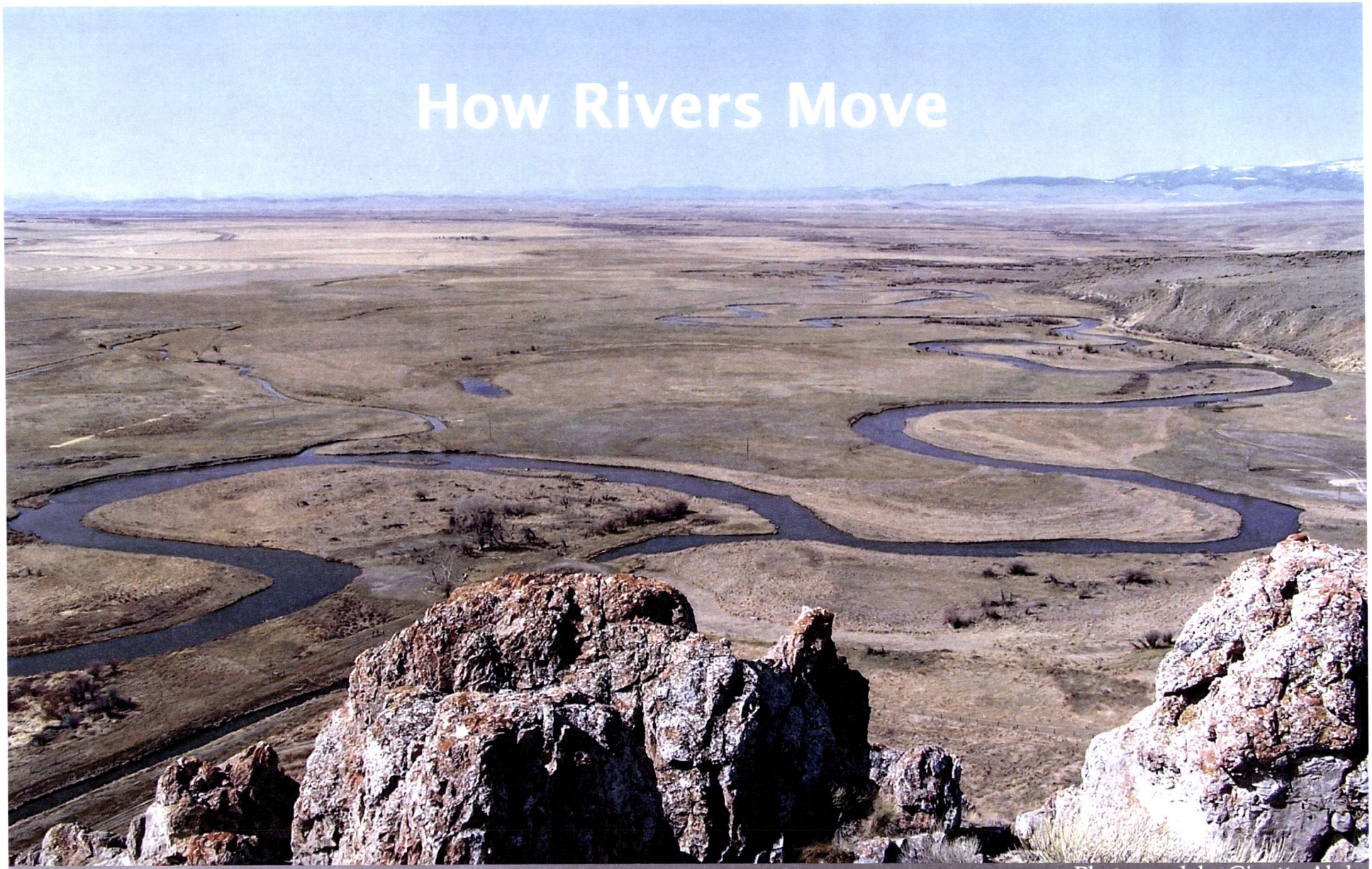
How Rivers Move



Photograph by Ginette Abdo

John Metesh
Presented to Water Policy Interim Committee
September 13, 2011
Helena, MT

WPIC
September 13, 2011
Exhibit 4

Montana Bureau of Mines and Geology
Earth Science Information

The Jargon

(maybe some other time)

Bank Erosion Hazard Index (BEHI)
Quantifies the potential or risk for stream bank erosion, using numeric
values range from 5 to 50, signifying relatively very low to relatively extreme erosion potential (Rosgen)

Hazard or Risk Rating		Bank Height to Bankfull Height (Ratio)	Root Depth to Bank Height (Ratio)	Root Density (%)	Bank Angle (Degrees)	Surface Protection (%)	Totals
Very Low	Value	1.0-1.1	1.0-0.9	100-80	0-20	100-80	
	Index	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	5-9.5
Low	Value	1.11-1.19	0.89-0.5	79-55	21-60	79-55	
	Index	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	10-19.5
Moderate	Value	1.2-1.5	0.49-0.3	54-30	61-80	54-30	
	Index	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	20-29.5
High	Value	1.6-2.0	0.29-0.15	29-15	81-90	29-15	
	Index	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	30-39.5
Very High	Value	2.1-2.8	0.14-0.05	14-5.0	91-119	14-10	
	Index	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0	40-45
Extreme	Value	> 2.8	< 0.05	< 5	< 119	< 10	
	Index	10	10	10	10	10	46-50

Perennial streams Water flows in the stream at least 90 percent of the time in a well defined channel.

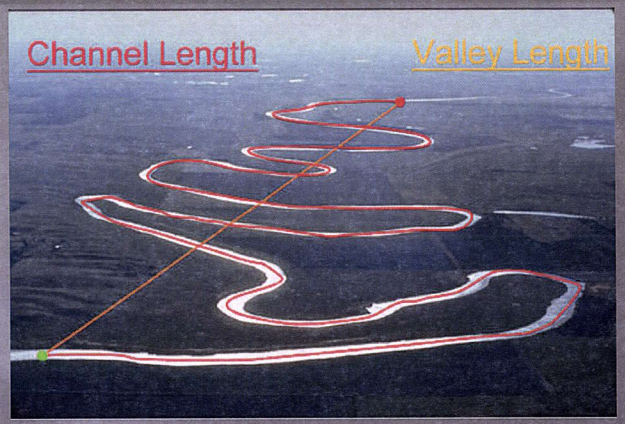
Intermittent streams Flow generally occurs only during the wet season (50 percent of the time or less).

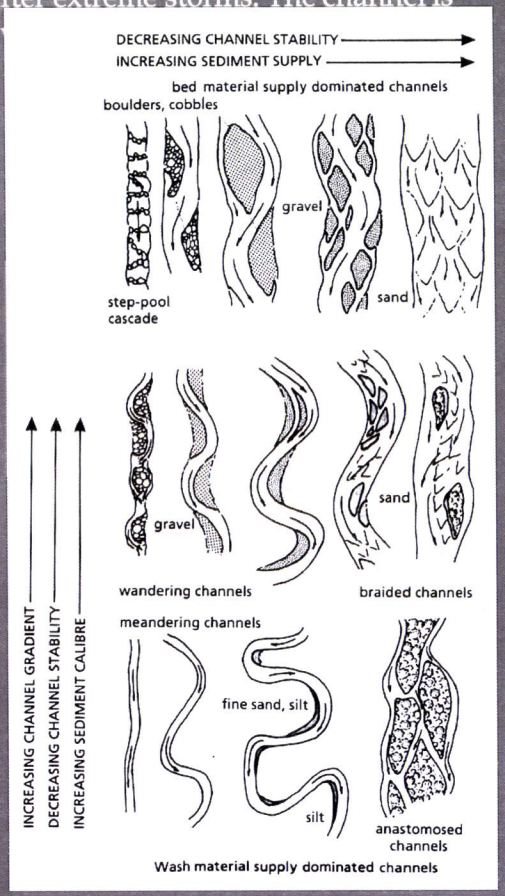
Ephemeral streams Flow generally occurs for a short time after extreme storms. The channel is usually not

Thalweg
- From a longitudinal view the deepest part of riverbed from the source to the mouth
- The line of steepest descent along the stream bed
- The deepest point in any given cross section

Channel Length
- Representative curvilinear distance measurement along the center of the channel

Valley Length
- Representative horizontal distance measurement in the thalweg of two cross sections in a linear depression between two adjacent uplands





A river's every effort is to make Montana look like Kansas, and to use Kansas to fill in the Gulf of Mexico

Stream Slope X Stream Discharge ≈ Sediment Size X Sediment Load

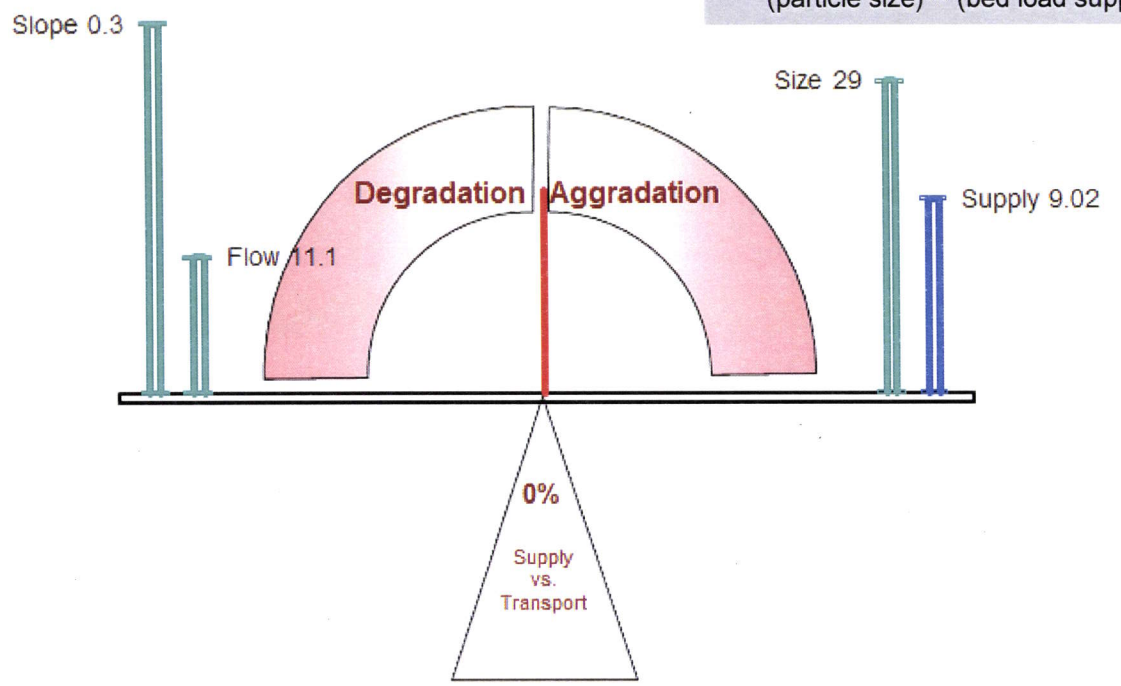
$(\text{slope})^2(\text{flow rate})^2$
is proportional to
$(\text{particle size})^{1.5}$ (bed load supply)

Aggradation

The process by which a stream's gradient steepens due to increased **deposition** of sediment

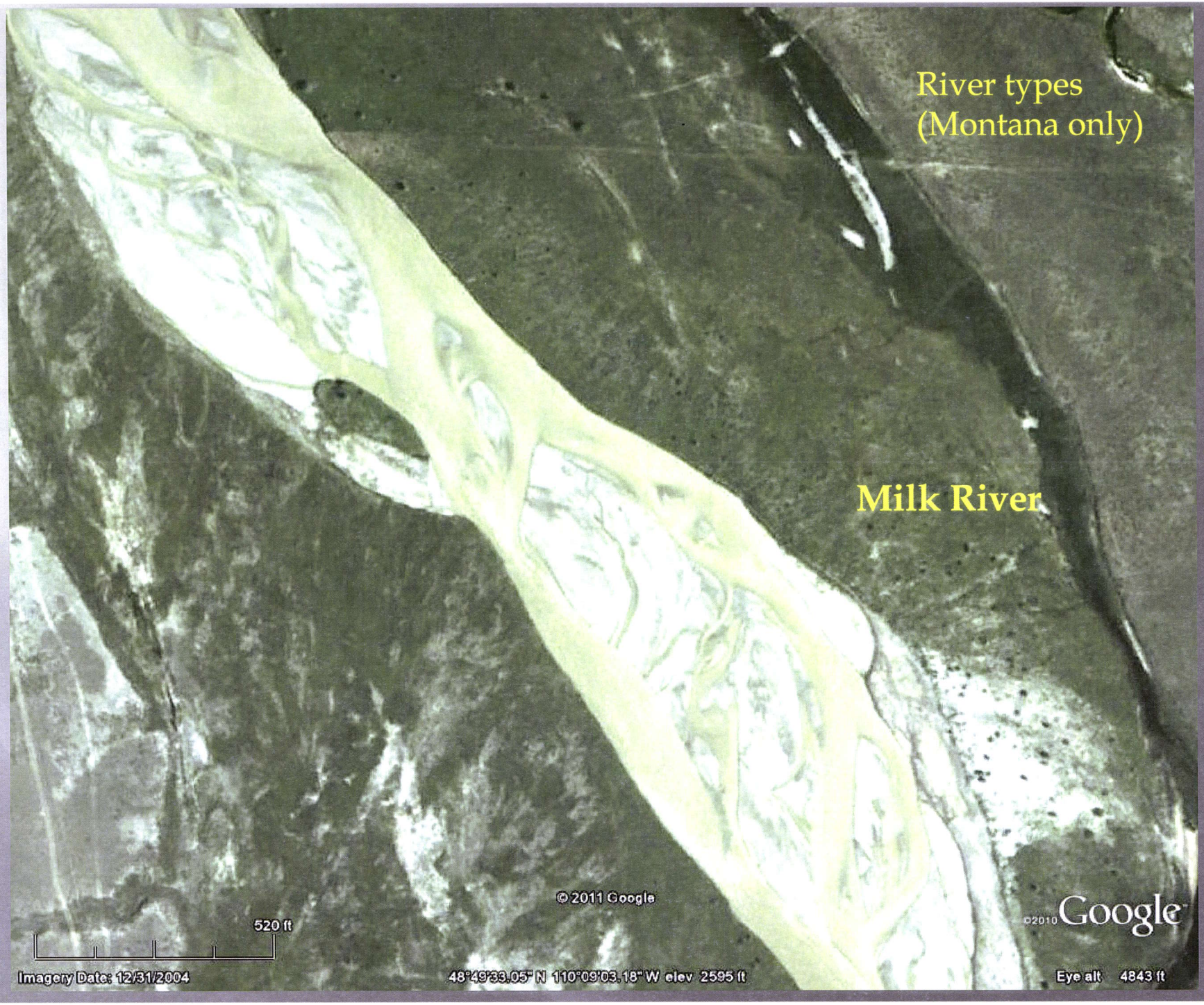
Degradation

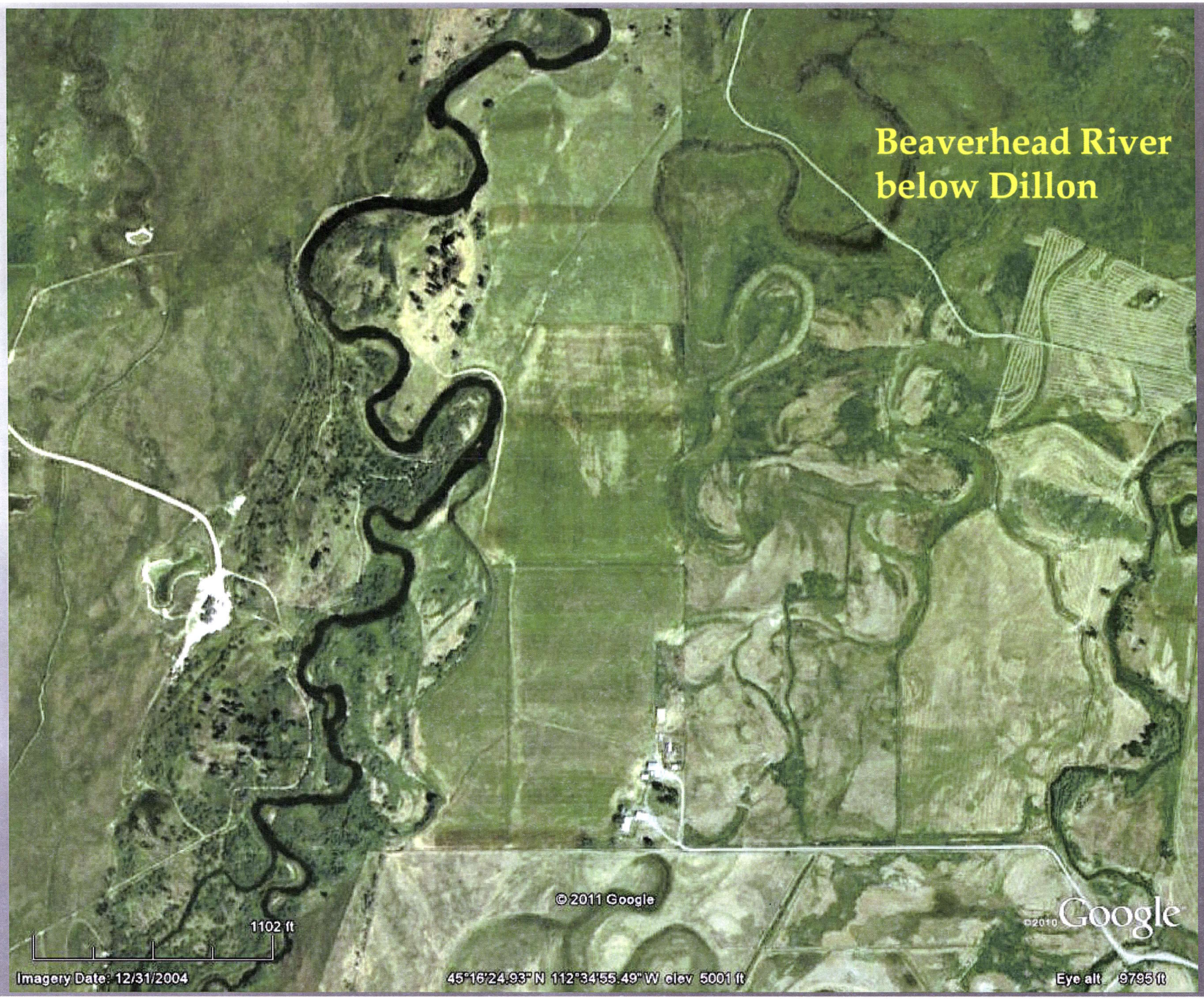
The process by which a stream's gradient becomes less steep, due to the **erosion** of sediment from the stream bed

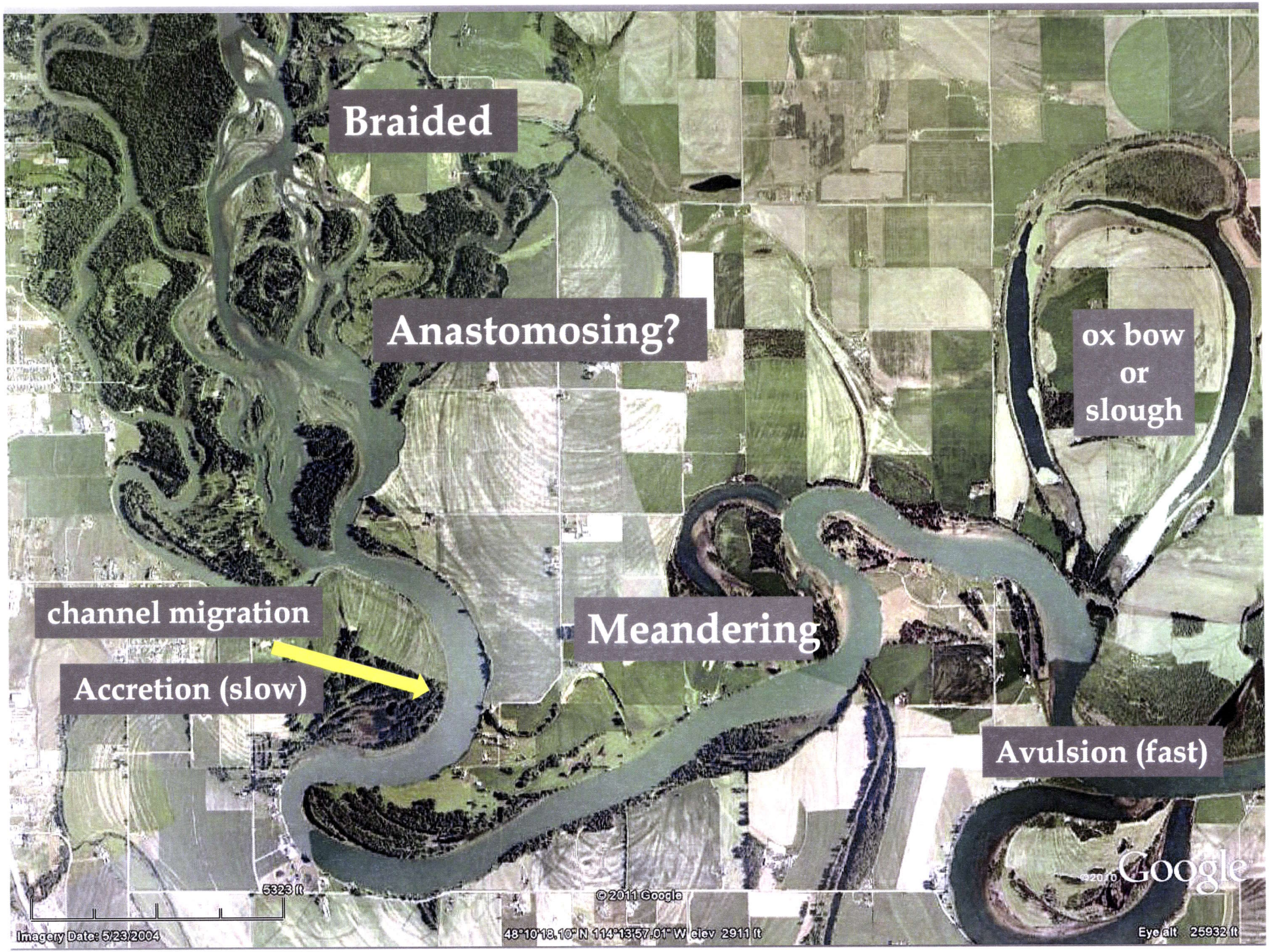


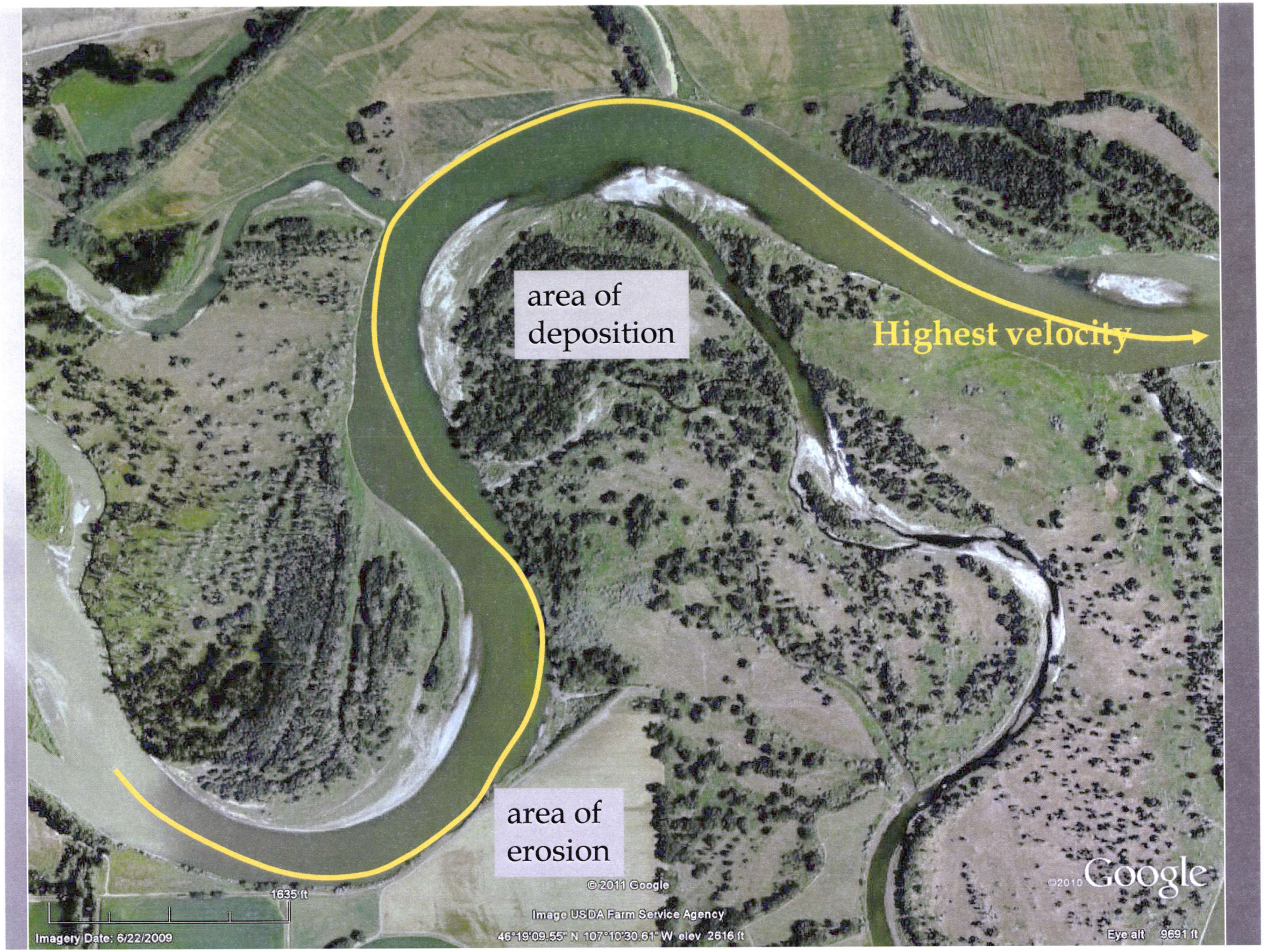
Channel Slope	0.30	%	Assume Values are Stable (zero balance)	Bed Material Size	29	mm
Flow Rate	11	cfs per foot width		Bed Load Supply	9.0	ft^3/hr per foot width

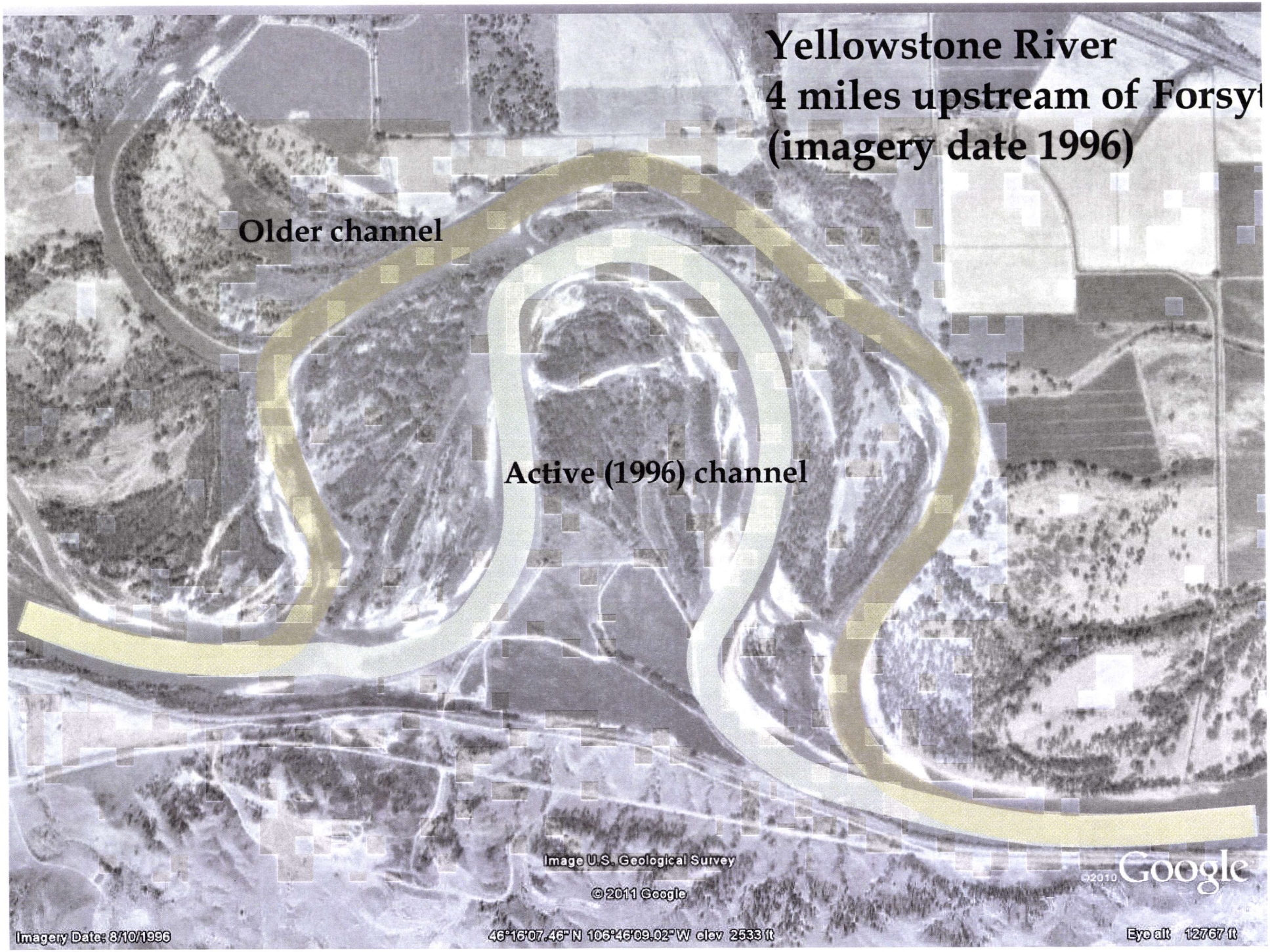
Drainage Area	15	sq.mi.	Set Estimated Stable
Slope	0.3	%	


River types
(Montana only)
Milk River
© 2011 Google
520 ft
©2010 Google
Imagery Date: 12/31/2004
48°49'33.05" N 110°09'03.18" W elev 2595 ft
Eye alt 4843 ft


Beaverhead River
below Dillon
© 2011 Google
1102 ft
Imagery Date: 12/31/2004
45°16'24.93" N 112°34'55.49" W elev 5001 ft
Eye alt 9795 ft
©2010 Google


Braided
Anastomosing?
ox bow
or
slough
channel migration
Meandering
Accretion (slow)
Avulsion (fast)
5323 ft
© 2011 Google
Imagery Date: 5/23/2004
48°10'18.10" N 114°13'57.01" W elev 2911 ft
Eye alt 25932 ft
Google


area of
deposition
Highest velocity
area of
erosion
1635 ft
Imagery Date: 6/22/2009
©2011 Google
Image USDA Farm Service Agency
46°19'09.55" N 107°10'30.61" W elev 2616 ft
©2010 Google
Eye alt 9691 ft


Yellowstone River
4 miles upstream of Forsyt
(imagery date 1996)
Older channel
Active (1996) channel
Image U.S. Geological Survey
© 2011 Google
©2010 Google
Imagery Date: 8/10/1996
46°16'07.46" N 106°46'09.02" W elev 2533 ft
Eye alt 12767 ft

4 miles upstream
of Forsyth
(imagery date 2009)
1997 avulsion
Image USDA Farm Service Agency
© 2011 Google
©2010 Google
Imagery Date: 6/22/2009
46°16'07.46" N 106°46'09.02" W elev 2533 ft
Eye alt 12767 ft

Predicting Channel Migration – two approaches

1) The mapping approach:

Historic air photo (especially Soil Conservation Service photos, LANDSAT)

Historic ground photos (MDOT, USFS, news)

Historic records/ news (events)

Elevation Analyses:

- Ground survey / GPS
- DEMs (30 meter)
- NED (1 meter)
- Light Detection and Ranging (LiDAR) (sub meter)

Coupled with stream discharge and flood history, frequency analyses

Recent channel
Older channel
30 Meter DEM

3875 ft
©2011 Google
©2010 Goog
5/23/2004
48°07'36.07" N 114°13'27.01" W elev 2908 ft
Eye alt 20344

1Meter NED
LiDAR? You can count cows…

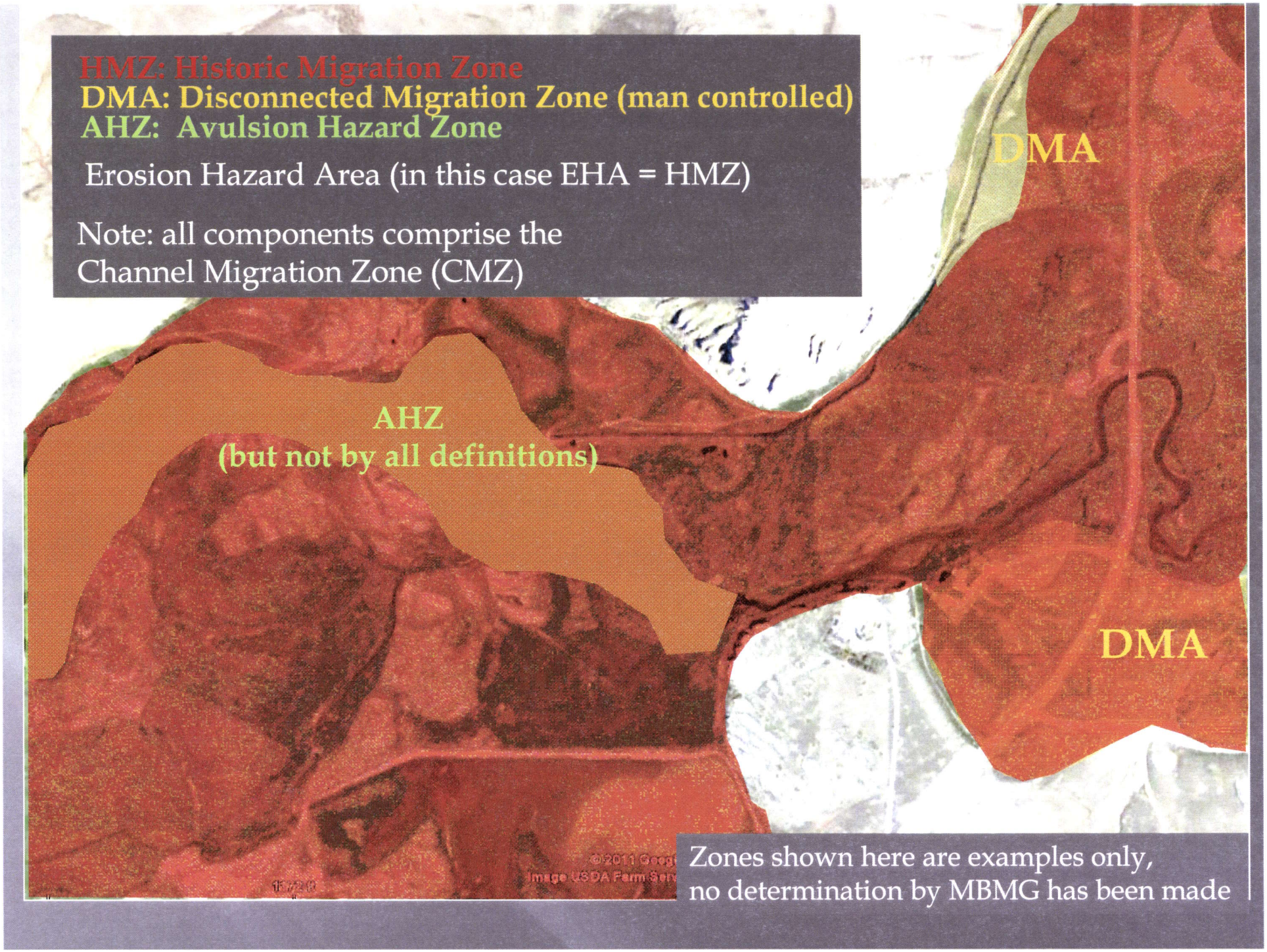
Historical Migration Zone (HMZ)
The collective area the channel occupied in the known historical record.

Avulsion Hazard Zone (AHZ)
The area not included in the HMZ that is at risk of avulsion over the timeline of the CMZ. **Avulsion** is the process in which a stream rapidly abandons a developed channel and creates a new one. Channels may avulse into an abandoned channel (second-order avulsion) or create a new channel (first-order avulsion) depending on the preexisting boundary conditions that initiate the avulsion. Conversely, **accretion** is the gradual deposition of sediment along the edges of a channel by lateral migration. One of the bar formation processes that creates bars opposite of the meander bend.

Erosion Hazard Area (EHA)
The area not included in the HMZ or the AHZ that is at risk of bank erosion from stream flow or mass wasting over the timeline of the Channel Migration Zone (defined below). The EHA comprises 1) the Erosion Setback Zone (ESZ) which is the area at risk of future bank erosion by stream flow and 2) the Geotechnical Setback Zone (GSZ) which the channel and terrace banks that are at risk of mass wasting.

Disconnected migration zone (DMA)
The area located in CMZ where man-made structures restrict channel migration.

Channel Migration Zone (CMZ) is the area comprised of HMZ+AHZ+EHA-DMA.
That is, CMZ is the sum of its components. Note : the DMA is not always excluded in some determinations.


HMZ: Historic Migration Zone
DMA: Disconnected Migration Zone (man controlled)
AHZ: Avulsion Hazard Zone
Erosion Hazard Area (in this case EHA = HMZ)
Note: all components comprise the Channel Migration Zone (CMZ)
DMA
AHZ
(but not by all definitions)
DMA
Zones shown here are examples only, no determination by MBMG has been made

Predicting Channel Migration – two approaches

2) The modeling approach:

Direct solution of equations related to

a) sediment, load
b) sediment size,
c) slope, and
d) stream discharge

Stream Slope X Stream Discharge $\approx$ Sediment Size X Sediment Load

$(\text{slope})^2(\text{flow rate})^2$
is proportional to
$(\text{particle size})^{1.5}$ (bed load supply)

Models range from direct solutions…

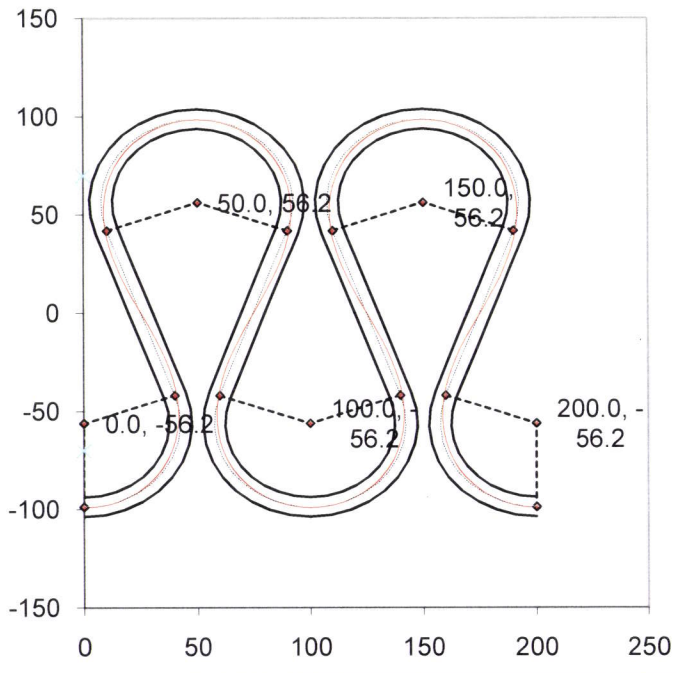
Resistance Manning's and D'Arcy-Weisbach

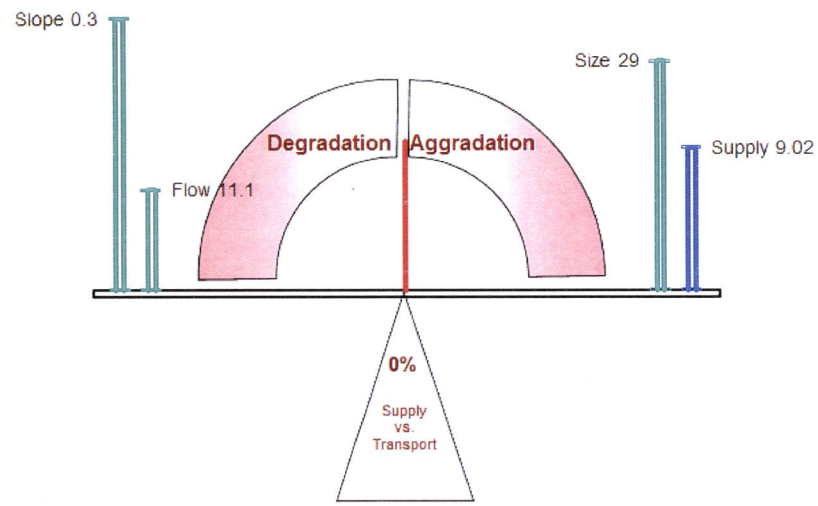
		metric units	conversion	English units with grain size in mm
depth	d	1m	3.28	3.3ft
slope	S	0.005m/m	1	0.005ft/ft
diameter sediment	d_s	0.04m	1000	40mm
max depth	d_{max}	1.5m	3.28	4.9
gravitational acceleration	g	9.81m/sec^2	3.28	32.2ft/sec^2

Resistance factor = sqrt(8/f)

Colebrook-White Eq (Hey 1979) for D_{84}	u/u*	11.2
Leopold,	u/u*	11.3
	u/u*	10.0
	n	0.0284
	n	0.0282
	n	0.0320

(slope)^2(flow rate)^2
is proportional to
(particle size)$^{1.5}$ (bed load supply)





Channel Slope	0.30	%	Assume Values are Stable (zero balance)	Bed Material Size	29	mm
Flow Rate	11	cfs per foot width		Bed Load Supply	9.0	ft^3/hr per foot width
Drainage Area	15	sq.mi.				
Slope	0.3	%				

Set Estimated Stable

...to numeric solutions...

SRH-Meander (US Bureau of Reclamation)

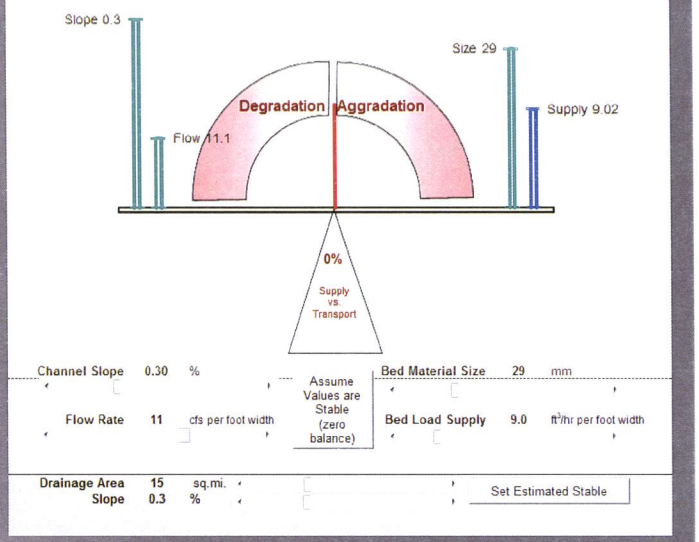
"The model predicts channel migration as a function of river discharge, sediment transport capacity, channel radius of curvature, channel width, hydraulic depth, and the bank material properties of the river channel including vegetation, large woody debris, cohesion, and armoring. The model can simulate the migration of tens of river miles, over a period of decades using daily or hourly variations in flow. Each model simulation can be completed in a period of minutes so that a wide range of hydrology could be individually simulated."

Channel Migration Modeling (2007-2057) near River Miles 197 to 191 of the Sacramento River, Final Technical Memorandum

Previous discussion relates to lateral or horizontal migration

What about vertical?

$(\text{slope})^2(\text{flow rate})^2$
is proportional to
$(\text{particle size})^{1.5}$ (bed load supply)



The same principles apply

Stream Slope
Stream Discharge
vs
Sediment Load
Sediment Size

For example, an increase stream discharge without a change in the other factors promotes degradation.

Localized = scour

Aggradation
The process by which a stream's gradient steepens due to increased **deposition** of sediment

Degradation
The process by which a stream's gradient becomes less steep, due to the **erosion** of sediment from the stream bed

Scour Types:

1) general scour
Bank erosion, flooding, lowering of streambed elevation (degradation);

2) contraction scour
bridges, pilings

3) local scour
erosion control structures (eg rip rap)
often 10X depth of other scours

NOTE: Scour is an additive process – one can/will complement the others

…and models?

HEC-6
(US Army Corps of Engineers)

Scouring depth

$$d = 0.473 \times \left(\frac{\text{stream discharge}}{1.76 \times \sqrt{\text{particle size}}} \right)$$

$$Y_2 = \left[\frac{0.0077 Q^2}{D_m^{\frac{2}{3}} W^2} \right]^{\frac{3}{7}}$$

Where:

Y_2 = Average scour depth in the contracted section
Q = Flow through bridge in the contracted section
D_m = Particle size in mixture equal to 1.25 X D_{50}
W = Bottom width of contracted section

Zeller General Scour

ygs = ymax [(0.0685 Vm0.8) / (yh 0.4 Se 0.3) -1] or 0, whichever is greater.

Ygs : zeller general scour
Ymax: maximum depth of flow
Vm: average velocity of flow
Se: energy slope or bed slope

A river's every effort is to make Montana look like Kansas, and to use Kansas to fill in the Gulf of Mexico

Sediment Load X Sediment Size $\approx$ Stream Slope X Stream Discharge

$(\text{slope})^2(\text{flow rate})^2$
is proportional to
$(\text{particle size})^{1.5}$ (bed load supply)