Channel Form and Process in a Tectonically Active, Glaciated , River Valley: Upper Yellowstone River, Park County, Montana, USA

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Water Management Bureau
Helena MT

Rocky Mountain and Cordilleran Joint Meeting
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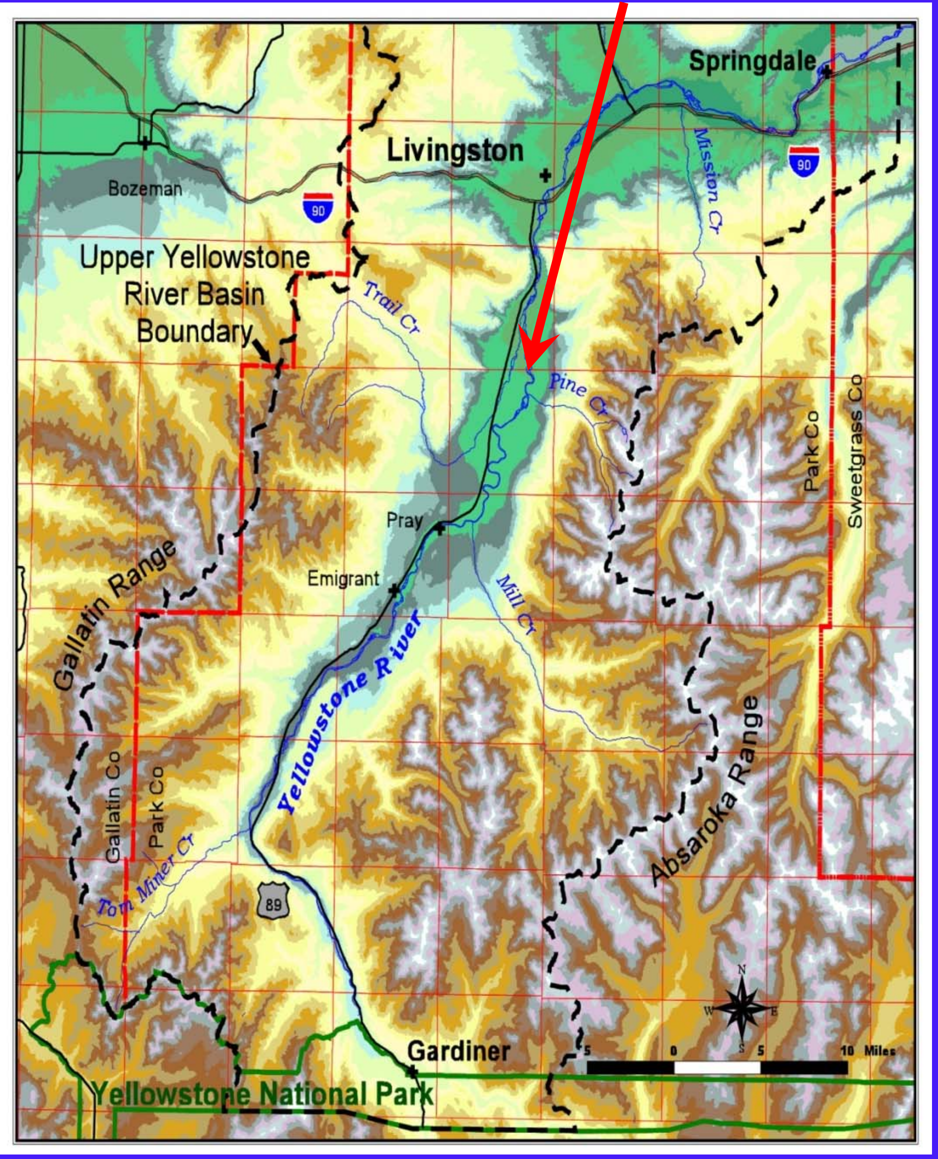
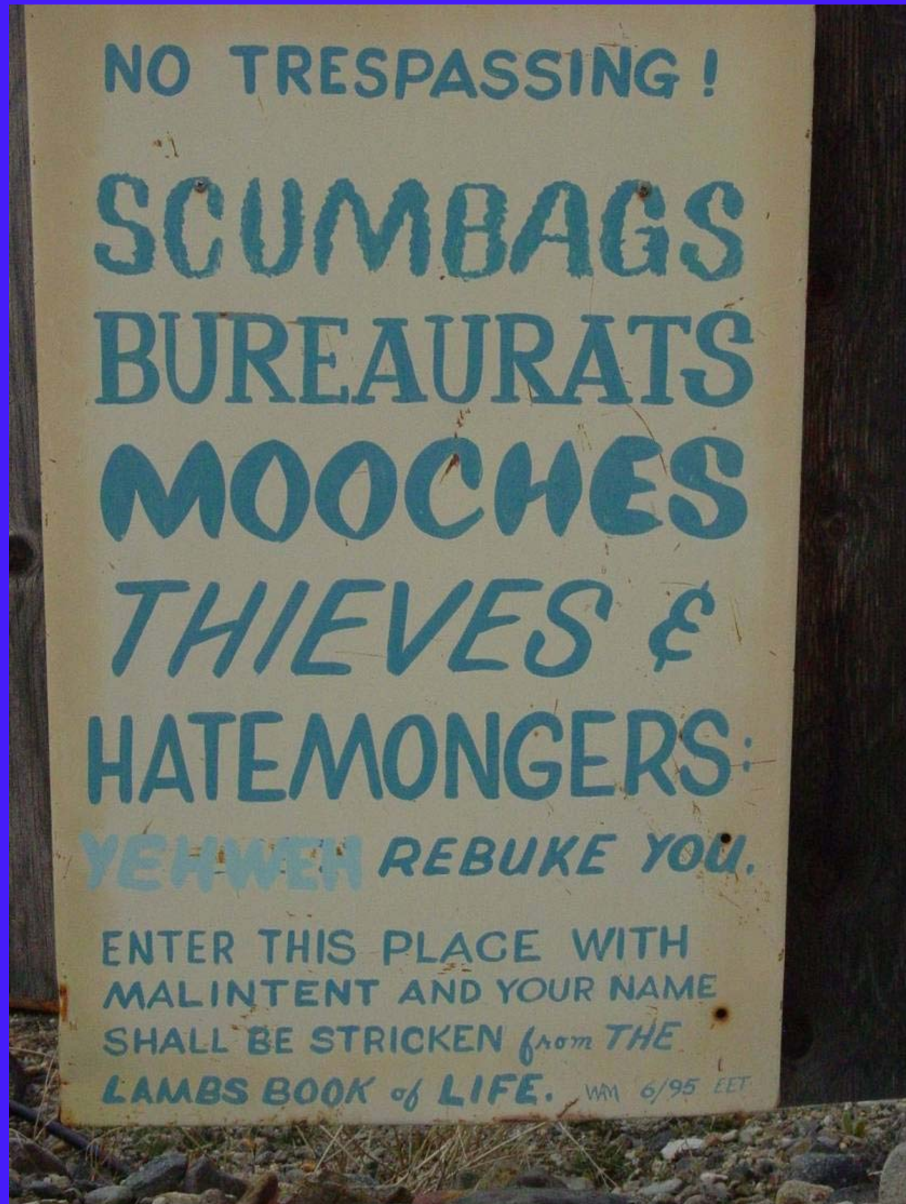
Bozeman, Montana

MONTANA DNRC

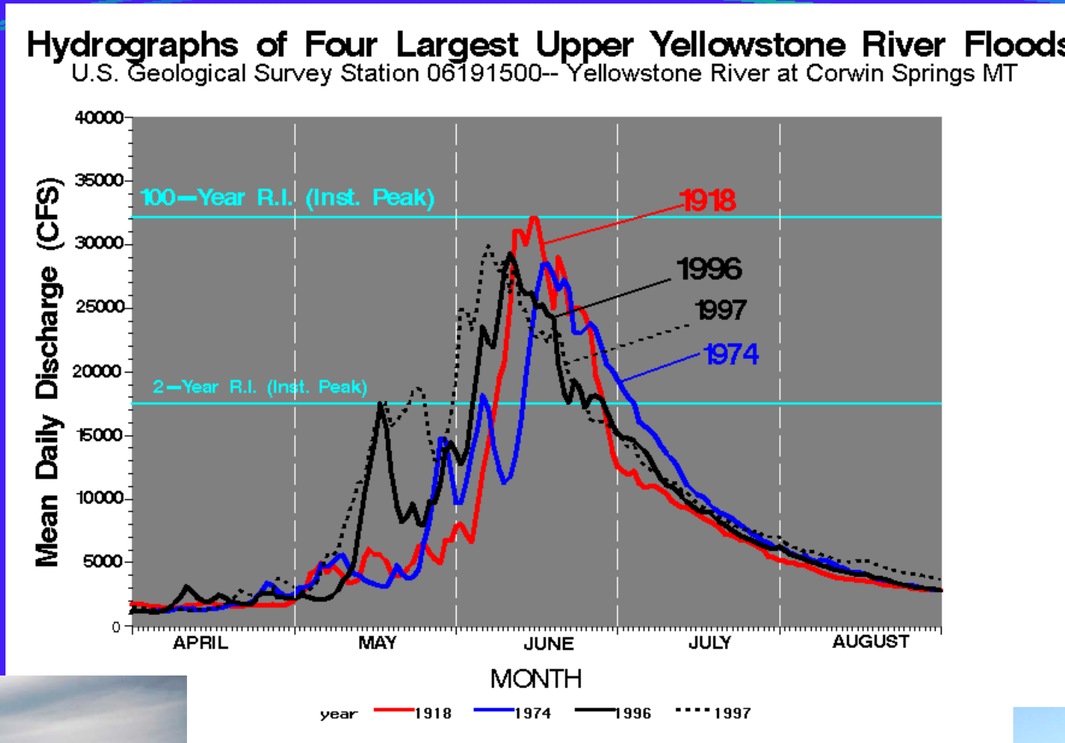
Upper Yellowstone Watershed and Paradise Valley



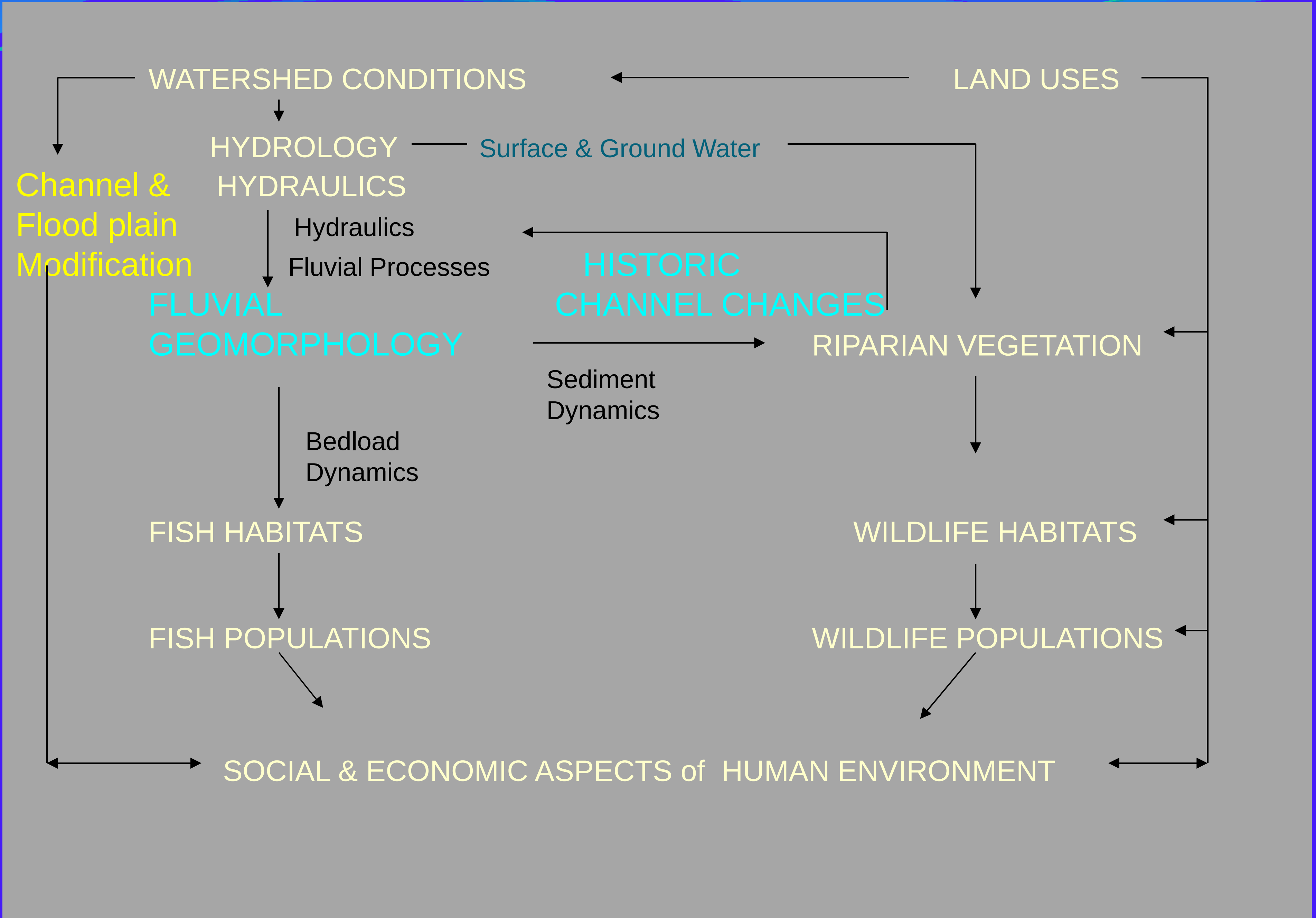
Welcome to Paradise --but beware !



1996-1997 "near" 100-year floods cause extensive lateral erosion. Governor's Upper Yellowstone River Task Force Mission: Evaluate flood "damage"-- advise on permitting.



Upper Yellowstone Task Force Studies



Information used for channel classification and historic channel changes:

Topography and Photography:

--1999, 1:6000 and 1:8000, 1:24000 scale
aerial photos and orthophotos
--2ft and 4ft contour mapping at low flow,
-- high resolution dtm for 3 channel segments
-- channel X-secs (USGS-WRD)

Field Data and Interpretative Mapping:

-- Channel slope (project dtm's and field survey)
-- Particle size (particle counts)
-- Bankfull channel (field ID and stereo photo)
-- Side-channels (classification and change)
-- LWD (contemporary inventory)
-- Channel confinement (--human/natural)
-- 1948,1954, 1974,1976,1999 "bankfull" channel
and time-series of lateral channel changes

To support Task Force deliberations and recommendations, we posed several questions:

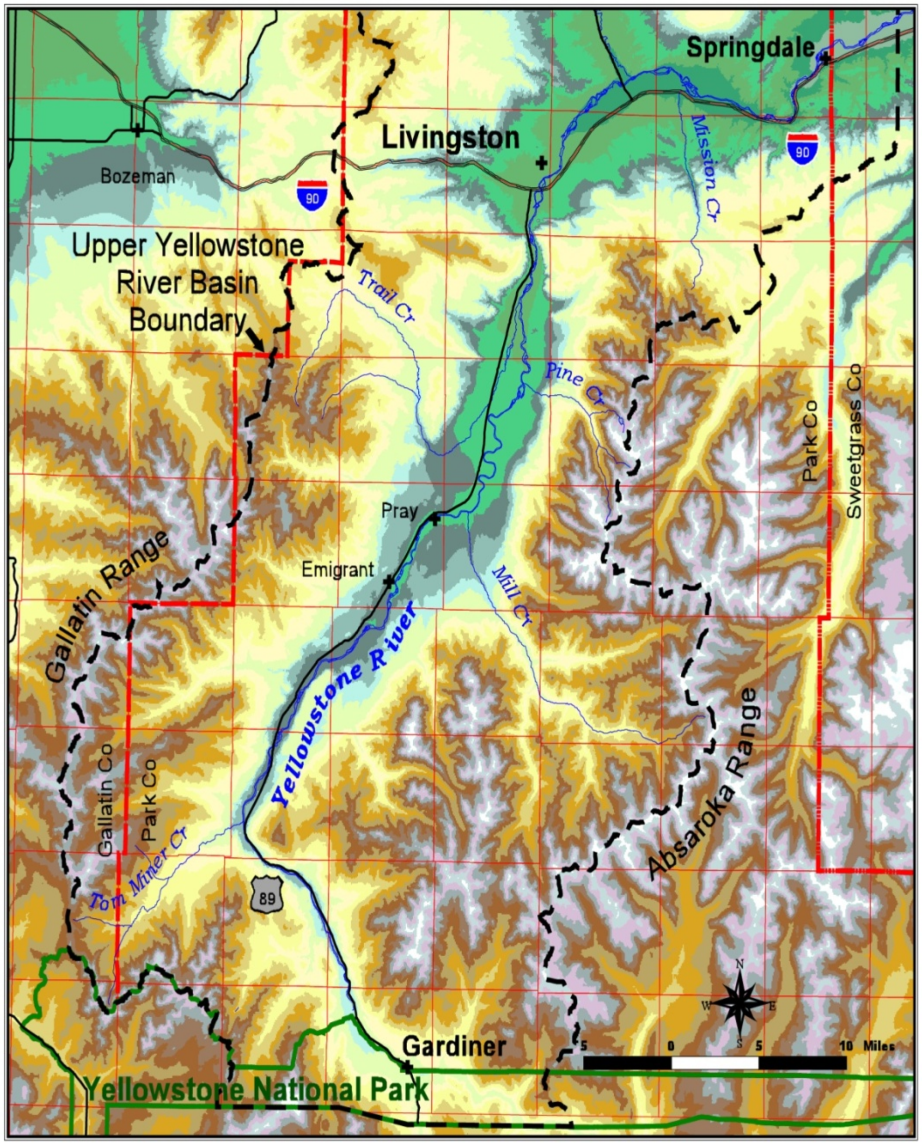
1. How has valley's tectonic and glacial history influenced fluvial geomorphology and distribution of channel types ?

2. What is the present day distribution of human channel modification ? how has this affected channel process and stability over the the period 1948 to 1999 ?

3. How effective are large floods (e.g. 100 yr. peak) in shaping the fluvial landscape--compared with more recent events—2 yr. peak.

What is the channel forming discharge for the Upper Yellowstone River ?

1. How has valley's tectonic and glacial history influenced fluvial geomorphology and distribution of channel types ?

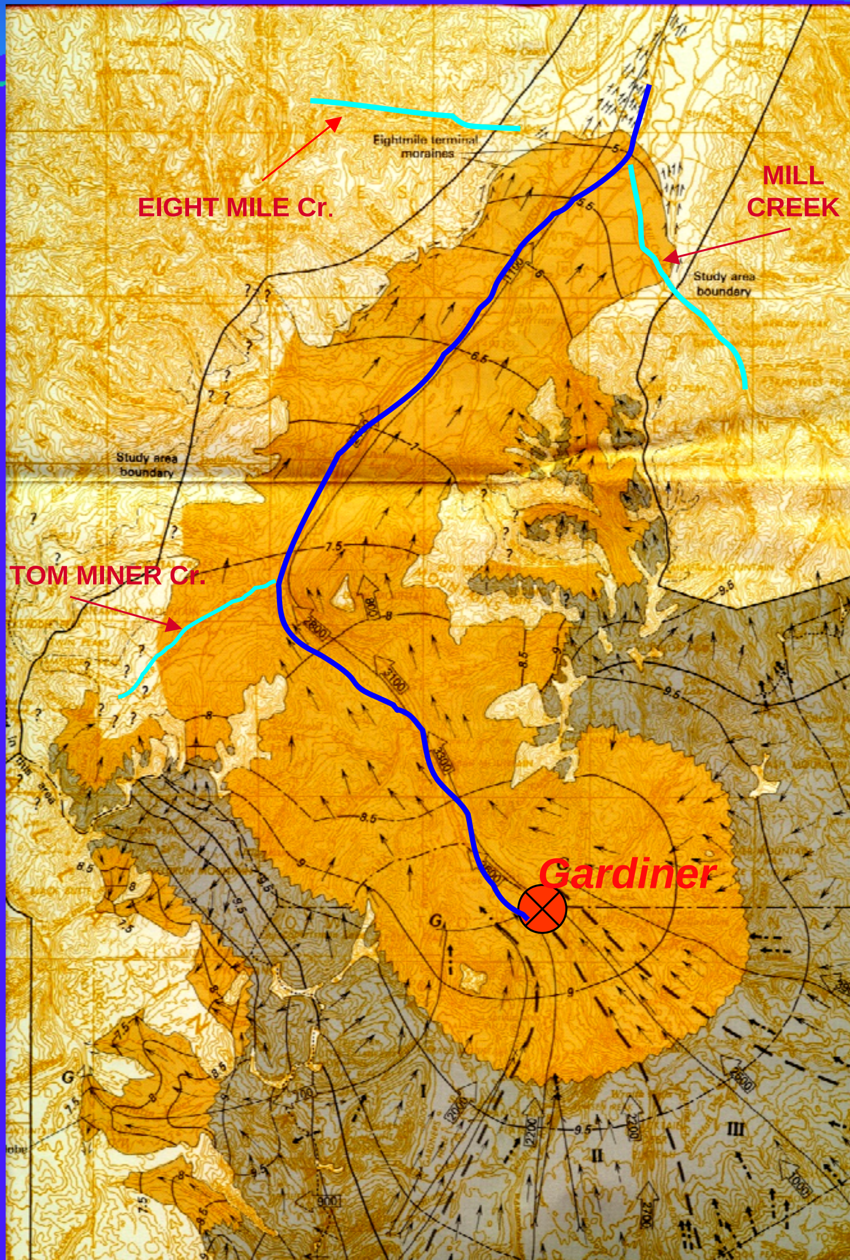


Tectonic History

Laramide compression along N-S axis

--raised north end of valley
--formed Gallatin Range to west
--valley down-dropped block, with uplift of Beartooth/Absaroka Mtns to east along normal extensional faults on east side of valley

--Paradise valley remains tectonically active with 15 ft of post glacial off set along Barney Creek Fault scarp



PARADISE VALLEY GLACIAL HISTORY

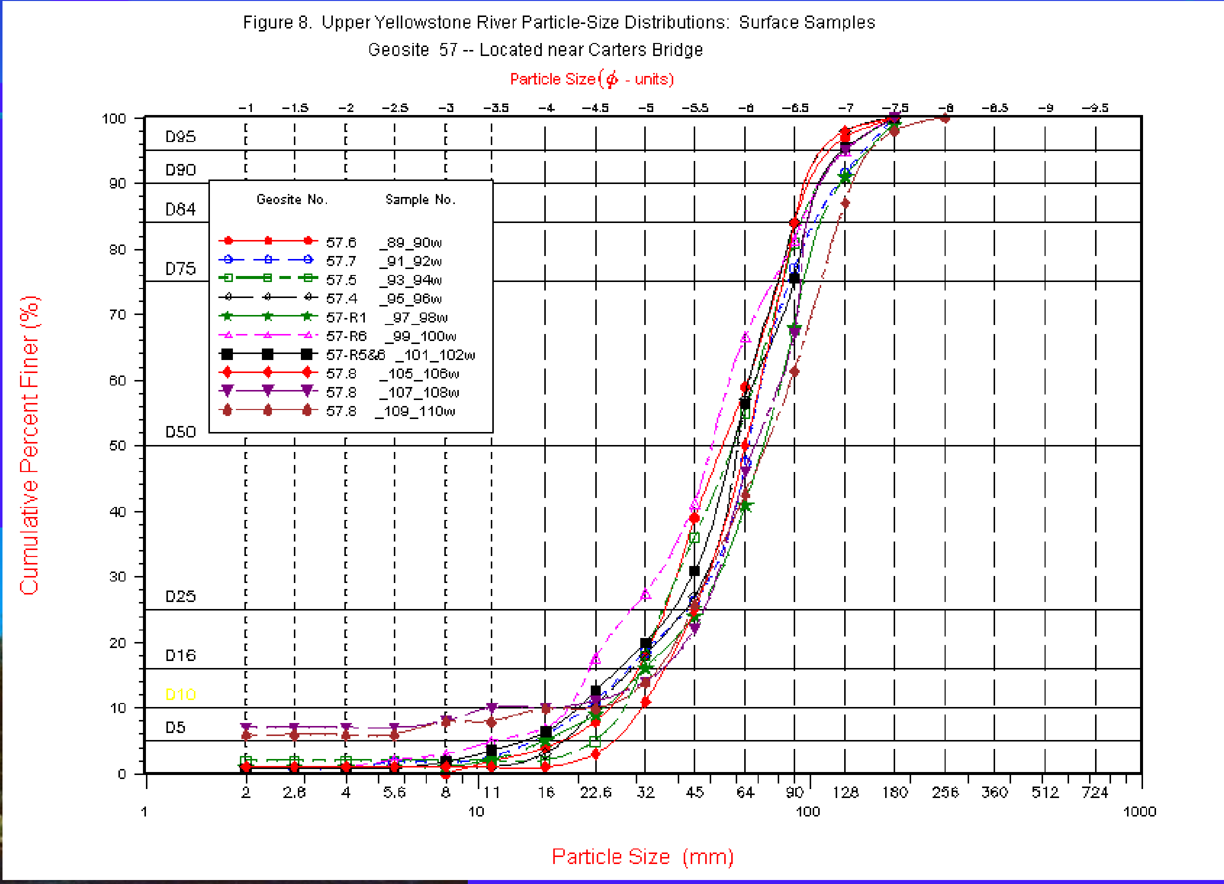
130 ka. (BULL LAKE max.)
Little evidence left behind

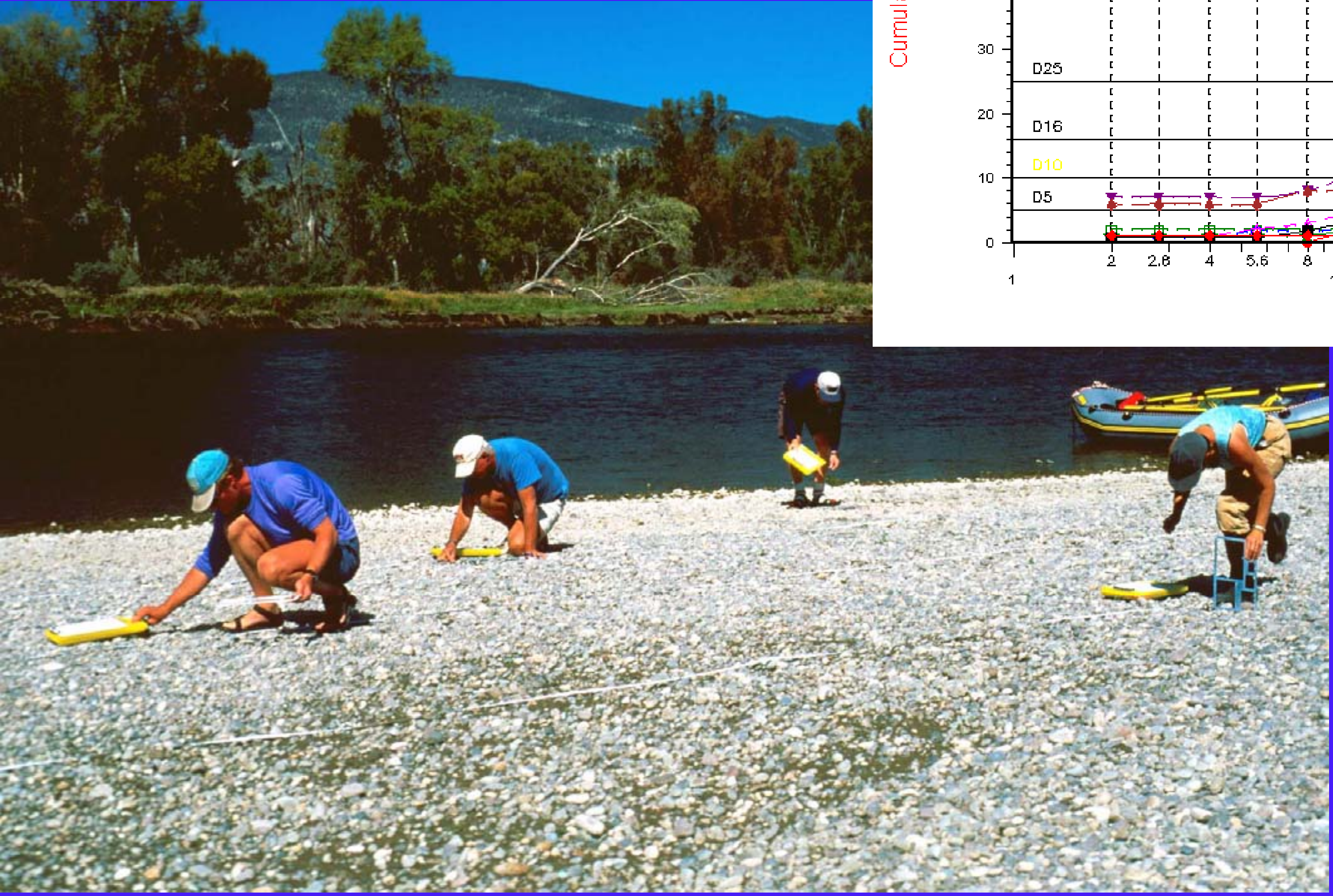
16.5 ± 0.4 3He ka and
16.2 ± 0.3 10Be ka,
(PINEDALE max.)

Dr. Kenneth Pierce
Distinguished Geologist

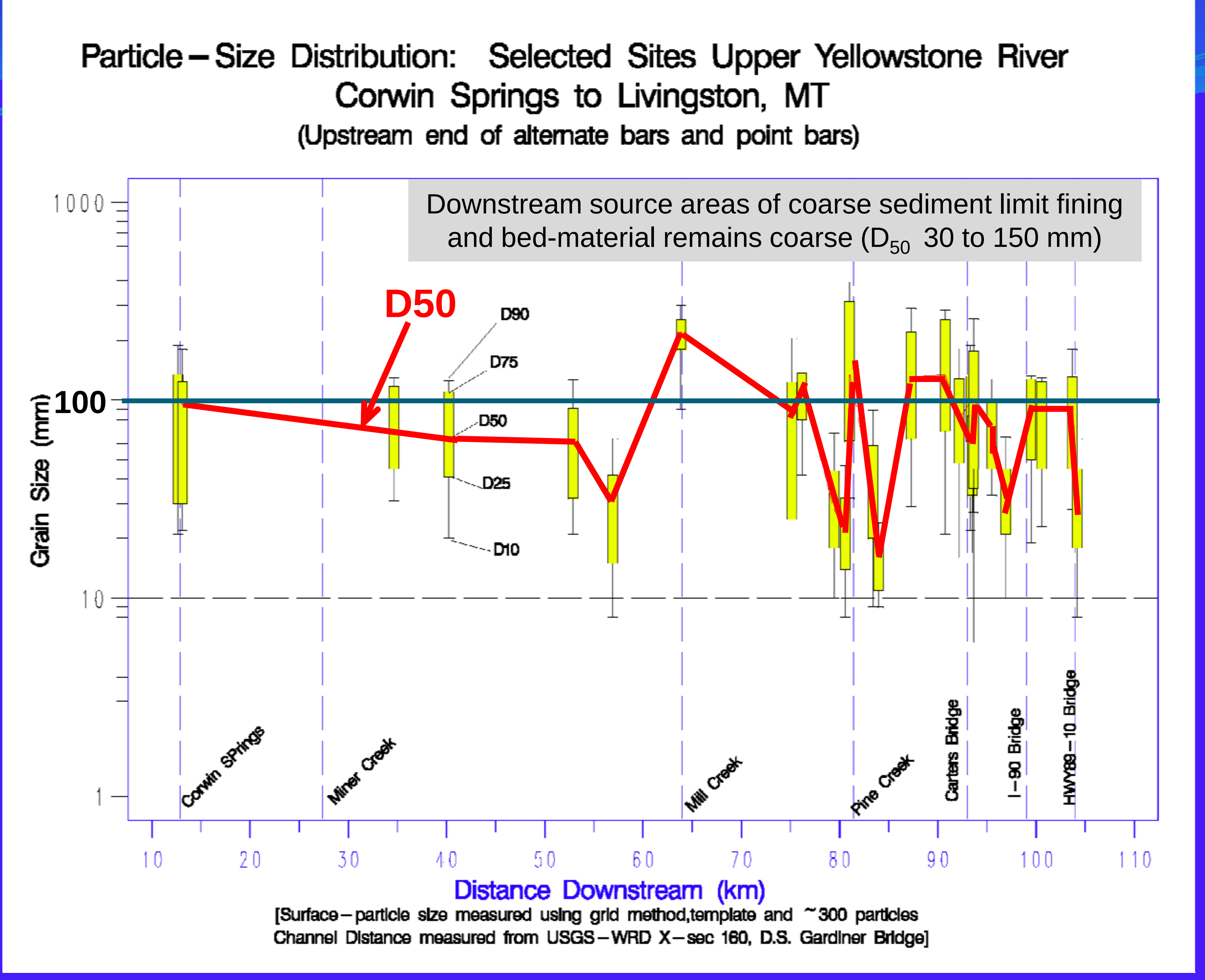
Source: Pierce, K.L. 1979. History and dynamics of glaciation in the northern Yellowstone National Park area : U.S. Geological Survey Professional Paper 729 F.

Pebble counts describe variation in surface bed-material

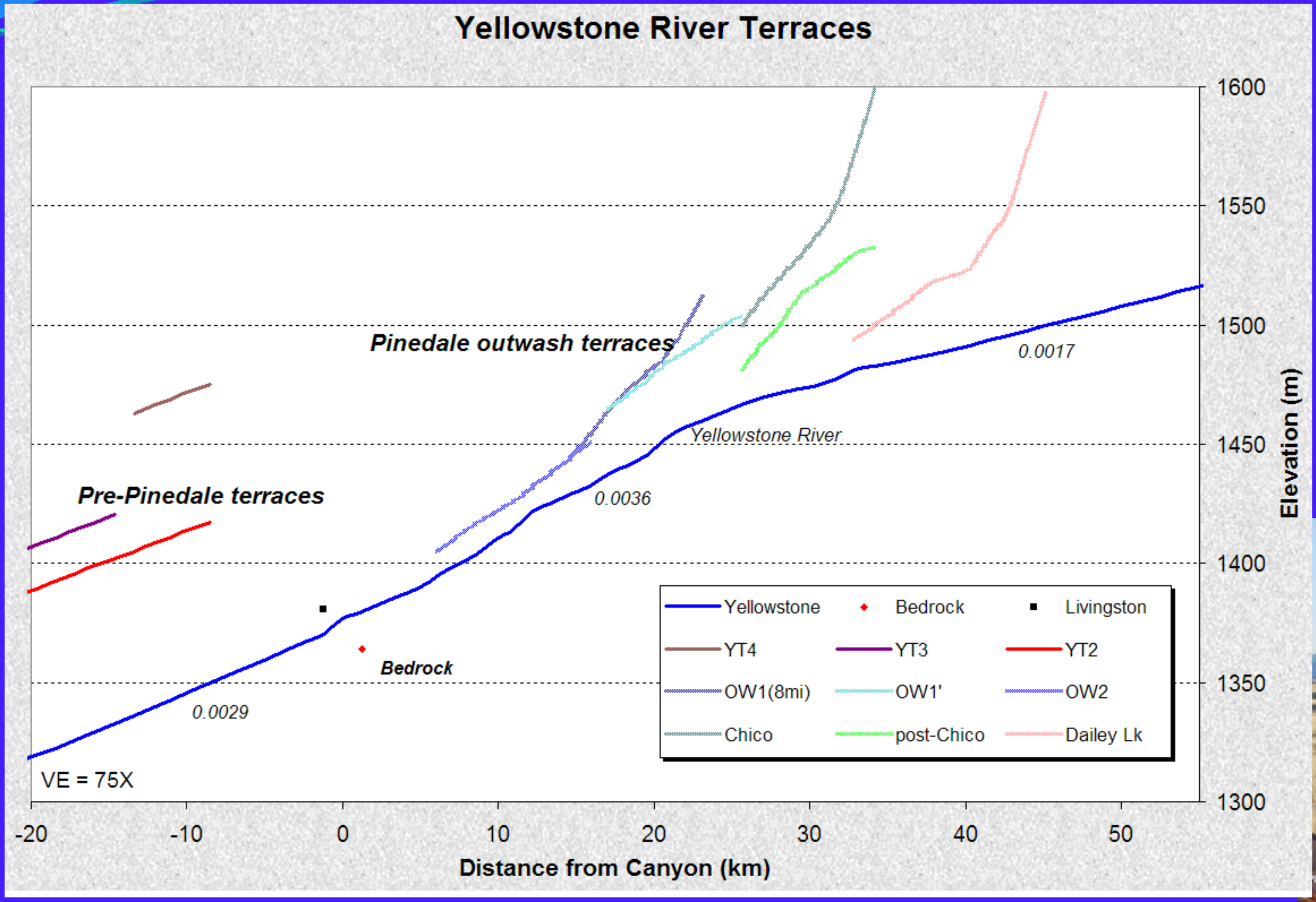




Coarse-bed channel near Pine Cr.

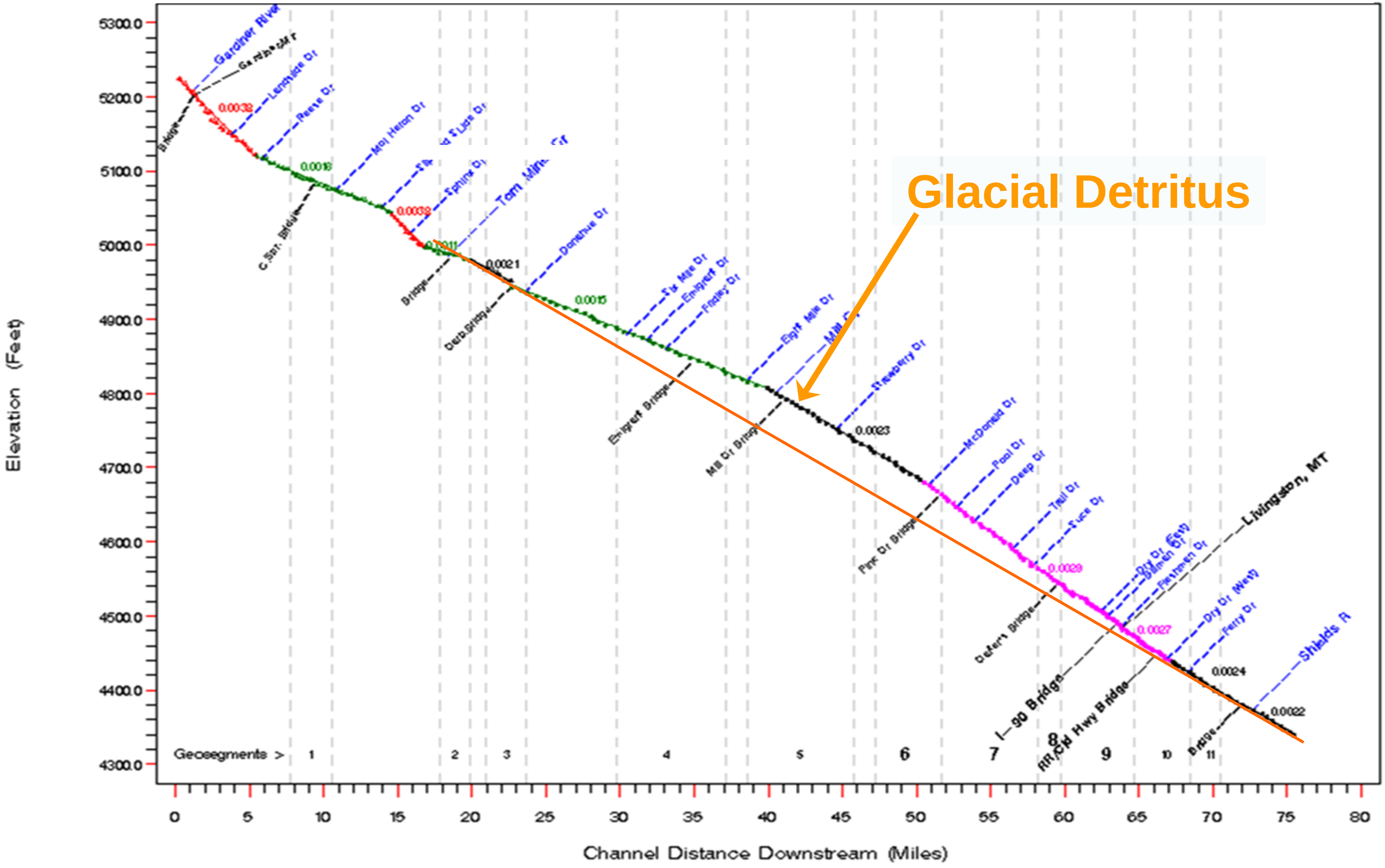


Particle – Size Distribution: Selected Sites Upper Yellowstone River
Corwin Springs to Livingston, MT
(Upstream end of alternate bars and point bars)
Downstream source areas of coarse sediment limit fining and bed-material remains coarse (D_{50} 30 to 150 mm)
D50
D90
D75
D50
D25
D10
100
1000
10
1
Grain Size (mm)
Corwin SPrings
Miner Creek
Mill Creek
Pine Creek
Carters Bridge
I–90 Bridge
HWY89–10 Bridge
10
20
30
40
50
60
70
80
90
100
110
Distance Downstream (km)
[Surface – particle size measured using grid method,template and ~300 particles
Channel Distance measured from USGS – WRD X – sec 160, D.S. Gardiner Bridge]

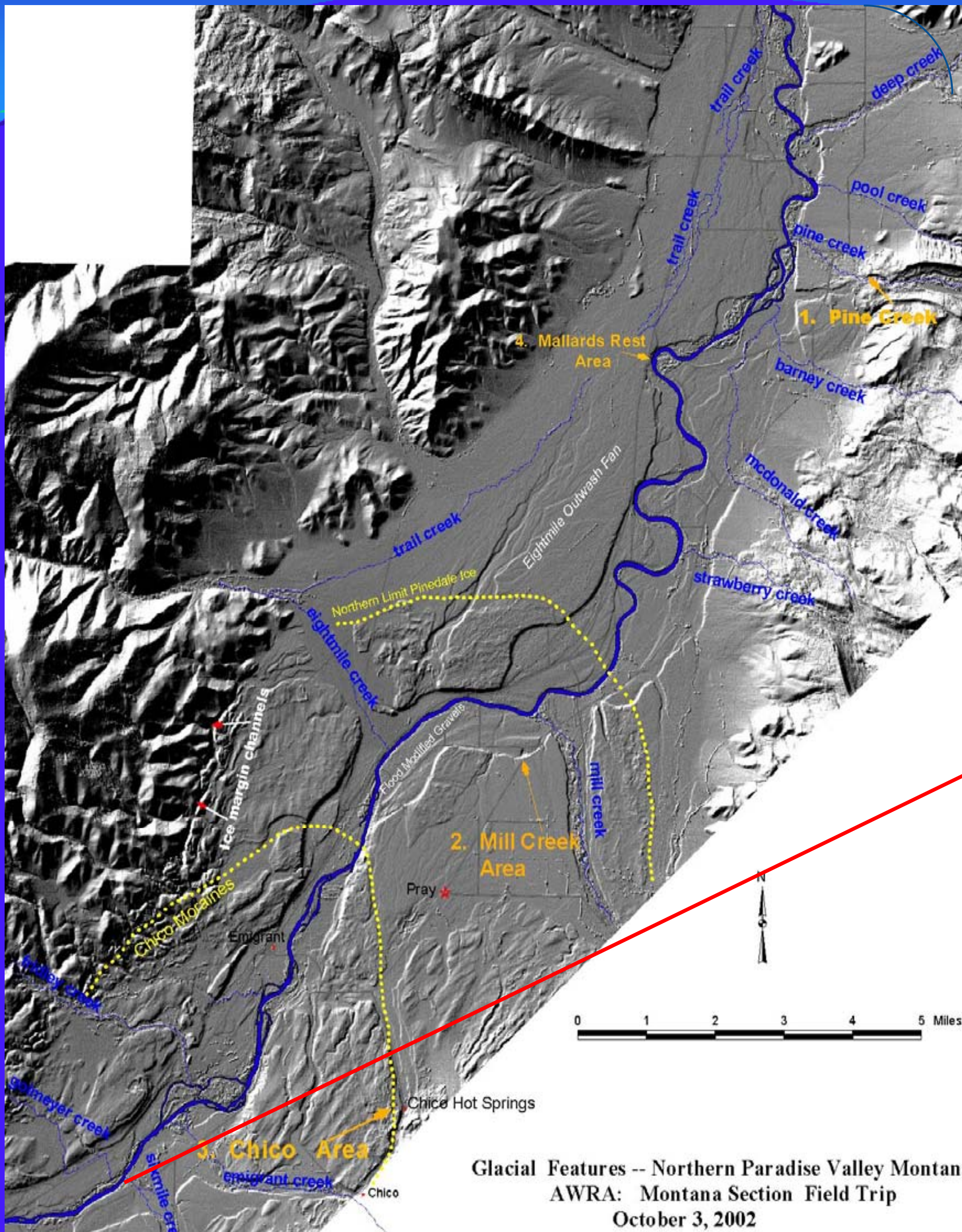


Graph courtesy of Bill Locke, Montana State University Earth Sciences

Longitudinal Channel Profile: Gardiner to Springdale Montana



(Data from USFS and USACE orthophotography and topographic mapping. Data compiled by DNRC-WRD Helena, MT.)


trail creek
deep creek
pool creek
pine creek
1. Pine Creek
4. Mallards Rest Area
barney creek
mcdonald creek
strawberry creek
Eightmile Outwash Fan
Northern Limit Pinedale Ice
eightmile creek
Ice margin channels
Flood Modified Gravels
mill creek
2. Mill Creek Area
Pray
Chico Moraines
Emigrant
Chico Hot Springs
3. Chico Area
emigrant creek
sixmile creek
Chico
0 1 2 3 4 5 Miles
Glacial Features -- Northern Paradise Valley Montana
AWRA: Montana Section Field Trip
October 3, 2002

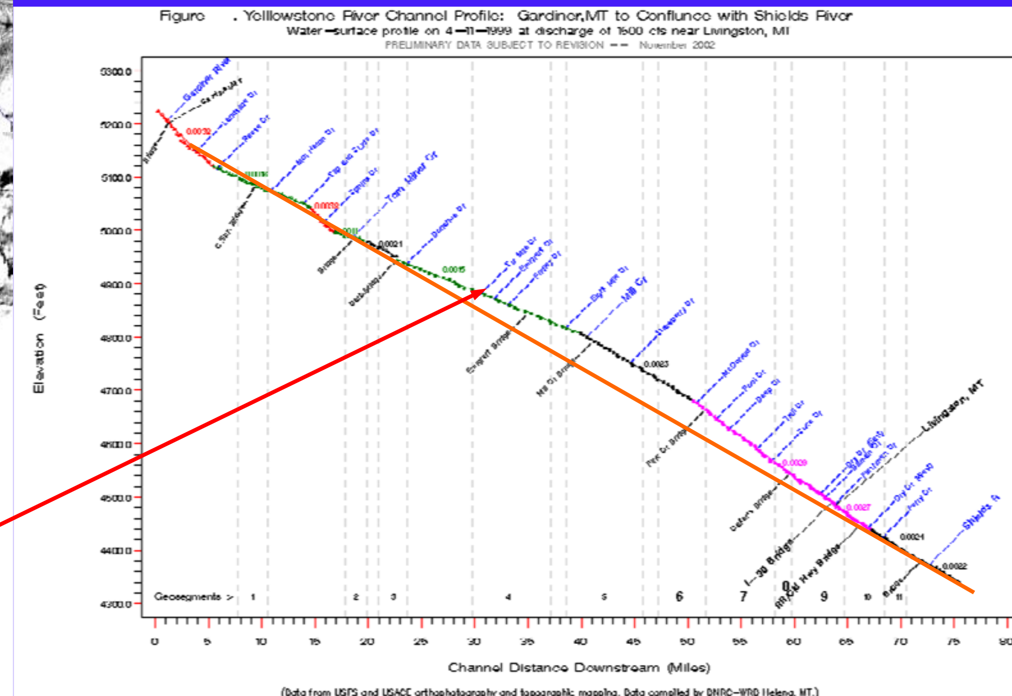
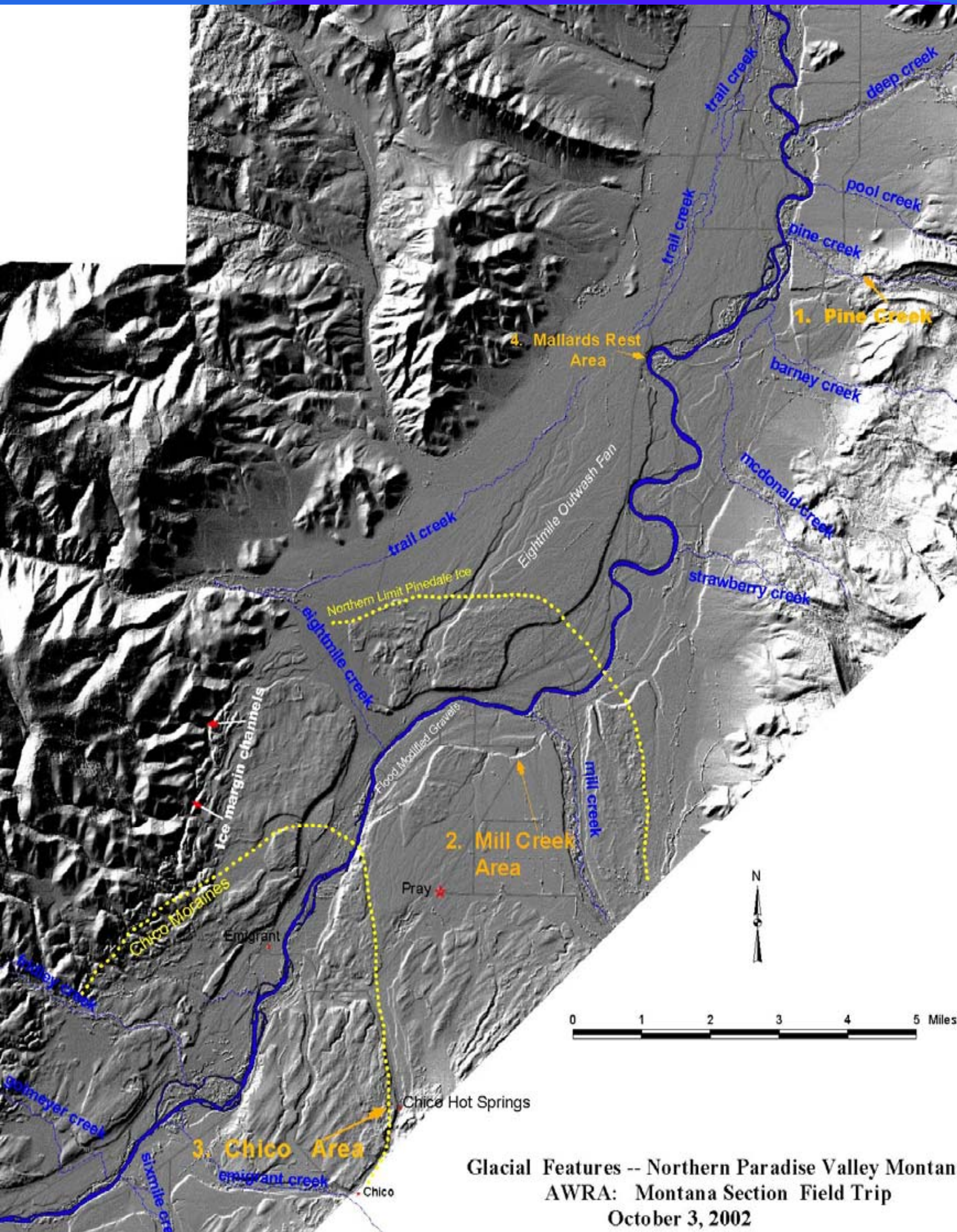


Figure . Yellowstone River Channel Profile: Gardiner, MT to Confluence with Shields River
Water-surface profile on 4-11-1999 at discharge of 1600 cfs near Livingston, MT
PRELIMINARY DATA SUBJECT TO REVISION -- November 2002
Elevation (Feet)
Channel Distance Downstream (Miles)
Geosegments >
Livingston, MT
I-90 Bridge
(Data from USFS and USACE orthophotography and topographic mapping. Data compiled by DNRC-WRD Helena, MT.)



Legacy of Glaciation and Paleofloods

Lateral confinement by large terraces

Very coarse gravel-cobble, boulder bed

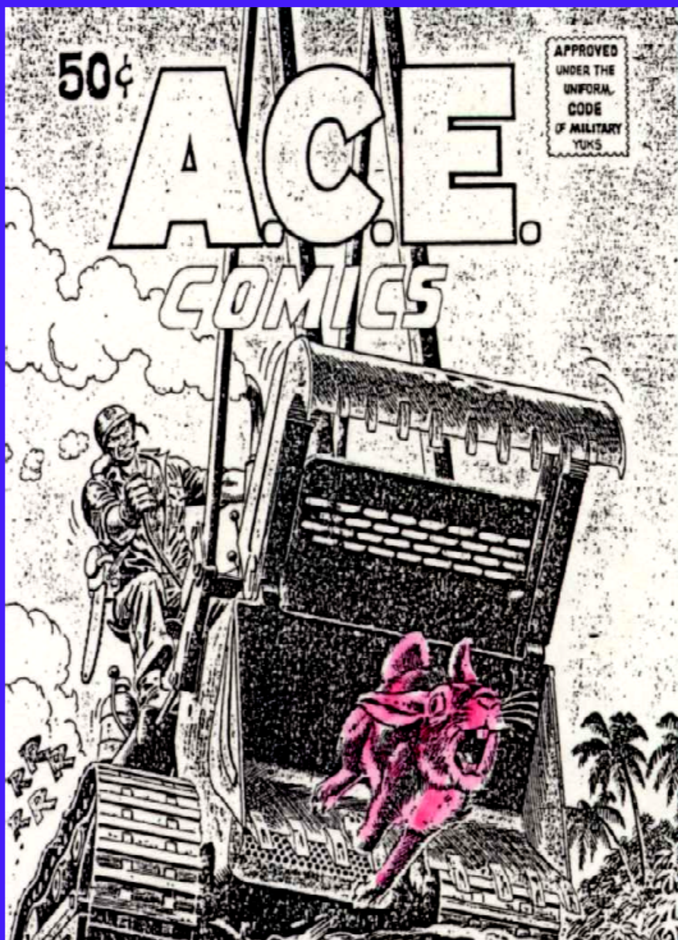
Bed-slope 0.001 to 0.005

Convex long profile in Paradise Valley

Paleo-template controls spatial distribution of channel types, number and type of side channels, riparian forest and aquatic habitat and terrestrial wildlife habitat.

and where humans want to farm, ranch, recreate, retire, and “stabilize” river banks

2. What is the present day distribution of human channel modification and how has this affected channel process and stability over the the period 1948 to 1999 ?



Principal response of alluvial channels to bank stabilization:

Vertical changes:
- --channel incision, downcutting
- --disconnection of main channel and floodplain

Lateral changes:
- --reduce or eliminate channel migration
- --alter channel alignment
- --alter downstream/upstream processes

Overview of Stream Classification Schemes

Geomorphic Classification Scheme	Fluvial Attributes	Number of Types
Montgomery& Buffington (1997)	**7 reach styles based on sediment, channel roughnes elements, sediment sources, sediment storage elements, confinement, pool spacing**	**7 (or so) +qualifiers**
Leopold&Wolman (1957)	channel pattern, slope, discharge	3
Kellerhals et al. (1976)	pattern, floodplain char., sediment size ,hydraulic char.	Many
Schumm (1977)	basin scale (conceptual) erosion/transport/deposition reaches	3
Nanson and Croke (1992)	energy (stream power), floodplain char., sediment , channel pattern, vegetation	15 + suborders
Whiting&Bradley (1993)	slope, channel width, valley width sediment size	42
Rosgen (1994)	slope, pattern, sediment, channel width, valley width	9 or so + suborders
Miall (1996)	16 styles based on fluvial depositional environments	16

Montgomery-Buffington Channel Classification

7 reach styles based on sediment, channel roughness elements, sediment sources, sediment storage elements, confinement, pool spacing

***Modified* Montgomery-Buffington Classification**

(85 miles: Gardiner to Springdale, MT)

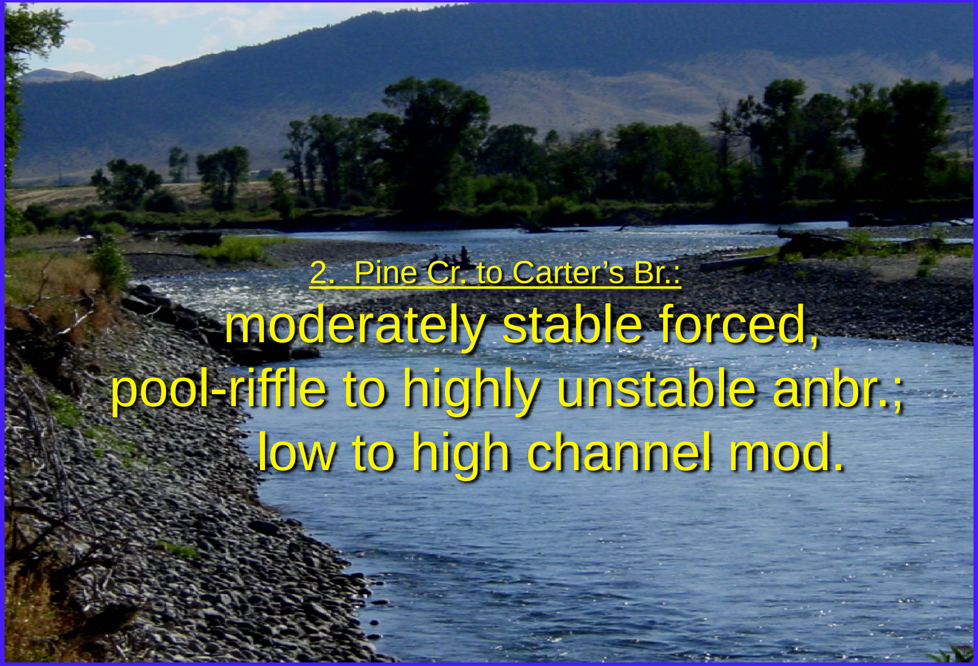
Bedrock, Cascade, Plane-bed (49 %)
Pool-Riffle , Anabranching (40 %)
Anabranching-Braided (11 %),

and

Forced Channel Types (14 %)

PR to PB and ANBR to PR

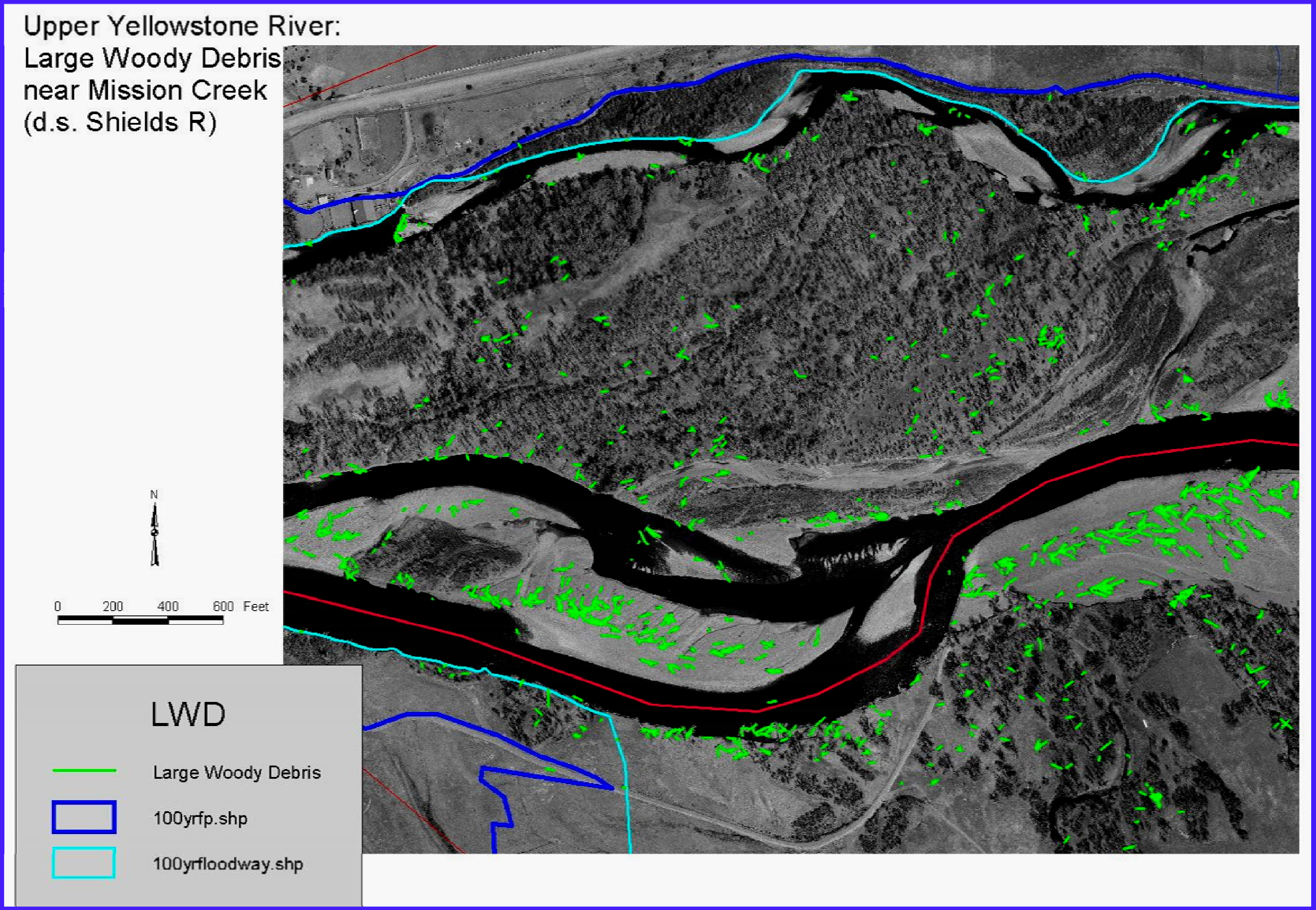
Upper Yellowstone River Channel Types



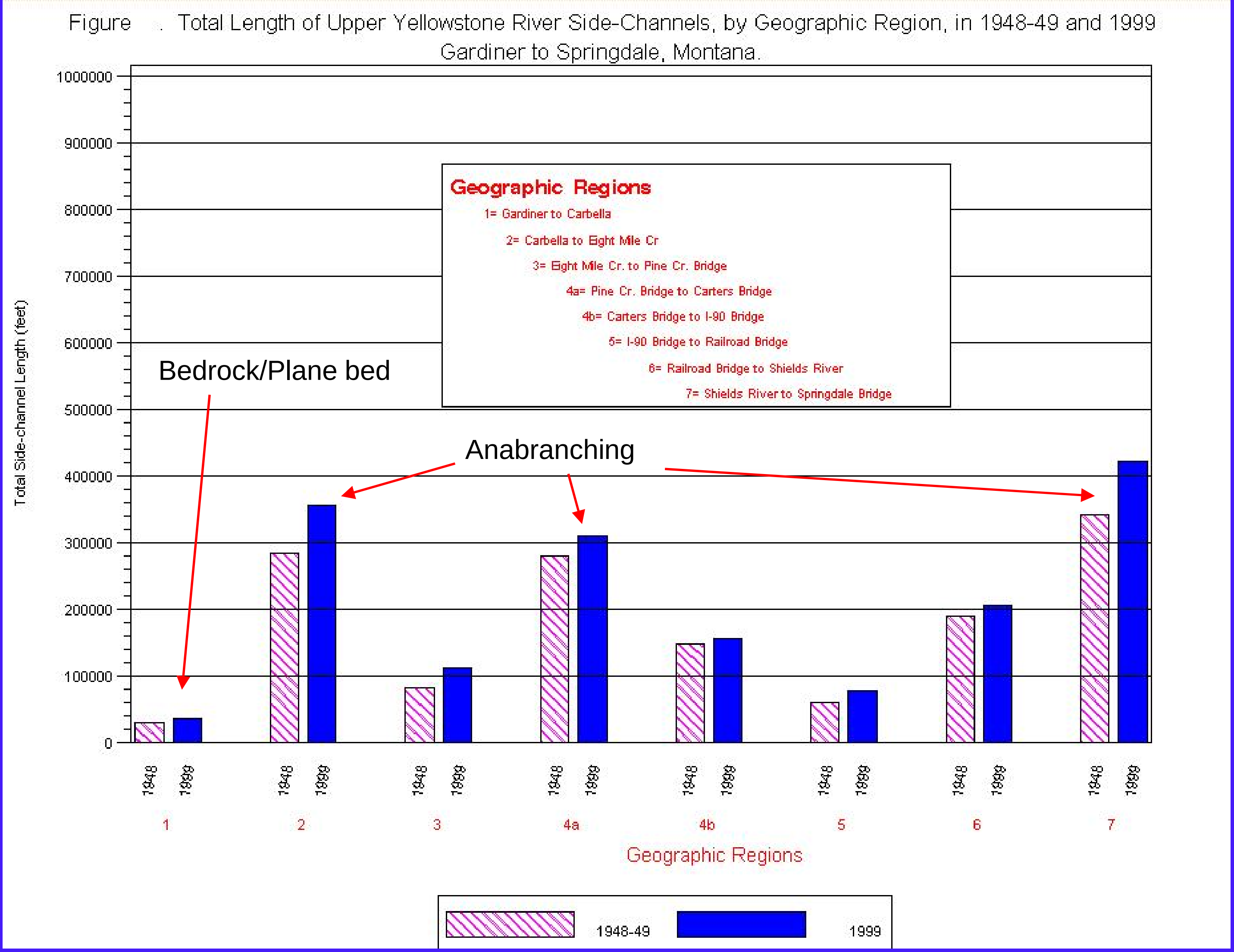
Large woody debris abundance:

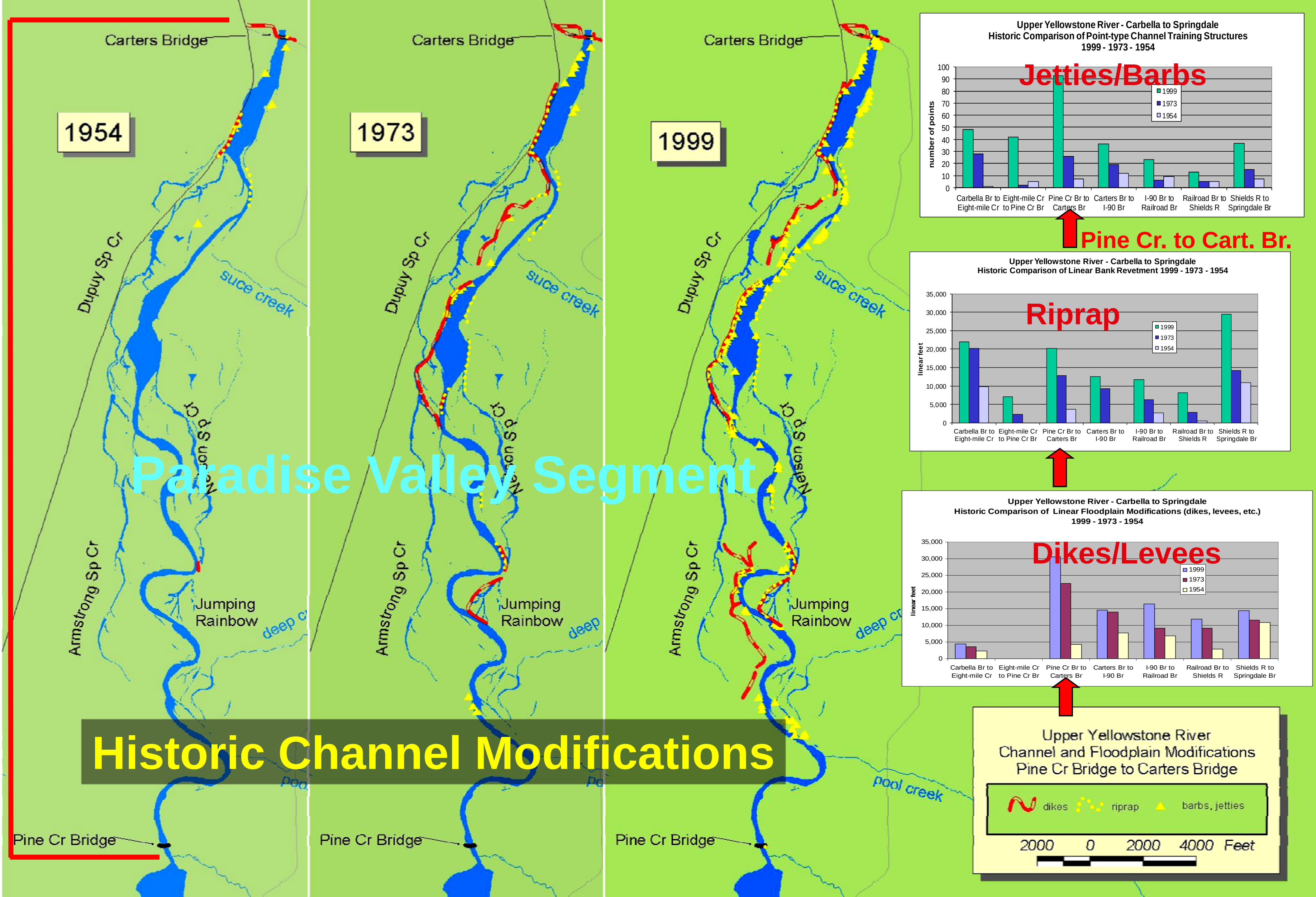
bed-cas-pln-pr-an-anbr

almost none → abundant



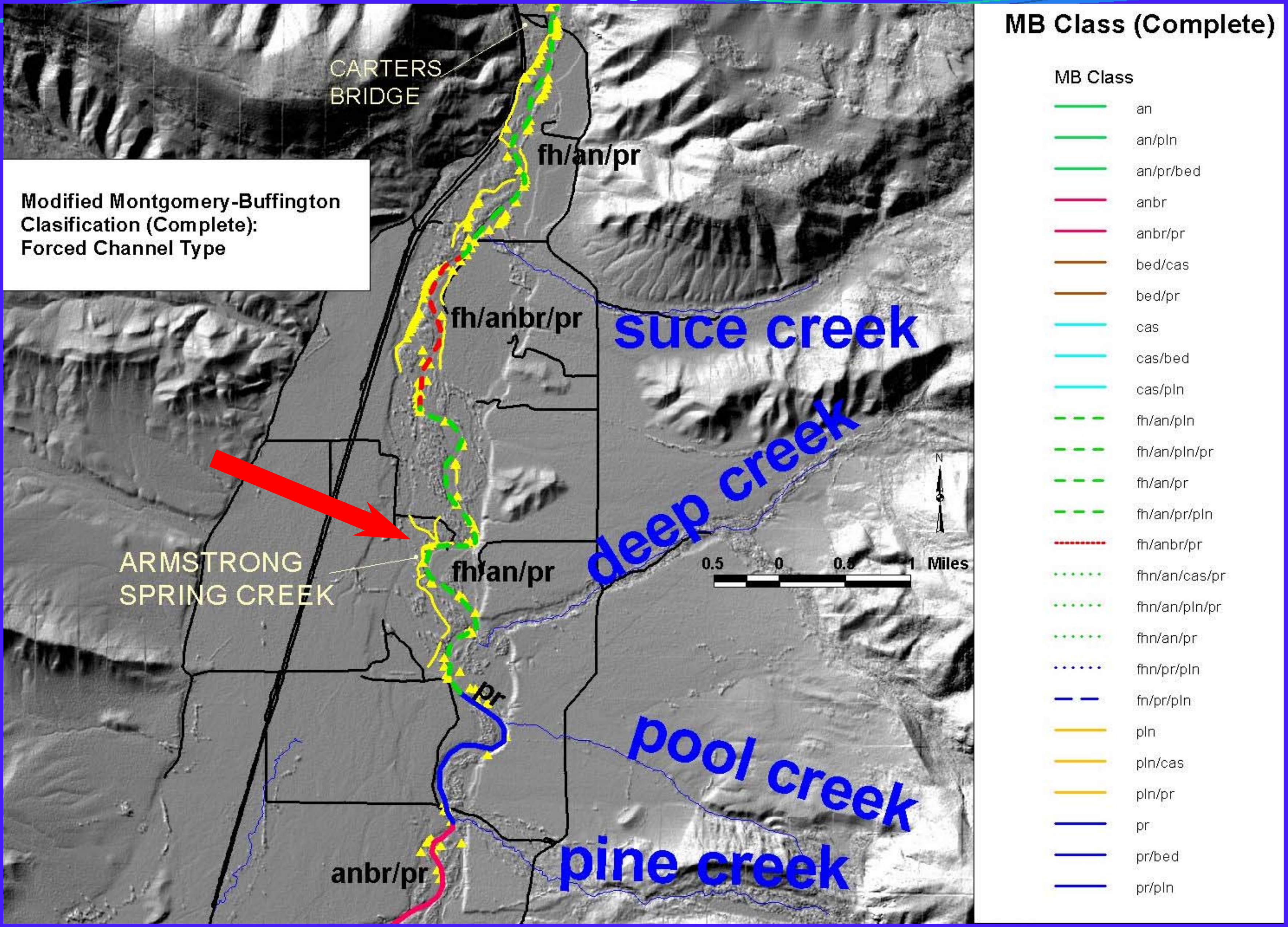
Side Channel Length by Channel Segment: Gardiner to Springdale MT.



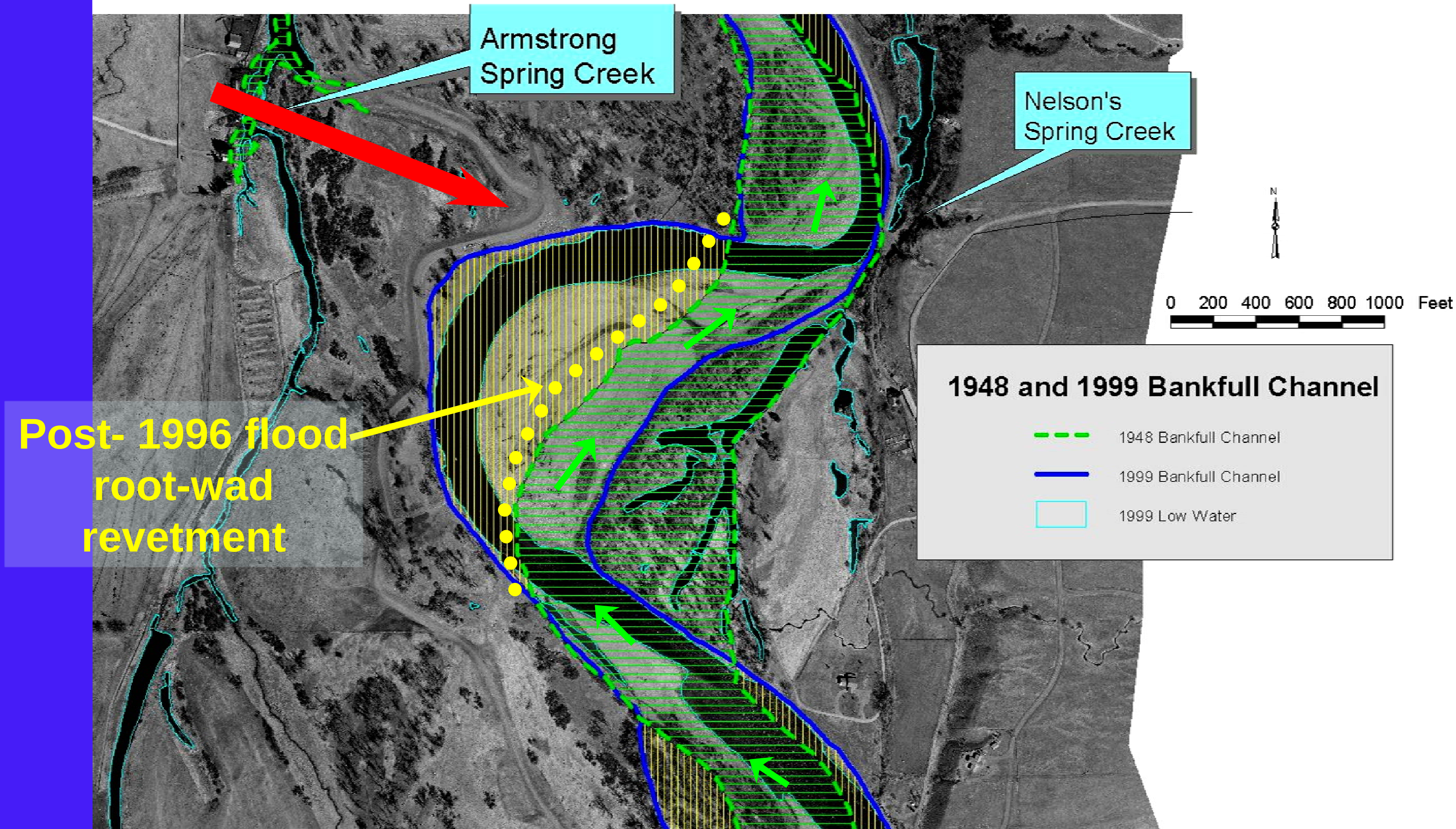


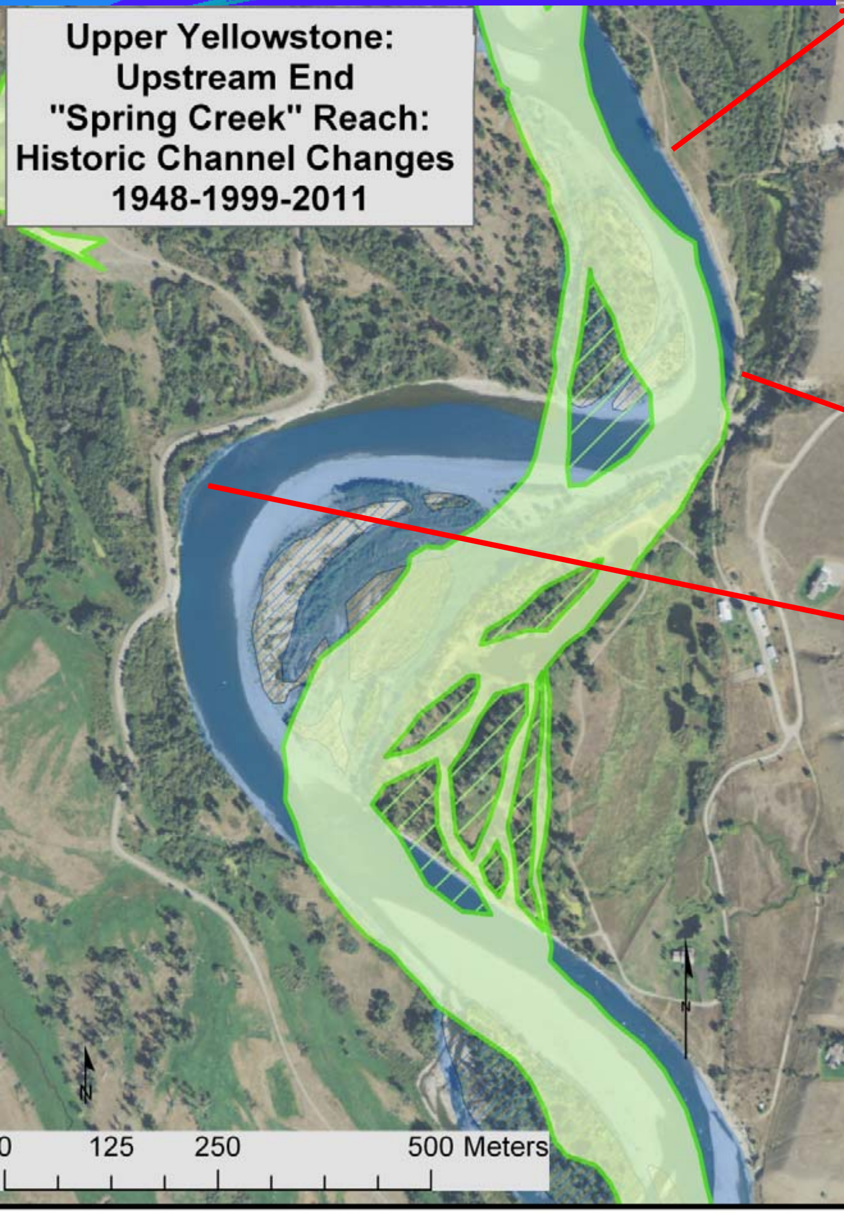
Historic Channel Modifications
Paradise Valley Segment
1954
1973
1999
Carters Bridge
Dupuy Sp Cr
suce creek
Nelson Sp Cr
Armstrong Sp Cr
Jumping Rainbow
deep cr
pool creek
Pine Cr Bridge
Upper Yellowstone River - Carbella to Springdale
Historic Comparison of Point-type Channel Training Structures
1999 - 1973 - 1954
Jetties/Barbs
number of points
1999
1973
1954
Carbella Br to Eight-mile Cr
Eight-mile Cr to Pine Cr Br
Pine Cr Br to Carters Br
Carters Br to I-90 Br
I-90 Br to Railroad Br
Railroad Br to Shields R
Shields R to Springdale Br
Pine Cr. to Cart. Br.
Upper Yellowstone River - Carbella to Springdale
Historic Comparison of Linear Bank Revetment 1999 - 1973 - 1954
Riprap
linear feet
Upper Yellowstone River - Carbella to Springdale
Historic Comparison of Linear Floodplain Modifications (dikes, levees, etc.)
1999 - 1973 - 1954
Dikes/Levees
linear feet
Upper Yellowstone River
Channel and Floodplain Modifications
Pine Cr Bridge to Carters Bridge
dikes
riprap
barbs, jetties
2000 0 2000 4000 Feet

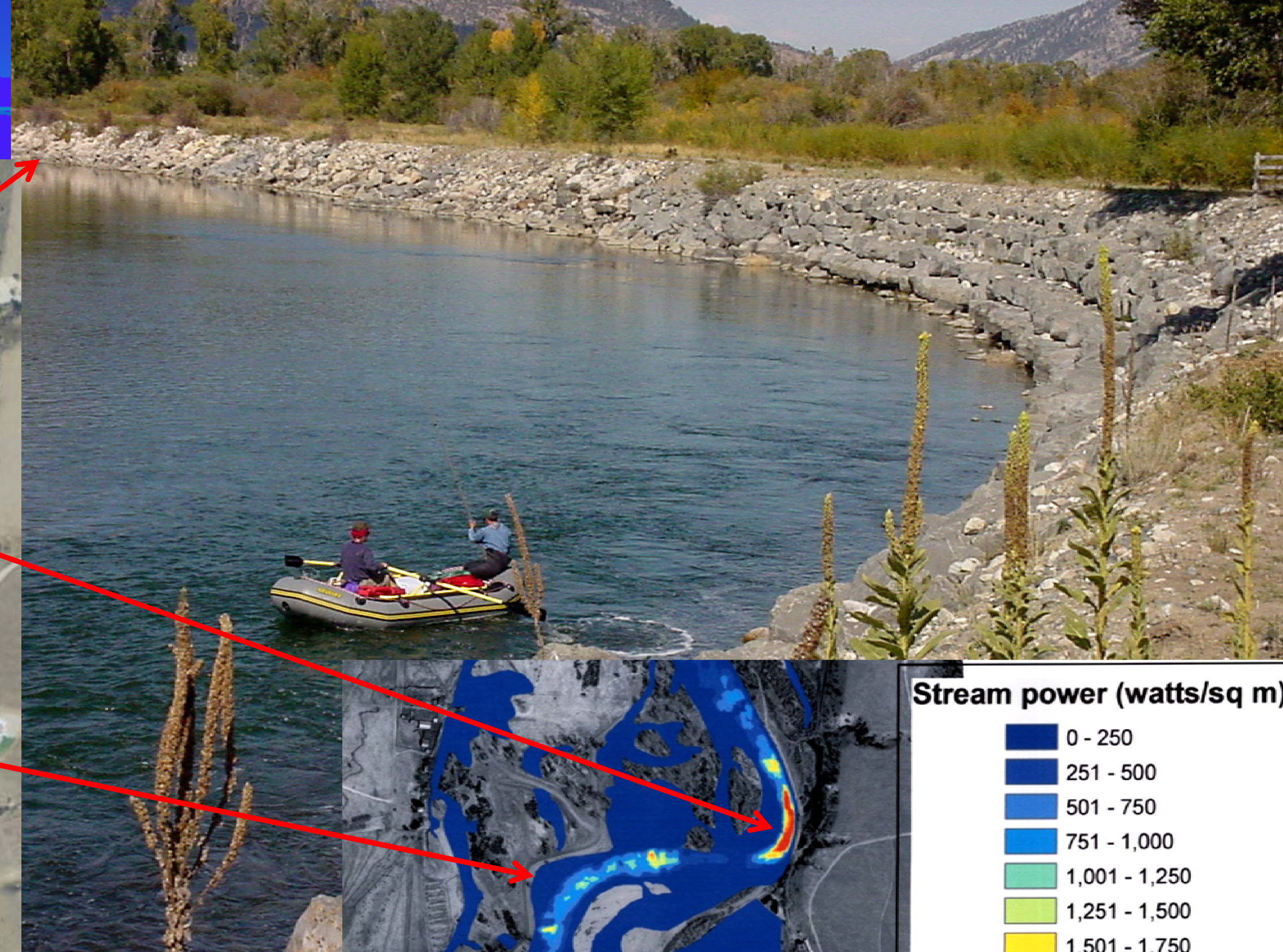
Paradise Valley Segment

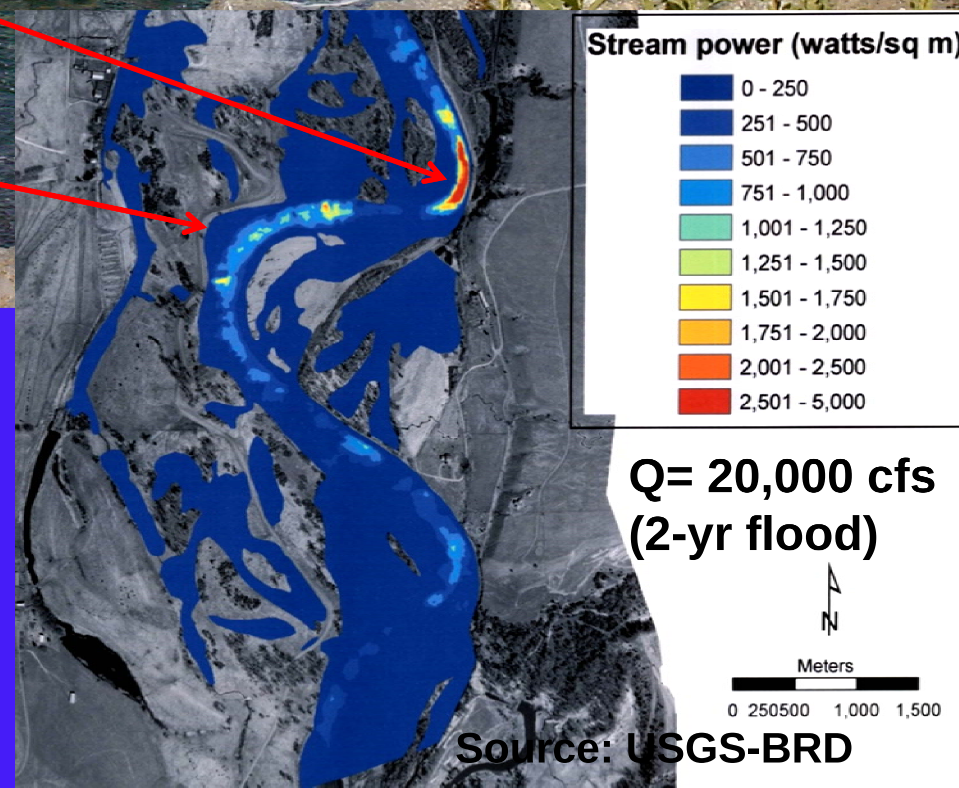


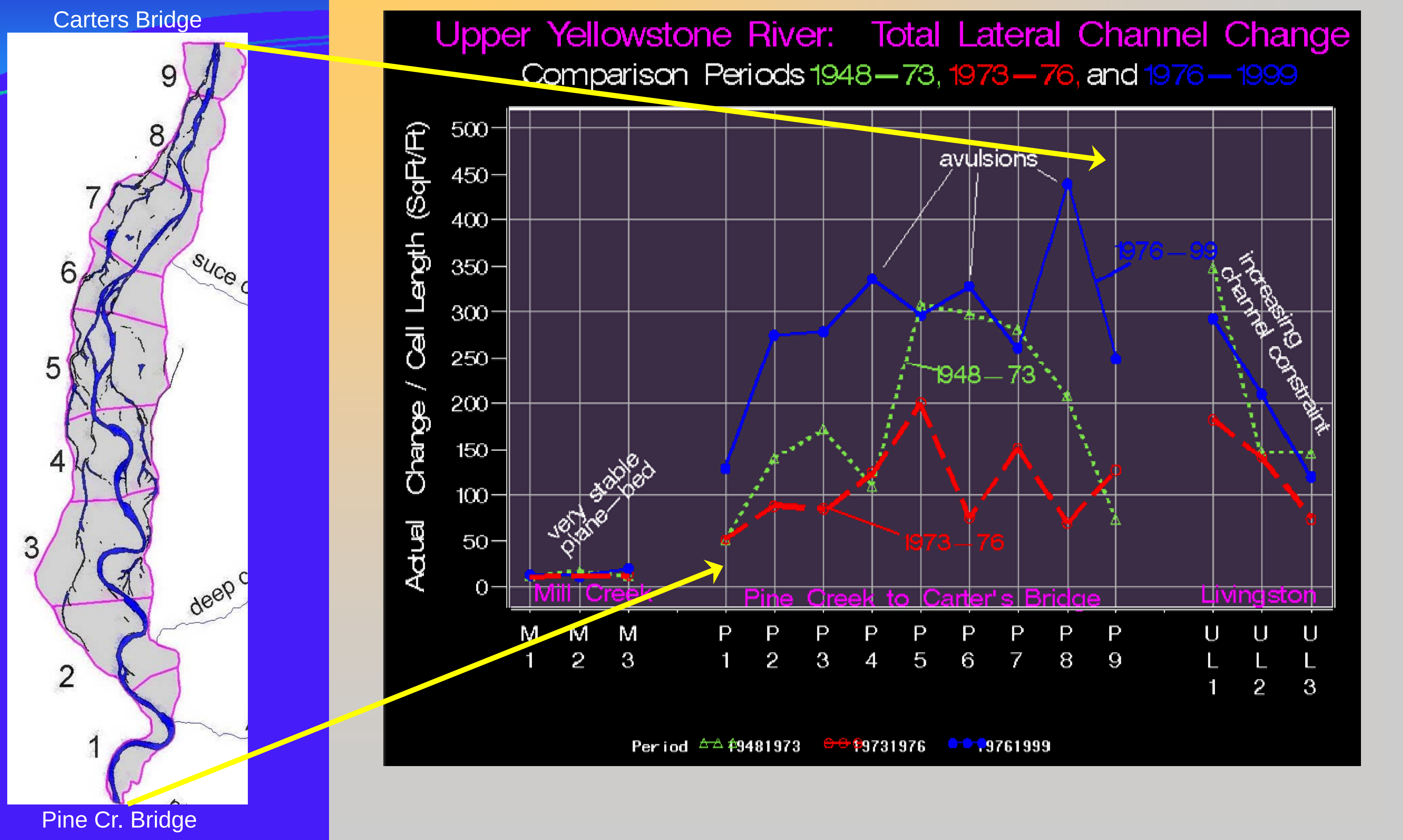
1948 to 1999 Changes in Bankfull Channel: Armstrong and Nelson Spring Creeks



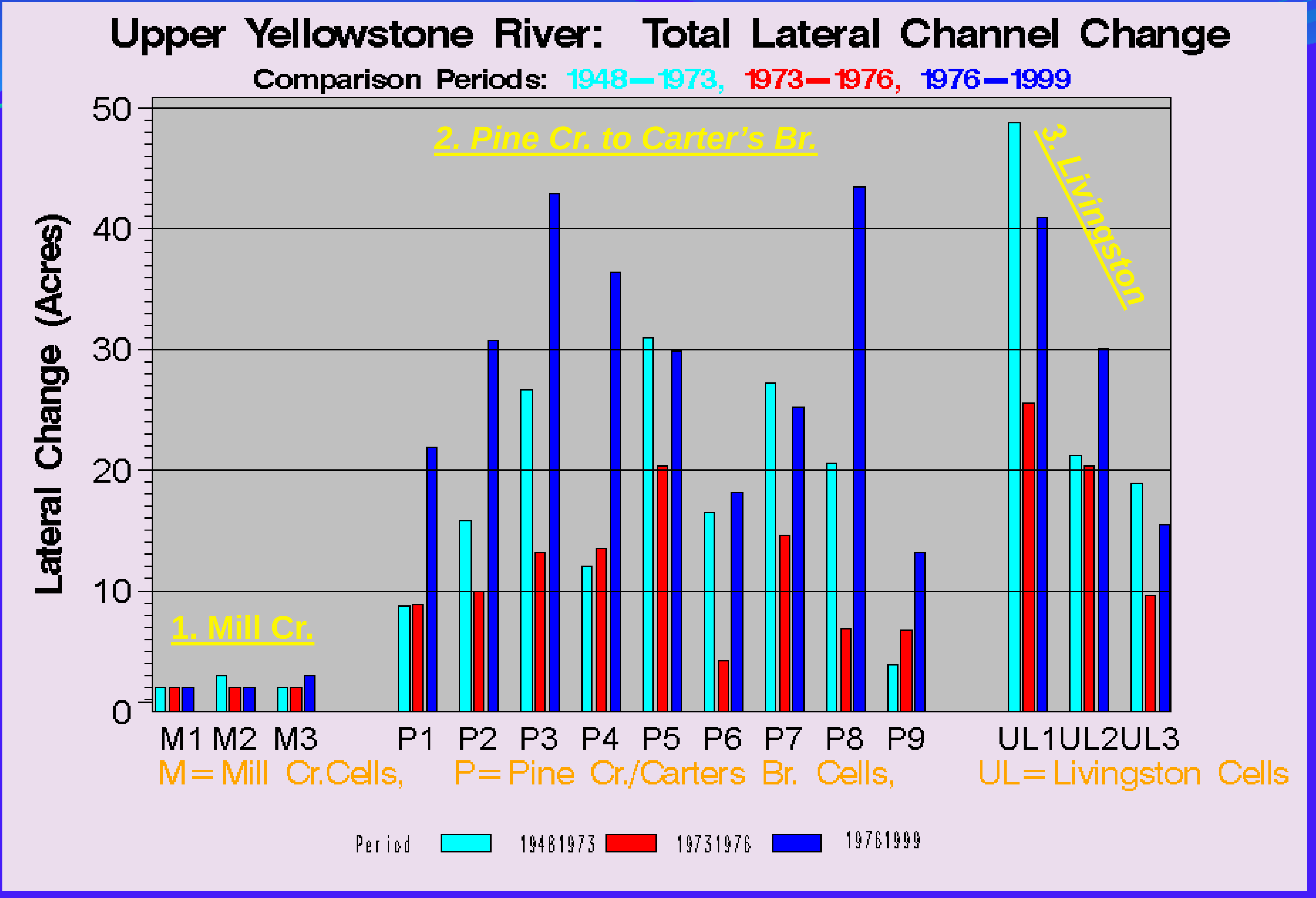

Upper Yellowstone:
Upstream End
"Spring Creek" Reach:
Historic Channel Changes
1948-1999-2011
0 125 250 500 Meters




Stream power (watts/sq m)
0 - 250
251 - 500
501 - 750
751 - 1,000
1,001 - 1,250
1,251 - 1,500
1,501 - 1,750
1,751 - 2,000
2,001 - 2,500
2,501 - 5,000
Q= 20,000 cfs
(2-yr flood)
Meters
0 250500 1,000 1,500
Source: USGS-BRD



Total Unit Lateral Channel Change 1948 to 1973, 1973 to 1976, and 1976 to 1999.
(Note: Total lateral change includes both erosion and deposition, and is defined as the area of change normalized (i.e. divided by) channel length.)



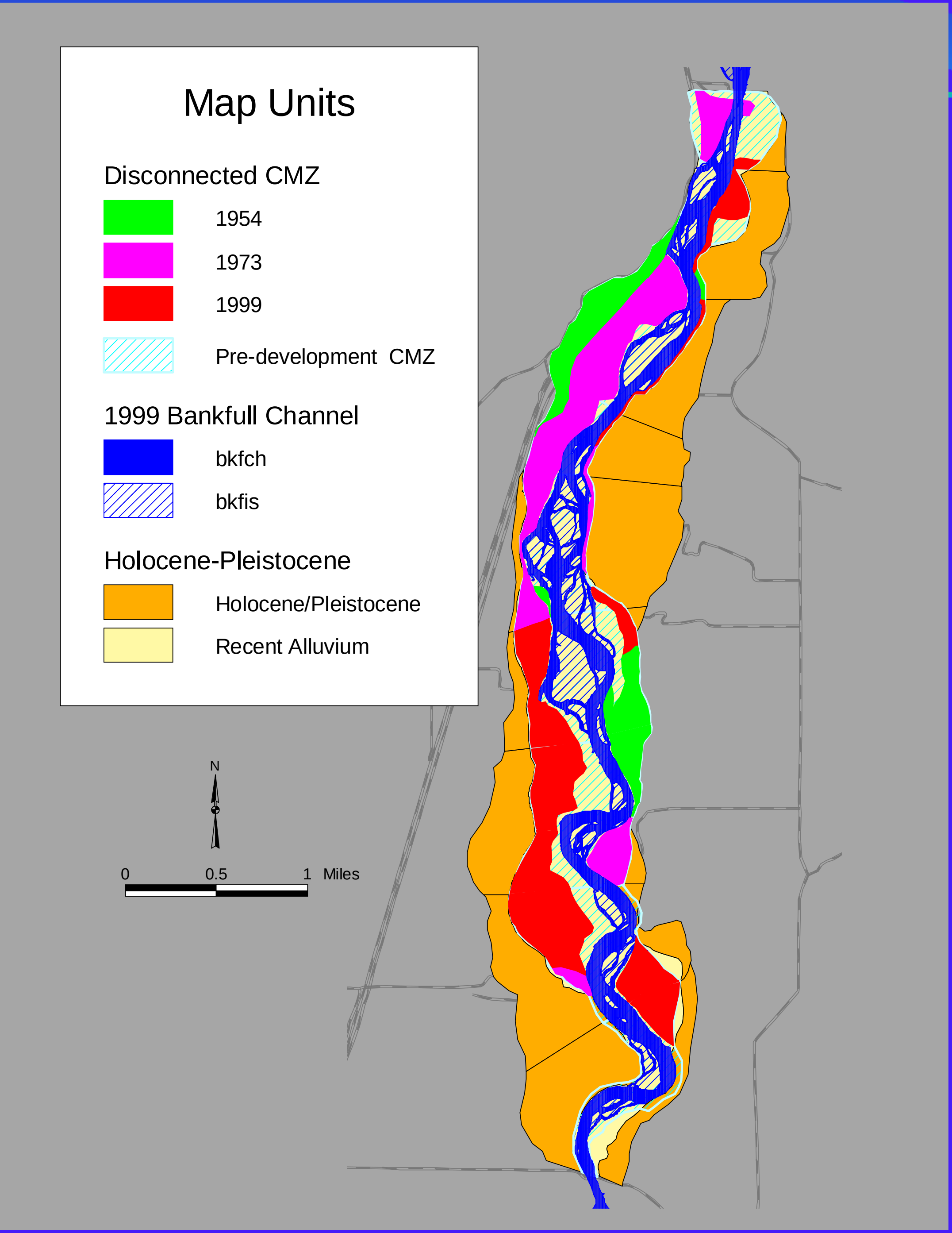
Upper Yellowstone River: Total Lateral Channel Change
Comparison Periods: 1948—1973, 1973—1976, 1976—1999
Lateral Change (Acres)
0
10
20
30
40
50
2. Pine Cr. to Carter's Br.
3. Livingston
1. Mill Cr.
M1 M2 M3
P1 P2 P3 P4 P5 P6 P7 P8 P9
UL1 UL2 UL3
M=Mill Cr.Cells,
P=Pine Cr./Carters Br. Cells,
UL=Livingston Cells
Period
19481973
19731976
19761999

Montgomery-Buffington Channel Types: Upper Yellowstone (Gardiner-Springdale)

Bedrock	5.0 mi	5.8 %
Cascade	9.6	11
Anabranching/ Braided	9.4	10.9
Anabranching	13.6	15.7
Pool-Riffle	20.9	24
Plane Bed	28.3	32.6

Forced Channels:

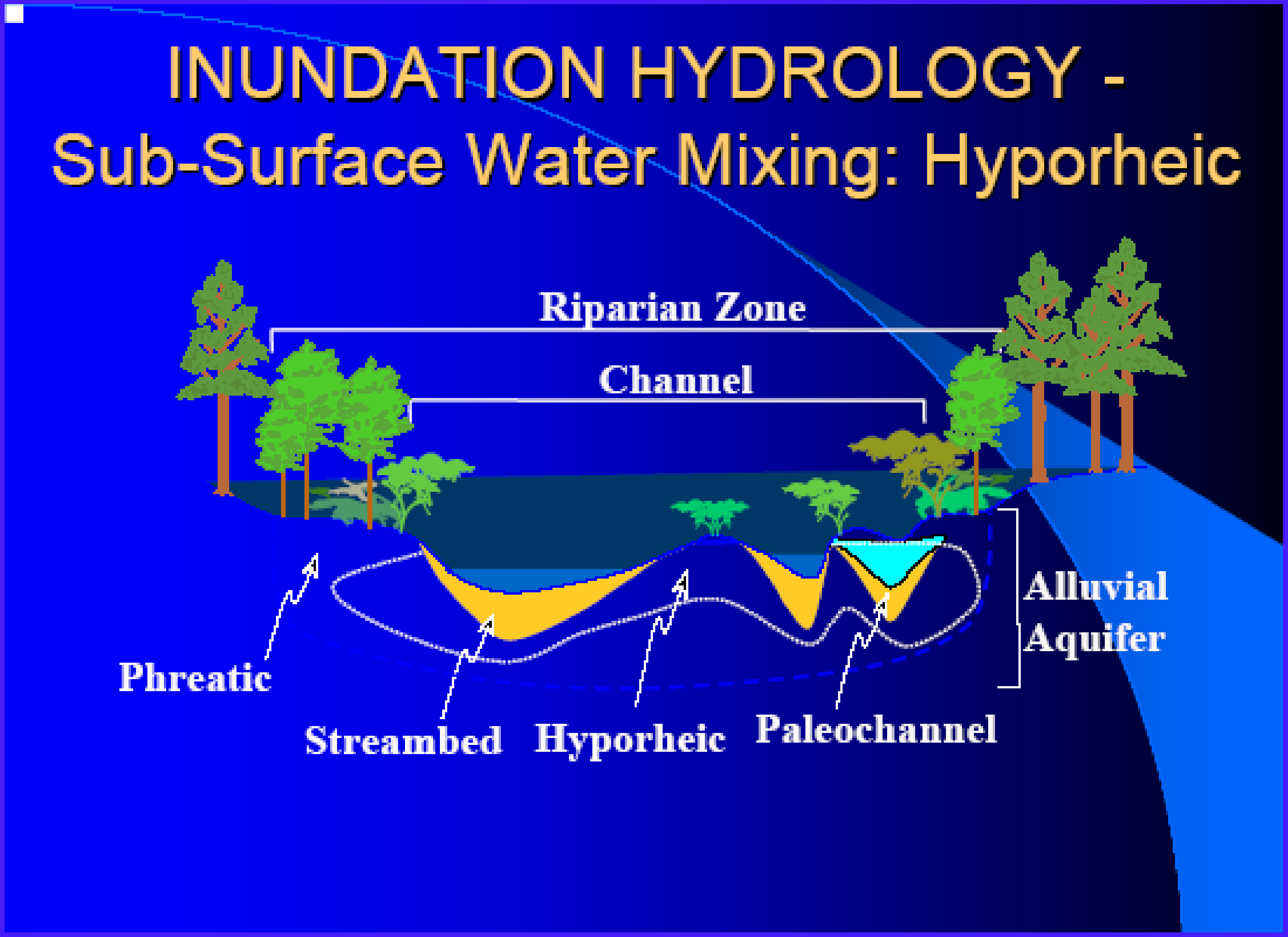
Human	11.8	13.6%
Natural/Human	4.9	5.6



Channel Migration Zone between Pine Creek and Carters Bridge largely disconnected from flood plain by dikes, levees, and bank revetment between 1954 and 1999

Flood plain and channel benefits* scale directly with width of “active” flood plain (Power et al. 1995)

* hyperheic exchange, nutrient cycling, water temperature moderation, aquatic and terrestrial wildlife habitat



3. How effective are large floods (e.g. 100 yr. peak) in shaping the fluvial landscape -- compared with more recent events—1.5 to 2 yr. peak ? What is channel forming discharge ?

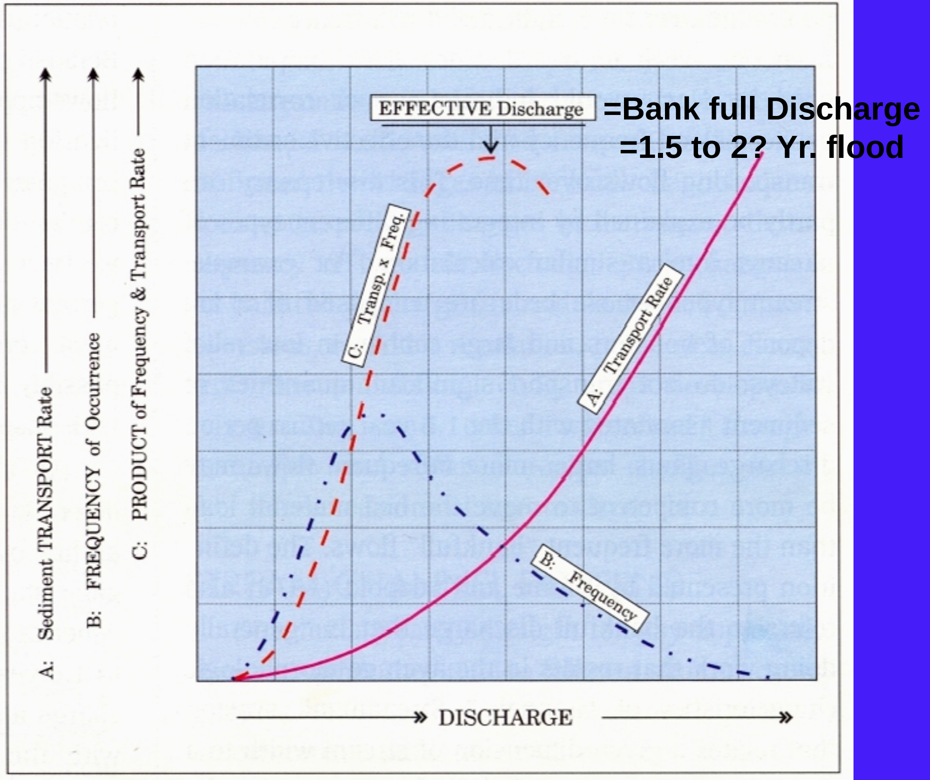


FIGURE 2-2. Relations between DISCHARGE, Sediment TRANSPORT Rate, FREQUENCY of Occurrence, and the PRODUCT of Frequency and Transport Rate. *(After Wolman and Miller, 1960)*

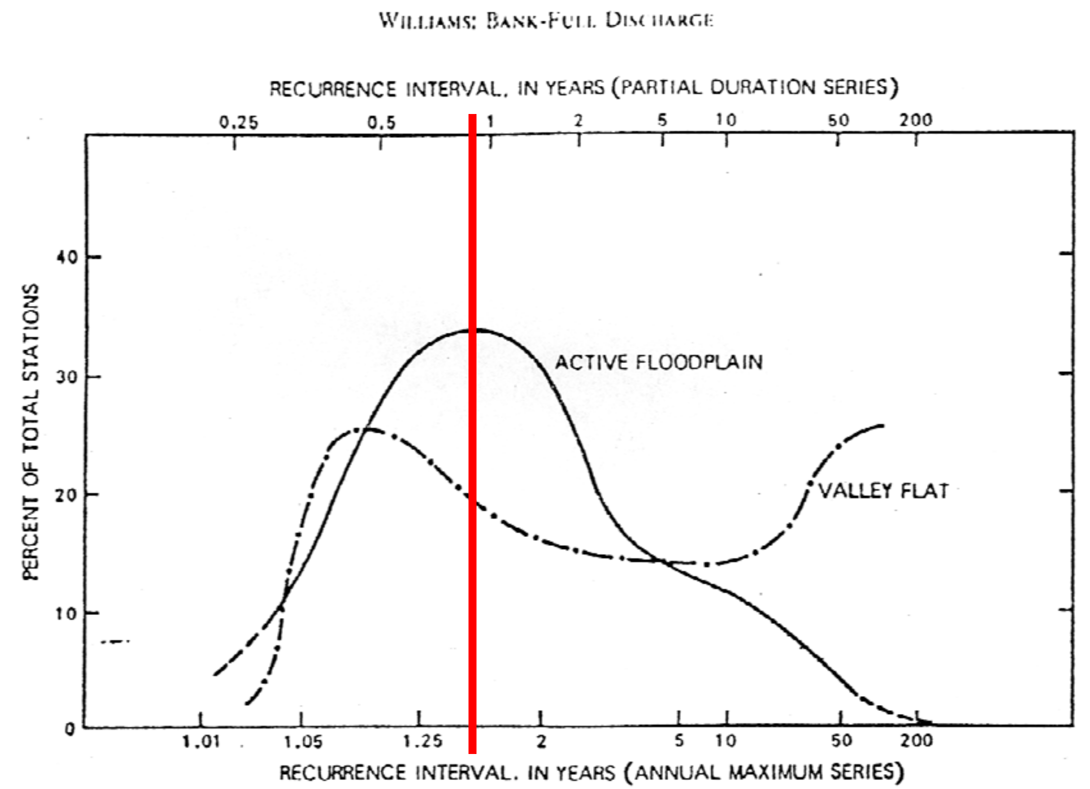
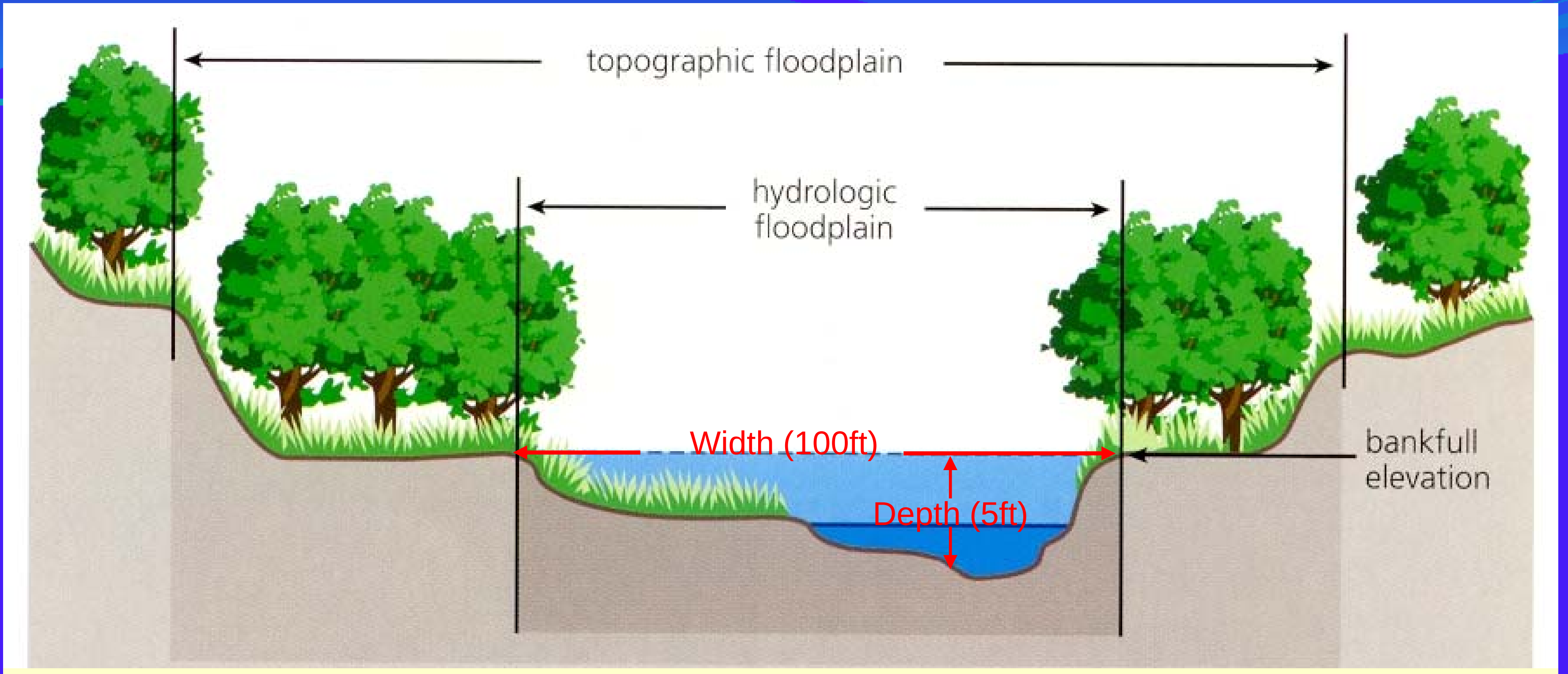


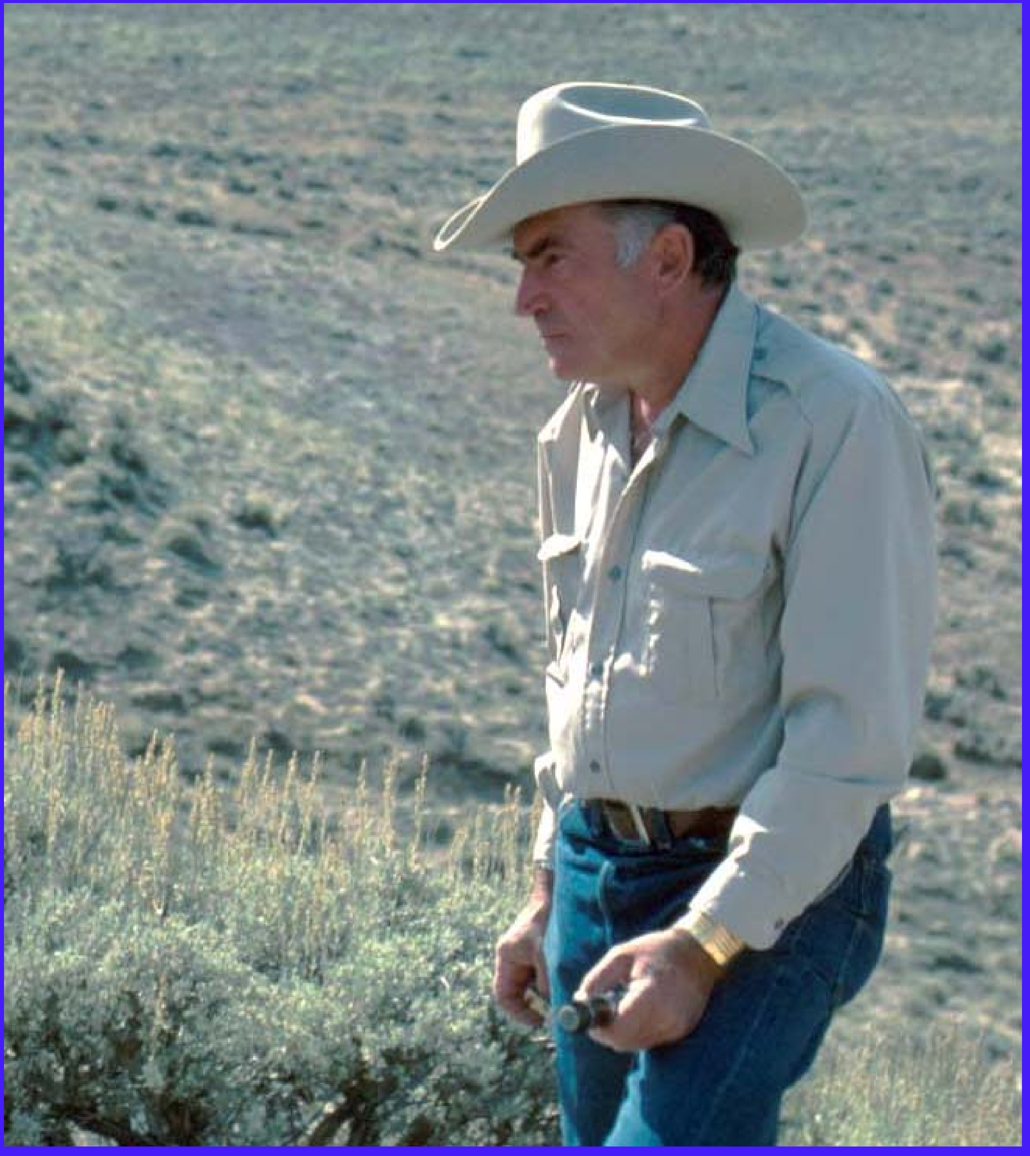
Fig. 2. Frequency distribution of recurrence intervals for bank-full flow.



Definition of bankfull stage

(Ideal Channel)

Problems with BANKFULL Stage as indicator of channel forming discharge



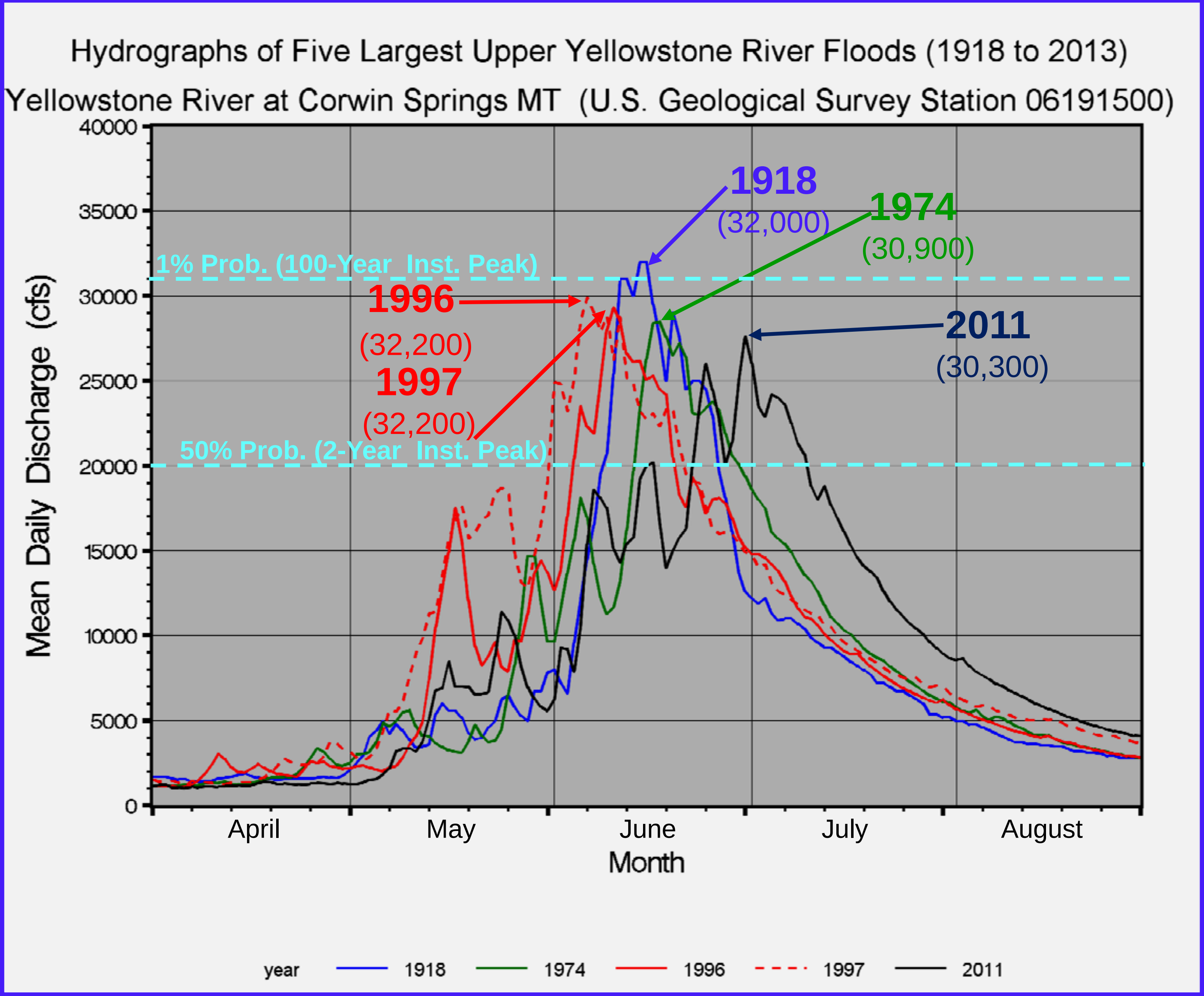
Bankfull Dogma
(no disrespect intended)

be sure to visit UC Berkeley's
Virtual Luna B. Leopold site
http://eps.berkeley.edu/people/lunaleopold/

Qbkf always = 1.5 to 2 year inst.pk flow ?

Cases when it may not be:

a. Steep streams in coarse material (and step-pool channels)
b. Channels enlarged after significant floods
c. Arid-lands where mass-wasting dominates
d. Disturbed channels, aggrading channels, incising channels



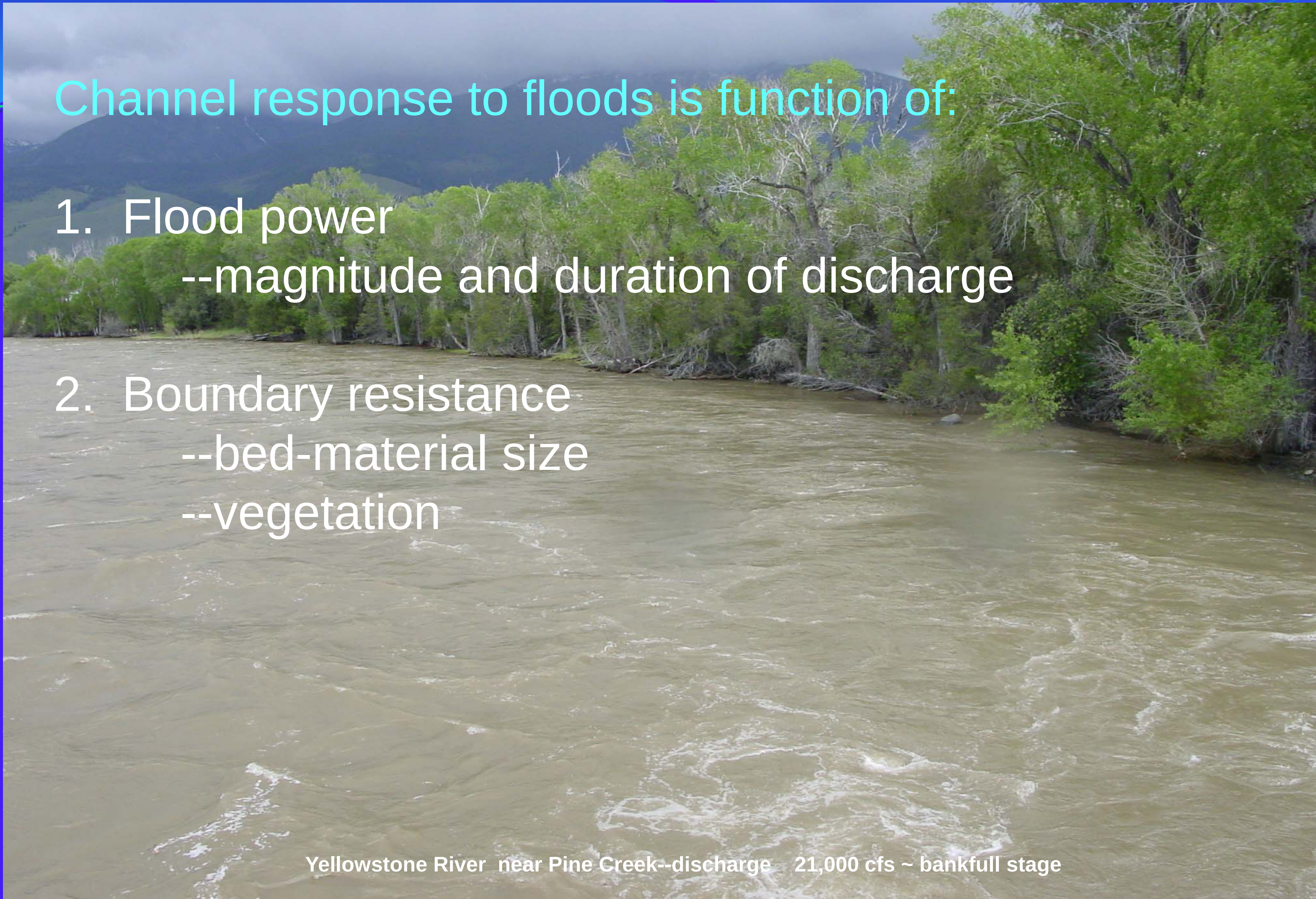
Hydrographs of Five Largest Upper Yellowstone River Floods (1918 to 2013)
Yellowstone River at Corwin Springs MT (U.S. Geological Survey Station 06191500)
Mean Daily Discharge (cfs)
40000
35000
30000
25000
20000
15000
10000
5000
0
April
May
June
July
August
Month
1% Prob. (100-Year Inst. Peak)
50% Prob. (2-Year Inst. Peak)
1918
(32,000)
1974
(30,900)
1996
(32,200)
1997
(32,200)
2011
(30,300)
year
1918
1974
1996
1997
2011


Upper Yellowstone bankfull, base of woody vegetation = ~ 2 to 5 yr. inst. peak--but don't forget importance of large events for maintaining anabranches

Channel response to floods is function of:

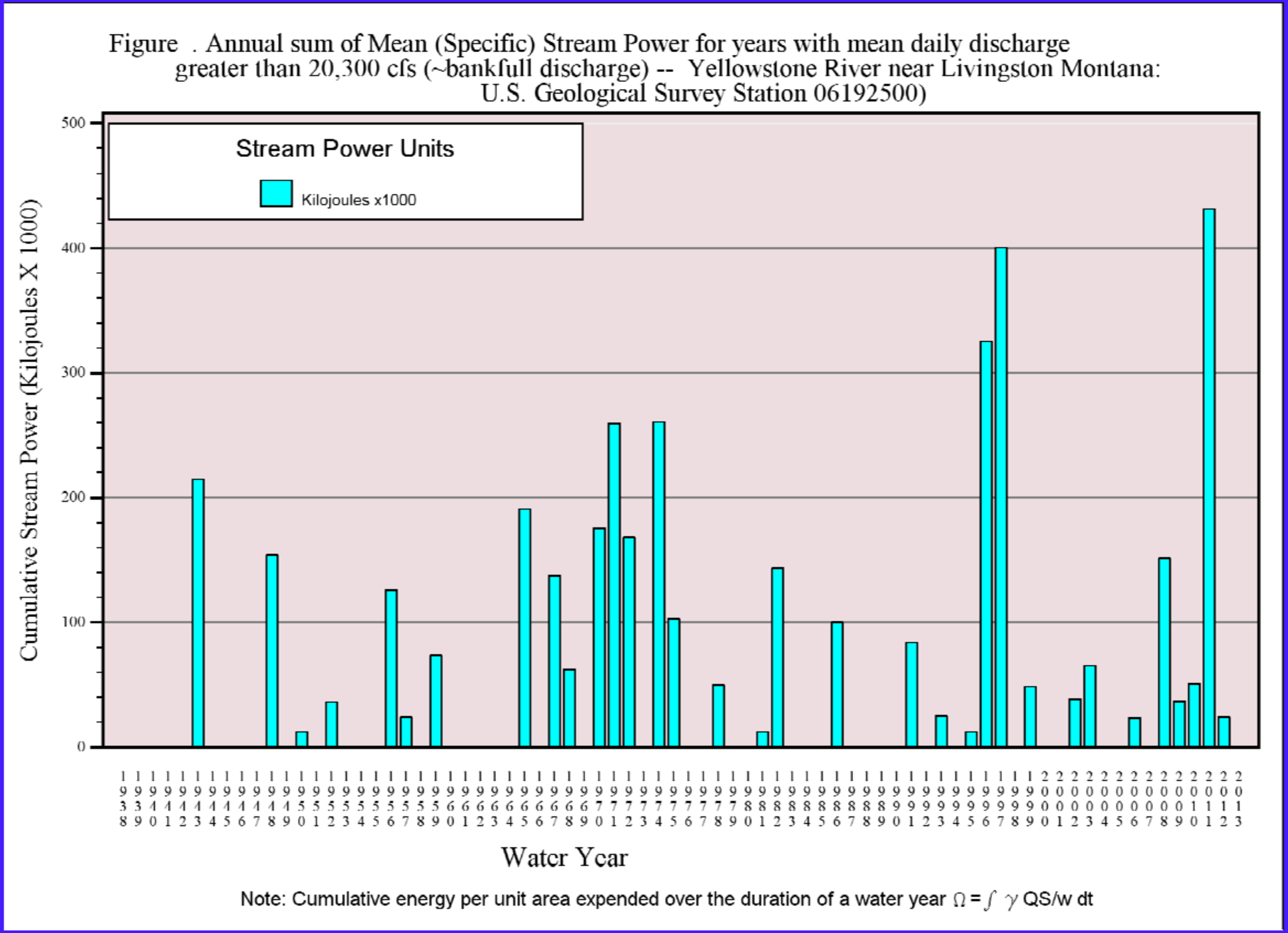
1. Flood power
   --magnitude and duration of discharge

2. Boundary resistance
   --bed-material size
   --vegetation



Yellowstone River near Pine Creek--discharge 21,000 cfs ~ bankfull stage

Geomorphically effective stream power: In the Upper Yellowstone basin >50% of stream power, at flows > 2yr flood, expended in 6 flood years between 1938 and 2013.



Side channels created and maintained by 100-year (and greater) peak flows

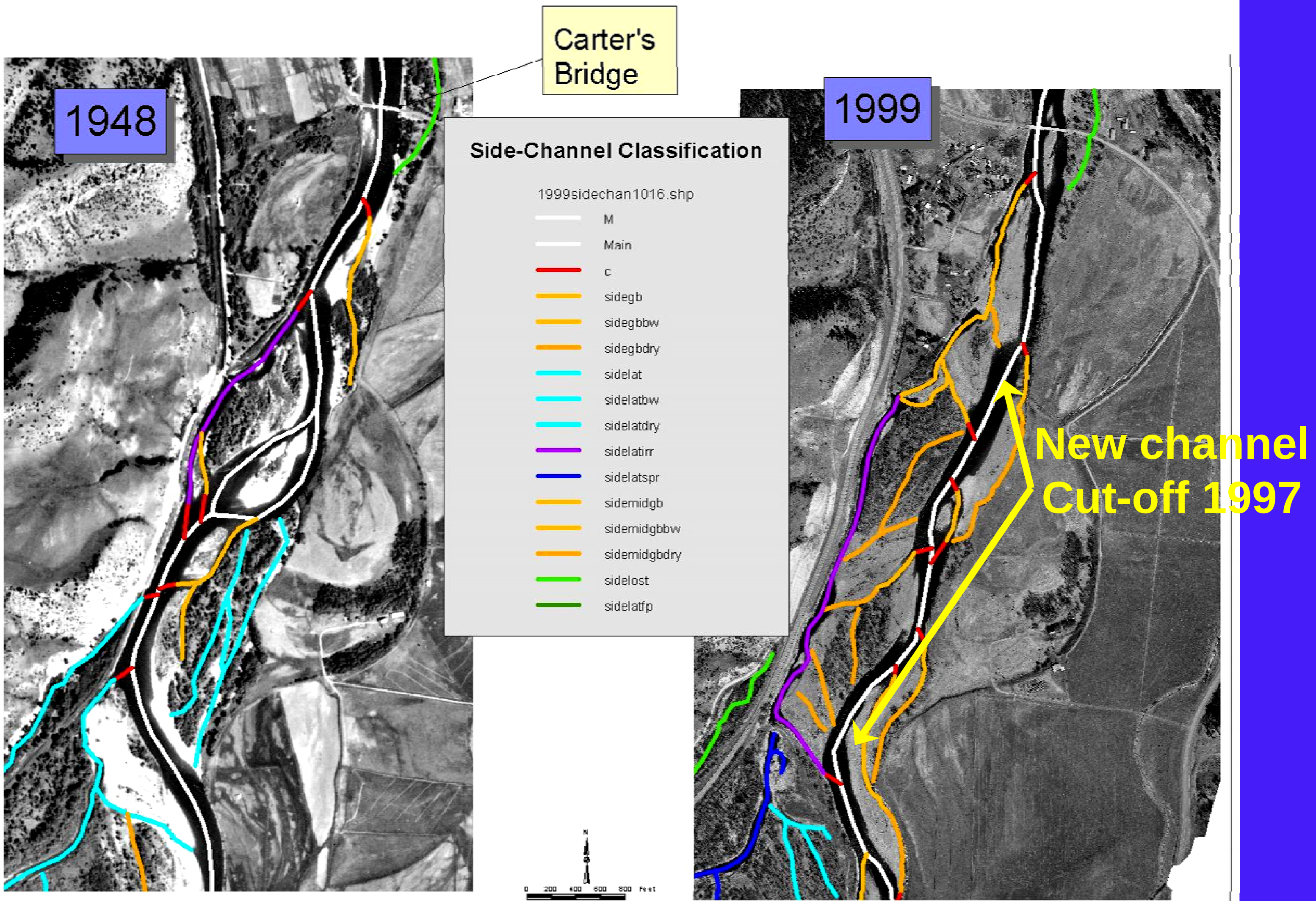
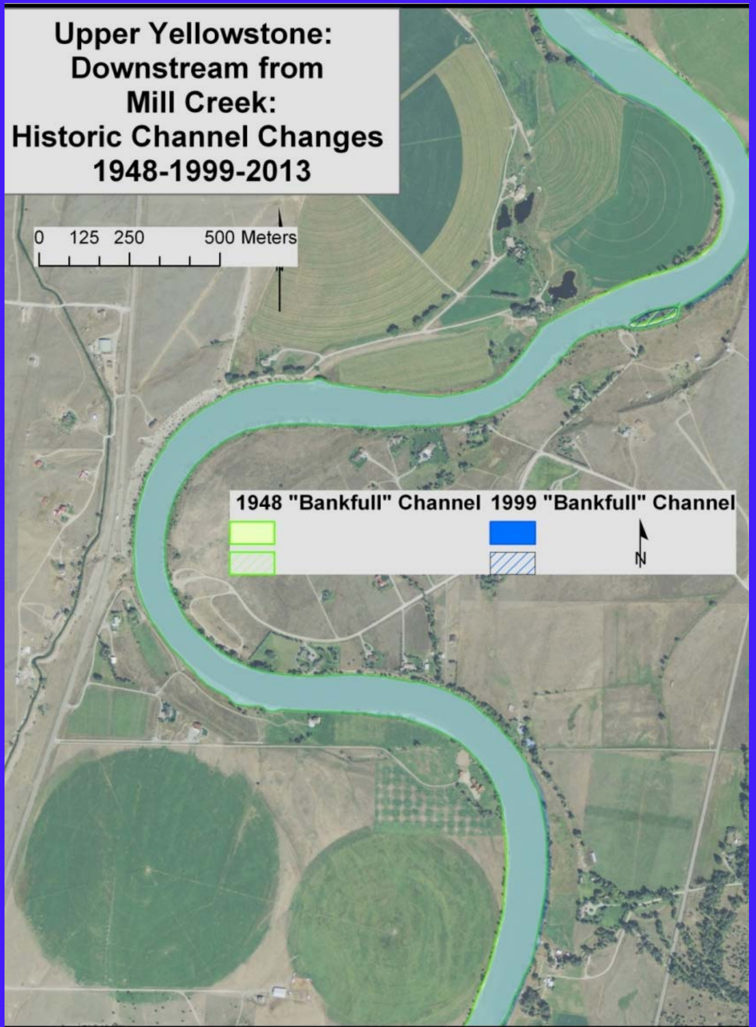


Figure 3b Main channel and side channels between Carters Bridge and outlet from Depuy's Spring Creek. Note loss of side channels in southwest and northeast of view, and creation of side channels associated with new gravel bars.
(Note: red line, C , denotes connection to main channel. Length of line not included in side channel inventory).

"Bankfull" channel geometry of pool-riffle and anabranching channels maintained by ~2-5 year floods

Plane bed channels nearly static--even in 100-year floods (channel forming flow ?)



Summary

Paradise Valley glacial history has strongly influenced the current-day distribution of geomorphic channel types

Human channel modification has significantly affected about 14% of mainstem in the study area, with about 5% of the channel disconnected from the floodplain

Channel forming flows in pool-riffle and anabranching channel segments include large floods that create side channels and more frequent flows with return periods close to the conventional "bankfull" discharge (e.g. 2 to 5- year floods), that shape and maintain average characteristics main channel and individual anabranches.