Use of Channel Migration Zone Analysis to Evaluate Effects of Channelization and Identify Opportunities for Restoration: Upper Yellowstone River, Park County, Montana

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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

1. Delineate CMZ for Upper Yellowstone River;

2. Examine extent of CMZ relative to Holocene and Pleistocene alluvium;

3. a) Estimate effect of historic and, b) future channel confinement on extent of pre-development CMZ;

4. Identify opportunities for restoration.
Location and Channel Characteristics:

- 75 mile segment
- Gravel-Cobble, Boulder Bed
- Bed-slope 0.001 to 0.005
- $Q_2 = 20,000$ cfs ($560$ m$^3$/s)

Yellowstone National Park
Longitudinal Channel Profile: Gardiner to Springdale Montana

(Data from USGS and USACE orthophotography and topographic mapping. Data compiled by DNRC–WRD Helena, MT.)
Particle Size Distribution: Selected Sites Upper Yellowstone River
Corwin Springs to Livingston, MT
(Upstream end of alternate bars and point bars)

Distance Downstream (km)

Grain Size (mm)

D10
D25
D50
D75
D90

[Surface particle size measured using grid method, template and ~300 particles
Channel Distance measured from USGS - WRD X - sec 160, D.S. Gardiner Bridge]
Coarse-bed channel
Hydrographs of Four Largest Upper Yellowstone River Floods
U.S. Geological Survey Station 06191500—Yellowstone River at Corwin Springs MT

Mean Daily Discharge (CFS)

100-Year R.I. (Inst. Peak)

2-Year R.I. (Inst. Peak)

MONTH

year 1918 1974 1996 1997
1954-1999 Historic Analysis of Channel Modifications:

Dikes and levees > 265% (35,000 to 92,000)
Riprap > 400% (28,000 to 111,000 feet)

Point structures (i.e. jetties and barbs) > 600% (from 50 to 290).
1948 to 1999 Changes in Bankfull Channel: Armstrong and Nelson Spring Creeks

Armstrong Spring Creek

Nelson’s Spring Creek

Post-1996 flood-root-wad revetment

1948 and 1999 Bankfull Channel

- 1948 Bankfull Channel
- 1999 Bankfull Channel
- 1999 Low Water
Q = 20,000 cfs (2-yr flood)

Source: USGS-BRD
1. Delineate CMZ for Upper Yellowstone River

- Selection of Historical Aerial Photos
- Mapping of Historic Migration Zone
- Mapping of Avulsion Hazard Zone
- Estimation of Erosion Hazard Area

\[ \text{CMZ} = \text{HMZ} + \text{AHZ} + \text{EHA} - \text{DMA} \]

(Rapp and Abbe (2003)—Washington State Method)
Figure: Historic Annual Peak Flows: Yellowstone River near Livingston, MT
U.S. Geological Survey Station 06192500

Observed data (for 1897–1905, 1929–1932, 1938–2001) and flood frequency recurrence intervals from USGS—WRD Helena, MT.

Missing record estimated by correlation with Corwin Springs station from Meriglliano 2001
**Figure**. Annual sum of Mean (Specific) Stream Power for water years with mean daily discharge greater than 20,300 cfs (~bankfull discharge) -- Yellowstone River near Livingston Montana: U.S. Geological Survey Station 06192500.

**Note**: Average energy per unit area expended over water year calculated as, \( \Omega = \int \gamma Q S / w \, dt \) where, \( \gamma \) = specific weight of water (9800 N/m\(^2\)), \( Q \) = mean daily stream discharge (m\(^3\)), \( S \) = energy gradeline, \( w \) = width of flow (m), \( t \) = time (days). Assumed constants = \( \gamma \) and \( S \) (0.0024), mean daily flow width estimated from LOESS fit of water-surface width against historic instantaneous discharge measurements for period of record 1938 to 2003.
Lateral Channel Changes

- NCFP
- D
- E
- NG

200 0 200 400 800 1000 1200 2000 Feet

Pine Creek to Carter’s Bridge

“Bankfull” channel

1999
1976
1973
1948
Uncertainty derives from three principal sources:

- positional error in image data;
- delineation (or digitizing) error; and,
- feature identification error.

Channel changes measured on temporal sequences of rectified images (e.g. aerial photos) are valid only if the amount of change exceeds errors inherent in successive traces of features (e.g. bankfull banklines) compared over time.
Total error: ±33 to ±57 feet:
15 to 20% of CMZ width at narrowest (500 ft)
<1% at widest (3500 feet)...........but ±~60 feet
(can be significant!)

[Image of a river bank with erosion]
2. Extent of CMZ relative to Holocene and Pleistocene alluvium;

- Pre-development CMZ = 54% of geologic floodplain (recent and Holocene/Pleistocene fluvio-glacial alluvium), and 90% of recent (~1500 year) floodplain;
3a. Estimate effect of historic channel confinement on extent of pre-development CMZ.
43% of pre-development CMZ disconnected by bank protection and other flood plain development between 1948 and 2005.
Plate 4. 100-Year Channel Migration Zone: Pine Creek to Carter's Bridge

1999 Channel: Pine Creek to Carter's Bridge

- Holocene / Pleistocene alluvium
- Recent Alluvium
- 100-year Channel Migration Zone (CMZ)
- Disconnected CMZ

1999 dikes and levees
- dike

1999 jetties and bars
- LB rock barb
- LB rock jetty
- RB rock barb
- RB rock jetty

1999 riprap
- LB rip rap
- RB rip rap
Livingston Area: ~80 % of pre-development CMZ disconnected by bank protection and other flood plain development between 1948 and 2005.
Flood plain and channel benefits* scale directly with width of “active” flood plain (Power et al. 1995)

* hyporheic exchange, nutrient cycling, water temperature cooling, aquatic and terrestrial wildlife habitat
3.b. Estimate Effect of Future Flood Plain Development On Channel Migration Zone

A. Overlay subdivision platts, and eroding bank inventory—assume developed “high” erosion risk sites will eventually protect banks;

B. Assume illustrative future levels of subdivision and Trophy home development, and associated floodplain transportation corridors;

C. Estimate additional disconnected migration area associated with development
4. Opportunities for Restoration

♦ Improve permitting process (do no further harm):
  1. Recognition of importance of maintenance of CMZ;
  2. Identify segments of "special concern", where the level of design, permit scrutiny, and monitoring are robust:

♦ Conservation Easements: Work with locals and conservation groups to establish restoration management zones (easements) that permit lateral erosion through use of “alternative” restoration treatments and removal of revetment;
Thank You!
Upper Yellowstone River: Total Lateral Channel Change


Actual Change / Cell Length (Sq/Ft)

- Very stable plane bed
- Avulsions
- Increasing channel constraint


Locations:
- Mill Creek
- Pine Creek to Carter's Bridge
- Livingston

Graph shows changes in channel length and shape over different periods.