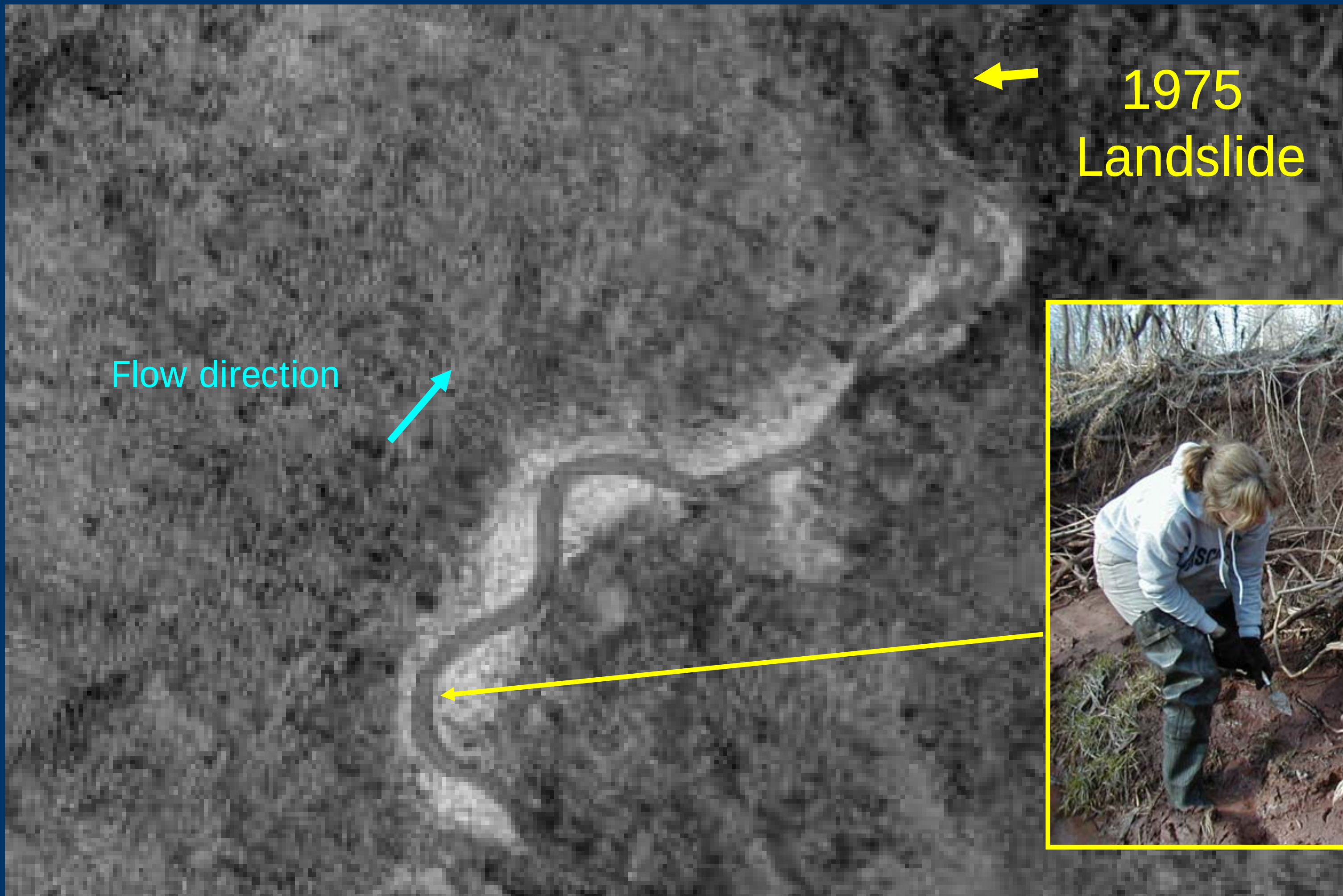
Whittlesey Creek, WI

USGS

Photo by Bernard Lenz

US

Upstream effects from landslides



Cranberry River, WI

Measuring sediment transport

- Rate of sediment movement at a point in space and time
- Short term studies
- In-channel only

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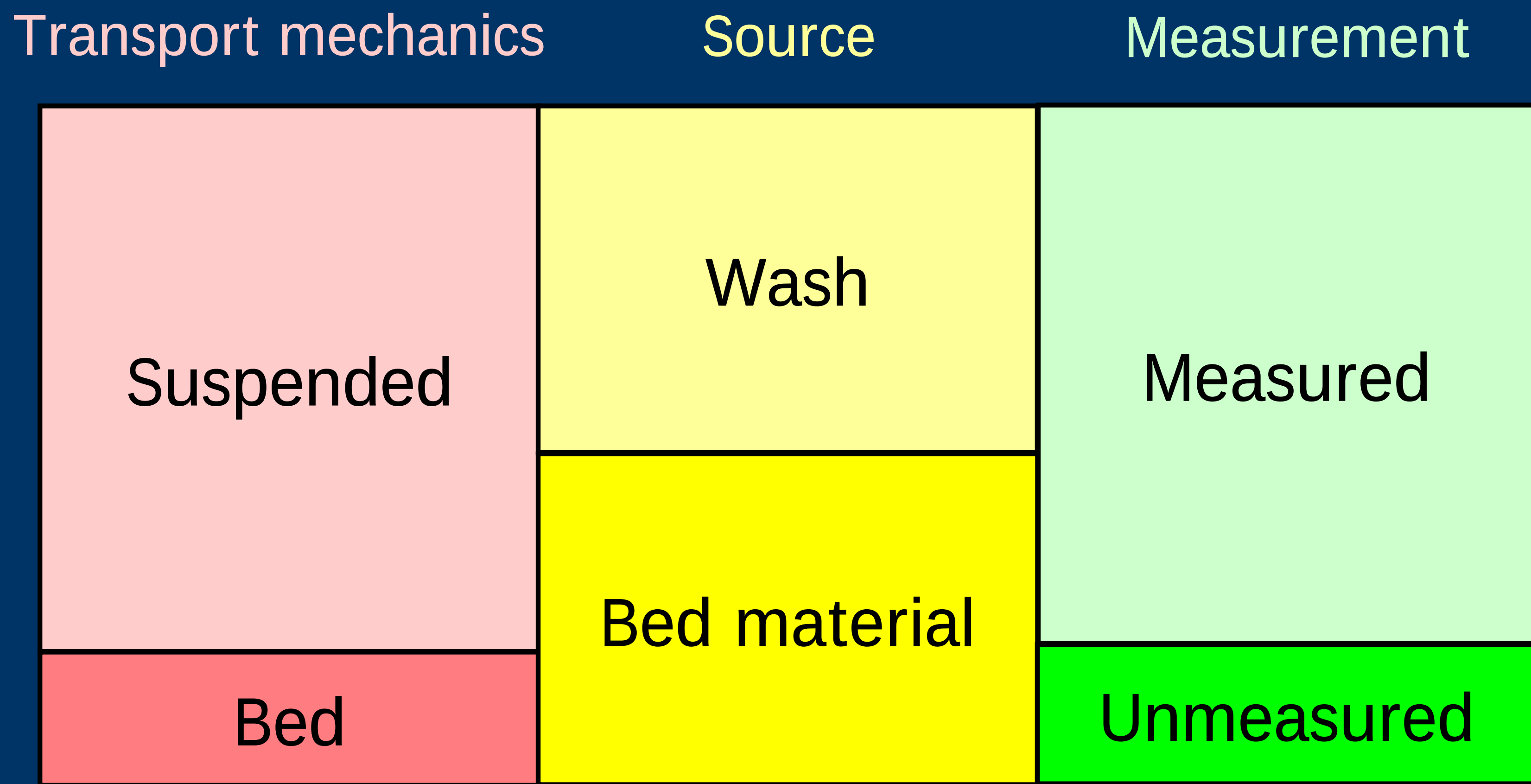
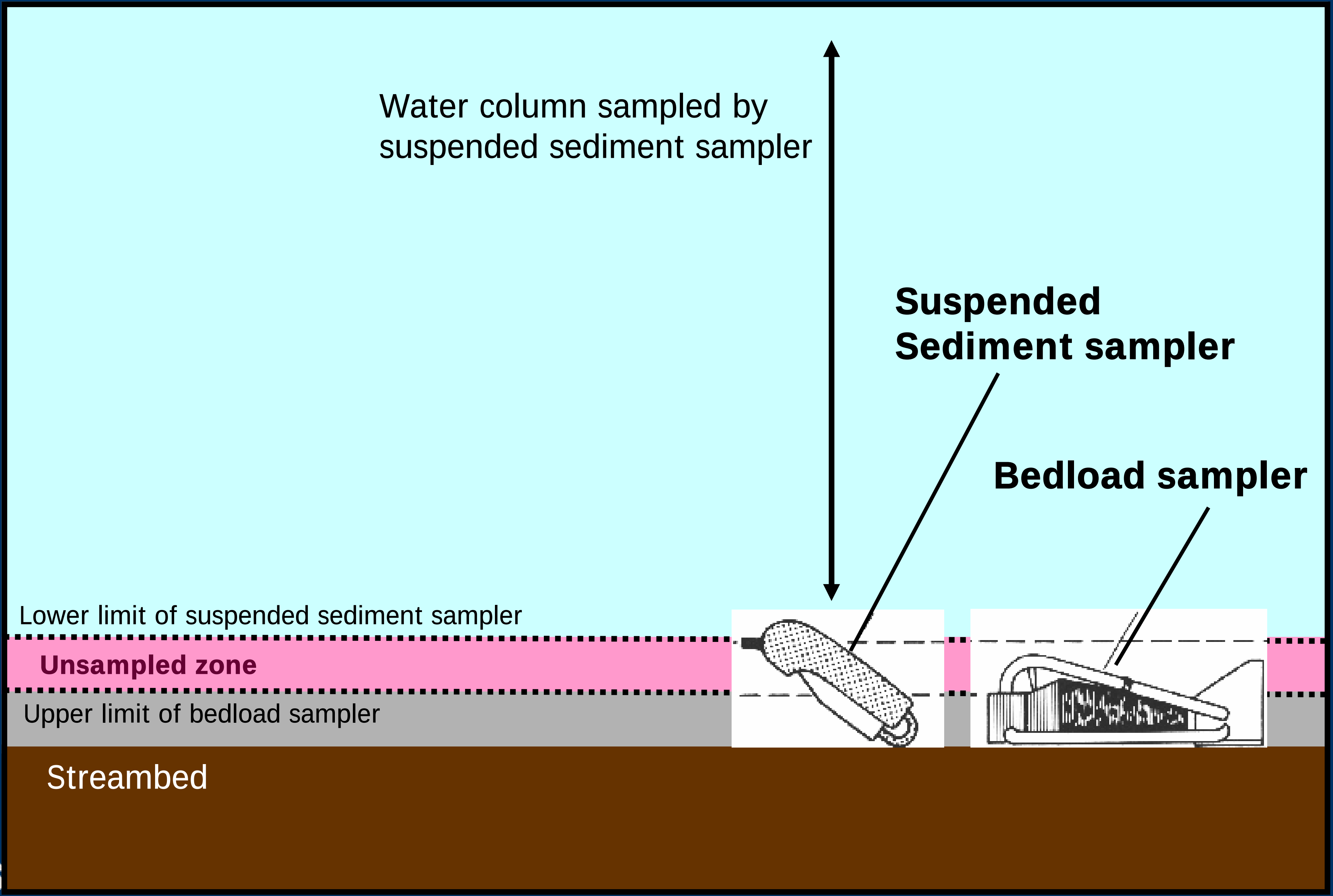
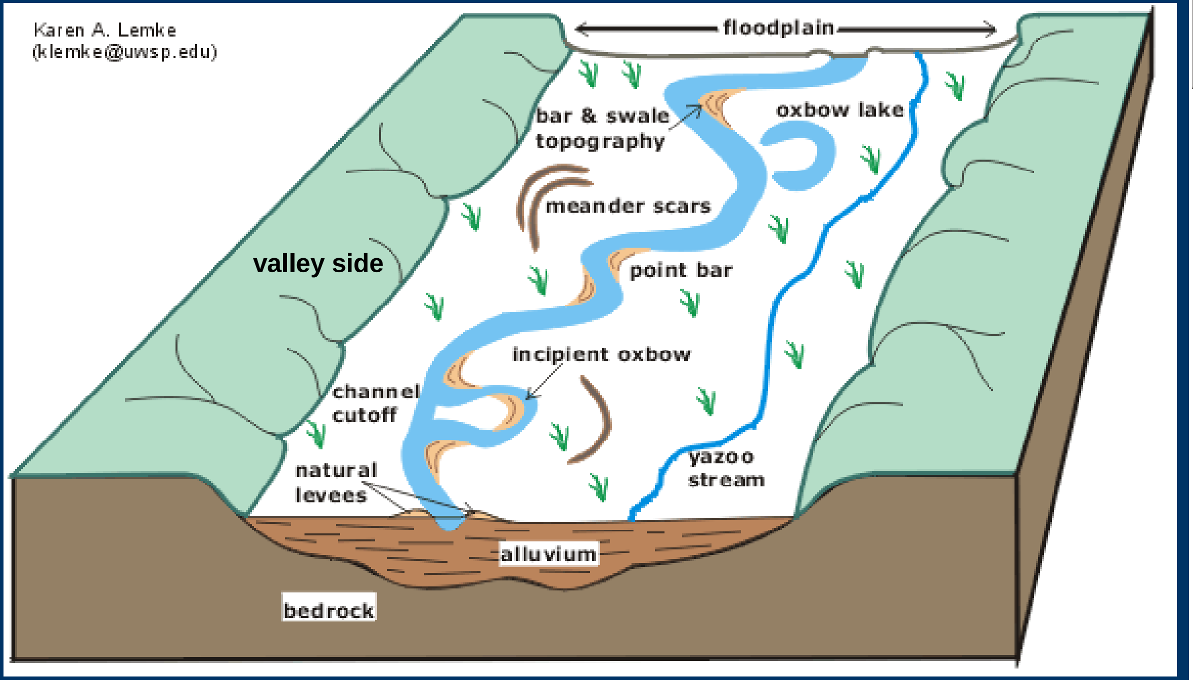
Definitions of Total Sediment Load

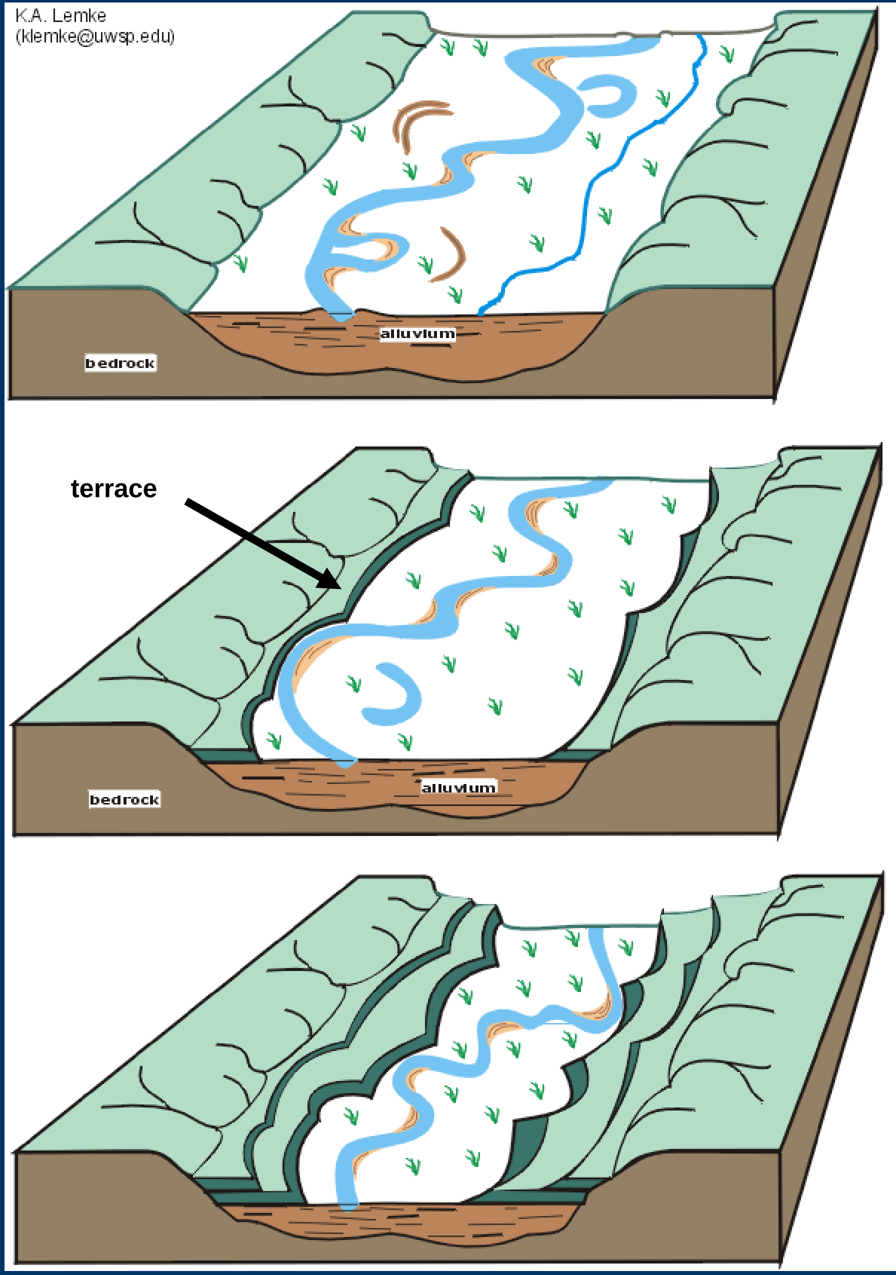


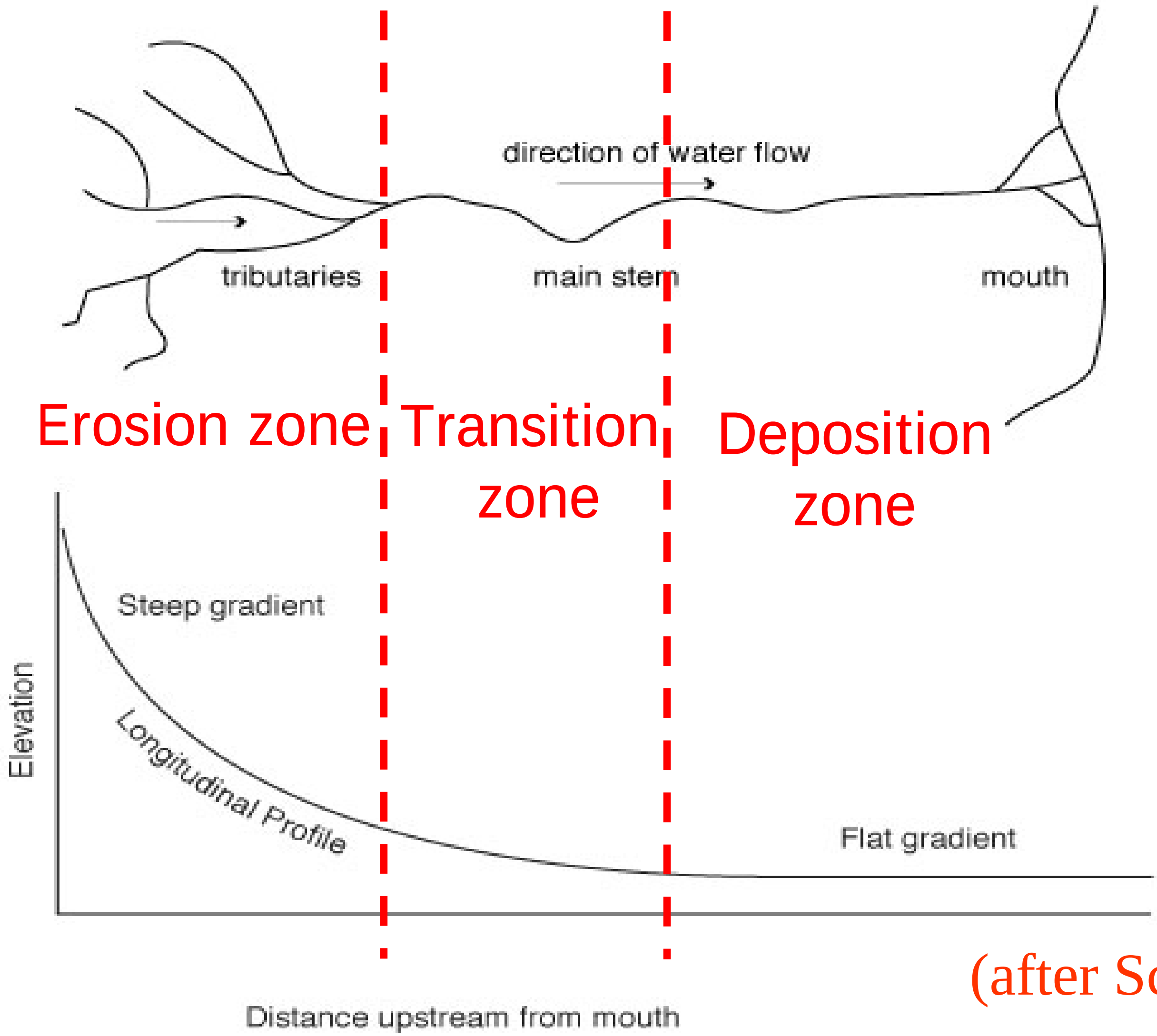


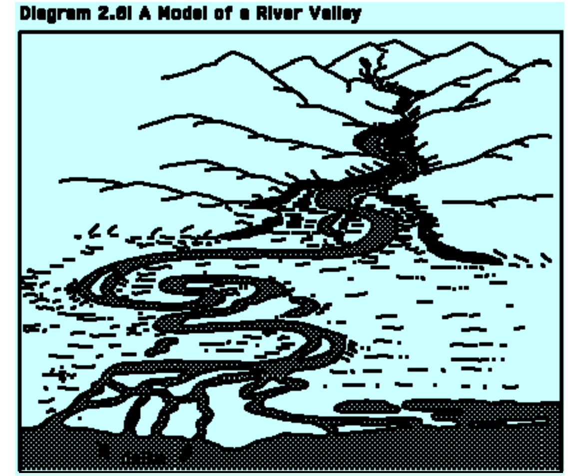
Water column sampled by suspended sediment sampler
Suspended Sediment sampler
Bedload sampler
Lower limit of suspended sediment sampler
Unsampled zone
Upper limit of bedload sampler
Streambed

Fluvial landforms









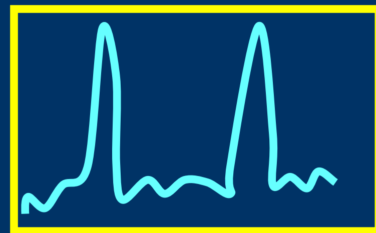
Plan view

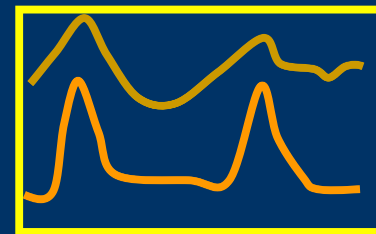
Elevation profile

(after Schumm, 1977)

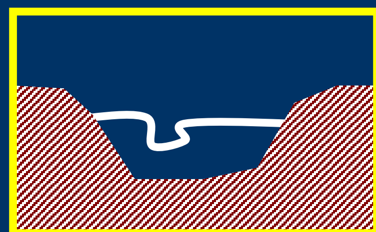
Controls on channel form

Driving variables

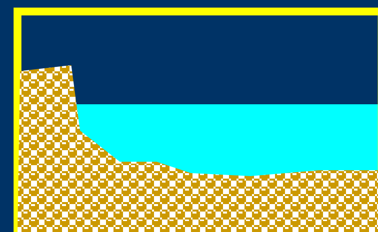




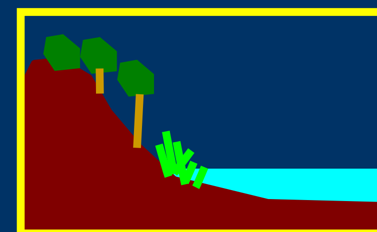
Boundary characteristics



Valley slope and topography

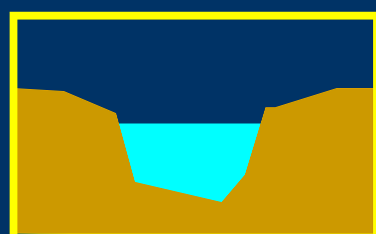


Bank and bed materials

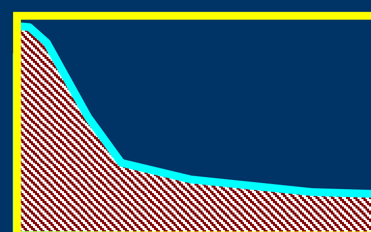


Riparian vegetation

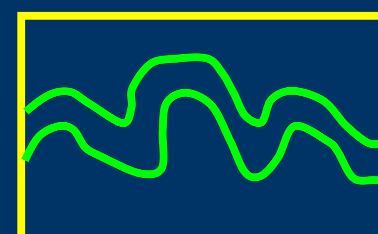
Channel form



XS geometry



Long profile



Planform

(from Thorne, 1997)

Schumm's (1969) qualitative model of channel response:

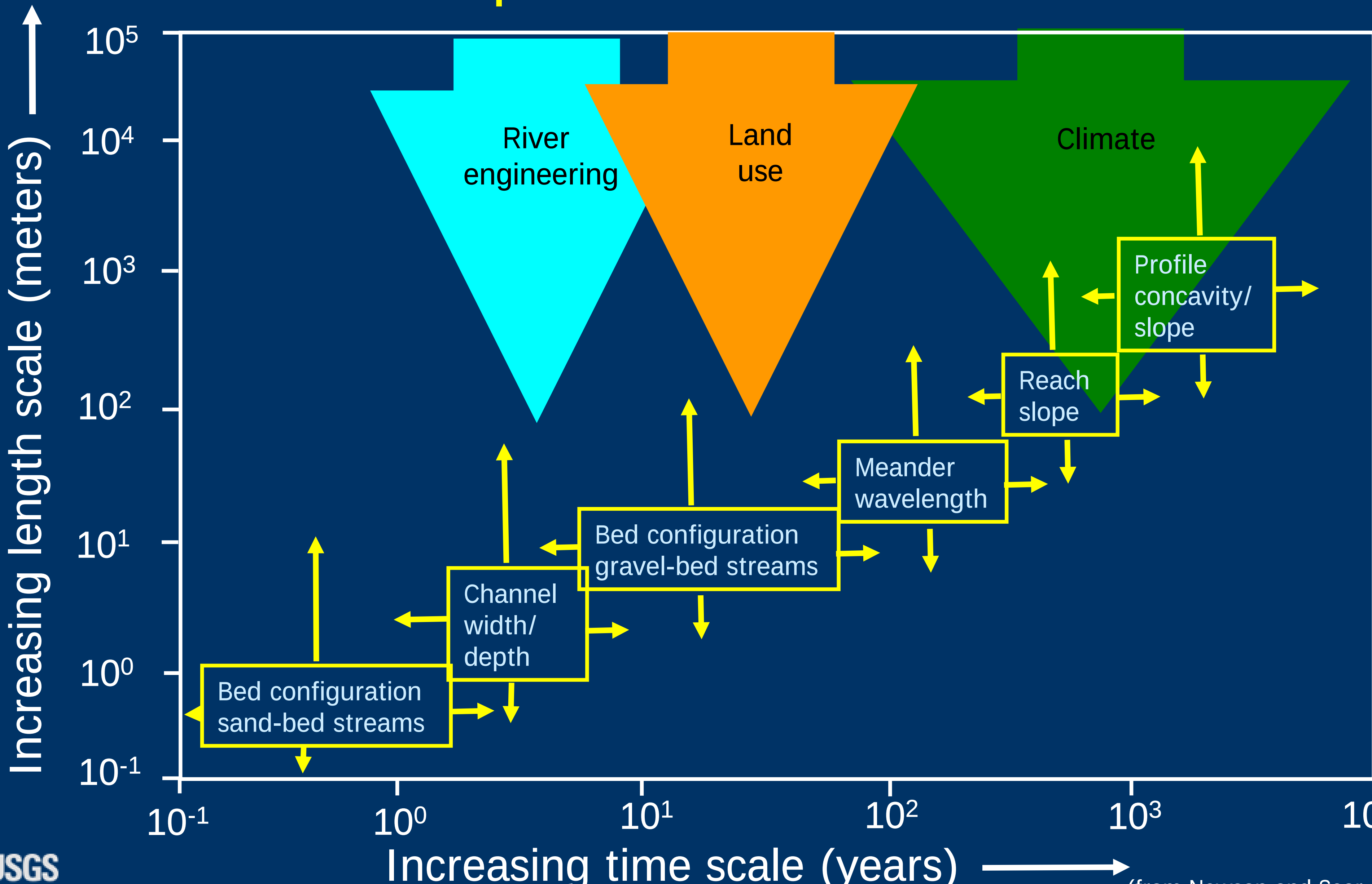
$$Q^{+} \sim B^{+}D^{+}F^{+}\lambda^{+}S^{-}$$

$$Q_s^{+} \sim B^{+}D^{-}F^{+}\lambda^{+}S^{+}P^{-}$$

$$Q^{+}Q_s^{+} \sim B^{+}D^{\pm}F^{+}\lambda^{+}S^{\pm}P^{-}$$

Q = discharge
Qs = bed material discharge
B = width
D = depth
F = width/depth ratio
λ= meander wavelength
S = slope
P = sinuosity

The importance of time scale



(from Newson and Sear, 1993)

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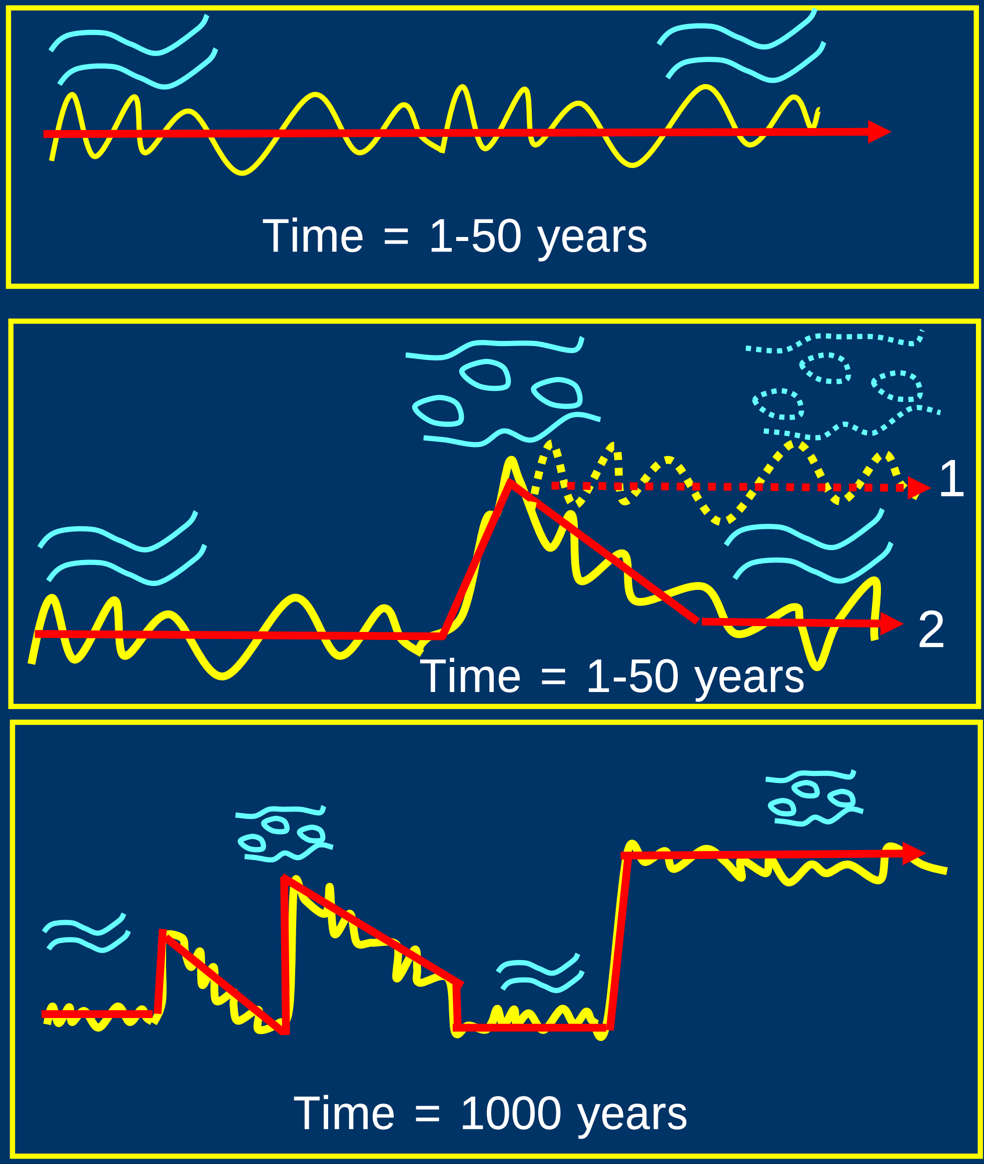
Time Scales, Equilibrium, and Threshold Response

Channel in equilibrium with water and sediment load. Minor change (scour and fill).

Threshold effects – (1) no return to original state – morphology changed to new equilibrium, or (2) adjustment to previous equilibrium

Dynamic adjustments expected over longer time periods – river restoration needs to plan for these?



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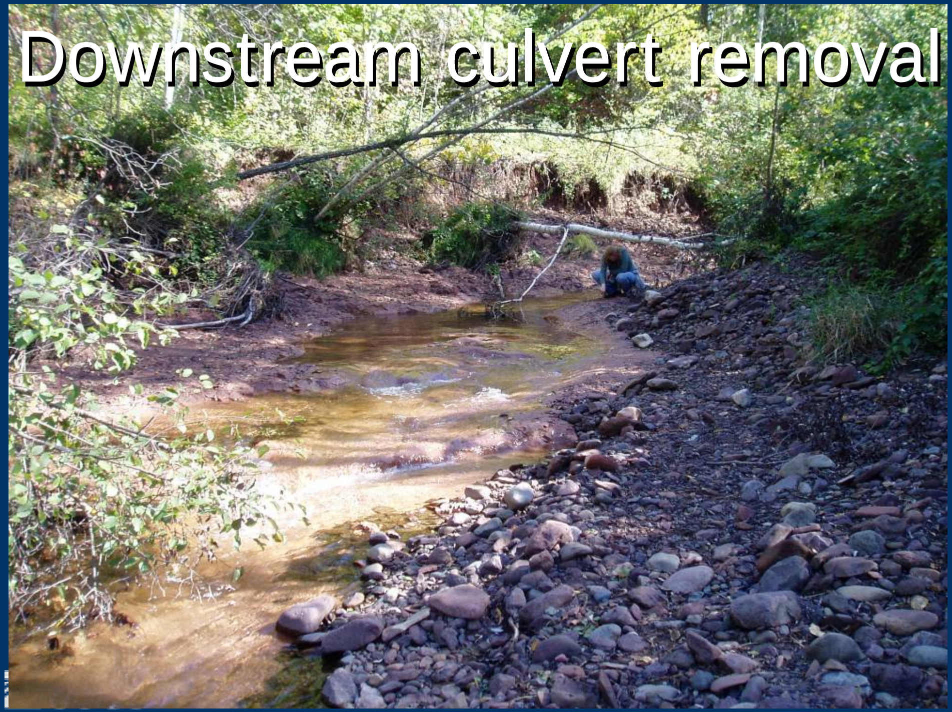
(from Sear, 1996)

Geomorphic responses



Exogenic and endogenic disturbance

- magnitude
- order
- frequency
- concentration

(Haschenburger and Souch, 2004)

Geomorphic adjustments

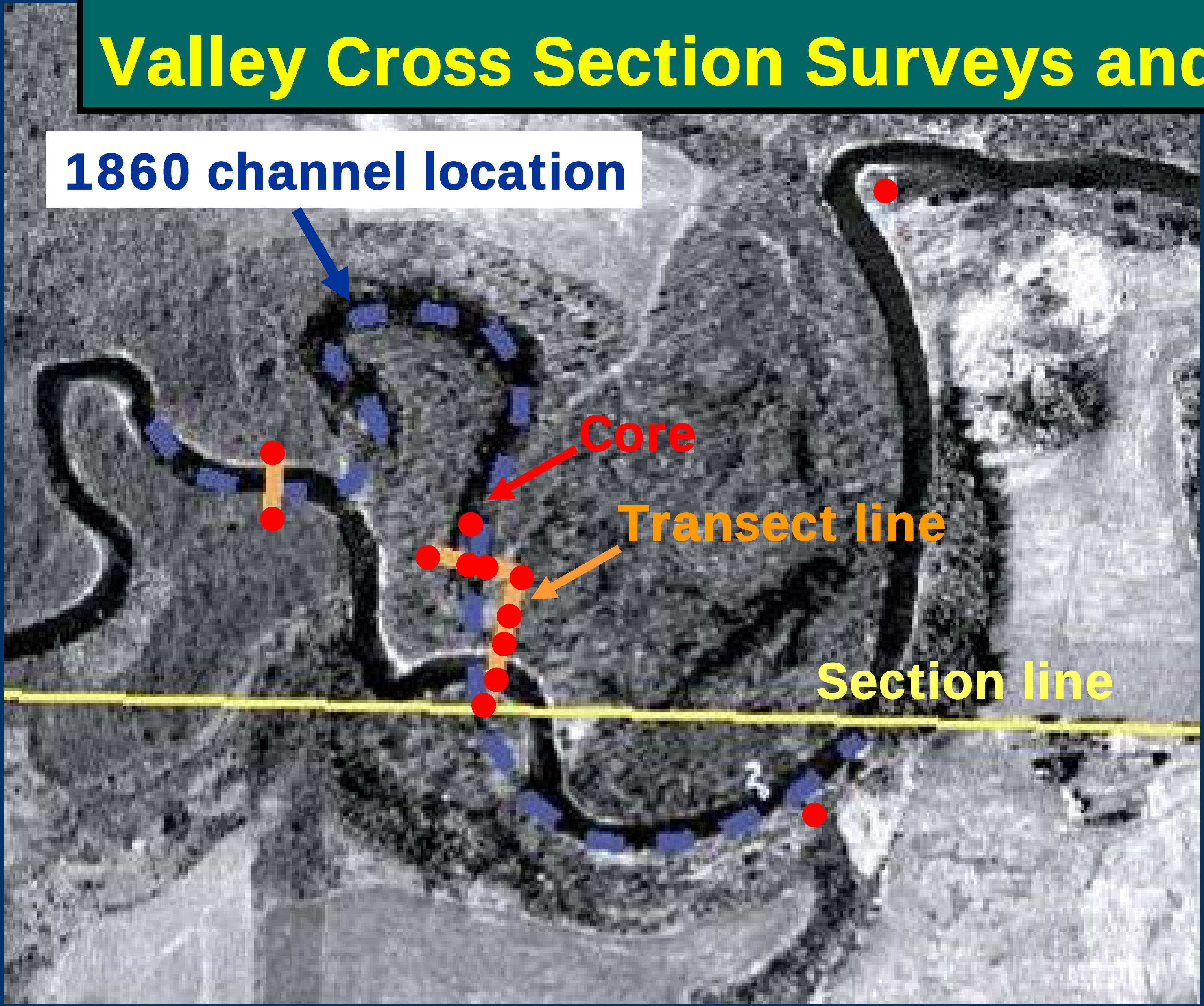
- Internal functioning
- Threshold exceedance
- Time lag depend on rates of processes
- Limited by history of landform development

(Haschenburger and Souch, 2004)

Geomorphic Assessment Methods

- Compile watershed data—geology, soils, topography, land cover
- Construct longitudinal profiles
- Identify valley types and local geologic setting (3D)
- Compile historical streamflow and sediment load data
- Collect historical maps, photos, bridge designs, surveys
- Identify past disturbances
- Identify potential areas of erosion, transport, or deposition
- Conduct field reconnaissance survey of watershed—helicopter or driveby
- Conduct stream reach surveys (representative of entire stream network)
  - Channel/flood-plain cross sections, slope, streambed and bank substrate characterization, riparian conditions

Valley Cross Section Surveys and Coring



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Typical Midwest / Great Lakes valley development

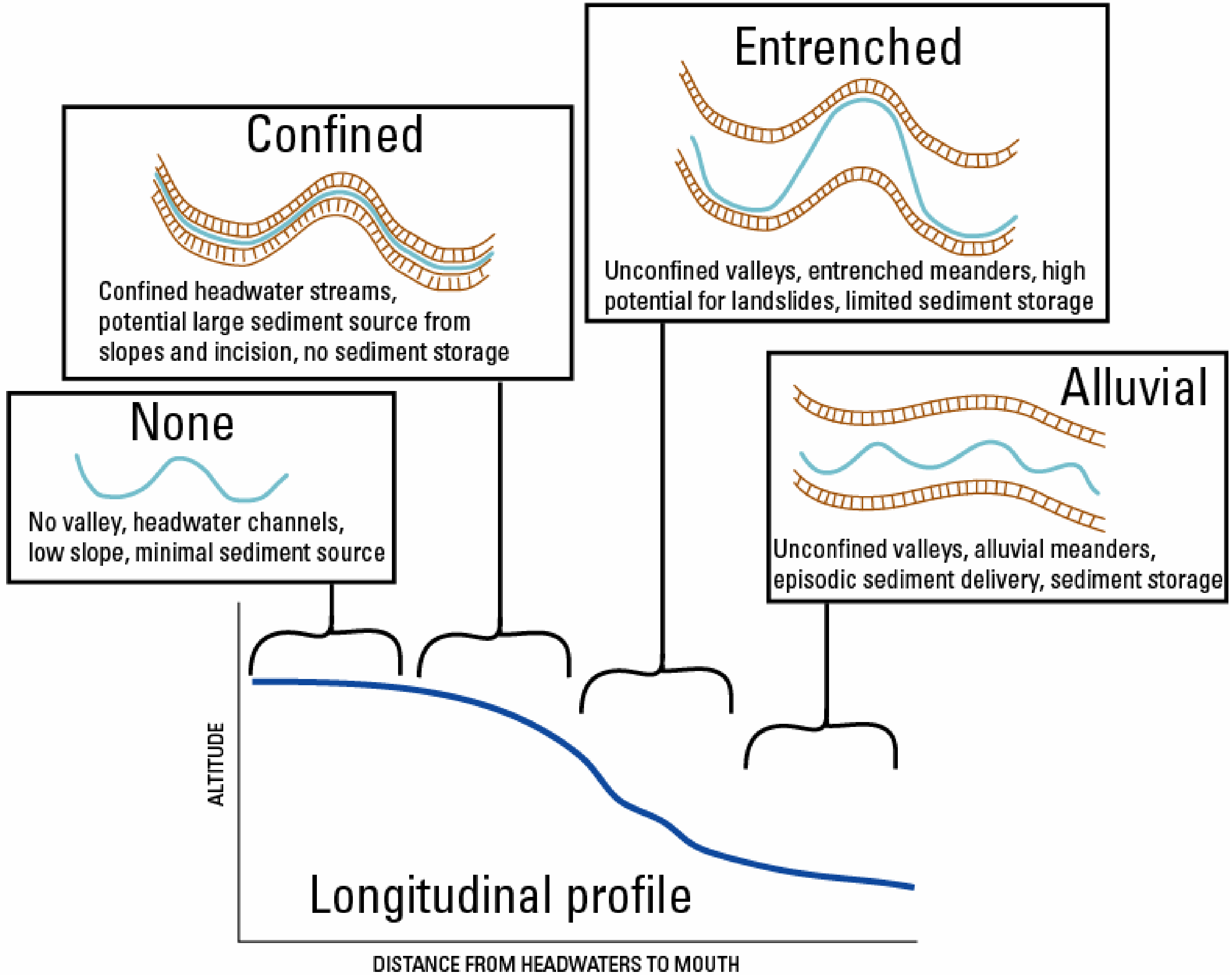
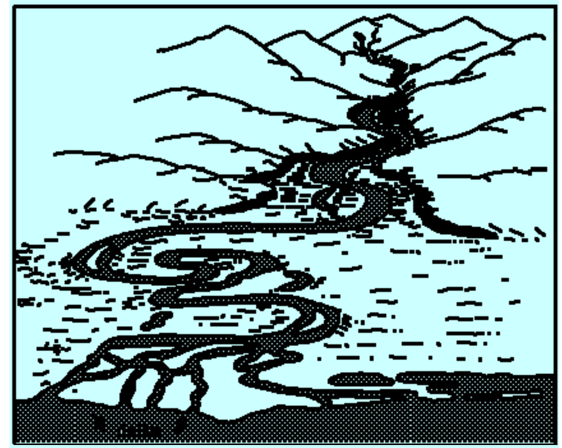
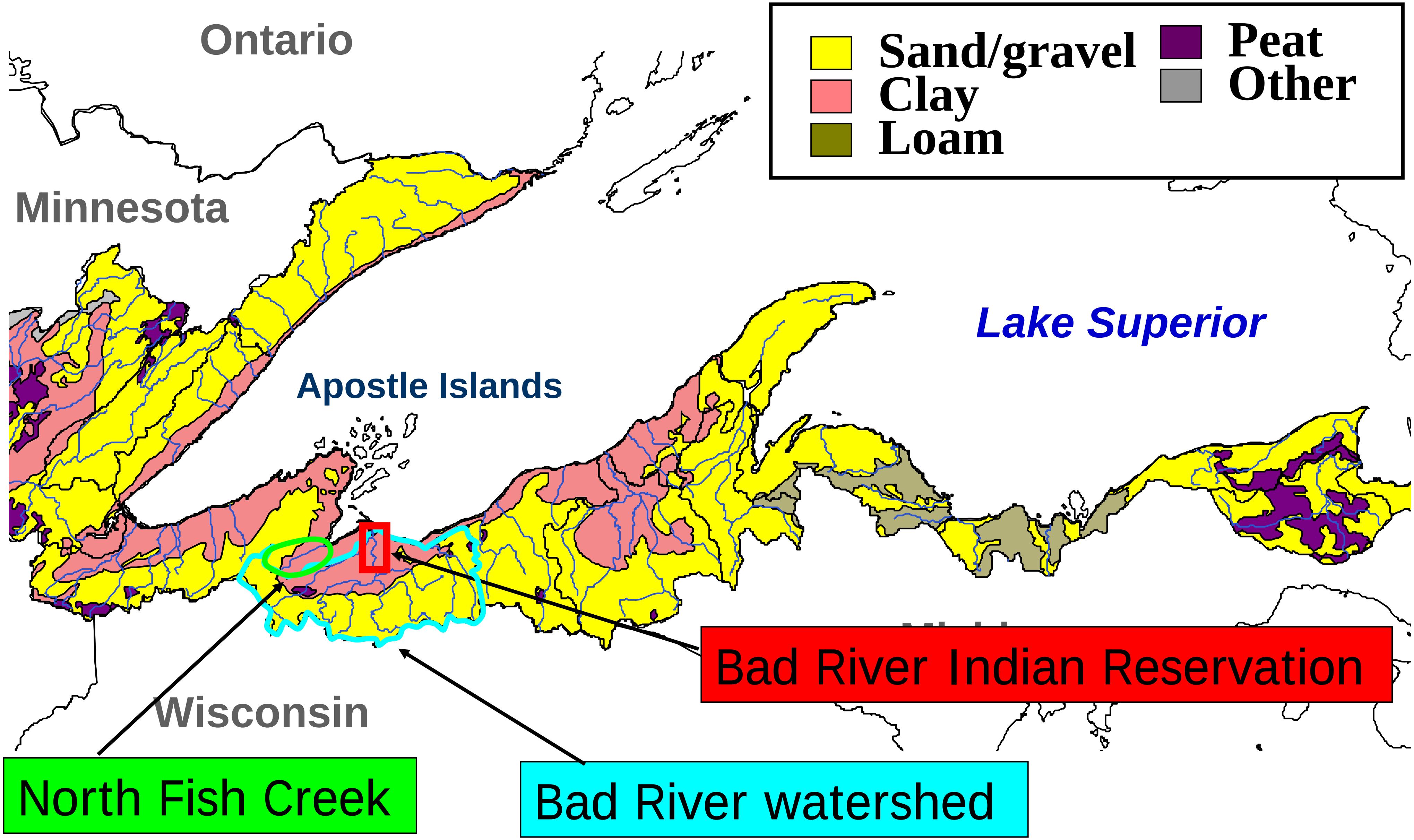


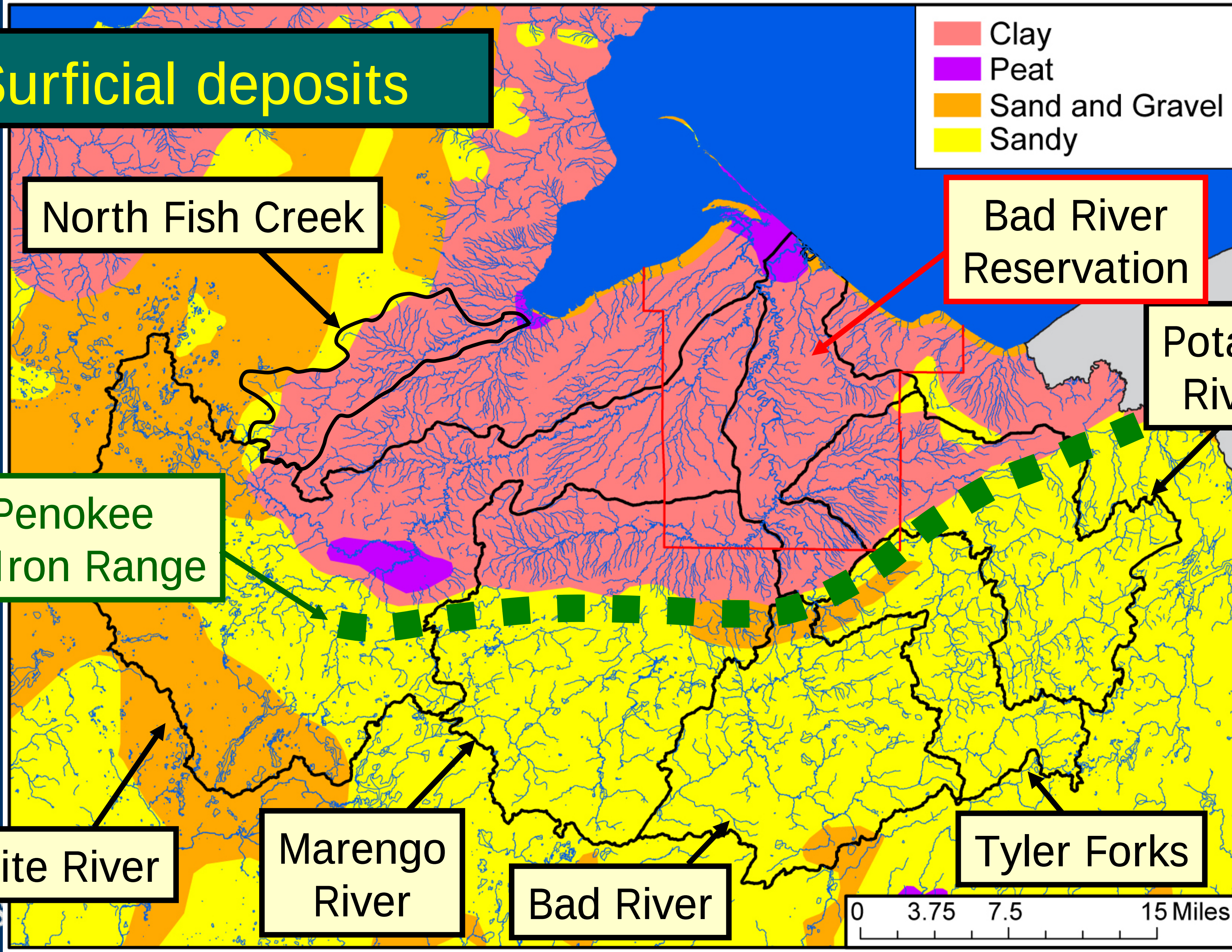
Diagram 2.6I A Model of a River Valley

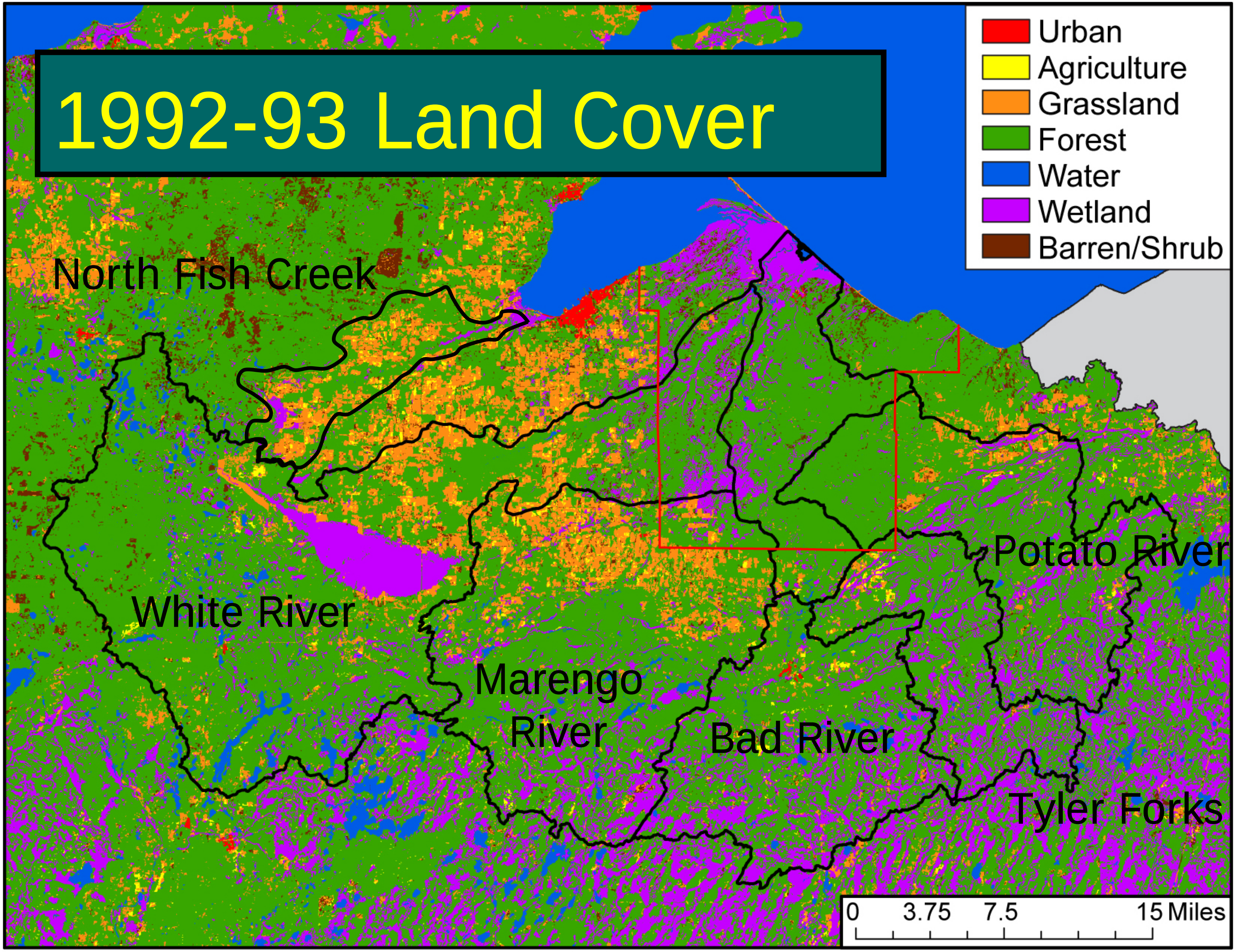




Sand/gravel
Clay
Loam
Peat
Other
Ontario
Minnesota
Apostle Islands
Lake Superior
Wisconsin
Bad River Indian Reservation
North Fish Creek
Bad River watershed

Surficial deposits

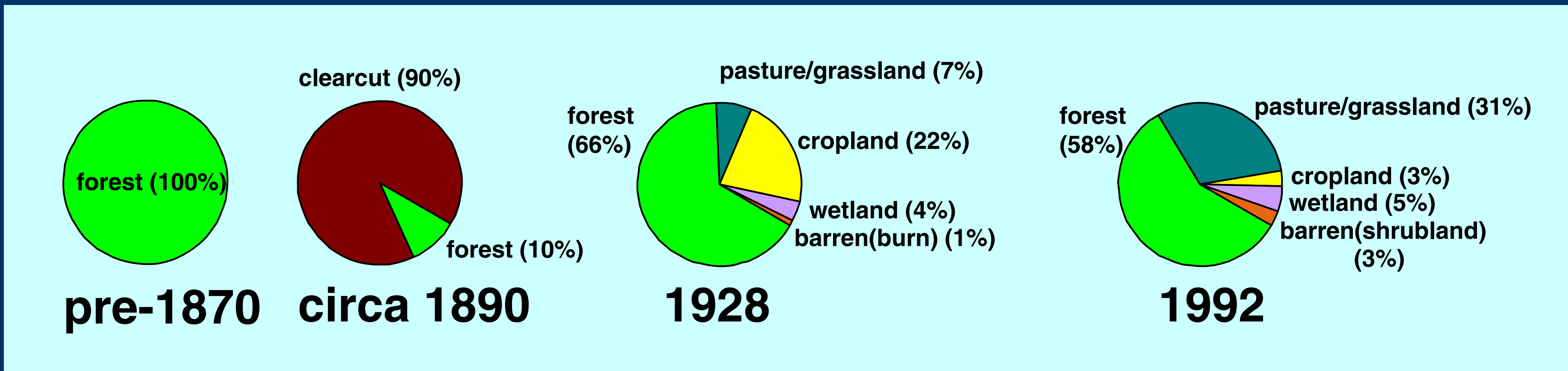



1992-93 Land Cover
Urban
Agriculture
Grassland
Forest
Water
Wetland
Barren/Shrub
North Fish Creek
White River
Marengo River
Bad River
Potato River
Tyler Forks
0
3.75
7.5
15 Miles

Northern Great Lakes Cutover —Late 1800s

Photos courtesy Wisconsin State Historical Society

History of Land Cover Changes
North Fish Creek



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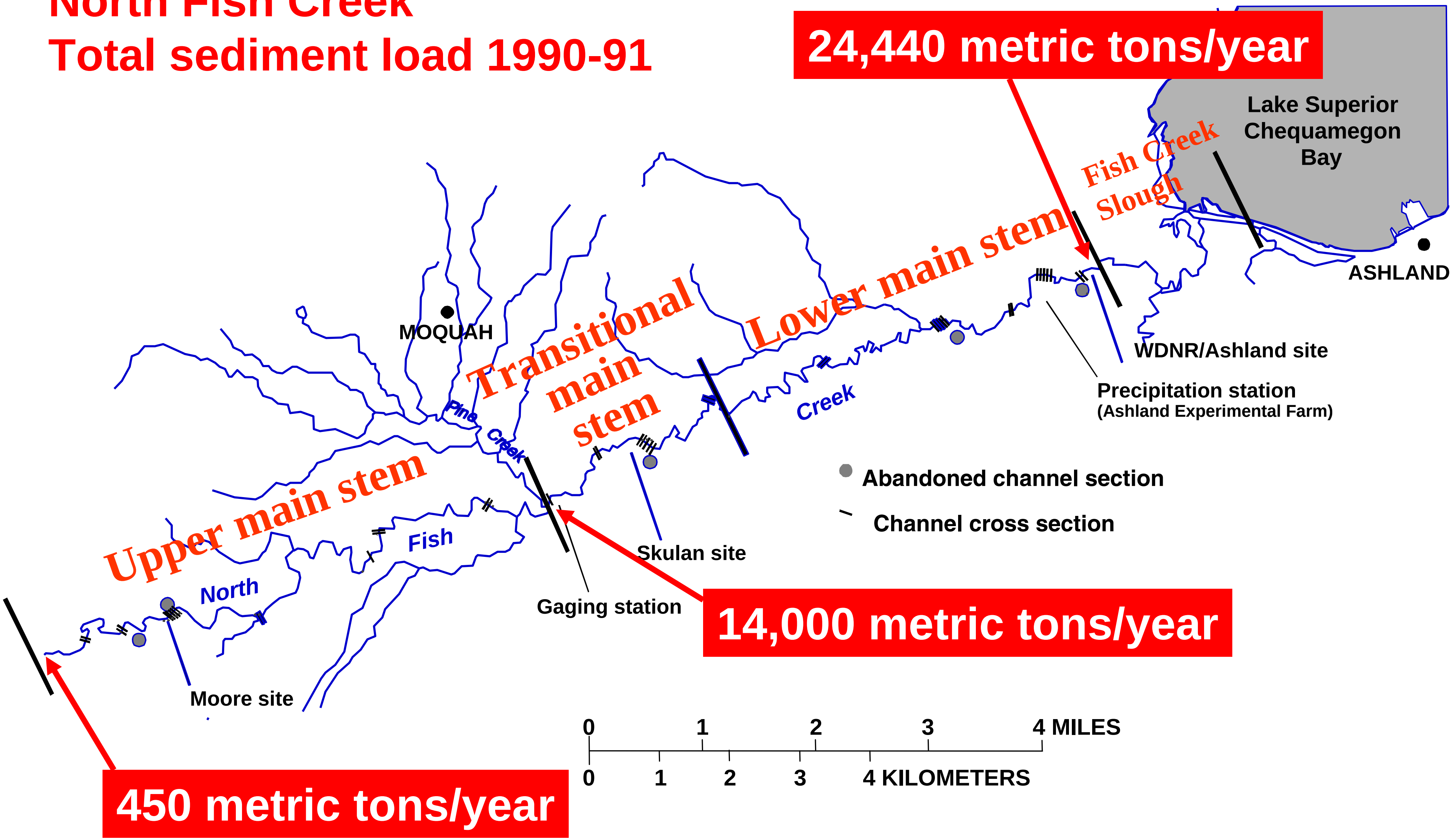
North Fish Creek
Total sediment load 1990-91



Geomorphic processes and sediment loads for North Fish Creek

Transitional main stem

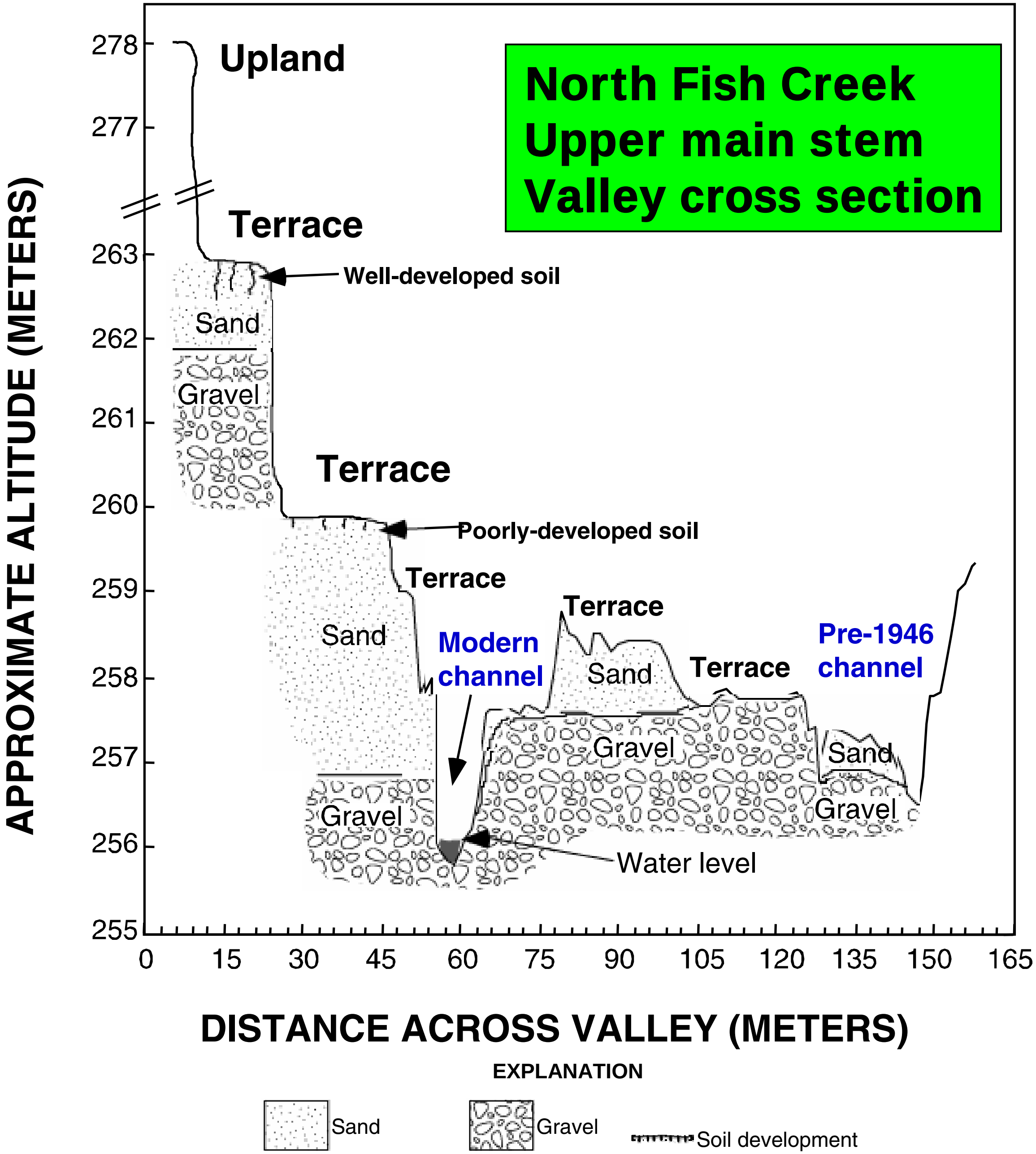
14,000 metric tons/year
140 tons/km^2/yr

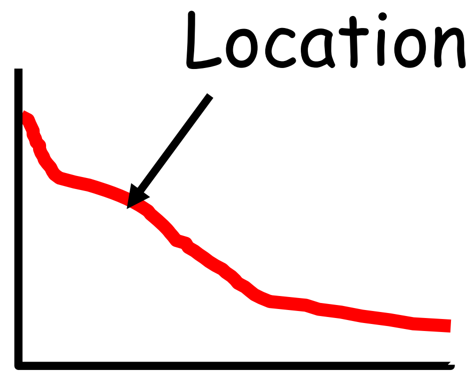
Lower main stem

24,440 metric tons/year
200 tons/km^2/yr

USGS

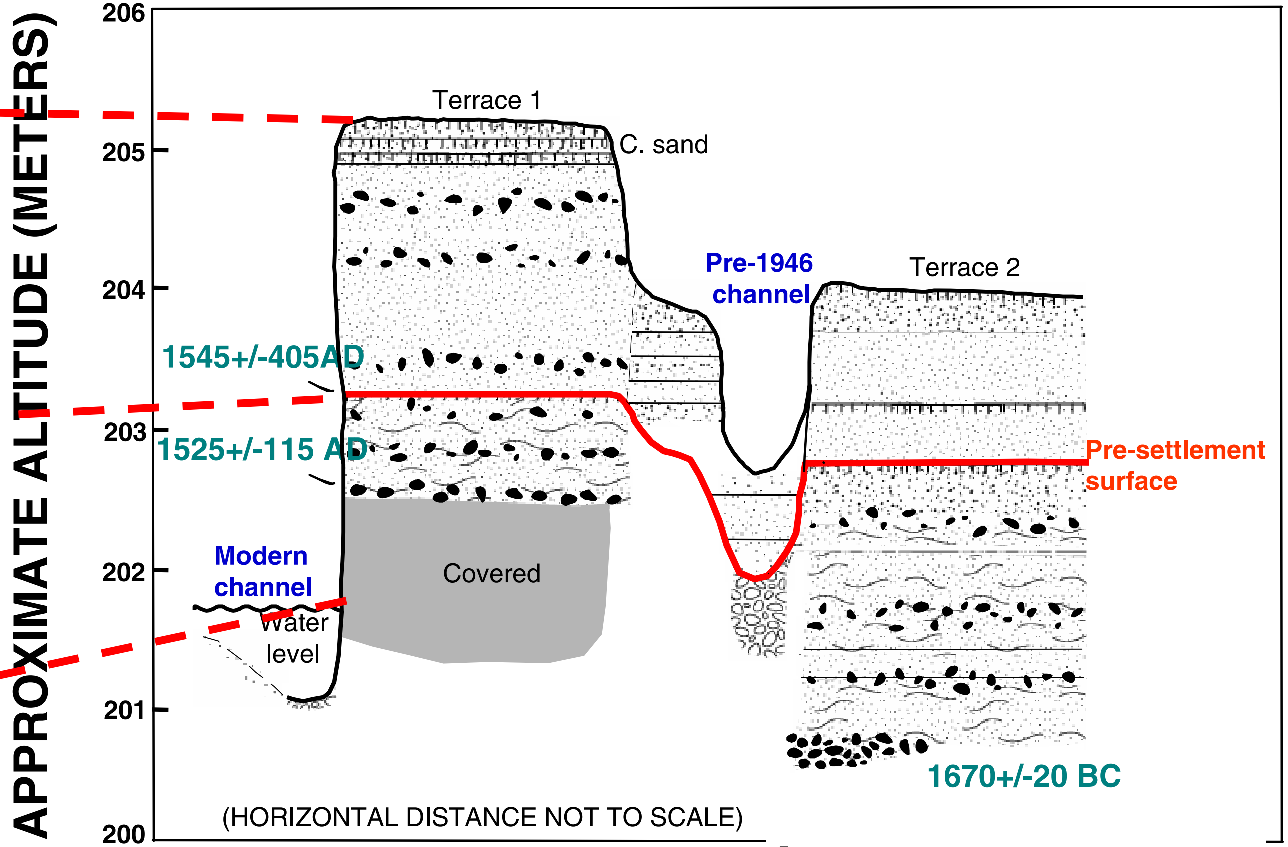
North Fish Creek, WI
Upper main stem

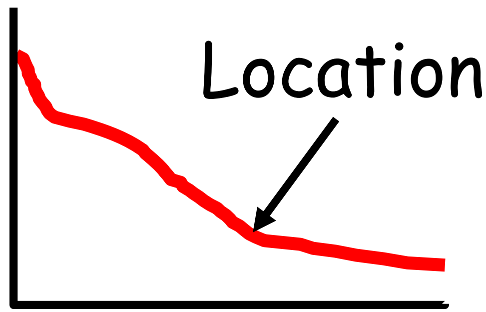

North Fish Creek
Upper main stem
Valley cross section
Upland
Terrace
Well-developed soil
Sand
Gravel
Terrace
Poorly-developed soil
Terrace
Sand
Modern channel
Terrace
Sand
Terrace
Pre-1946 channel
Gravel
Sand
Gravel
Gravel
Water level
APPROXIMATE ALTITUDE (METERS)
278
277
263
262
261
260
259
258
257
256
255
0
15
30
45
60
75
90
105
120
135
150
165
DISTANCE ACROSS VALLEY (METERS)
EXPLANATION
Sand
Gravel
Soil development


Location

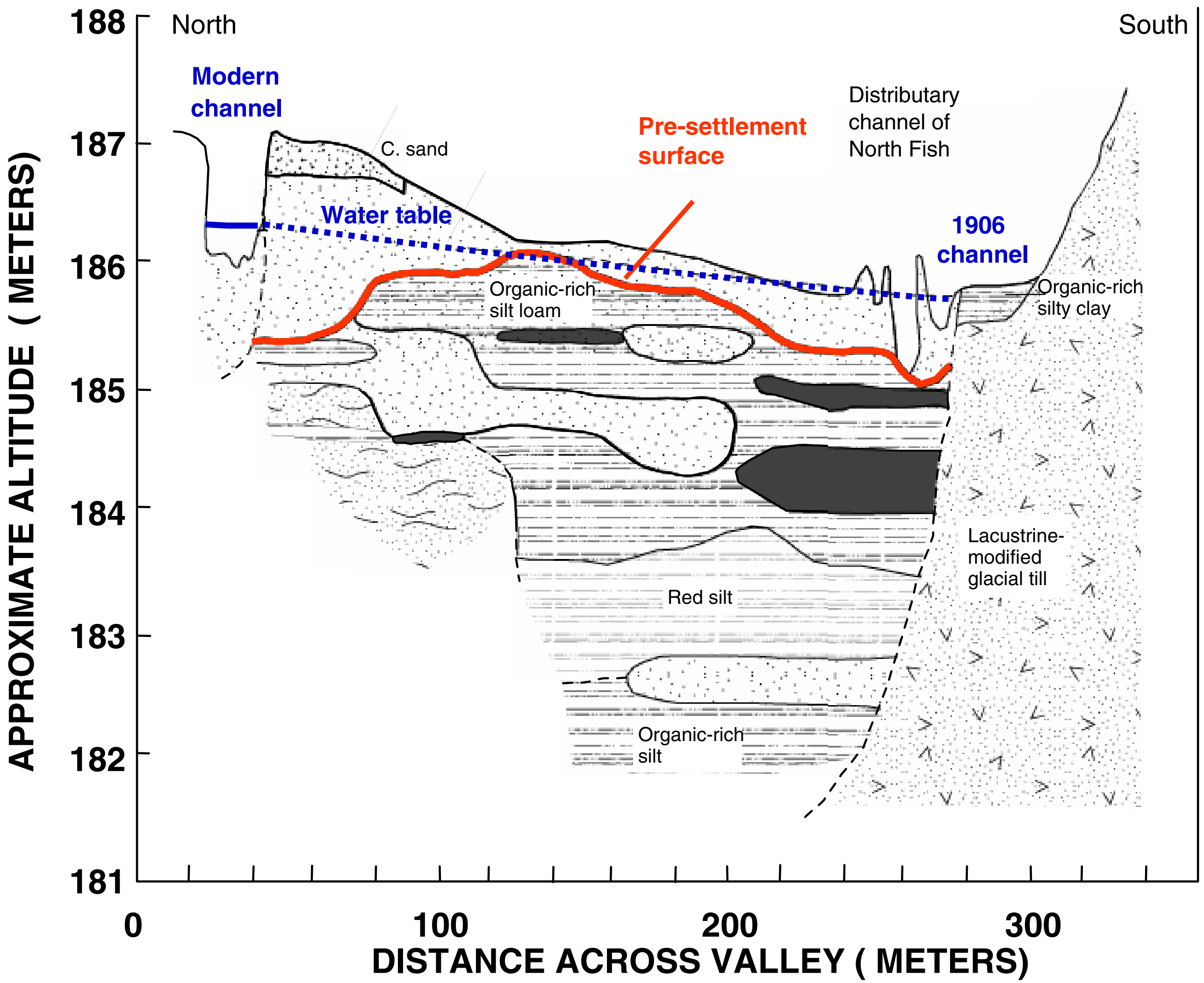
North Fish Creek middle main stem

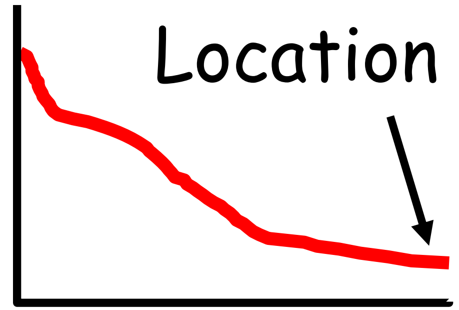
Photo of cut bank



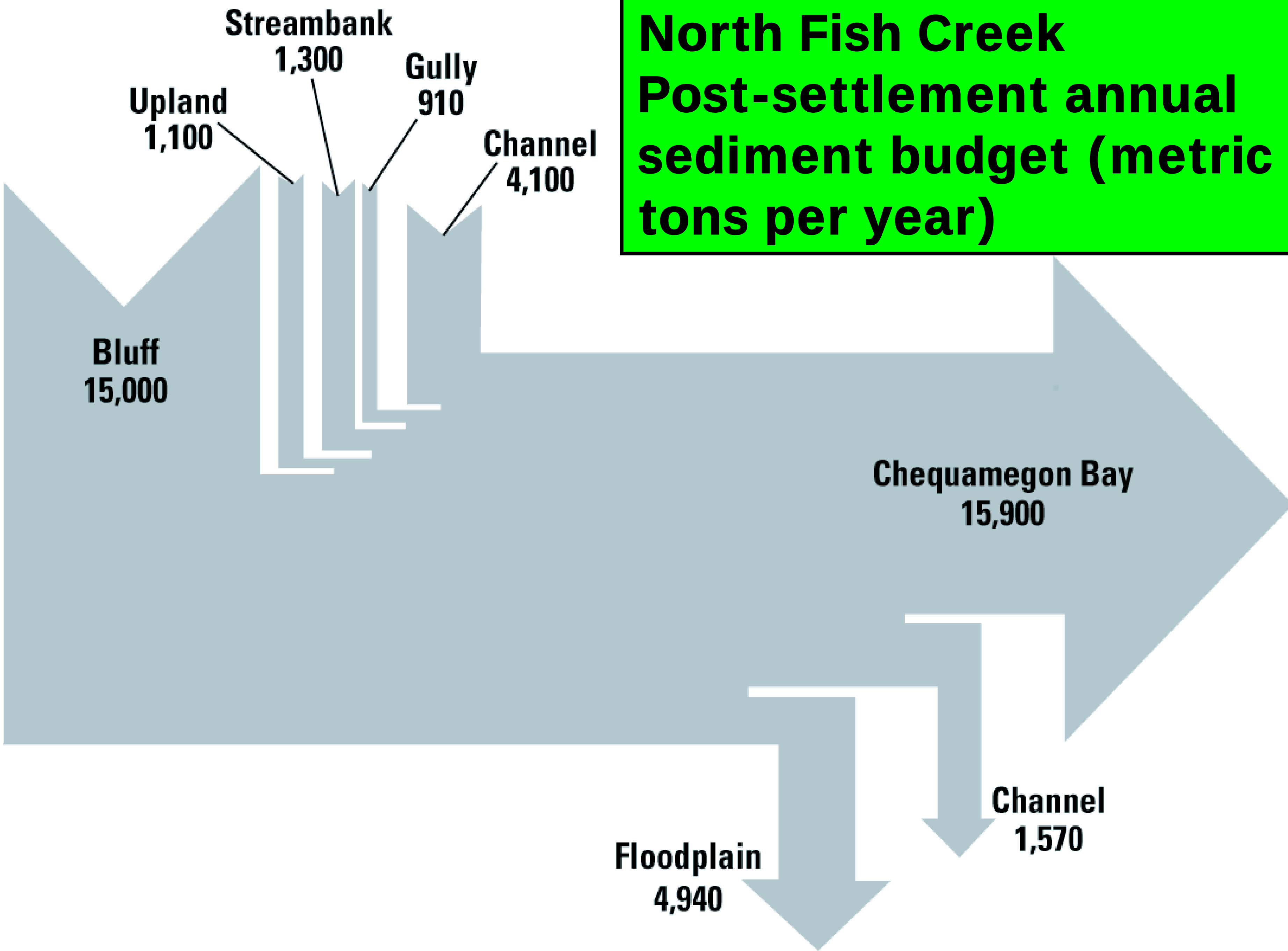


North Fish Creek lower main stem

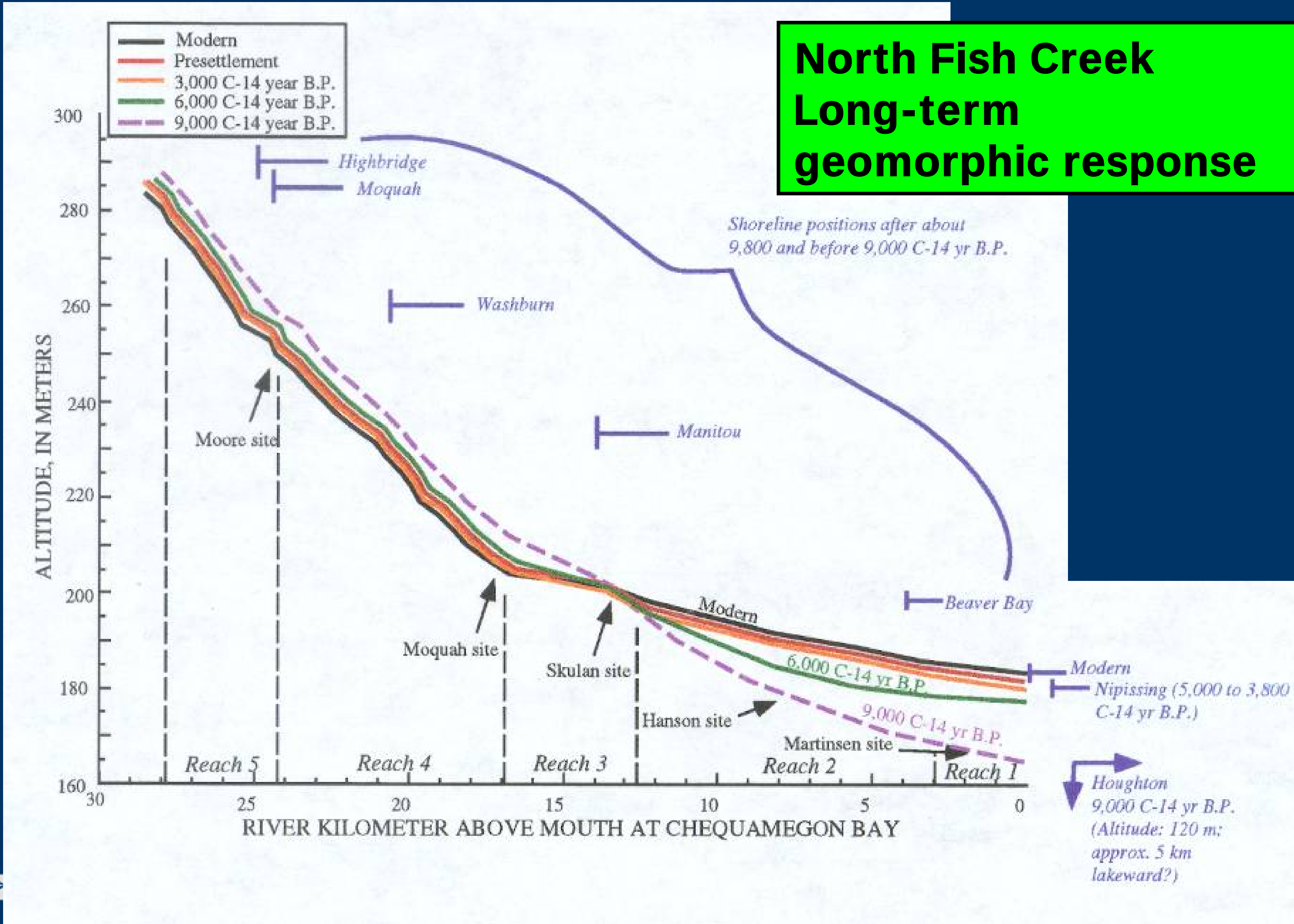


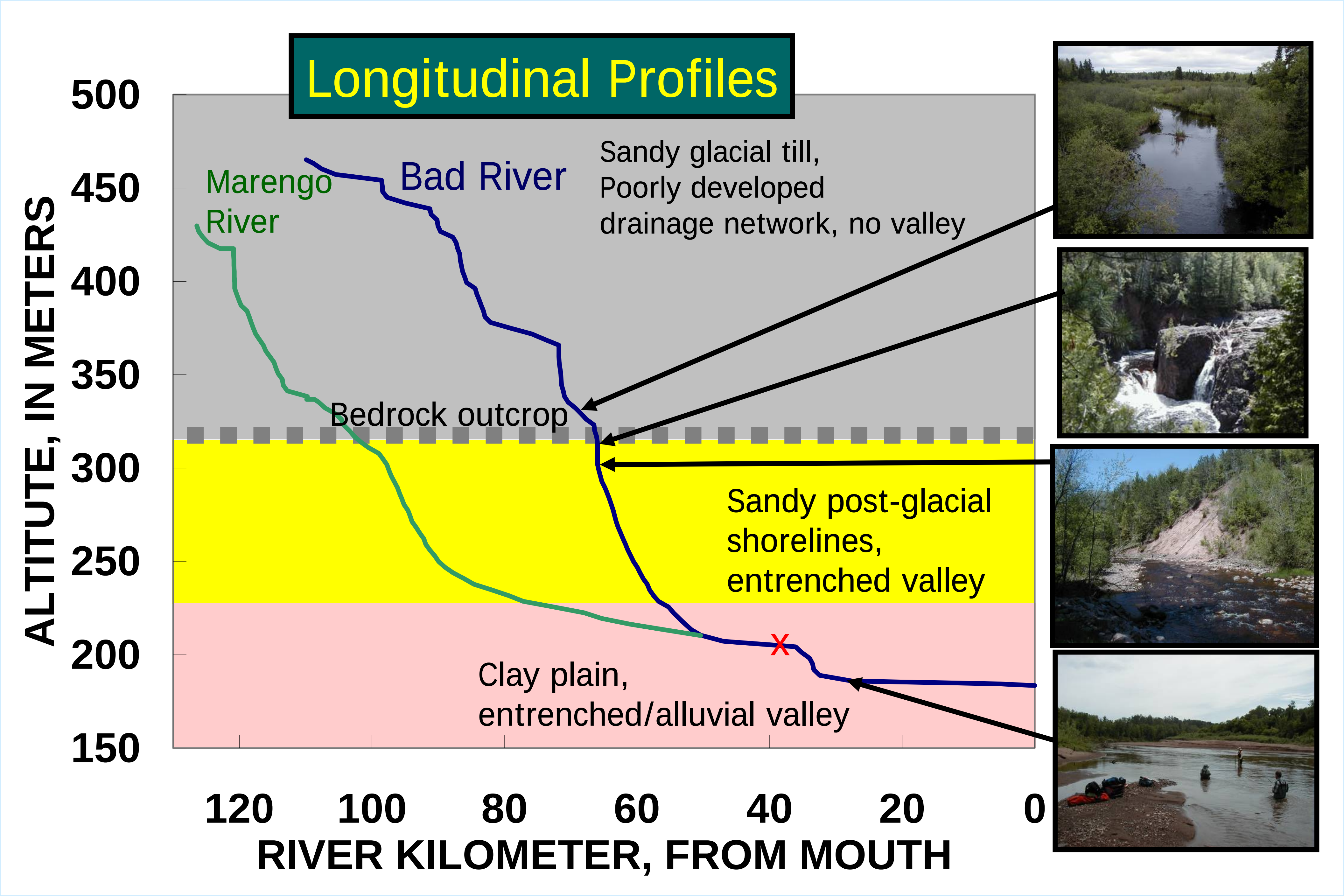


North Fish Creek Post-settlement annual sediment budget (metric tons per year)

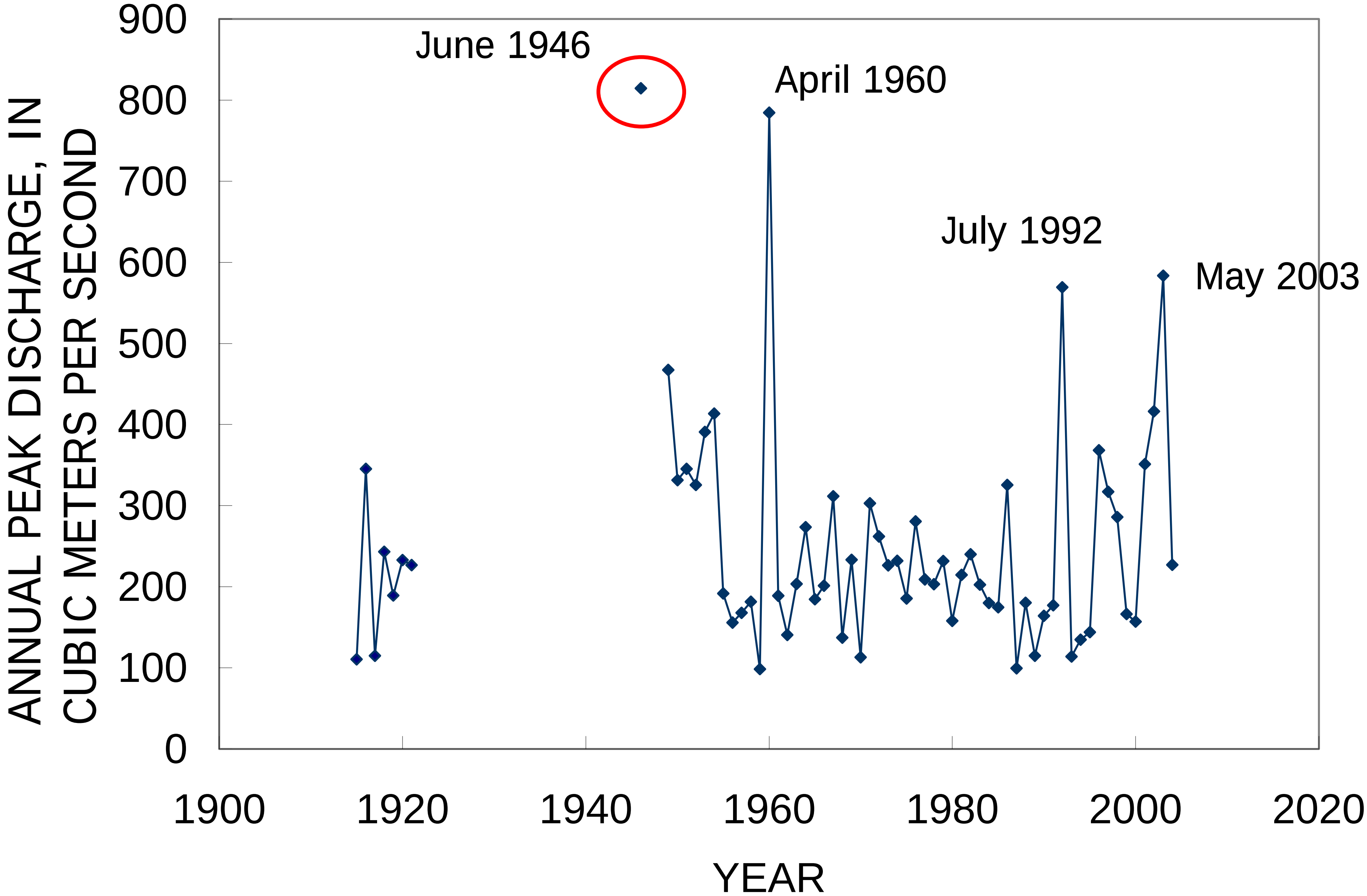


North Fish Creek Long-term geomorphic response

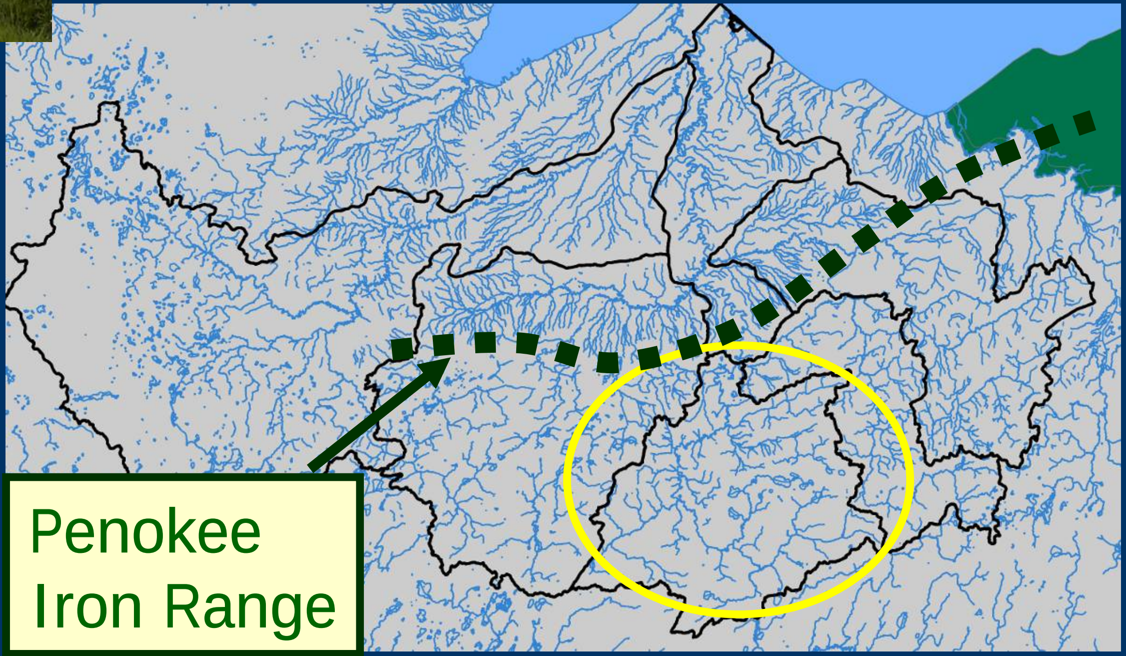



Longitudinal Profiles
ALTITUTE, IN METERS
500
450
400
350
300
250
200
150
120
100
80
60
40
20
0
RIVER KILOMETER, FROM MOUTH
Marengo River
Bad River
Sandy glacial till,
Poorly developed
drainage network, no valley
Bedrock outcrop
Sandy post-glacial
shorelines,
entrenched valley
X
Clay plain,
entrenched/alluvial valley

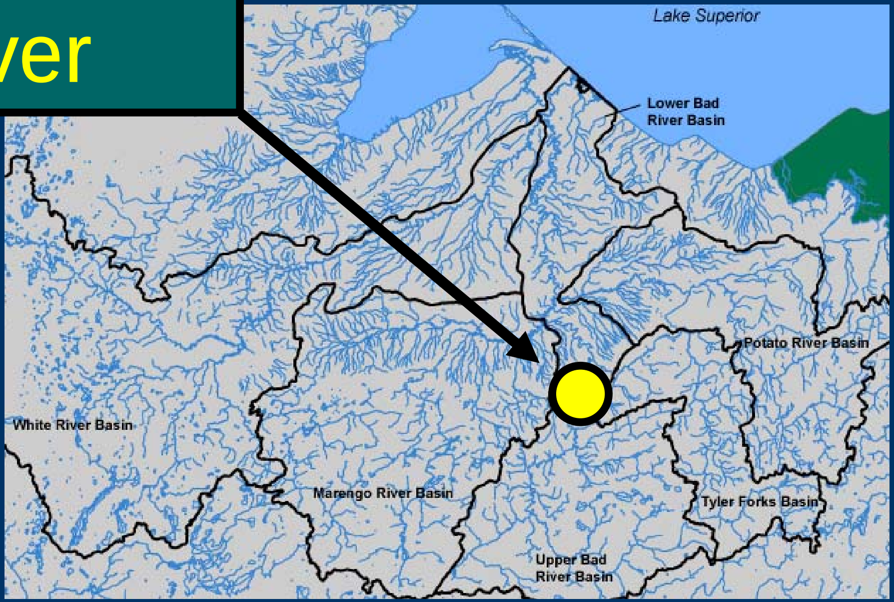
Bad River – Annual Peak Flow



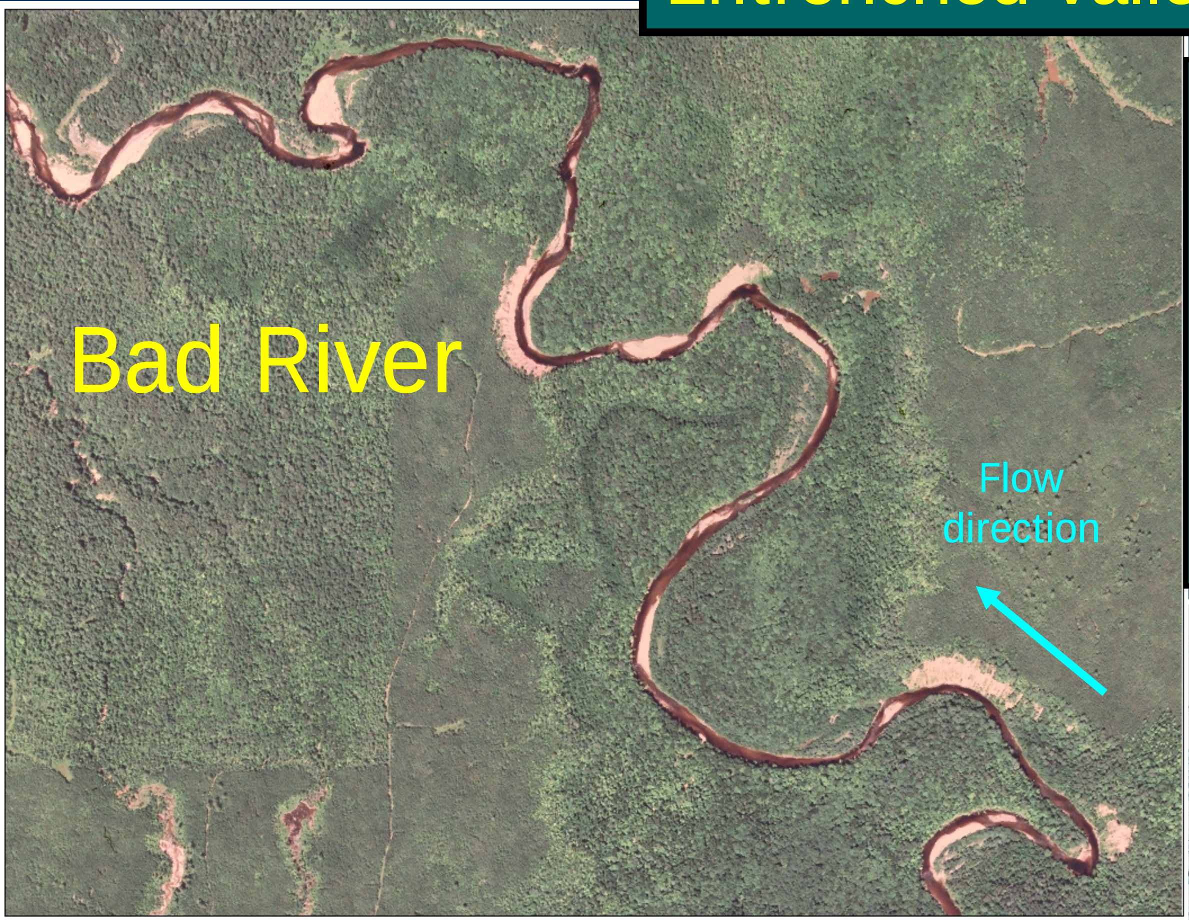
Bad River—upstream of the Penokee Range



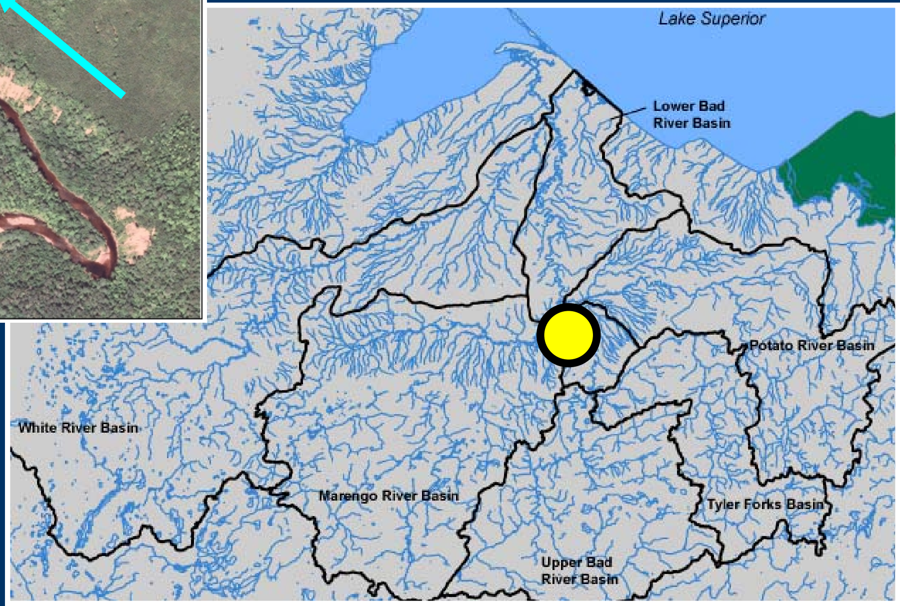
Copper Falls, Bad River



Entrenched valley – landslides common



Bad River



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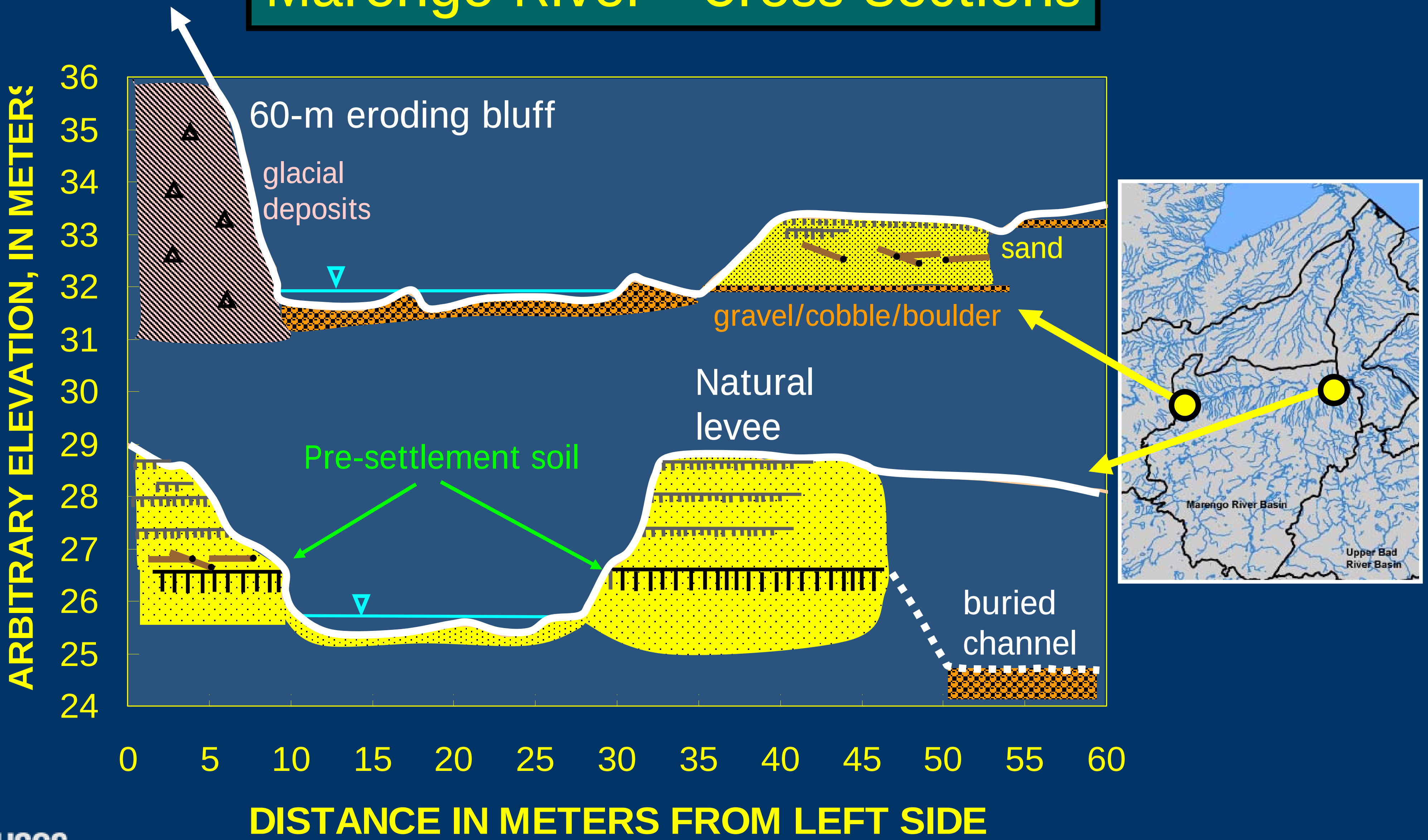
Marengo River—Cross Sections



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Marengo River—Levee building, May 2003 flood

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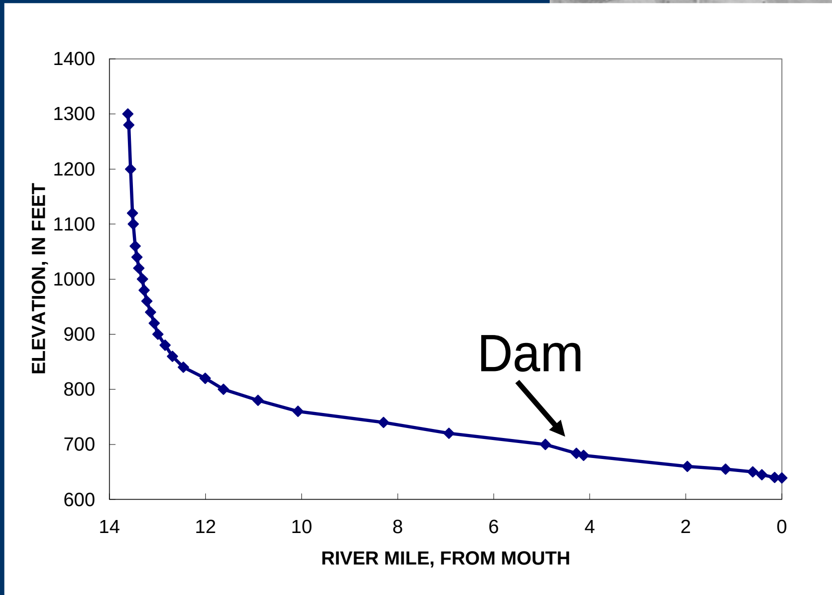
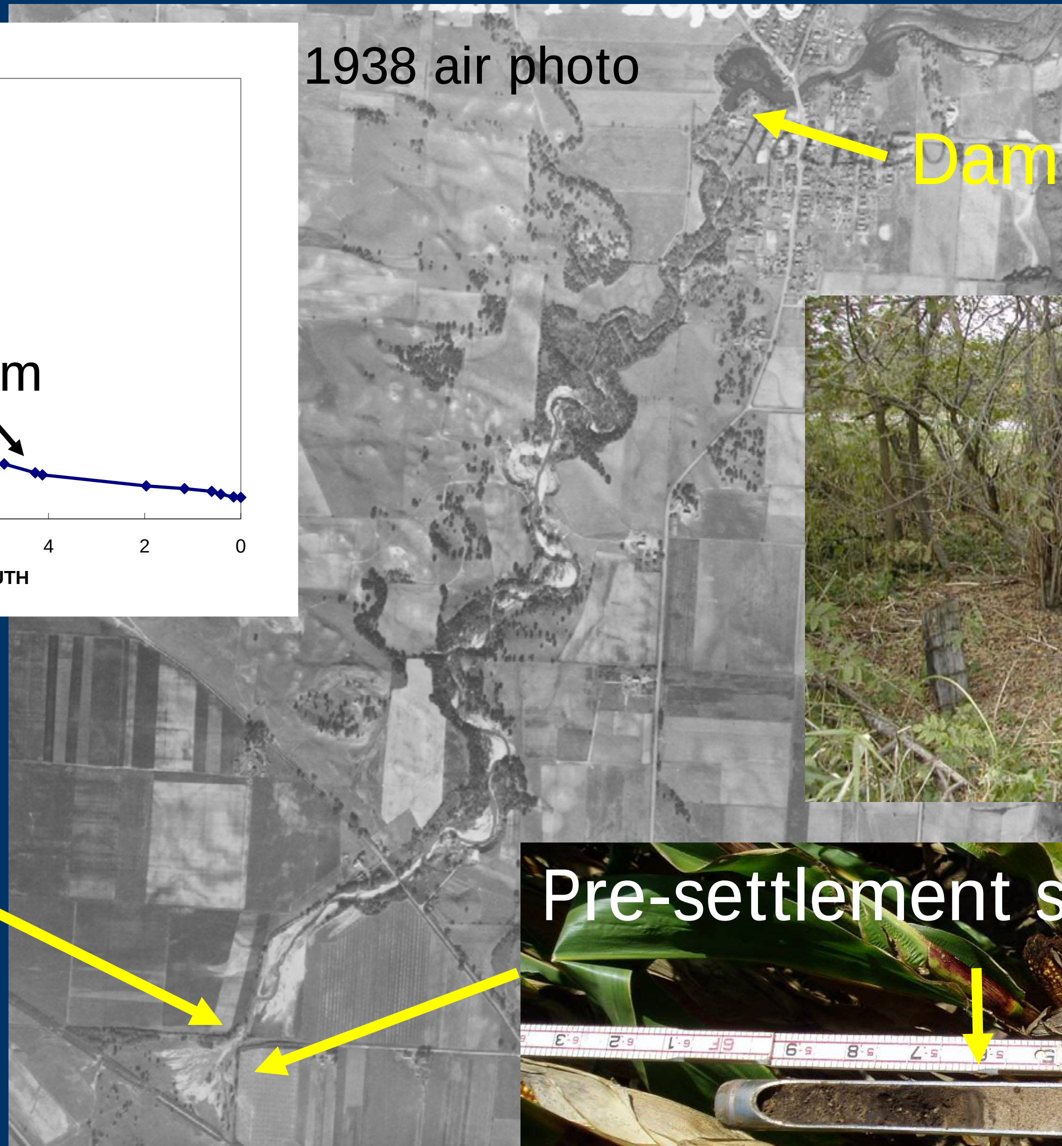
Halfway Creek, WI

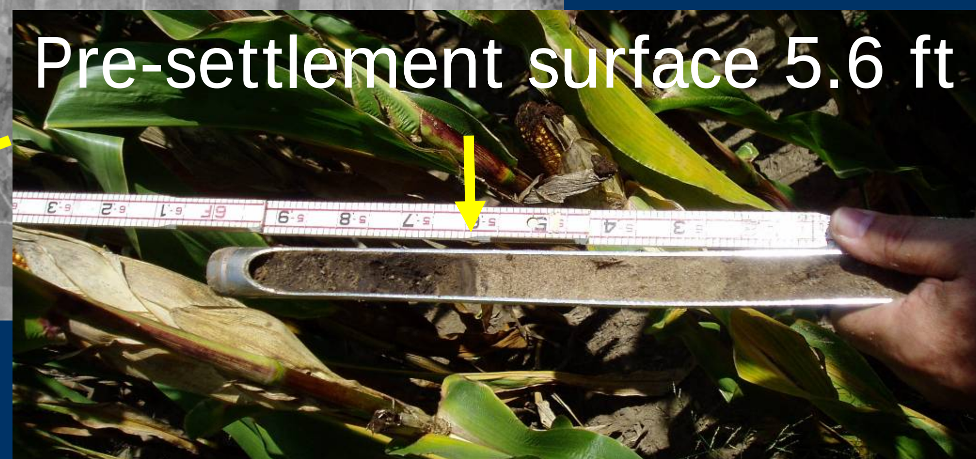


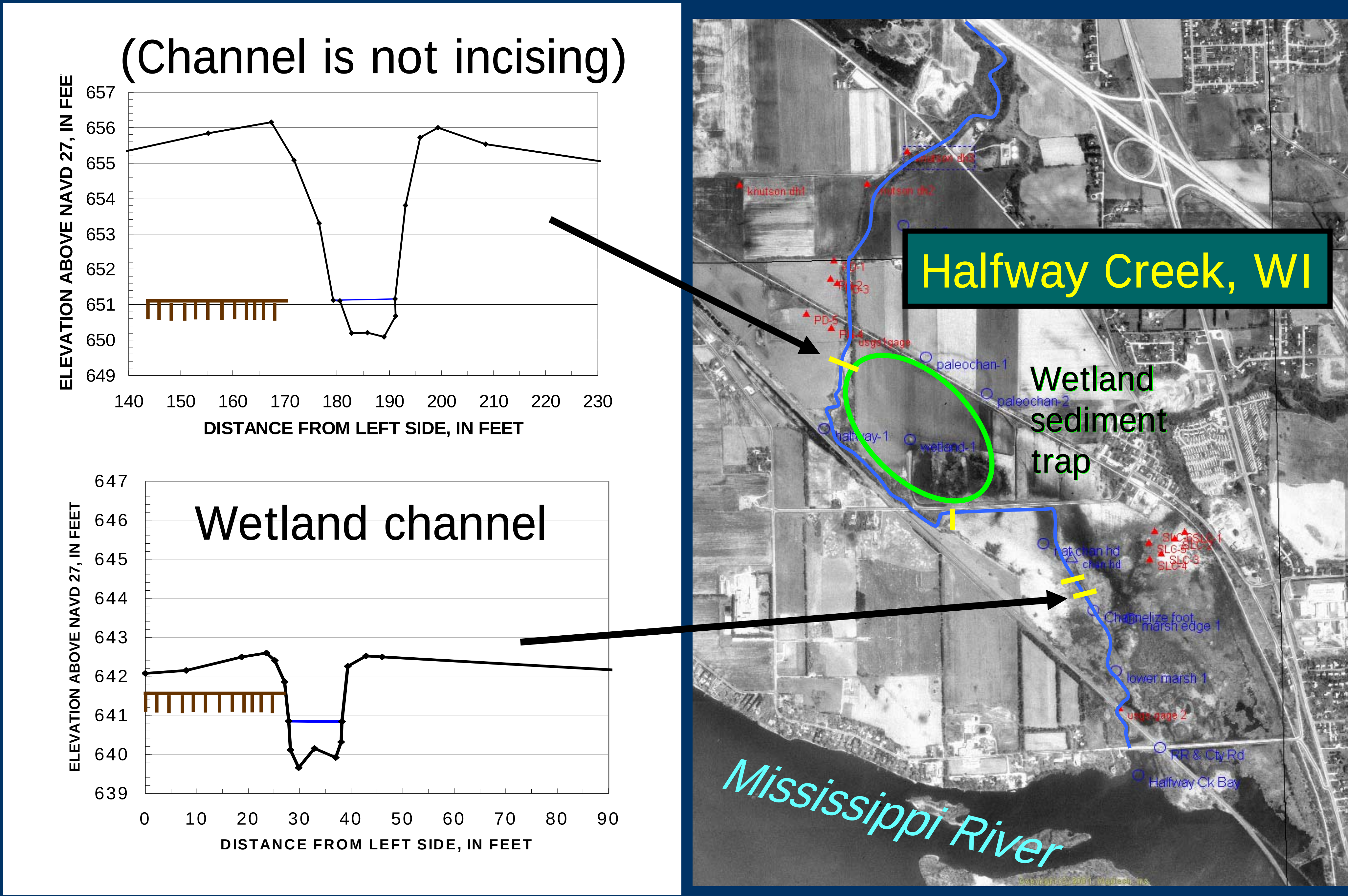


Dam 1850-1950

Levee break

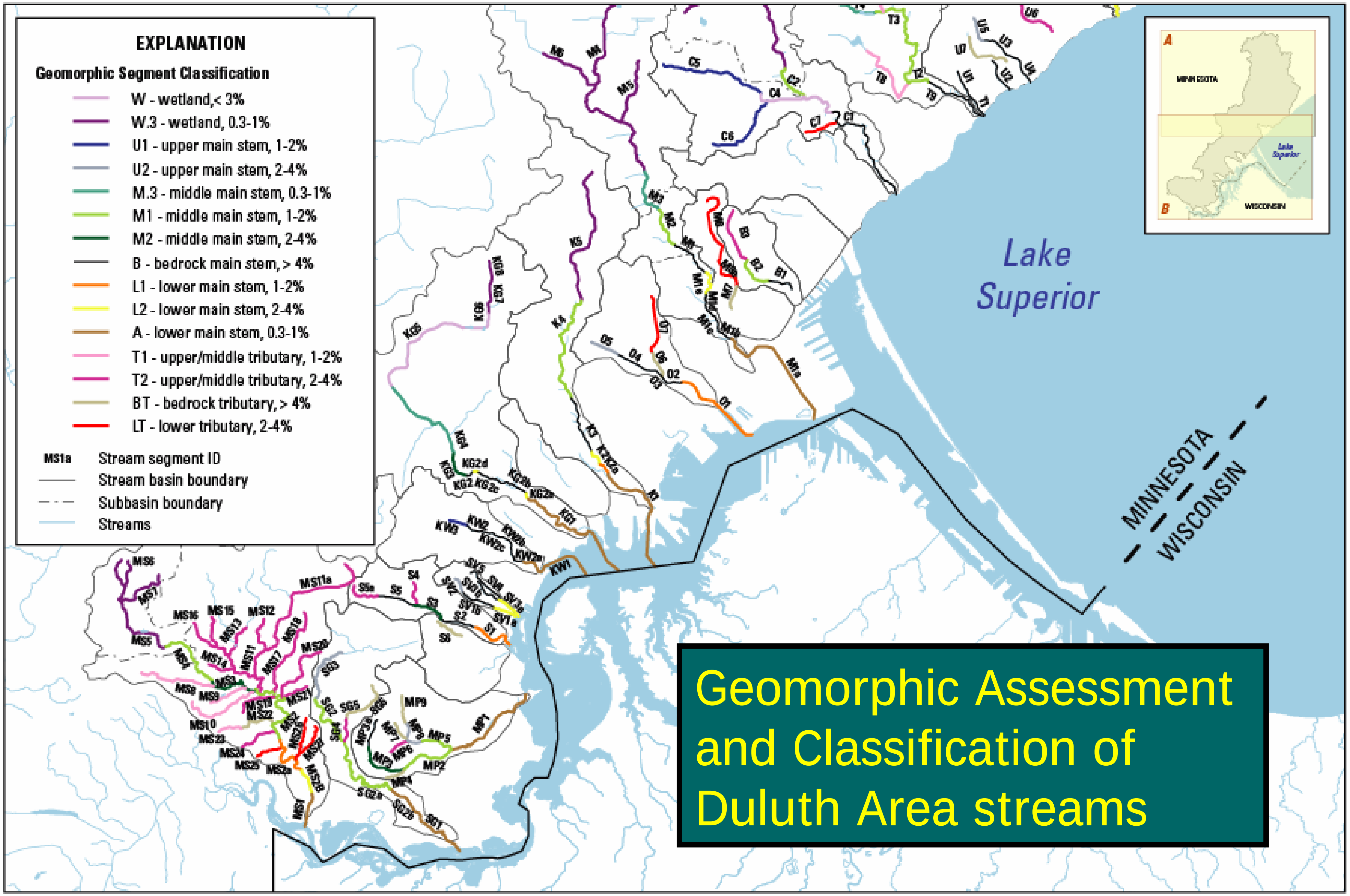
Photo by Jim Knox





(Channel is not incising)
ELEVATION ABOVE NAVD 27, IN FEE
657
656
655
654
653
652
651
650
649
140
150
160
170
180
190
200
210
220
230
DISTANCE FROM LEFT SIDE, IN FEET
Wetland channel
ELEVATION ABOVE NAVD 27, IN FEET
647
646
645
644
643
642
641
640
639
0
10
20
30
40
50
60
70
80
90
DISTANCE FROM LEFT SIDE, IN FEET
Halfway Creek, WI
Wetland sediment trap
knutson dh1
paleochan-1
paleochan-2
halfway-1
wetland-1
lower marsh 1
RR & Cty Rd
Halfway Ck Bay
Mississippi River

Geomorphic Assessment and Classification of Duluth Area streams



Base from Minnesota Department of Natural Resources hydrography and Wisconsin Department of Natural Resources hydrography: 1:24,000 digital data. Transverse Mercator Projection, NAD 83

Summary Thoughts

- For streams with historical land cover disturbance, post-settlement levee building and overbank sedimentation has been accelerated in valleys, resulting in entrenched-looking channels, loss of flood-plain storage, bank erosion, and downstream sedimentation and flooding problems.
- Zones of erosion, transport, and deposition are dependent on watershed and local geology, topography, drainage network position, historical geomorphic adjustments, and internal feedback.
- Overbank sedimentation is a underappreciated, widespread problem with long-term impacts on channel morphology, aquatic habitat, and riparian vegetation.
- Geomorphic assessments need to recognize internal adjustments and time lags associated with historical disturbance.

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How is this information used?

Photo by Bill Blust

Stream Restoration

- Identify main causes and processes for channel instability (external and internal)
- Guide where restoration efforts are concentrated
- Guide alternatives for restoration techniques

How is this information used?

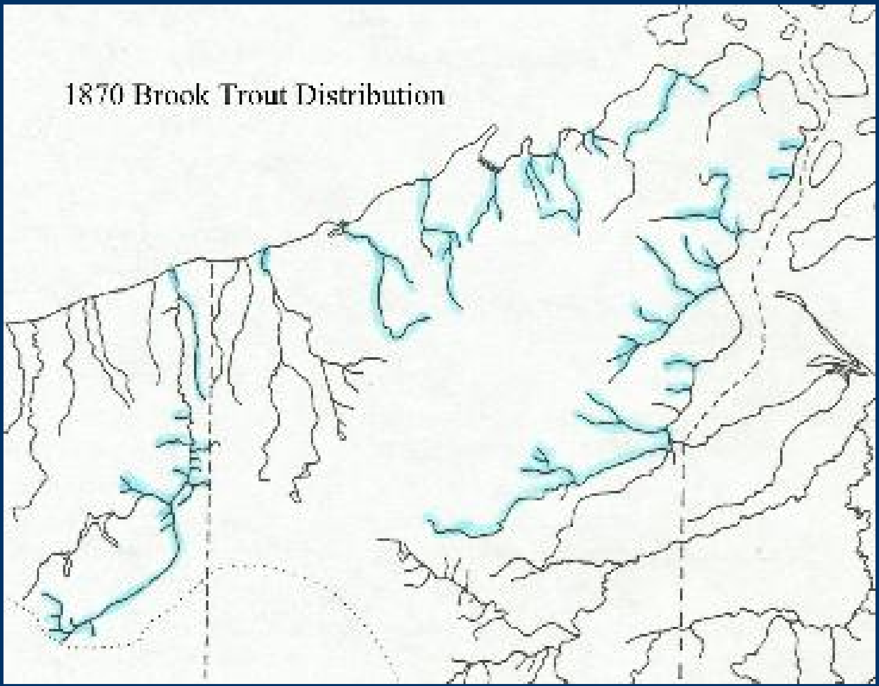

Photo and map by Dennis Pratt

Brook Trout Rehabilitation

Identify physical causes and processes for lack of habitat

Identify possible changes in current habitat conditions compared to presettlement conditions

Guide habitat improvement

USGS

How is this information used?

Sediment transport/water quality assessment

Provide framework for fitting intensive short-term water column studies into long-term conditions

Provide information on modern sources and sinks of sediment and related contaminants

Identify historical sources for sediment

Help guide sampling design and strategies

Help guide management plans

USGS

Photo by David Saad

Cooperative studies

Bad River Band of the Lake Superior Chippewa Tribe

Menominee Tribe

Wisconsin DNR

Ashland-Bayfield-Douglas-Iron Co. Land Conservation Dept.

U.S. Fish and Wildlife Service

U.S. Environmental Protection Agency

City of Duluth

USGS-BRD

University of Wisconsin-Madison

Trout Unlimited

The Nature Conservancy

Great Lakes Commission

Great Lakes Coastal Management