Understanding
Watershed Level Impacts to Streams

Northeast Landscape Planning Committee
Climate Change, Watershed, Fish & Wildlife Trends

Cloquet Forestry Center, May 17, 2012

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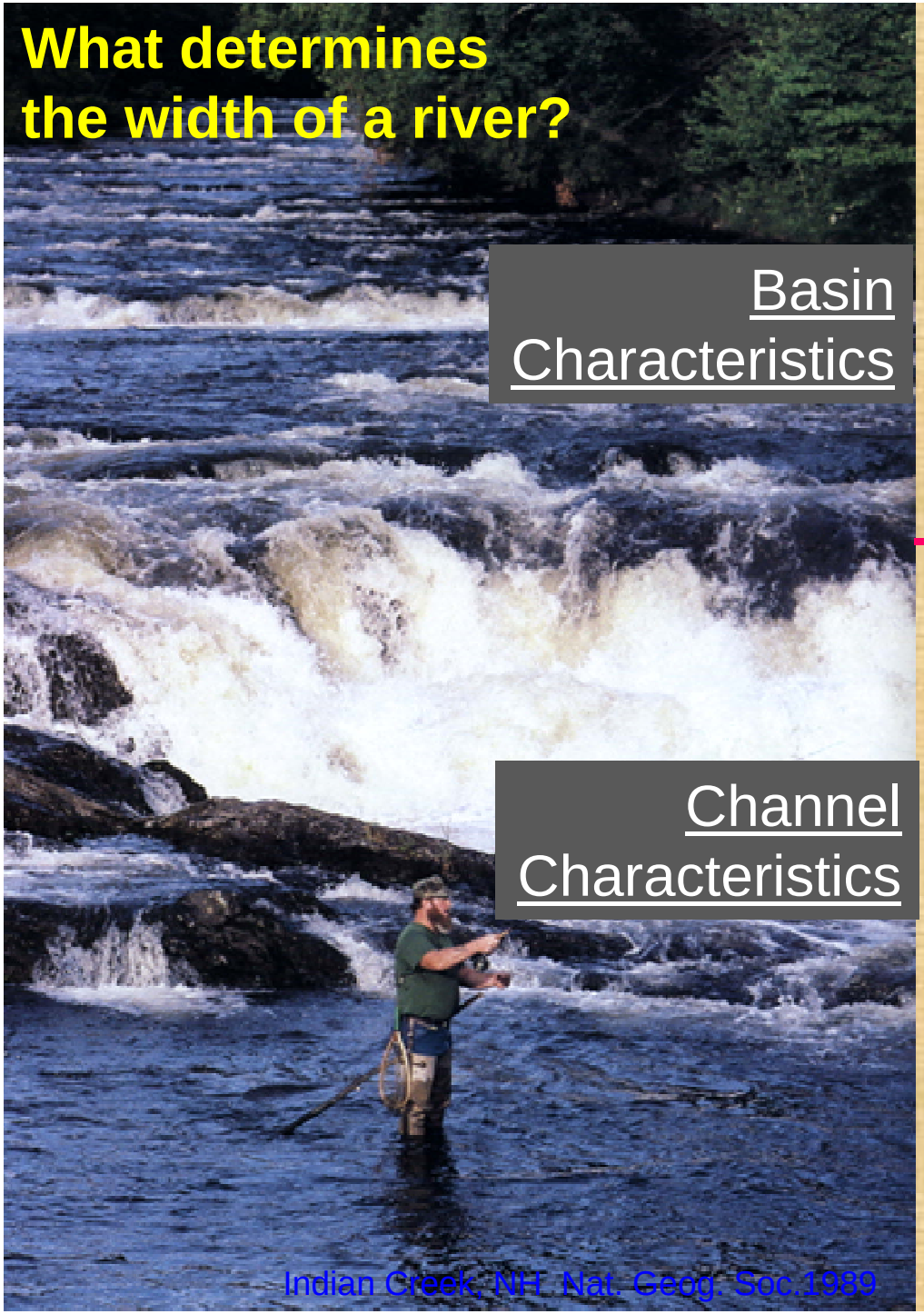
Hydrologist

Ellen River Partners

218 326 6120


Luther Aadland

What determines the width of a river?



Indian Creek, NH Nat. Geog. Soc.1989

Basin Characteristics

1

70%

Climate

Rainfall and Snowmelt Occurrence reflected in the ANNUAL Water Cycle

Watershed Area

Watershed Slope

Sediment Supply

Channel Characteristics

2

30%

Valley Width & Shape

Channel Slope

Sediment Type

Clay, Silt, Sand, Gravel, Cobble, Boulder, Bedrock

Bank Vegetation

3

50%

Land Use

Channel Obstacles

Trees, Dams, Culverts, Roads

How to Read the River & the Land

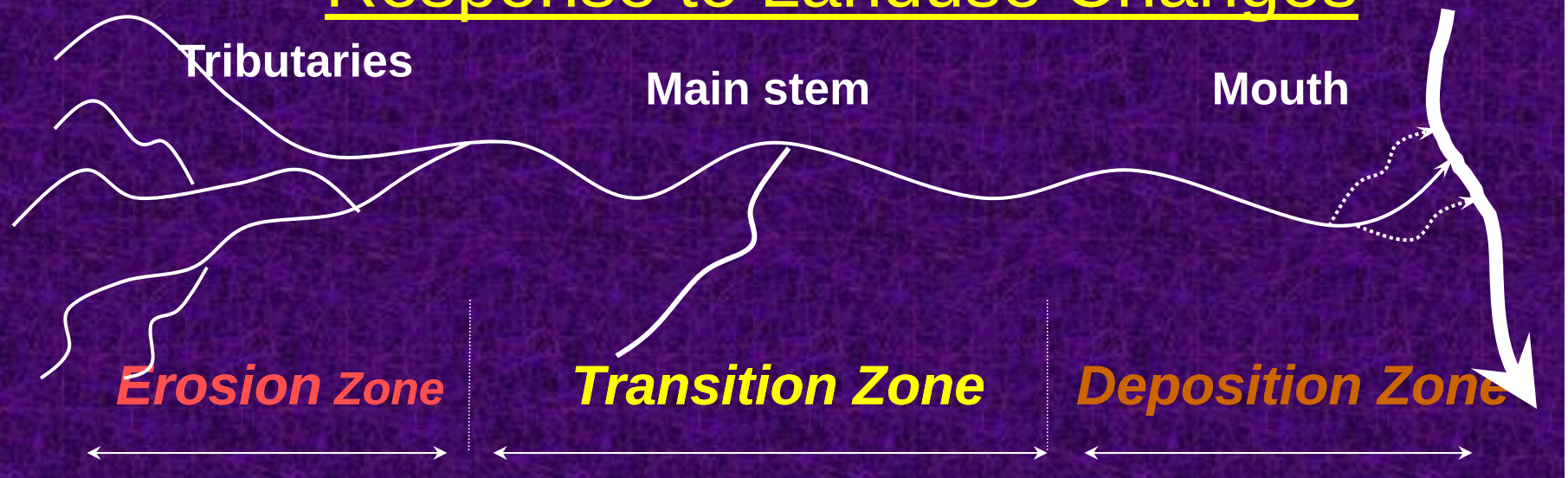
- Water that just fills the channel and begins to overflow on its floodplain is the Bankfull Flow

- At Bankfull flow, water velocity is high enough to move sediment in the channel bottom, yet low enough to allow fish migration during spawning.

- Land Use Change changes the magnitude of bankfull flow
- Mechanisms that allow LU Change to Impact Streams
- How Much LU Change on What Size Basin

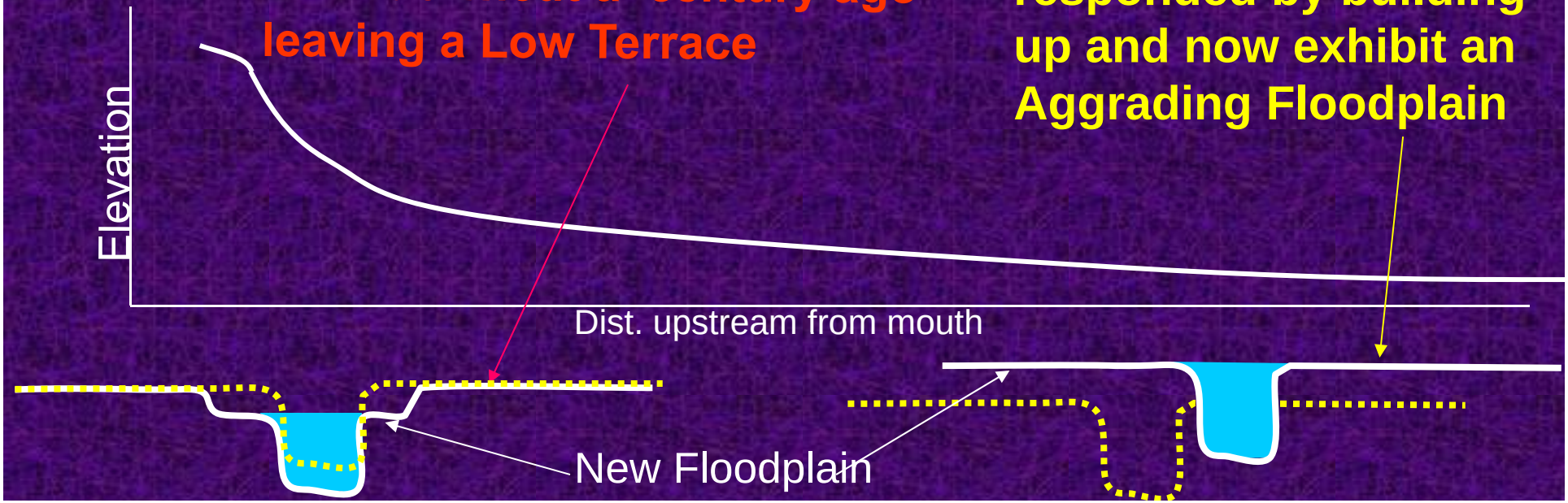
- What are our choices in Ag and Forested Watersheds

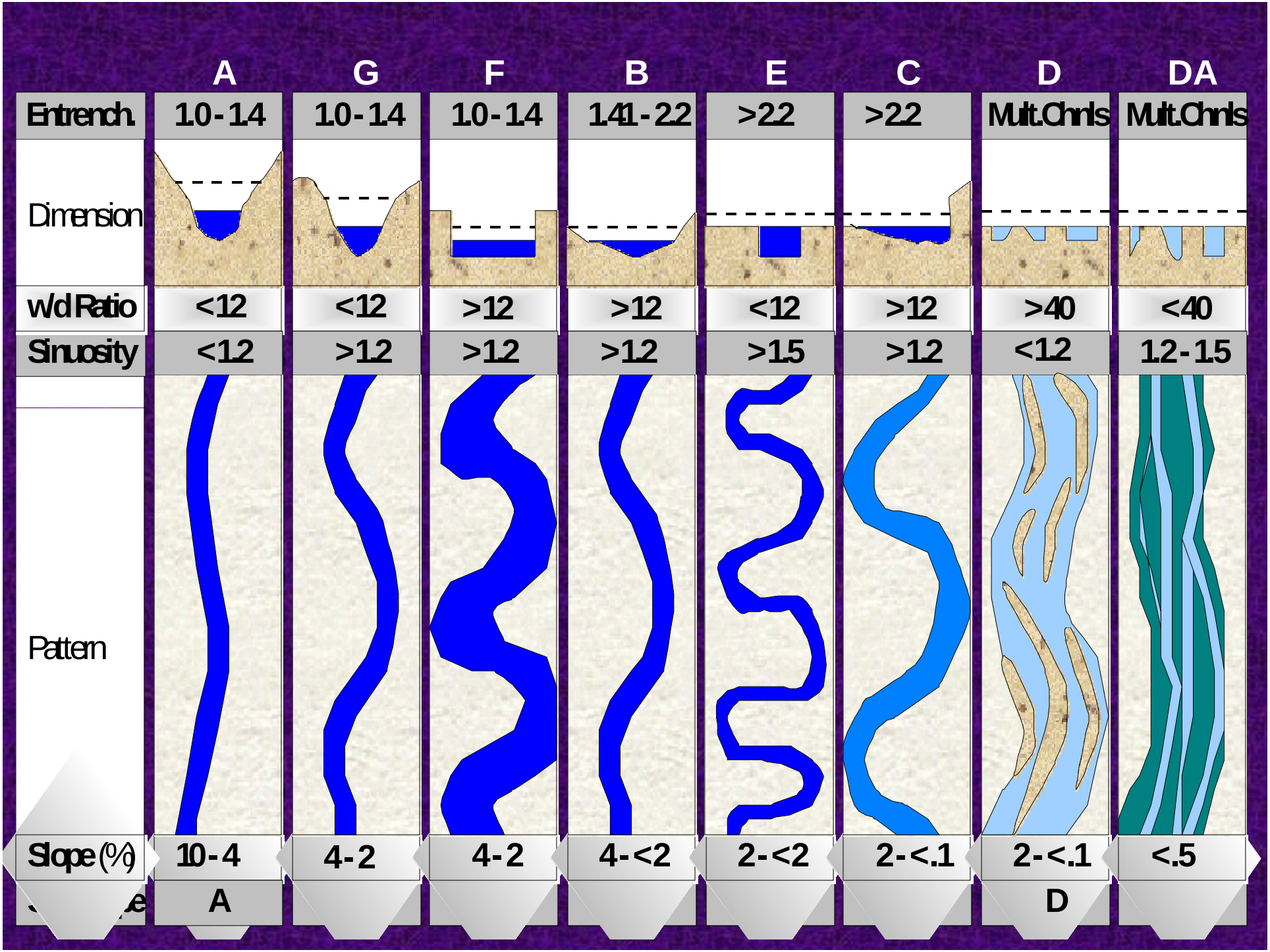
Response to Landuse Changes



High Gradient reaches may have downcut a century ago leaving a Low Terrace

Low Gradient reaches responded by building up and now exhibit an Aggrading Floodplain




A
G
F
B
E
C
D
DA
Entrench.
1.0 - 1.4
1.0 - 1.4
1.0 - 1.4
1.41 - 2.2
>2.2
>2.2
Mult.Chnls
Mult.Chnls
Dimension
w/d Ratio
<12
<12
>12
>12
<12
>12
>40
<40
Sinuosity
<1.2
>1.2
>1.2
>1.2
>1.5
>1.2
<1.2
1.2 - 1.5
Pattern
Slope (%)
10 - 4
4 - 2
4 - 2
4 - <2
2 - <2
2 - <.1
2 - <.1
<.5
A
D

Stream Stability

- The ability of a stream to maintain, over time, its Dimension, Pattern, and Profile
- So it neither aggrades nor degrades
- And is able to transport, without adverse effect, the flows and detritus of its watershed

Physical Cause May Include:

- Lowering of a larger order channel
- Cutting off meander bends to align culverts
- Straightening channels to pass floods quicker
- Blocking or using too much of the floodplain
  - Deep road fills with too small culverts
  - Broad road bases paralleling the stream
- Excessive removal of large woody debris
- Changes in land use

Unstable Streams Don't Like Their Type

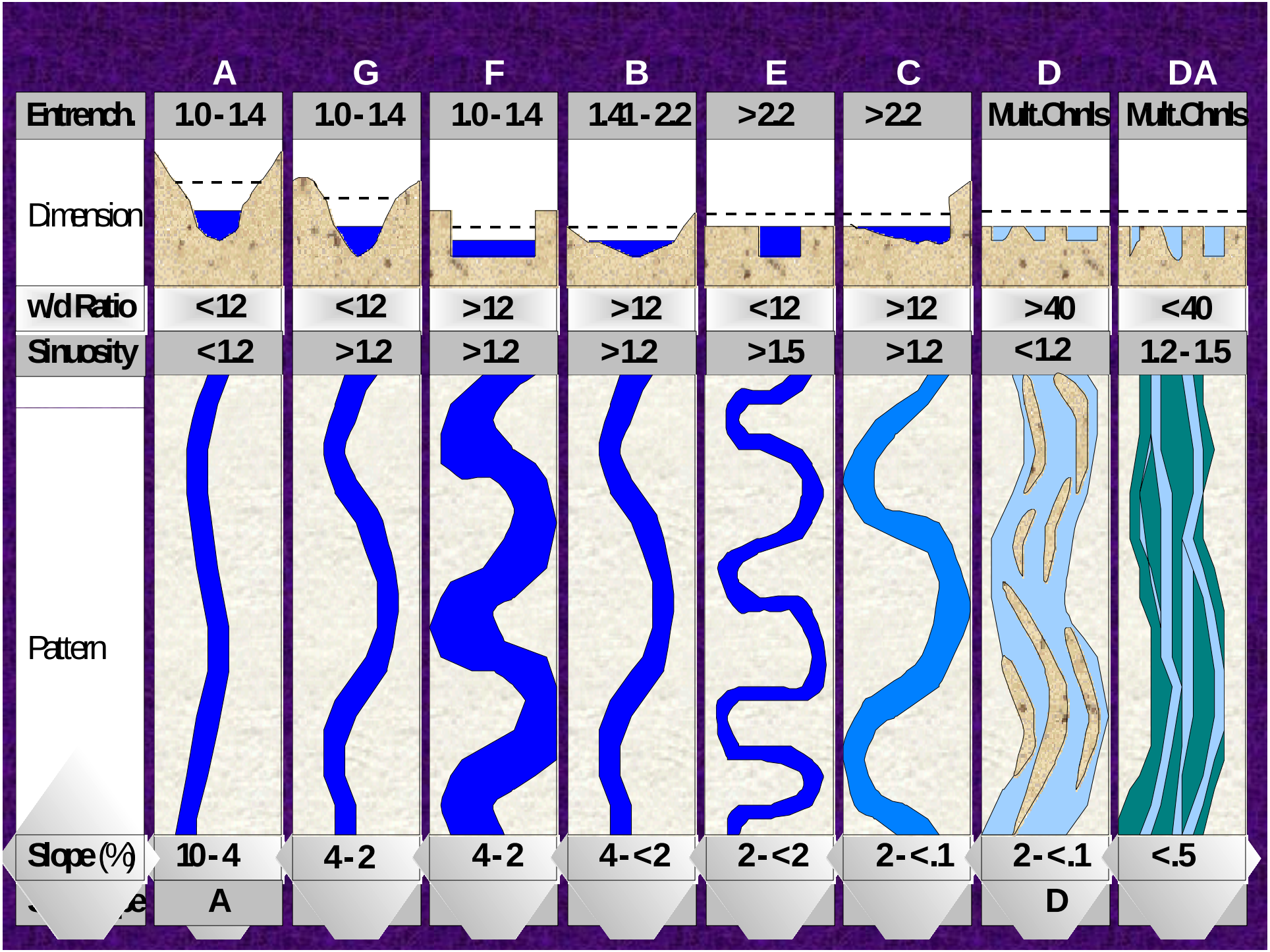
Unstable streams deviate from the mode of their class
They are in the process of changing from one type to another

Modal Stream Dimension Values for Stable Streams in the Eastern US

Stream Type	A	G	F	B	E	C	D	DA
W/D	7	7	20	20	8	24	50	40
Sinuosity	1.1	~1.5	1.5	~1.2	2.0	1.3	1.1	~1.2

Based on Annable 1995, Rosgen 1996, Stevens-Savory et al., 1998

Look for unstable streams when W/D > +25% (C&E) or Sinuosity < -33% (F&E)


A
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F
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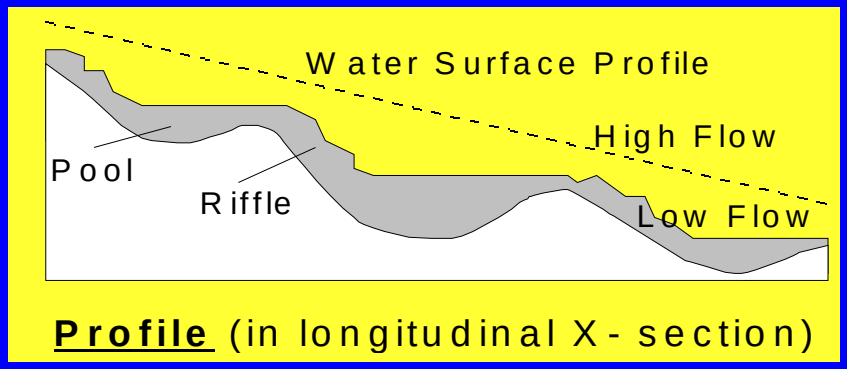
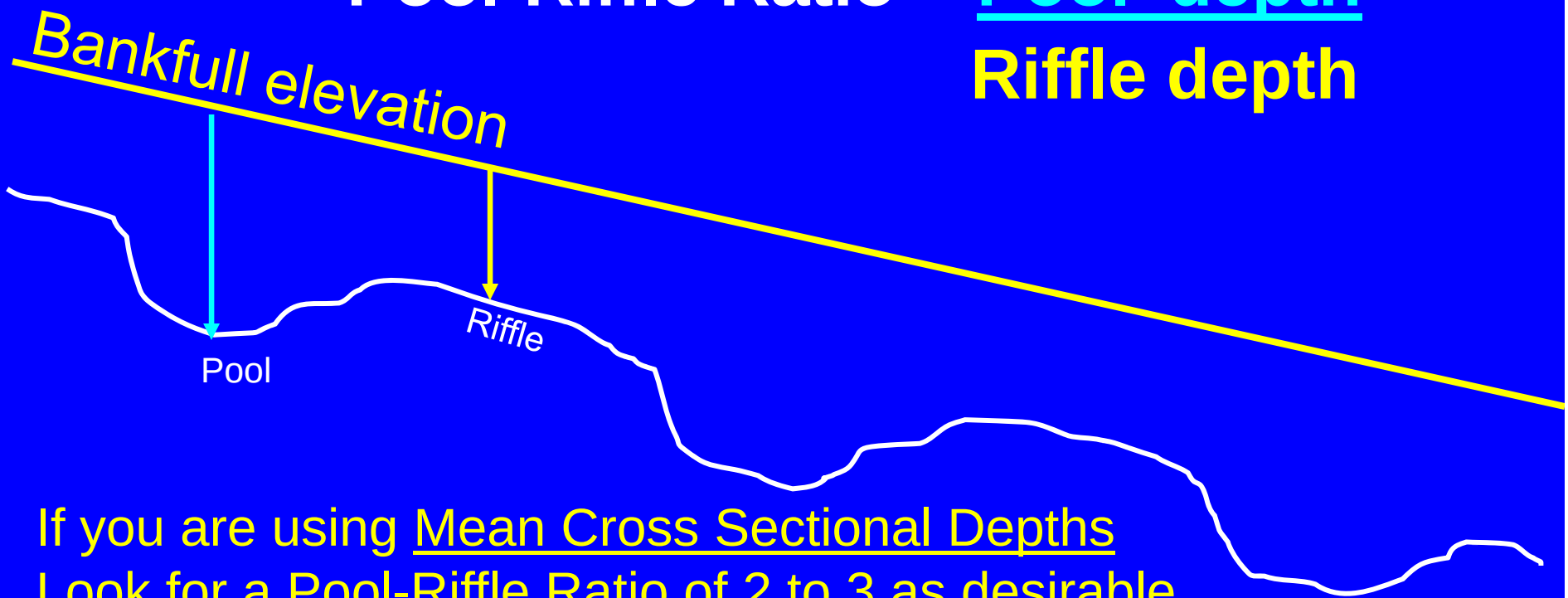
<.5
A
D



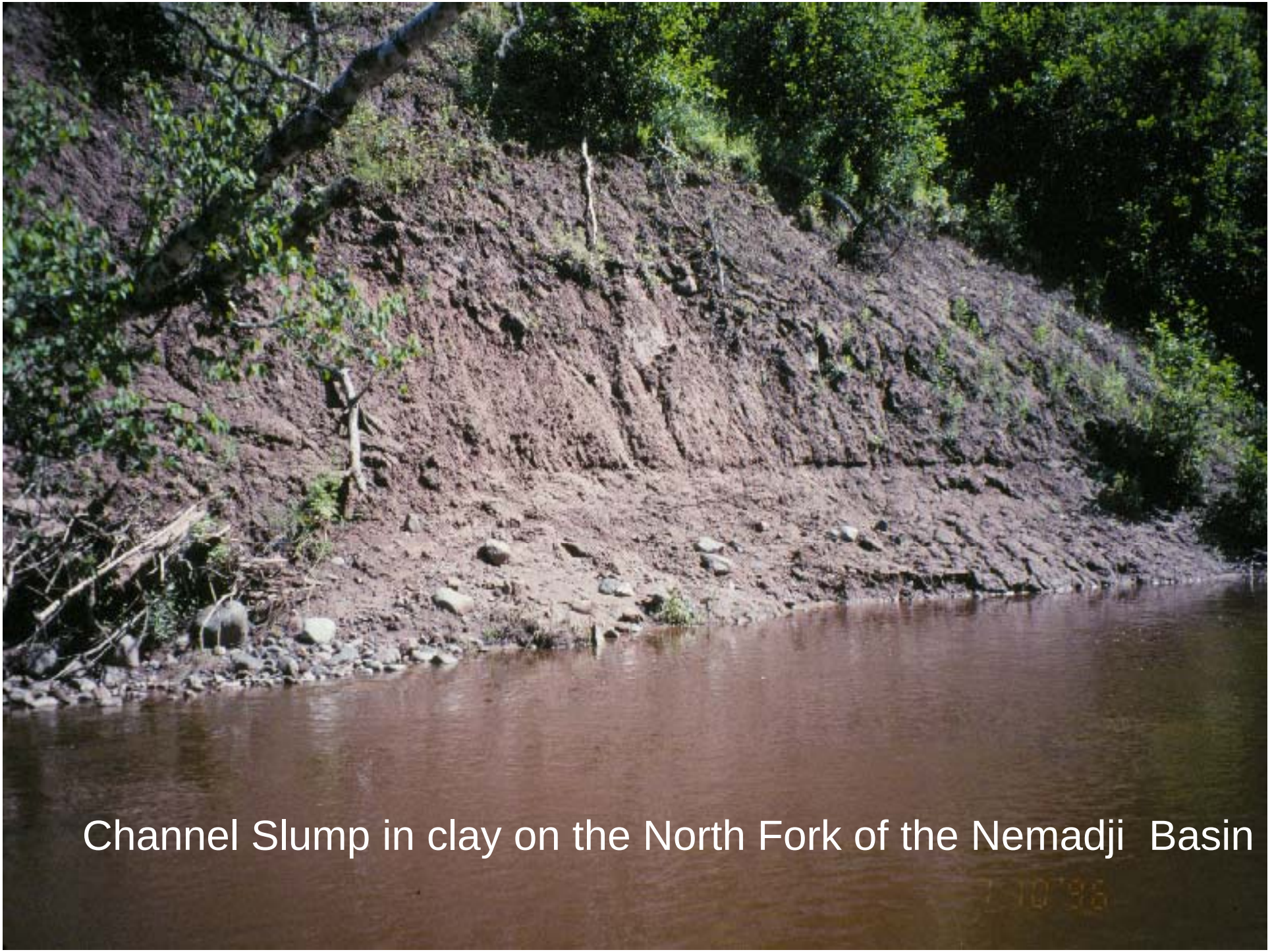
Profile (in longitudinal X-section)

Better habitat has a
Pool-Riffle Ratio
Based on Maximum Depths
of more than 1.4, 2.0 is better

Pool-Riffle Ratio = Pool depth / Riffle depth

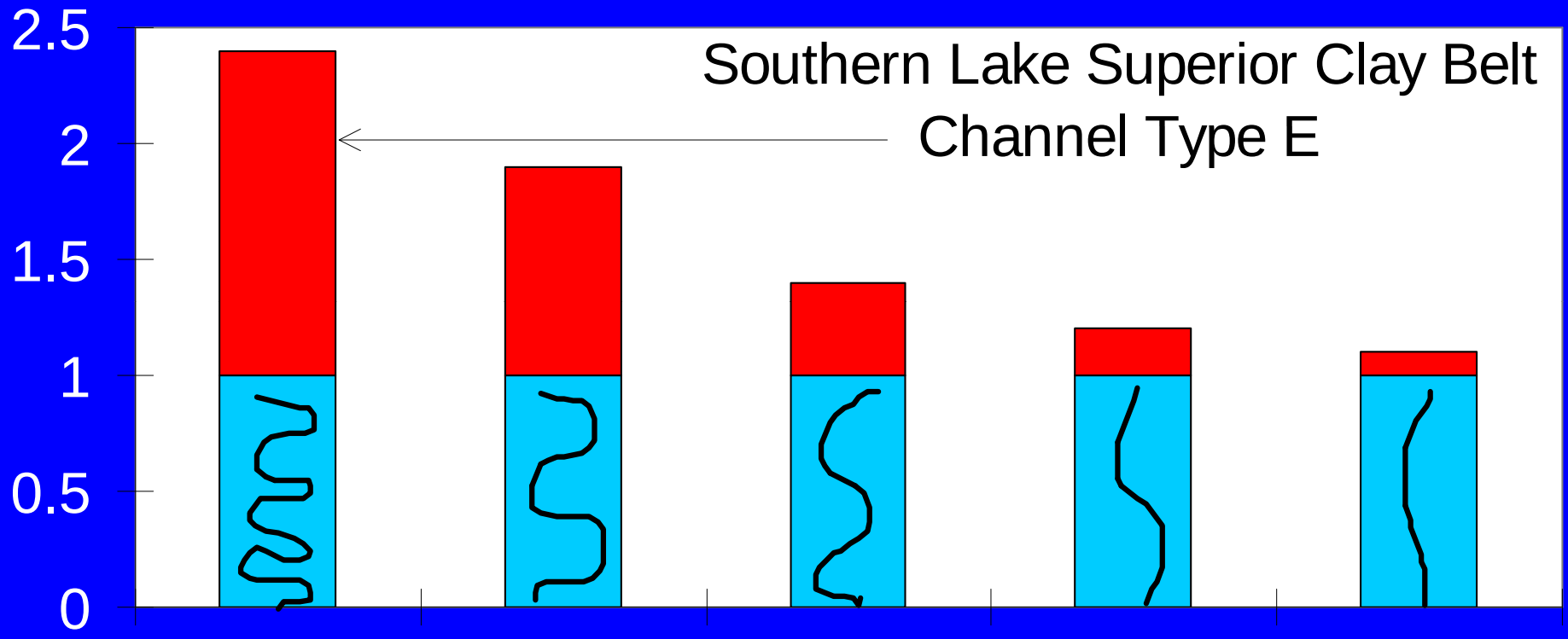


If you are using Mean Cross Sectional Depths
Look for a Pool-Riffle Ratio of 2 to 3 as desirable

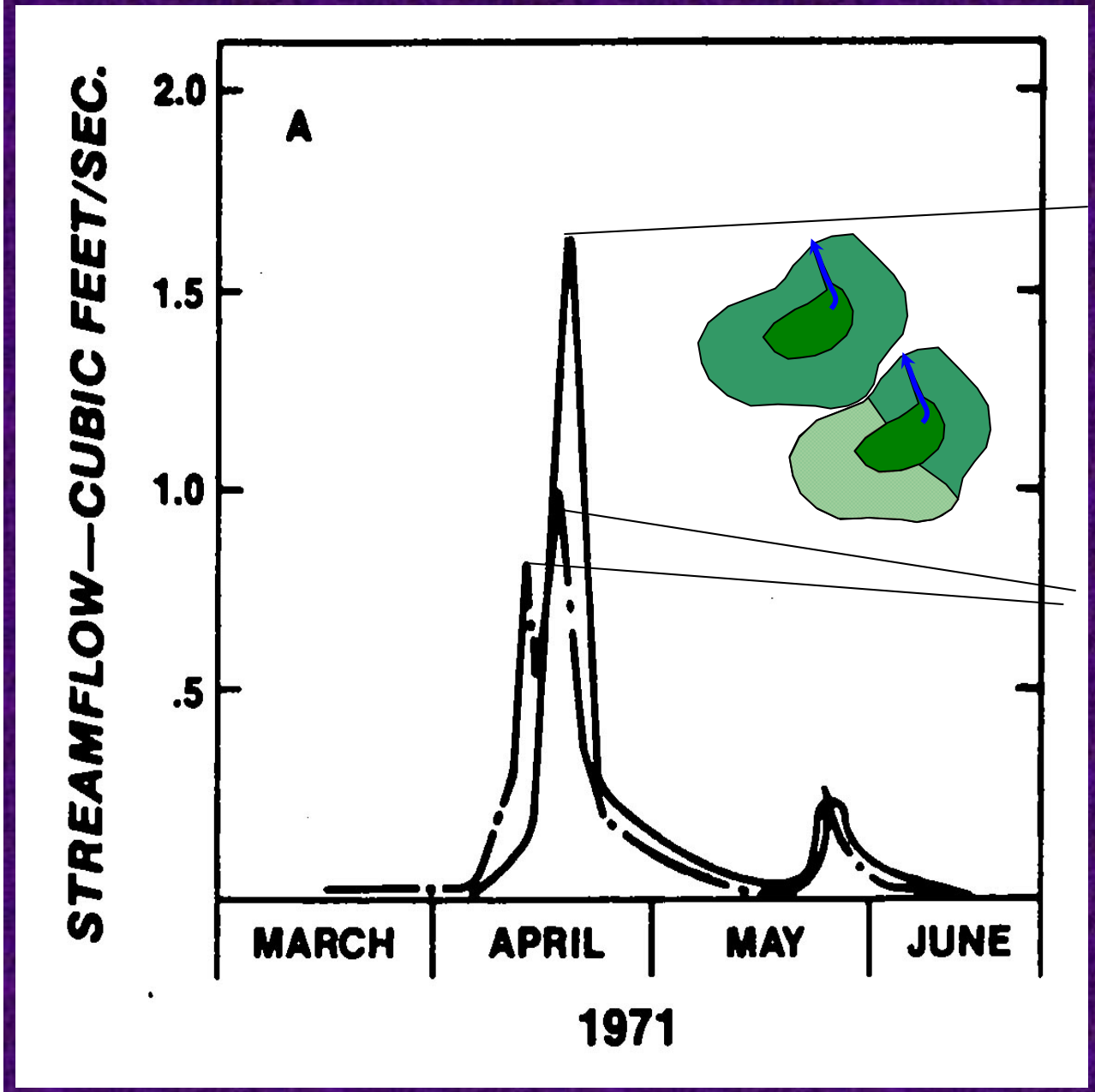


Channel Slump in clay on the North Fork of the Nemadji Basin

Loss of Stream Channel Sinuosity



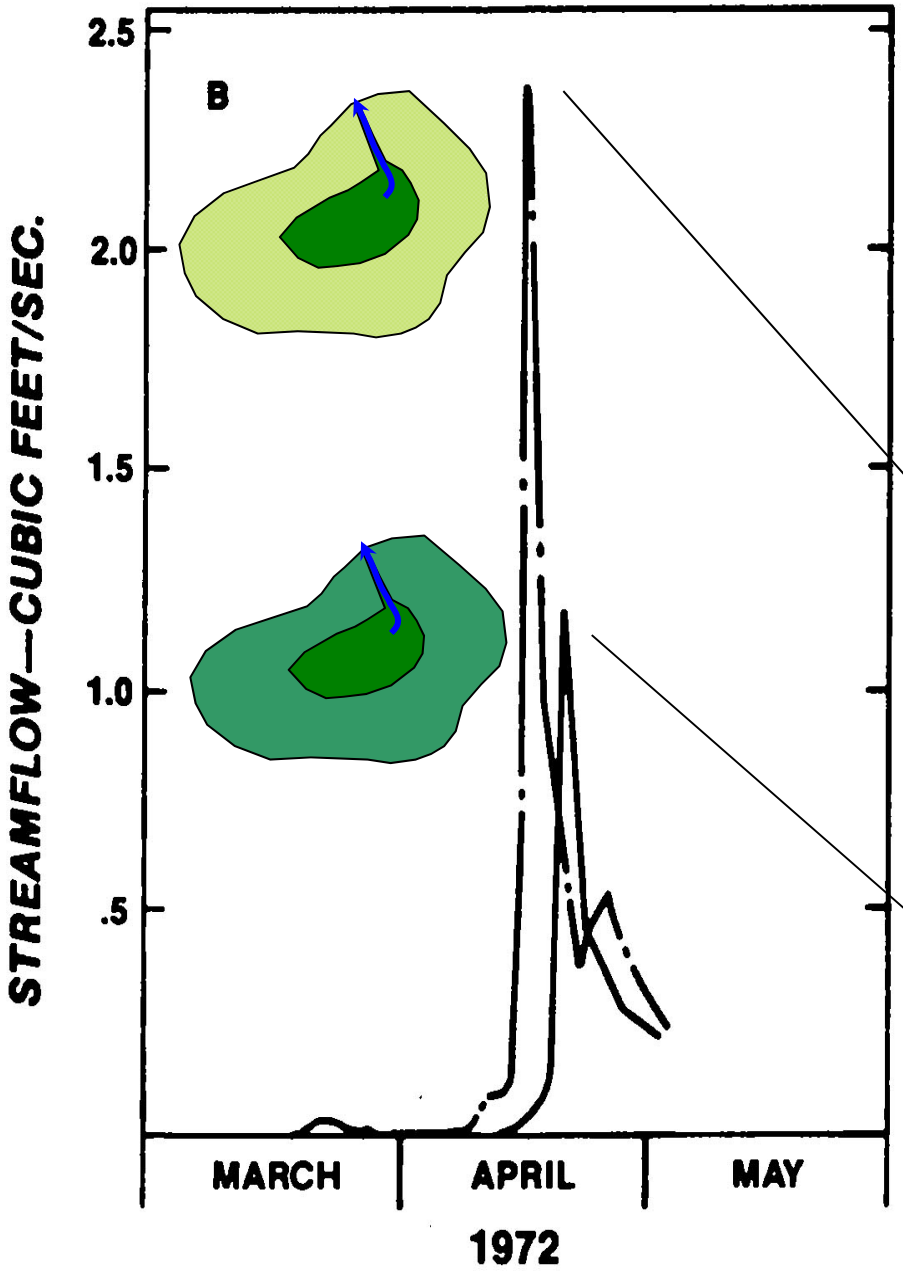
Cumulative impacts on the amount of stream habitat



Mature forest hydrograph

With 50% of the upland aspen forest clearcut, snowmelt peaks become de-synchronized yielding two smaller peak flows

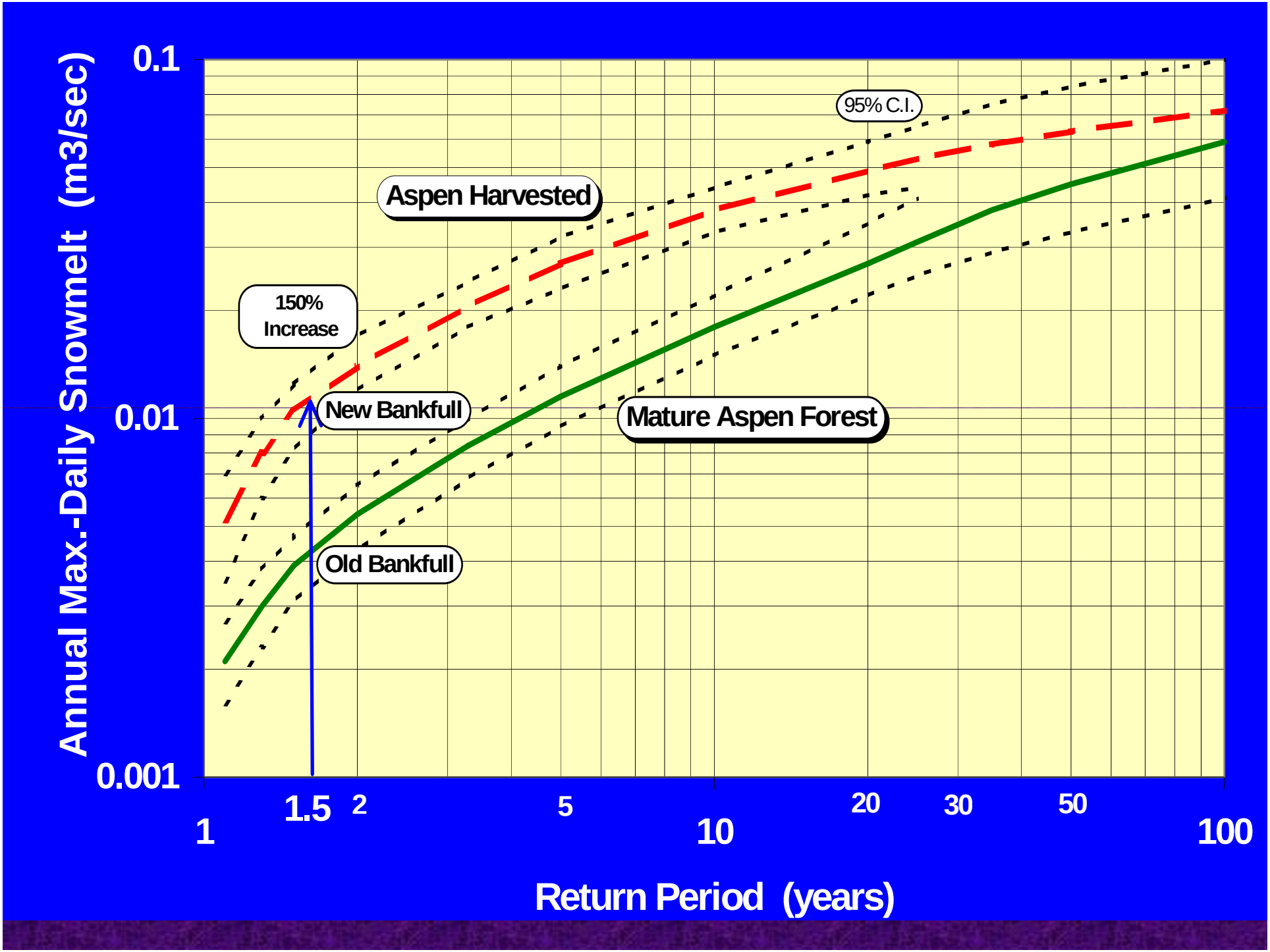
Marcell Experimental Forest, northern Minnesota, watershed no. 4

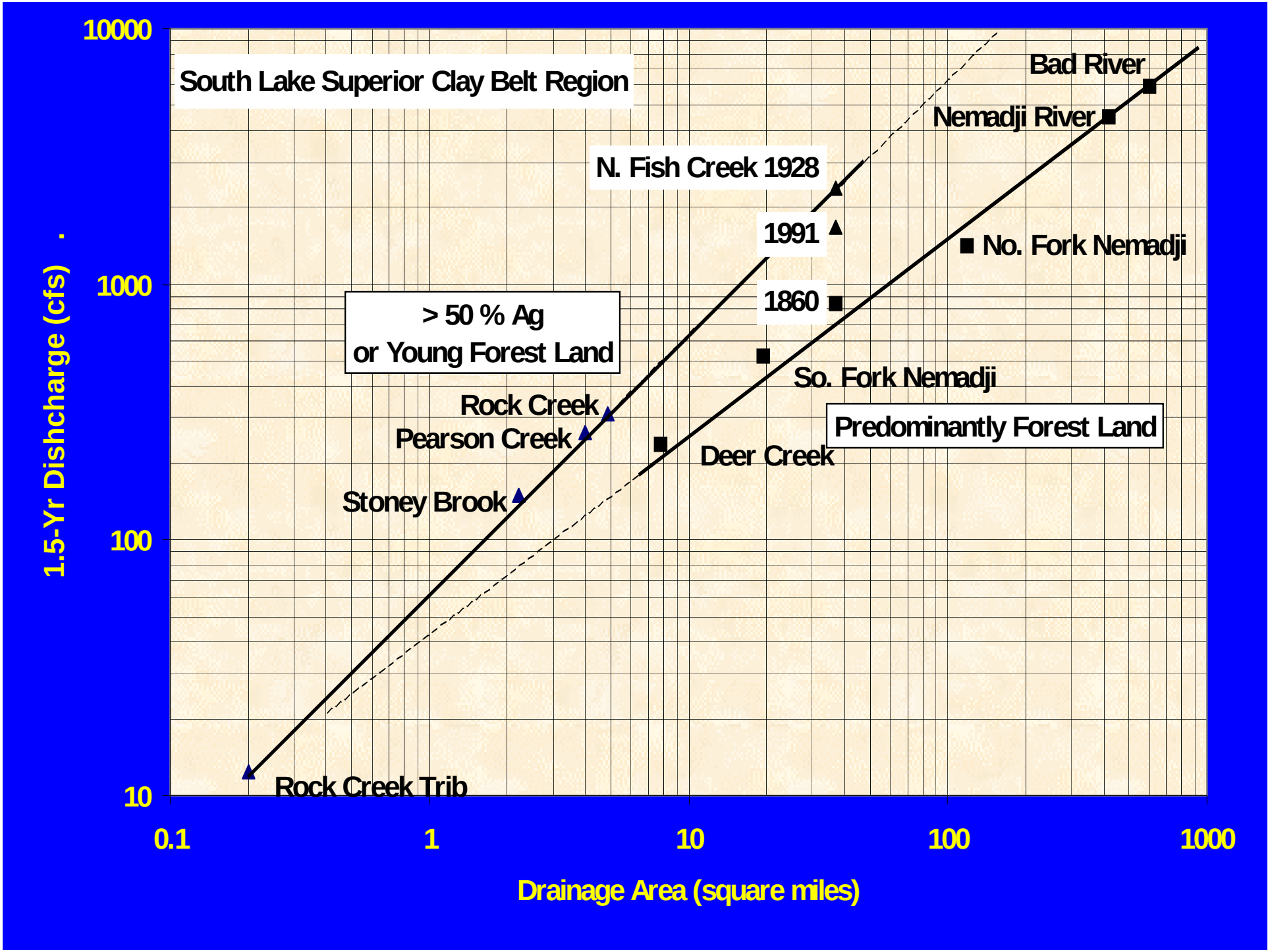


With all of the aspen upland clearcut, snowmelt peakflow is synchronized, occurring 4 days earlier than mature forest conditions, and at twice the peakflow rate.

Mature forest hydrograph

Marcell Experimental Forest, northern Minnesota, watershed no. 4


Annual Max.-Daily Snowmelt (m3/sec)
0.1
0.01
0.001
95% C.I.
Aspen Harvested
150% Increase
New Bankfull
Mature Aspen Forest
Old Bankfull
1
1.5
2
5
10
20
30
50
100
Return Period (years)


South Lake Superior Clay Belt Region
Bad River
Nemadji River
N. Fish Creek 1928
1991
No. Fork Nemadji
1860
> 50 % Ag
or Young Forest Land
So. Fork Nemadji
Rock Creek
Pearson Creek
Predominantly Forest Land
Deer Creek
Stoney Brook
Rock Creek Trib
10000
1000
100
10
0.1
1
10
100
1000
1.5-Yr Dishcharge (cfs)
Drainage Area (square miles)

Channel adjustments may occur in one storm, or they may take ½ to several centuries

In the North Fish Creek Basin near Ashland, Wisconsin

A headcut on the Nemaji River tributary

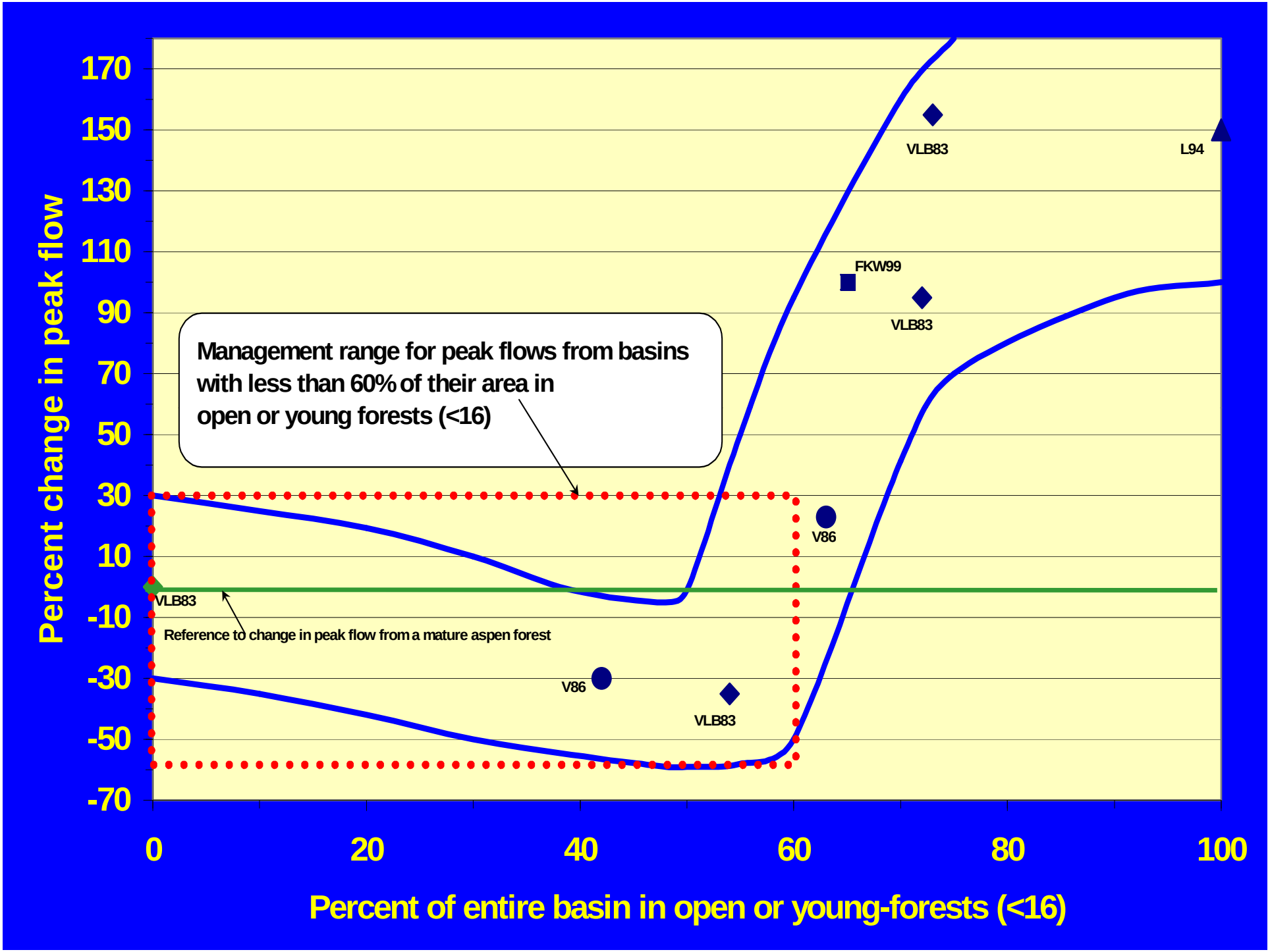
"The amount of channel sedimentation caused by land-cover changes over 125 years since European settlement is about equal to that caused mainly by an increase in base level change over 4,000 years before European settlement."
Fitzpatrick, Knox and Whitman, 1999

How much landuse change does it take to cause these changes ?

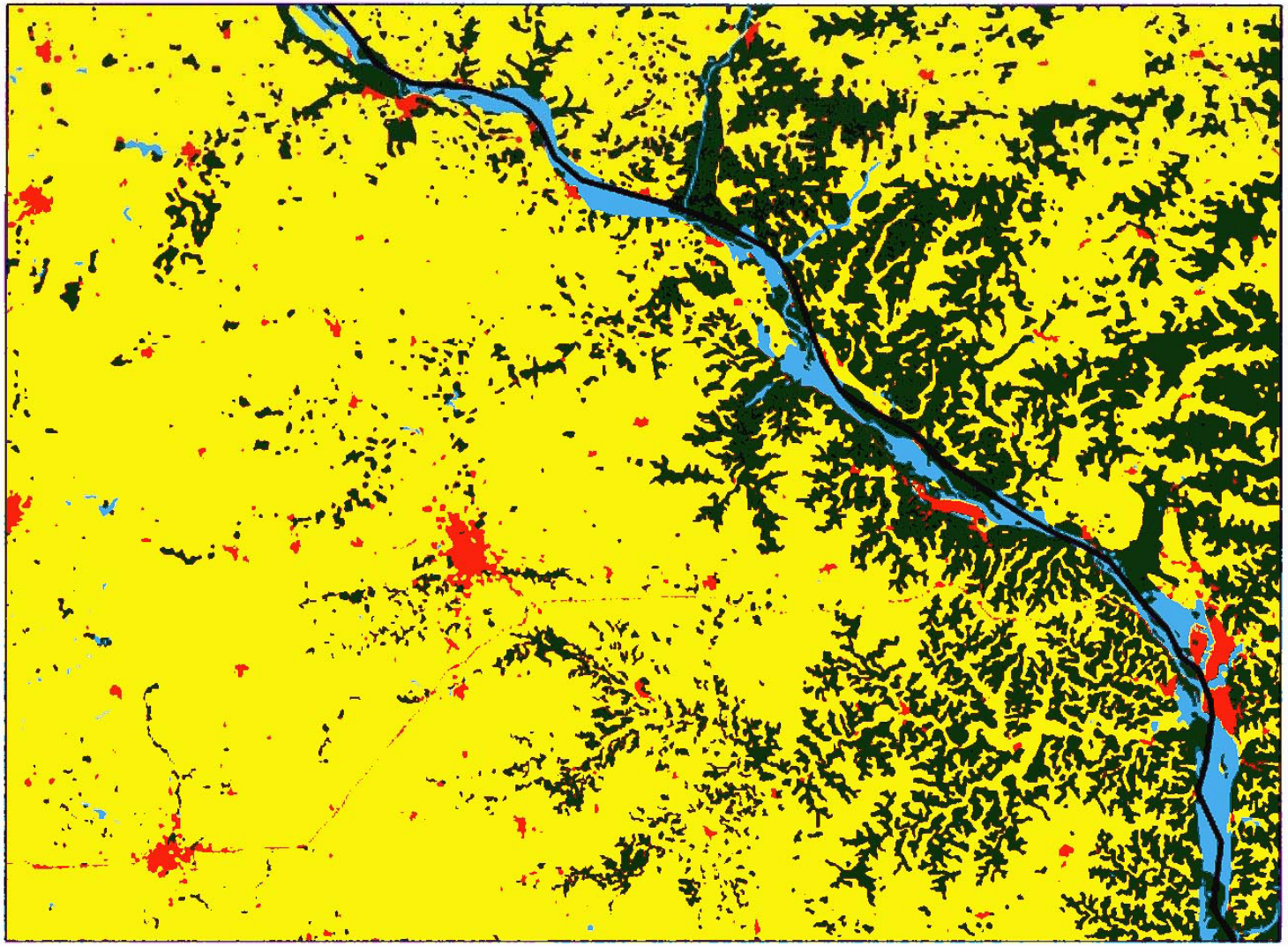
- Using a basin with all 15-year to 150-year aged forests as the normal condition
- Converting ½ the basin to agriculture would actually reduce bankfull flows about 20%
- Converting 2/3 of the basin to agriculture would double or triple bankfull flows
- Combinations of open land and young forest land (< 15 years old) does the same thing

How does this land use change work?

- The change is caused by more rapid snowmelt or by more rapid delivery of rain
- Either permanent conversion to open areas (agriculture, towns, roads, power lines, etc.) or high rates of forest harvest (more than 1 ½% per year)
- Will cause the bankfull flows that shape channels to double (or triple)


Percent change in peak flow
170
150
130
110
90
70
50
30
10
-10
-30
-50
-70
0
20
40
60
80
100
Percent of entire basin in open or young-forests (<16)
Management range for peak flows from basins with less than 60% of their area in open or young forests (<16)
VLB83
Reference to change in peak flow from a mature aspen forest
VLB83
L94
FKW99
VLB83
V86
V86
VLB83

Land Fragmentation in Southeast MN & Southwest WI



Land Cover

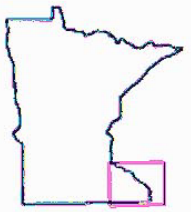
Forested

Agricultural

Urban/Barren

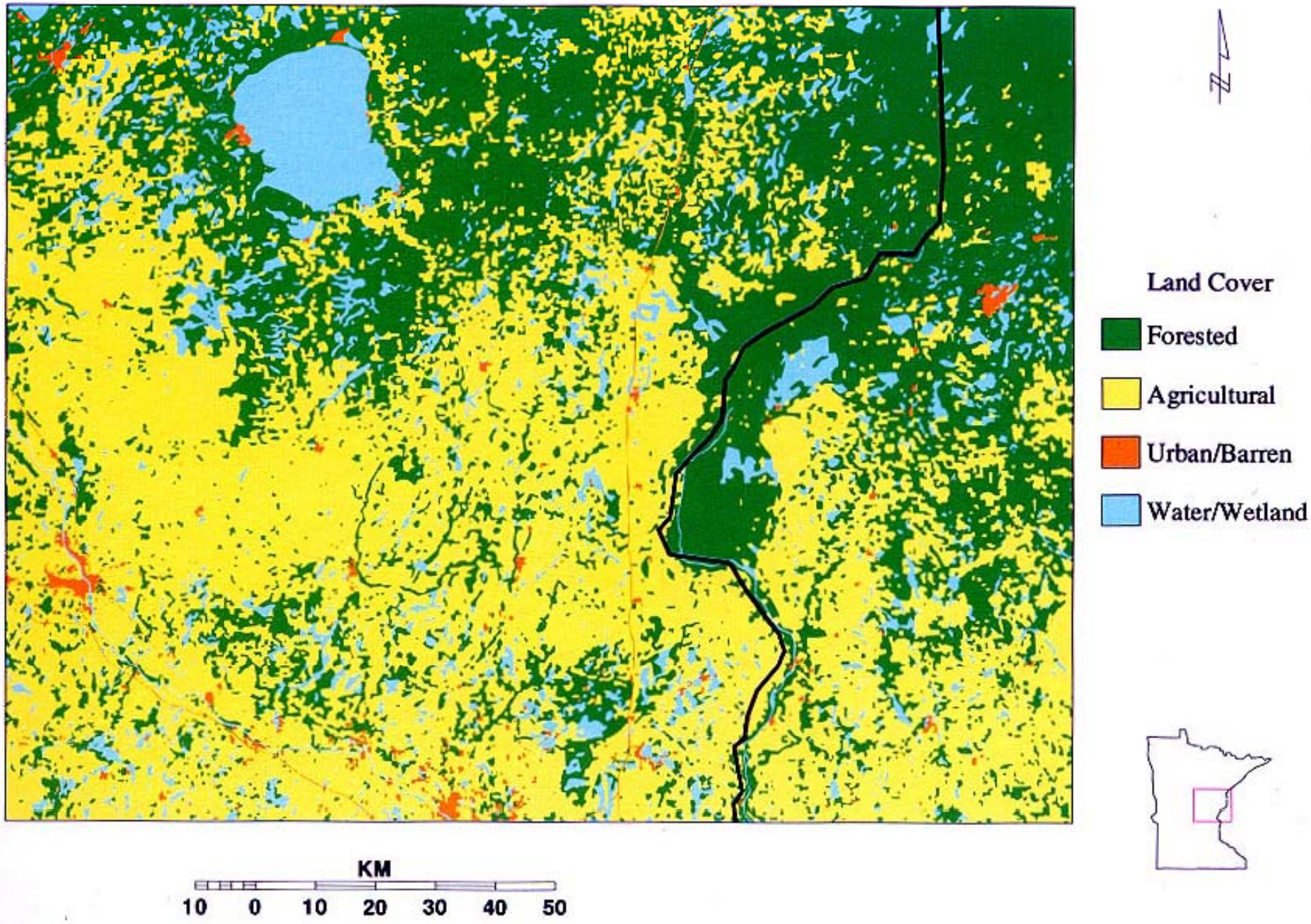
Water/Wetland

MNDNR

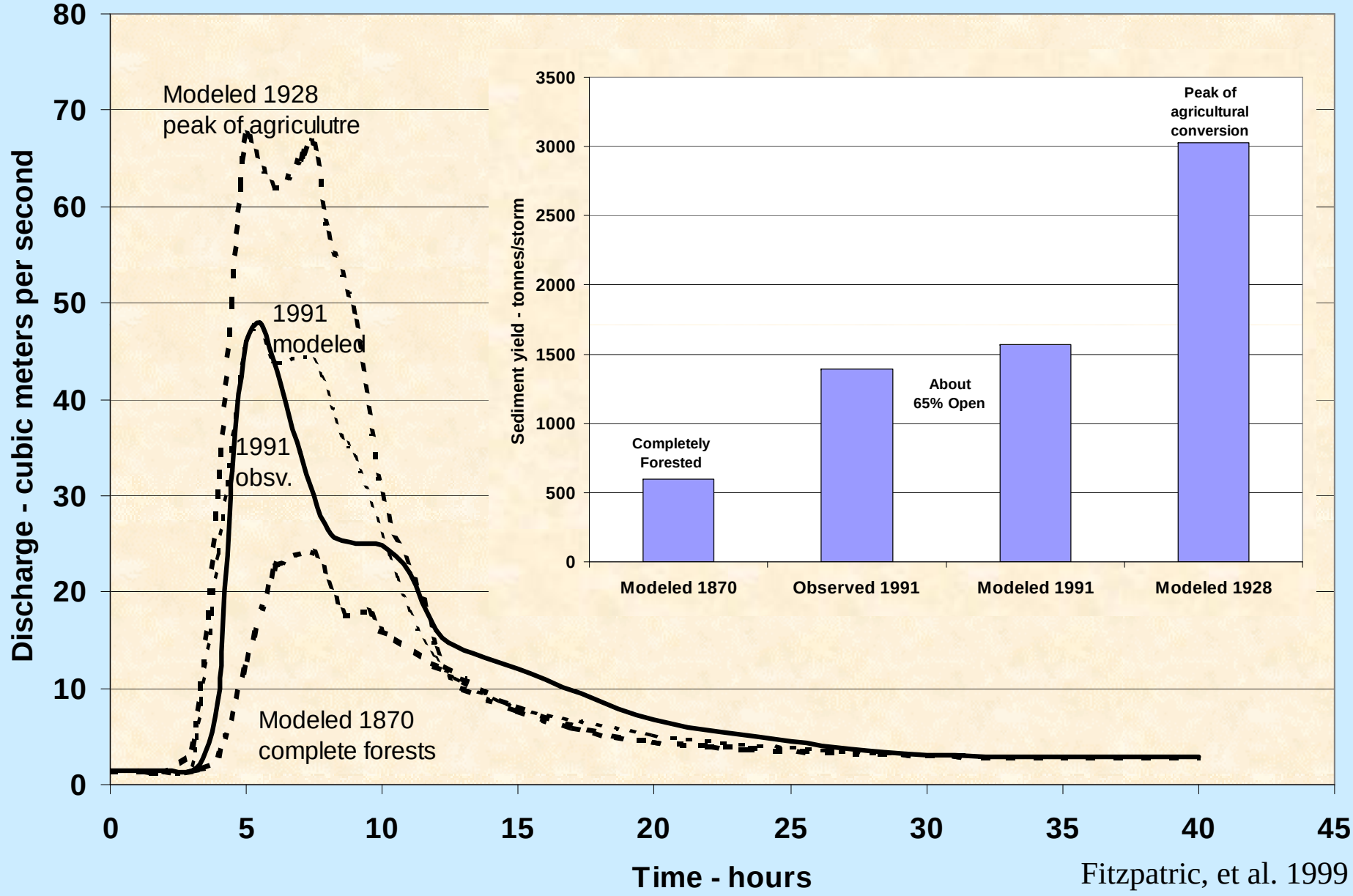


KM

10 0 10 20 30 40 50


N
Land Cover
Forested
Agricultural
Urban/Barren
Water/Wetland
KM
10 0 10 20 30 40 50

North Fish Creek, near Moquah, WI

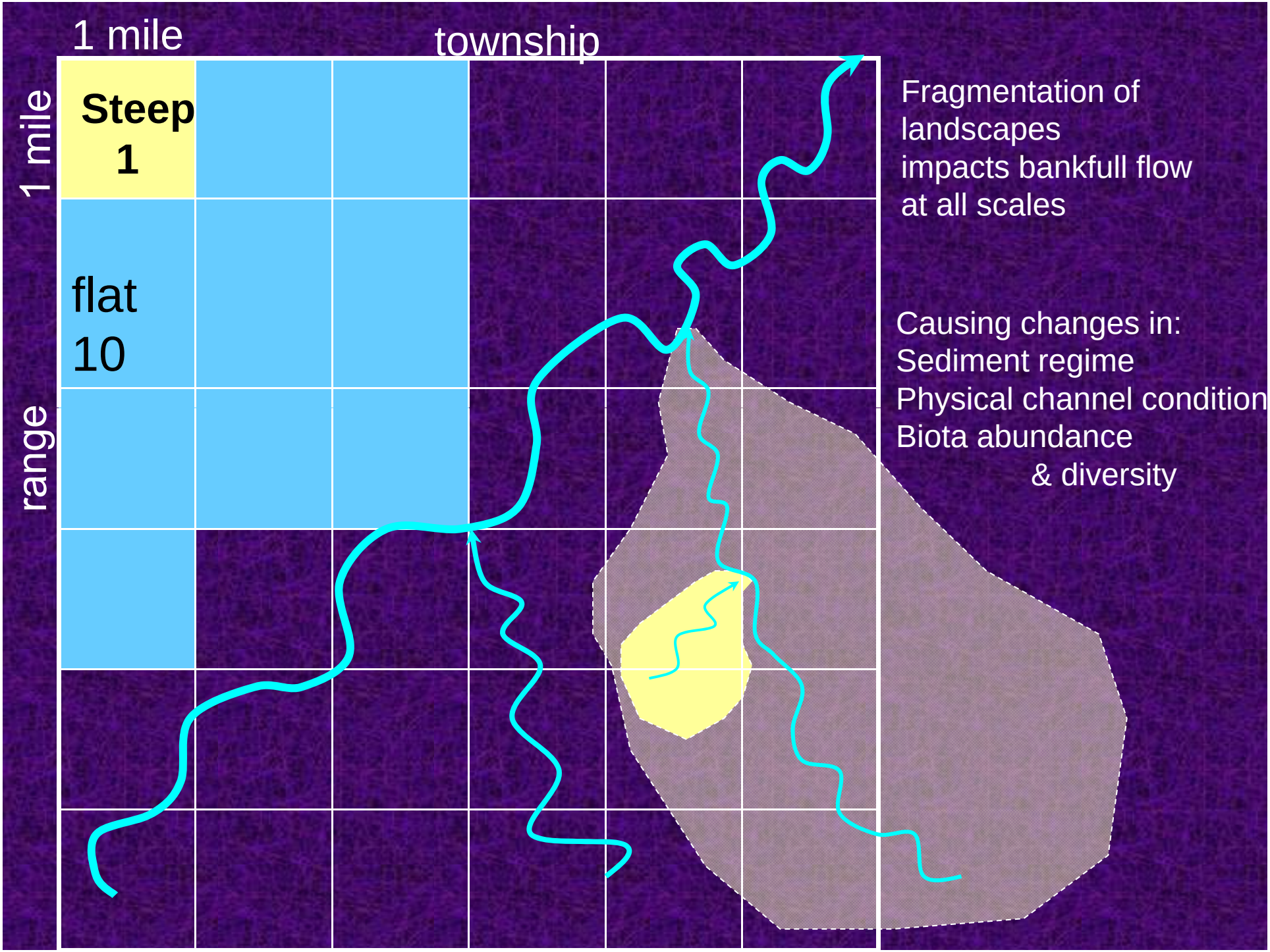


Fitzpatric, et al. 1999

On How Small of a Basin Will Land Use Change Actually Cause In-channel Erosion?

- For flat outwash or lake bed basins (< 3% slopes) they need to be 10 sq. Miles before there is enough power in the flowing water to cause excessive in-channel erosion

- For steep glacial moraine basins (3-40% hillslopes) they need to be 1 sq. Mile

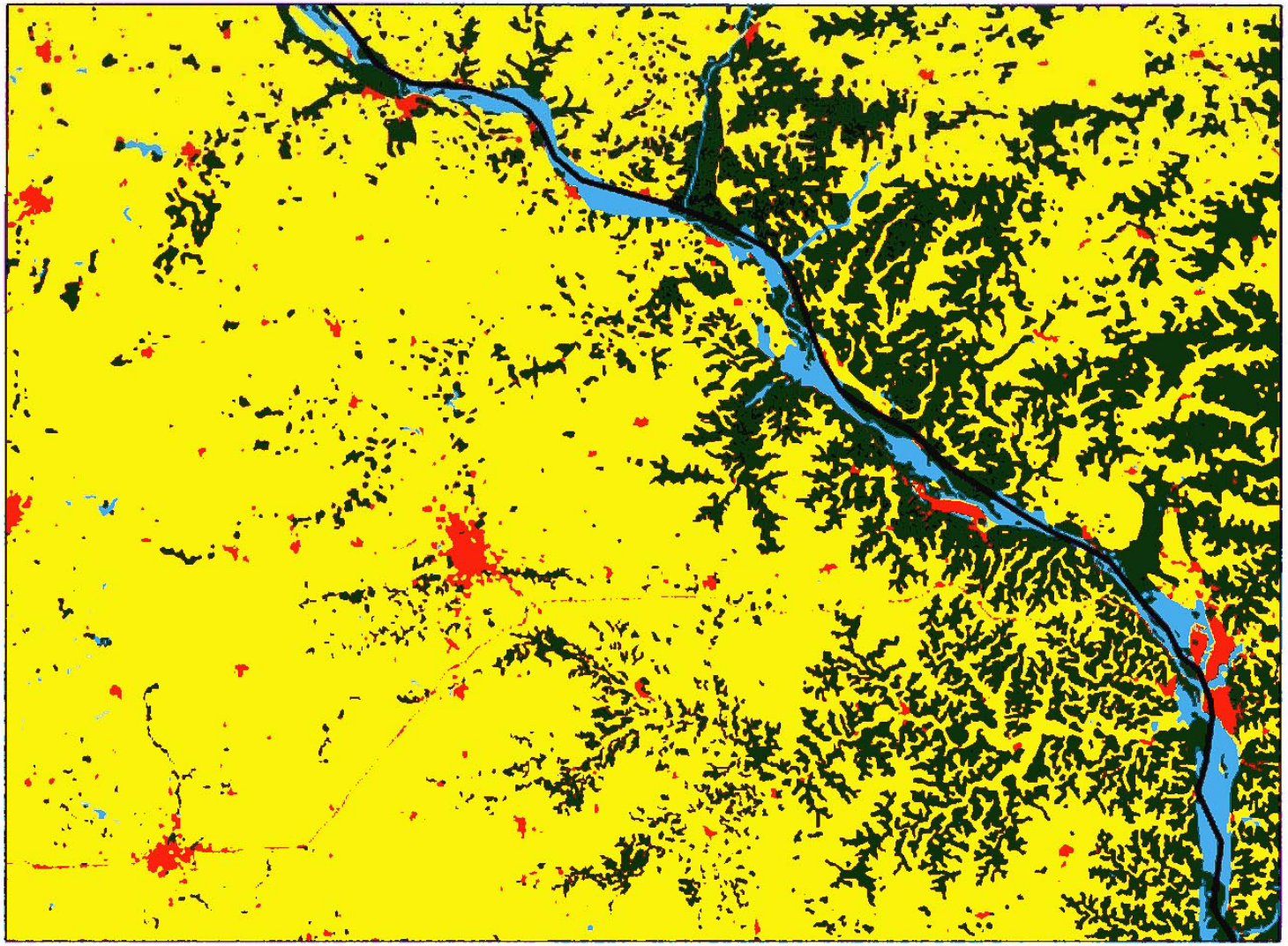

1 mile
township
1 mile
range
Steep
1
flat
10
Fragmentation of
landscapes
impacts bankfull flow
at all scales
Causing changes in:
Sediment regime
Physical channel condition
Biota abundance
& diversity


7 29 97


7 29 '97


Canada
United States
Mexico
Pacific Ocean
Atlantic Ocean
Gulf of Mexico
Lake Superior
Lake Michigan
Lake Huron
Lake Erie
Lake Ontario
Olympia
Seattle
Spokane
Portland
Salem
Eugene
Helena
Bismarck
Fargo
Duluth
Minneapolis
St. Paul
Boise
Pierre
Madison
Milwaukee
Lansing
Chicago
Detroit
Cleveland
Buffalo
Albany
Montpelier
Augusta
Concord
Boston
Providence
Hartford
New York
Trenton
Harrisburg
Philadelphia
Dover
Annapolis
Washington, D.C.
Richmond
Norfolk
Raleigh
Charleston
Frankfort
Columbus
Indianapolis
Springfield
Carson City
Sacramento
San Francisco
Salt Lake City
Cheyenne
Denver
Omaha
Lincoln
Des Moines
Kansas City
Topeka
Jefferson City
St. Louis
Nashville
Memphis
Oklahoma City
Tulsa
Santa Fe
Albuquerque
Phoenix
Tucson
Los Angeles
San Diego
El Paso
Dallas
Austin
Houston
San Antonio
Corpus Christi
Little Rock
Birmingham
Atlanta
Columbia
Charleston
Montgomery
Jackson
Baton Rouge
New Orleans
Tallahassee
Jacksonville
Tampa
Miami
Key West
Bahamas
Cuba
Tropic of Cancer
WA
OR
CA
ID
NV
MT
WY
UT
AZ
CO
NM
ND
SD
NE
KS
OK
TX
MN
IA
MO
AR
LA
WI
IL
MI
IN
OH
KY
TN
MS
AL
GA
FL
SC
NC
VA
WV
PA
NY
VT
NH
ME
MA
RI
CT
NJ
DE
MD
120°
105°
90° W
75°
45°
30° N
0
500 km
0
500 mi

Land Fragmentation in the Central and Upper Midwest Impacts to Streams and Fish



Land Cover

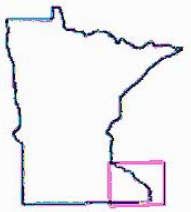
Forested

Agricultural

Urban/Barren

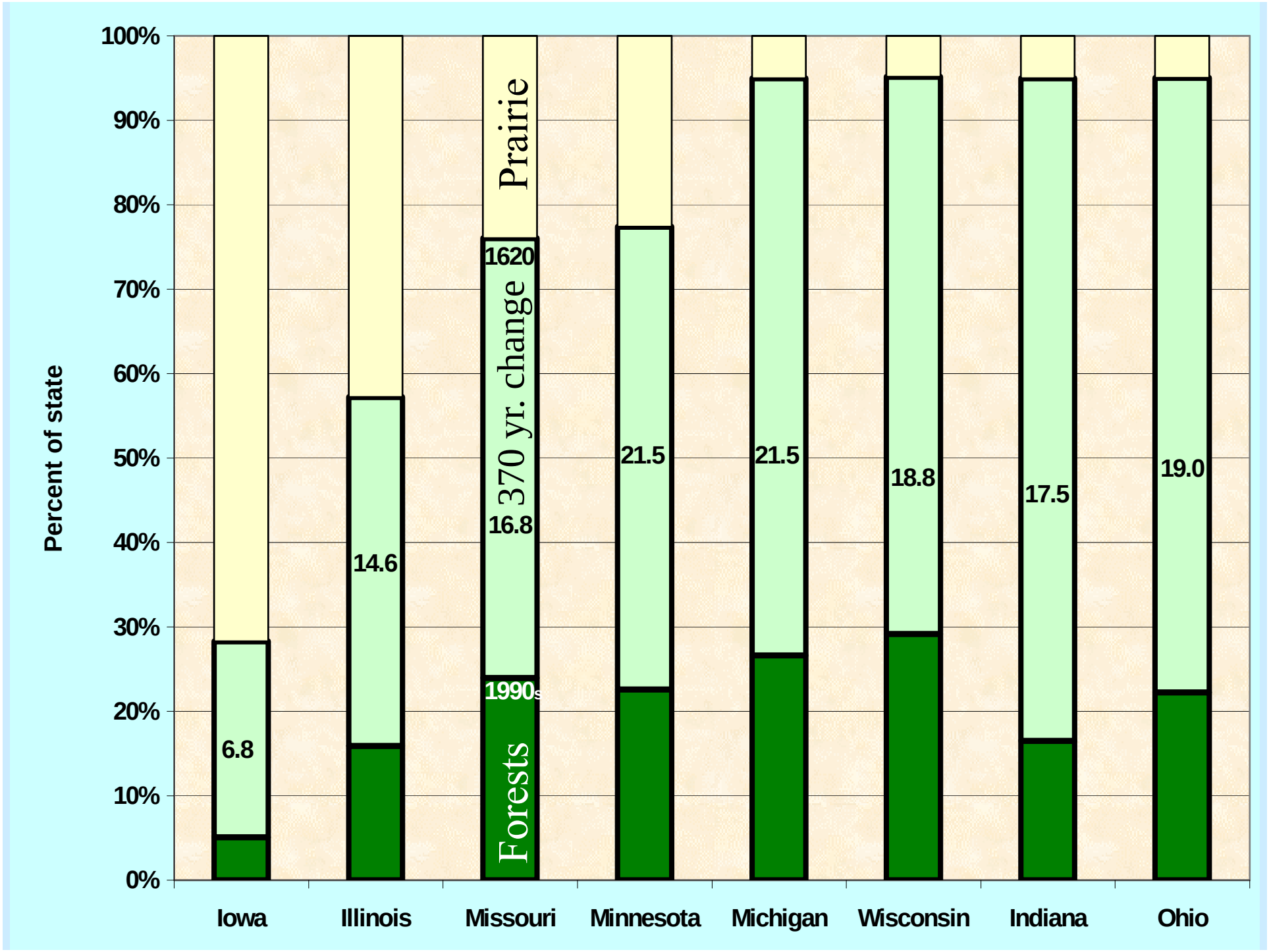
Water/Wetland

MNR - DNR



KM

10 0 10 20 30 40 50

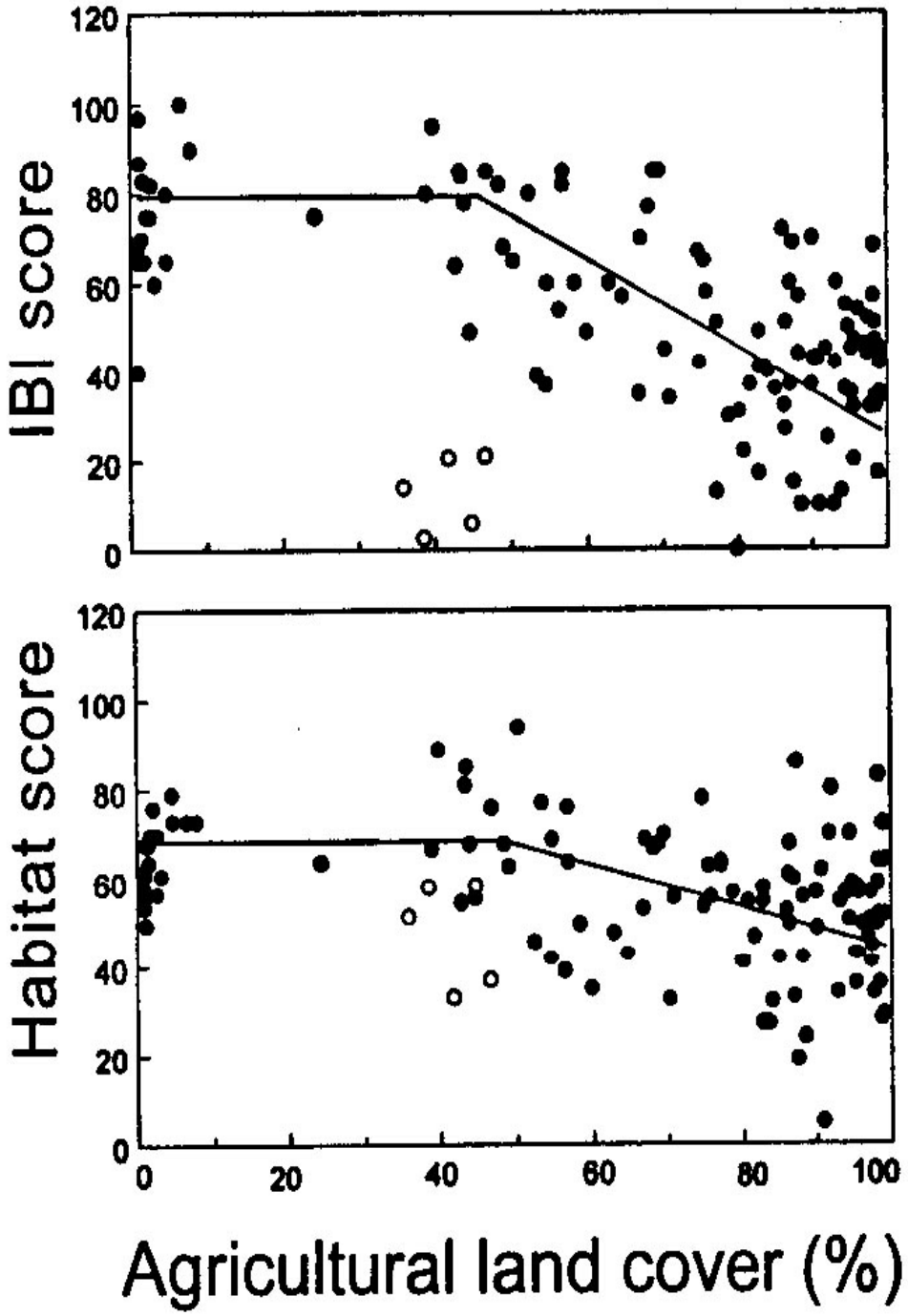

Percent of state
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Prairie
1620
370 yr. change
16.8
1990s
Forests
6.8
14.6
21.5
21.5
18.8
17.5
19.0
Iowa
Illinois
Missouri
Minnesota
Michigan
Wisconsin
Indiana
Ohio

Increases in rainfall & snowmelt bankfull flow may be caused by low infiltration rates (inches/hour)

Location & Soil	Mature Forests	High Compaction Harvest
Lower MI Sands	10	2
Northern MN Sandy Loam	5	0.2
Upper MI Clays	2	0.001

Mungovern, 1996

WISCONSIN STREAMS



Wang, et al. 1997

Kankakee River (NE IL) small mouth bass populations

Years	Adult Bass/ha
1915 -1925	65
1977-1990	27
2060	9

Range in forested watersheds from literature: 84-146

Kwak, et al., 1999

Causes of Decline

- Primarily caused by increases in the mean discharge during the spawning/rearing period (the bankfull discharge rate)
- Climate warming and spawning/rearing air temperature increases had only minor effects
- Variability in winter discharge had only minor effects

Kwak, et al., 1999

Fragmentation of landscapes impacts bankfull flow at all scales

- Causing changes in
  - sediment regime (mostly in-channel generated)
  - physical channel condition
  - biota abundance and diversity
- Cover condition over the watershed, whether at the1000, 100, 10, or 1 sq.mile scale, yields similar changes in channels

Within Mostly Forested Lands

- Forest Roads are, by far, the largest impact to streams
  - Undersized and poorly placed culverts fragment fish communities
  - Fine sand from eroding road surfaces, especially at stream crossings degrades channel habitat

- Roads in Agricultural Lands can also have large impacts to stream channels

DO NOT use Entrenchment Ratio Key Breaks For Floodplain Design Criteria !

Instead Use:

1. Average Floodplain Width Measured along several miles of valley
2. Minimum Floodplain Width Measured along several miles of valley

Verry

3. 10 times Bankfull Channel Width
   doing more really doesn't help with valley flood flows or improve channel habitat quality

4. 5 times Bankfull Channel Width
   maintains most but not all channel habitat qualities and reduces flood capacity

5. 3 times Bankfull Channel Width
   absolute minimum; any thing less results in degraded channel habitat and inability to maintain a stable floodplain form (channel cut offs, headcutting, degradation, aggradation channel widening)

Mathews, 2006 ODNR & additional criteria using drainage area. Appendix 7

Bridge and meander cutoff put in in 1982


Highway 15 North of Fairmount, Minnesota
Elm Creek Cutoff


Channel Diversion Elm Creek
Southern Minnesota

- In 1864, George Perkins Marsh observed land use impacts on streams in New England *(Man and Nature)*
- Were they man-caused or nature's way?

- For large floods (>20-yr event) - nature's way

- For the bankfull flow (~1.5-yr event) and more frequent floods it can be caused by fragmentation of the landscape
  - Cover changes
  - Synchronization of snowmelt (direct sunshine)
  - Soil compaction
  - Decreased rainfall infiltration rate
  - Heavy grazing
  - Meander cutoffs for bridges, channel diversions

Management Choices

- In Mixed Forested/Ag Landscapes
  - Keep field plus young forest cover conditions less than 60% of the basin - big basins and smaller subbasins (in the 10 - 1 sq.. mile ranges)
  - Manage for a community vision of income producing land and high quality recreation opportunities.

Management Choices

- In Forested Landscapes
  - – Manage logging sales to preserve
    - Macropore space
    - Organic matter
    - Ped structure in soils
  - – Quality soil with macropores and ped structure provide
    - optimum soil moisture
    - optimum soil aeration
    - optimum soil drainage
  - – Soils with these attributes will yield maximum wood and maximum amenity production

Management Choices

- In Forested Landscapes

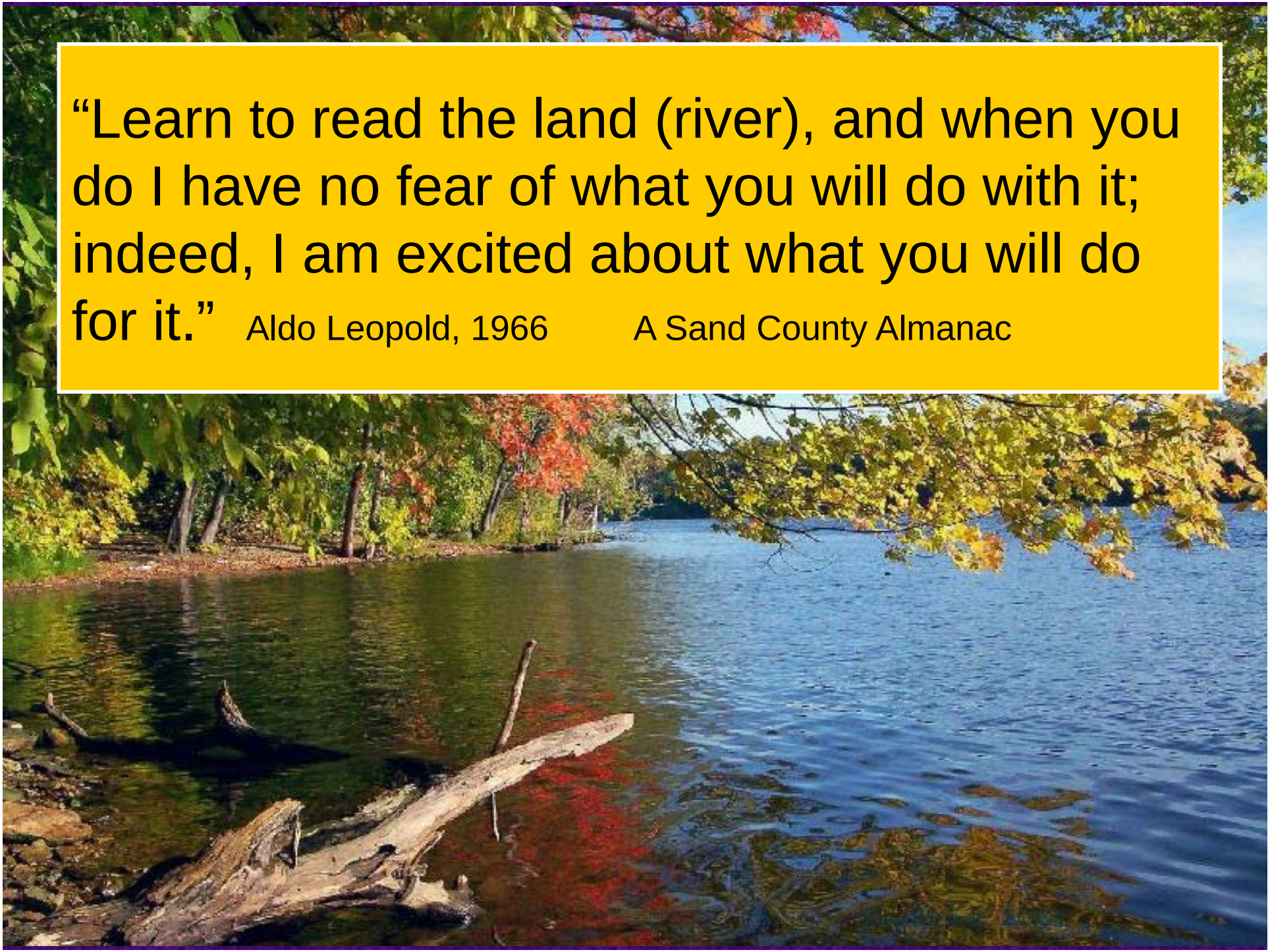
  – Soils with out these attributes will be
    - wetter and colder longer
    - poorly drained
    - highly resistant to tree root penetration
      – (only the fine roots of grasses and sedges, or roots and tubers with air cells (e.g. cattail) can penetrate or colonize highly compacted soils.

  – Highly compacted soils will cause at least a 20 to 30% reduction in next rotation wood biomass Stone & Elioff, 1998; Stone, Gates & Elioff, 1999; Stone & Elioff, 2000

1st Growing Season: Below the Knee, Above the Belt Guide for aspen suckers

Management Choices

- In All Landscapes
  - Manage streams, lakes, wetlands, and forests in a landscape perspective of how your watershed functions
    - See cold streams, northern hardwoods, and brook trout as a landscape unit to manage.
    - See warm water fish, beaver, and early succession forests as a landscape unit to manage


“Learn to read the land (river), and when you do I have no fear of what you will do with it; indeed, I am excited about what you will do for it.” Aldo Leopold, 1966 A Sand County Almanac